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Field Manuals for Marine Sampling in Australian Waters, Version 2

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https://marine-sampling-field-manual.github.io

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Contents

LIST OF ACRONYMS & ABBREVIATIONS

AMP	Australian Marine Park
AODN	Australian Ocean Data Network
AUV	Autonomous Underwater Vehicle
BRUV	Baited Remote Underwater Video
Chl-a	Chlorophyll-a
DOV	Diver-Operated Video
GA	Geoscience Australia
IMOS	Integrated Marine Observing System
LOI	Loss on Ignition
MaRS	Marine Sediments Database
MBES	Multibeam Echosounder
MPA	Marine Protected Area
NESP	National Environmental Science Program
OTU	Operational Taxonomic Unit
QA	Quality Assurance
QC	Quality Control
ROV	Remotely Operated Vehicle
RUV	Remote Underwater Video
SOP	Standard Operating Procedure
TOC	Total Organic Carbon
USBL	Ultra-Short Baseline
UVC	Underwater Visual Census

EXECUTIVE SUMMARY

Australia has one of the world's largest marine estates that includes many vulnerable habitats and a high biodiversity, with many endemic species crossing a wide latitudinal range. The marine estate is used by a variety of industries including fishing, oil & gas, and shipping, in addition to traditional, cultural, scientific and recreational uses. The Commonwealth government has recently established the Australian Marine Parks (AMPs), the largest network of marine protected areas in the world, complementing existing networks in State and Territory waters.

Monitoring the impacts of these uses on the marine environment is a massive shared responsibility that can only be achieved by making the best use of all the information that is collected. Australia now has a number of significant long-term marine monitoring and observing programs, as well as a national ocean data network. Without some common and agreed standards, much of the data collected will not be comparable with those from other areas, times or sectors. This may reduce the value of and restrict its application to localised management, while the individual project or survey may lose the opportunity to interpret results in a regional or national context.

We have therefore developed a suite of field manuals for the acquisition of marine benthic (i.e. seafloor) data from a variety of frequently-used sampling platforms so that data can become directly comparable in time and through space, thus supporting nationally relevant monitoring in Australian waters and the development of a monitoring program for the AMP network. This objective integrates with one of the eight high-level priorities identified by the National Marine Science Plan (2015-25): the establishment of national baselines and long-term monitoring.

Due to the large geographic area, diverse flora and fauna, and range of environmental conditions represented by the Australian marine estate, a single method of sampling is neither practical nor desirable. For this reason, we present a standard operating procedure (SOP) for each of seven key marine benthic sampling platforms that were identified based on their frequency of use in previous sampling and monitoring programs, as well as a pilot pelagic sampling platform included due to its similarity with benthic BRUVs:

- Multibeam sonar (MBES) provides bathymetry and backscatter data that are used to map the seafloor.
- Autonomous Underwater Vehicles (AUVs) acquire high-resolution continuous imagery of the seafloor and its associated habitats and organisms.
- Benthic Baited Remote Underwater Video (BRUV) systems acquire video of demersal fish attracted to a baited camera system dropped to the seafloor.
- Pelagic BRUVs acquire video of pelagic fish and other fauna that are attracted to a baited camera system suspended in the water column. This platform is included as an emergent sampling method for pelagic ecosystems.
- Towed cameras acquire video or still imagery of the seafloor and its associated habitats and organisms.
- Grabs and box corers collect sediment samples that can be analysed for biological, geochemical, or sedimentological variables.

- Sleds and trawls collect benthic or demersal fauna near the seafloor.
- Remotely Operated Vehicles (ROVs) acquire high-resolution continuous imagery of the seafloor (including sloped, vertical or rugose environments) and its associated habitats and organisms. ROVs can also collect specimens, but we limit the scope of this field manual to image acquisition.

The original Version 1 of these field manuals was released in 2018 and has since been integrated in a growing number of marine surveys. In 2020 the current version (Version 2) was released which contained a number of updates to address stakeholder feedback, corrections and updates where applicable. Major changes to the entire field manual package include the following:

- Amalgamation of the original Version 1 multibeam manual with the *Australian Multibeam Guidelines* from AusSeabed, a nationally seabed mapping coordination program;
- Inclusion of a new manual on ROVs; and
- Development of an online portal (https://marine-sampling-field-manual.github.io) that provides numerous benefits to users and authors.

The main challenge in the development of these manuals was to find a balance between being overly prescriptive (such that people prefer to follow their own protocol and ignore the manuals) and overly flexible (such that data is not consistent and therefore not comparable). A collaborative approach was paramount to addressing this concern. Ultimately, over 136 individuals from 53 organisations contributed to the field manual package. By engaging researchers, managers, and technicians from multiple agencies with a variety of experience, sea time, and subject matter expertise, we strove to ensure the field manuals represented the broader marine science community of Australia. This not only improved the content but also increased the potential for adoption across multiple agencies and monitoring programs.

1. INTRODUCTION

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Chapter citation:
Przeslawski R, Foster S, Gibbons B, Langlois T. 2020. Introduction. In *Field Manuals for Marine Sampling to Monitor Australian Waters, Version 2*. Przeslawski R, Foster S (Eds). National Environmental Science Program (NESP).

Background

Australia has one of the world's largest marine estates that includes many vulnerable habitats and a high biodiversity, with many endemic species crossing a wide latitudinal range. The marine estate is used by a variety of industries including fishing, oil & gas, and shipping, in addition to traditional, cultural, scientific and recreational uses. The Commonwealth government manages the Australian Marine Parks (AMPs), the largest network of marine protected areas in the world (Cochrane 2016). These marine parks complement existing networks in State and Territory waters.

Monitoring the impacts of these uses on the marine environment is a massive shared responsibility that can only be achieved by making the best use of all the information that is collected. Australia has a number of significant long-term marine monitoring and observing programs (Table 1), as well as a national ocean data network (aodn.org.au). Without some common and agreed standards, information collected may not be comparable with other areas or sectors. This may reduce its value to regional and national management, while the individual project or survey may lose the opportunity to interpret results in a regional or national context.

Australia is uniquely placed to develop standardised national approaches to monitor the marine environment. This objective integrates with one of the eight high-level priorities identified by the National Marine Science Plan (2015-25): the establishment of national baselines and long-term monitoring. Standardised national approaches will also contribute to the effective coordination across the marine science and observing community (including industry and citizen scientists). Such coordination has been recognised as integral to a governance system for sustained and effective monitoring in Australia's marine environment (Hayes et al. 2015) and yet was identified as highly variable and frequently inadequate in the 2016 State of the Environment Report (Evans et al. 2017). In order to facilitate objective and robust conclusions about the status and trends of the marine ecosystems, it is crucial that sampling methods are as consistent as possible while still allowing for practical differences among equipment, vessels, and weather conditions. This need for consistent methodology has been identified in several reports on regional and national marine monitoring frameworks (Hedge et al. 2013, Bowden et al. 2015, Hayes et al. 2015), and its contribution to supporting a blue economy is also recognised (Golden et al. 2017).

Although many biological monitoring programs focus on single elements of the marine environment (e.g. Wraith et al. 2013), several large-scale marine monitoring programs that include multiple areas are currently under development or implementation in Australian waters. Table 1 lists some of these programs, as well as the associated indicators to be measured or sampling platforms if specified. Standardised marine monitoring has been done successfully in Australian waters for shallow waters (e.g. underwater visual census in Reef Life Survey) and pelagic animals (e.g. acoustic tagging in IMOS Animal Tracking Facility), but it has yet to be developed, implemented, and adopted at a national scale for most other biological sampling platforms (but see IMOS AUV Facility in Table 1).

Table 1: Large-scale biological or ecological monitoring programs currently operating or under development in Australia as of Dec 2017. UVC = underwater visual census, DOV = diver-operated video, ROV = remotely operated vehicle, AUV = autonomous underwater vehicle, BRUV = baited remote underwater video, MBES = multibeam echosounder.

	Program	Region	Indicator	Sampling Platforms	Example Reference
PELAGIC	Continuous Plankton Recorder (CPR)	Global	Plankton assemblages, colour index	CPR	Hosie et al. 2003
	IMOS Animal Tracking Facility	National	Marine megafauna movement	Acoustic telemetry, satellite tracking	Taylor et al. 2017
	IMOS Ships of Opportunity	National	Temperature, salinity, water column backscatter, biochemistry	Bathythermograph, echosounder, biogeochemical and meteorological sensors	Alory et al. 2007
	IMOS National Reference Stations	National	Nutrients, microbes, phytoplankton, zooplankton, environmental factors	Moored sensors, water sampling	Sloyan and O'Kane 2015
BENTHIC & DEMERSAL	RIMREP	GBR	Various	Various (TBC)	GBRMPA 2015
	Marine Estate Management Authority	NSW	Various	Aerial imagery, UVC, BRUVs, AUVs, towed imagery, grabs, DOVs, ROVs	NSW Government 2017
	WAMSI estuary science program	WA	Various	Various (TBC)	Thomson et al. 2017
	Reef Life Survey	Global	Demersal fish and benthic invertebrate assemblages	UVC	Stuart-Smith et al. 2017
	Long-Term Monitoring Program (AIMS)	GBR and NW Australia	Fish and benthic invertebrate assemblage, coral health and cover	UVC, DOV, Towed imagery	De'ath et al. 2012
	IMOS AUV Facility	National	Benthic invertebrate assemblages	AUV	Perkins et al. 2017
	VIC Signs of Healthy Parks monitoring program	VIC	Various	UVC, drone/UAV, AUV, BRUVS, ROV, towed video, aerial photography	Parks Victoria's Technical Series
	WA marine monitoring program	WA	Various	Various	Dept Biodiv Conserv Attractions 2017
	NESP field manual package*	National	Various	MBES, AUV, BRUV, Towed camera, Sled/trawls, Grab/corer, ROV	Current study

* Primarily benthic and demersal platforms, but also includes an emergent pelagic method (Pelagic BRUVs)

Due to the large geographic area, diverse flora and fauna, and range of environmental conditions represented by the Australian Marine estate, a single method of sampling is neither practical nor desirable (Bouchet et al. 2018, Przeslawski et al. 2018). For this reason, we present a standard approach for each of seven key marine benthic sampling platforms that were identified based on frequency of use in previous open water sampling and monitoring programs: Multibeam sonar (MBES), Autonomous Underwater Vehicles (AUVs), benthic Baited Remote Underwater Video (BRUVs), towed video, grabs and box cores, sleds and trawls, and remotely operated vehicles (ROVs). Each of these platforms targets a discrete data type (bathymetry, imagery, biological and sediment samples) within particular environments (consolidated, unconsolidated substrates) (Table 2), with specific advantages (Table 3). In addition, we provide a field manual for pelagic BRUVs as a concept sampling method in pelagic ecosystems due to its similarity to benthic BRUVs. Importantly, the inclusion of these sampling platforms in the current version is not an assessment of their value but instead an indication of their frequency of use and suitability for national monitoring (e.g. established methods, dedicated users, integration with existing national programs).

One of the main challenges in assessing marine biodiversity is the lack of standardised approaches for monitoring it (Duffy et al. 2013, Teixeira et al. 2016). As such, the overarching goal of these field manuals is to reduce the bias and variance in data from differences in sampling procedures, thereby ensuring that patterns in data are due to patterns in the community rather than patterns of how or when the community was sampled. If the measured ecological variable and the variation in sampling techniques are confounded, it is challenging if not impossible to objectively determine if observed changes are due to real ecological change or sampling technique. If variability is sufficiently high, real changes that would trigger appropriate management may not be detected in time, if at all. Importantly, many state marine monitoring programs use their own standard operating protocols (SOPs) relevant for wetland, estuarine, embayment, or intertidal habitats (Table 1). The current package of field manuals is not meant to replace them, but rather to complement them for deeper waters and national monitoring purposes. At the same time, we hope that individual state marine monitoring programs will also identify opportunities to adjust current practices to increase national consistency and that the SOPs will provide an opportunity for industry and industry consultants to contribute to national monitoring through standardising their ongoing activities (Teytelman 2018). To that end, marine managers from all states and territories in Australia were engaged in the process of developing these field manuals. This ensured that methods were similar whenever possible and differences were clearly explained in relation to marine monitoring in Commonwealth waters.

Table 2: Summary of prioritised benthic sampling platforms and their acquisition targets.

	Data Type	Data Target	Spatial coverage	Environment	Chapter
MBES	Bathymetry, backscatter	Seafloor	Continuous	All	3
AUV	Imagery	Epifauna	Continuous	All	4
BRUV	Imagery	Demersal fish	Point (qualitative)	All	5
Towed	Imagery	Epifauna	Transect	All	7
Grab/Boxcore	Biological and sediment samples	Macrofauna, infauna	Point	Unconsolidated substrate	8
Sled/Trawl	Biological and sediment samples	Megafauna, epifauna	Transect (qualitative)	Consolidated substrate	9
ROV	Imagery*	Epifauna	Transect	All	10

* ROVs can collect biological and geological samples, but the focus of the manual in this package is on imagery.

Table 3: Advantages of prioritised benthic sampling platforms.

	MBES	AUV	BRUV	Towed	Grab/Boxcorer	Sled/Trawl	ROV
Continuous (i.e. grid) broad-scale spatial coverage	X						
Continuous (i.e. grid) fine-scale spatial coverage		X					
Non-extractive	X	X	X	X			X
Able to revisit exact sites (repeatability)	X	X					X
Able to sample over variety of environments	X	X	X	X			X
Species-level identifications[1]					X	X	X[2]
Genetic, morphological etc analysis possible					X	X	X[2]
Behaviour observed			X	X			X
Cryptofauna included					X	X	
Quantitative	X	X	X	X	X		X
Concurrent physical and biological data		X		X	X		X
Minimal technical expertise			X	X	X	X	X[3]
Vessel flexibility			X	X	X		X[3]

[1] Refers to identifications able to be made with unknown or cryptic species (i.e. well-known, distinctive species can be identified via imagery)
[2] Only possible when the ROV is equipped with sampling capability. This is outside the focus on the ROV manual
[3] This only applies to small off-the-shelf ROVs, Working class ROVs require technical expertise and specific vessel specifications

Scope

This field manual package aims to provide a standardised national methodology for the acquisition of marine data from a prioritised set of frequently-used sampling platforms (below diver depths) so that data are directly comparable in time and through space. This will then facilitate national monitoring programs in Australian open waters and contribute to the design of an ongoing monitoring program for AMPs. The long-term goal is to produce a set of manuals that is applicable to a broad range of users and to be prescriptive enough that all data are collected without unnecessary technical variation.

Survey planning

The decision to use particular marine sampling platforms depends on a variety of factors, including depth (e.g. reef vs slope), substrate (e.g. hard vs soft), purpose (e.g. voyage of discovery vs impact assessment), and resources (e.g. minimal expertise vs technologically complex, Salvanes et al. 2018). However, regardless of sampling platform we strongly advise that Survey Design should be considered at all levels of Survey Planning (Figure 1.1), as it is essential to ensure sampling provides efficient and representative information to inform management (Hayes et al., 2019). If information is lacking, then evidence-based decision frameworks, e.g. a Monitoring Evaluation, Reporting and Improvement (MERI) framework, cannot proceed without being compromised. Chapter 2 of this field manual package provides details of sampling design considerations and how they can be navigated, as well as example code and data for implementing a spatially-balanced design, as outlined in Foster et al. (2017). Chapter 2 also emphasises the foundational role of seafloor data from sonar (Chapter 3), which can facilitate the production of base maps covering tens or hundreds of square kilometres, with accurate geo-location. These maps can form the input needed to generate an efficient spatial survey design. Where no seafloor data exists, the principles in the Chapter 2 can also be used to design efficient and representative sonar surveys.

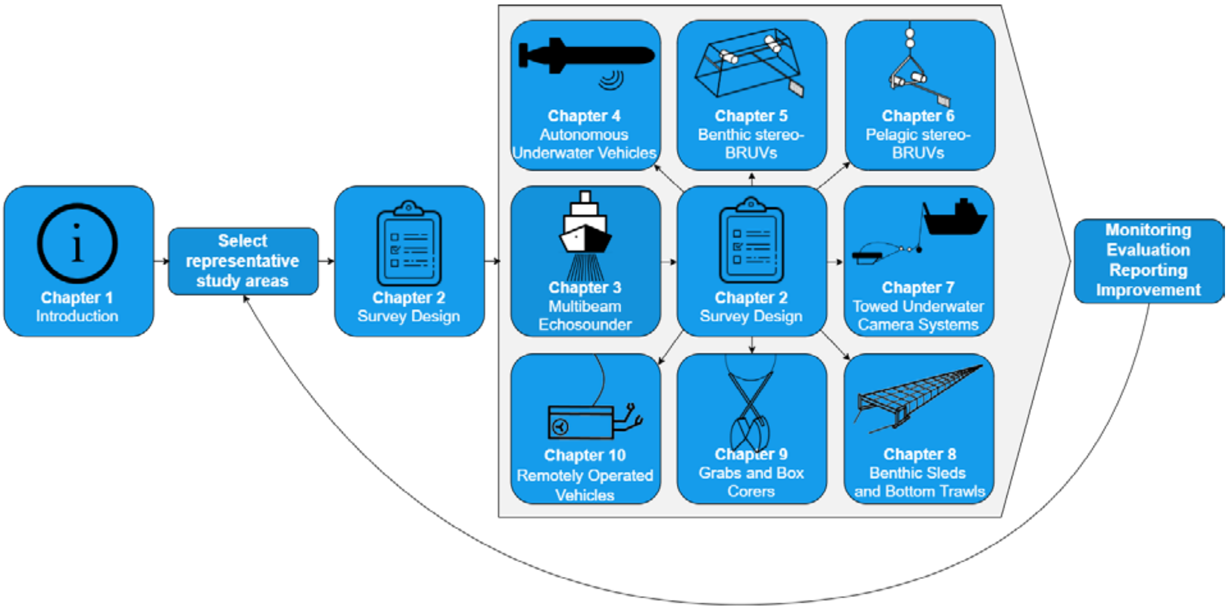

Figure 1.1: Recommended role of Survey Design (Chapter 2) in Survey Planning, including the foundational role of seafloor data from multibeam sonar (Chapter 3), to inform sampling (Chapters 4-10) and management frameworks (e.g. a Monitoring Evaluation, Reporting and Improvement framework).

Sampling platforms

We generally limit these platforms to benthic biological sampling, with a few exceptions (e.g. pelagic BRUVs included as a proof-of-concept due to its similarity to benthic BRUVs; water column, sedimentology, and geochemistry data included for comprehensiveness related to the relevant platform). These field manuals focus on data acquisition and post-processing including data management, particularly as applied to marine monitoring. Standardisation of sampling design is important to ensure rigor and reproducibility (National Academies of Sciences, Engineering, and Medicine 2019) and is addressed accordingly in Chapter 2. Data analysis and reporting are generally not included in the field manuals, although we direct users to useful methods or resources within each field manual.

For each field manual, a scope specific to that particular sampling gear and data type is presented in a separate section. Overall, these field manuals are meant to cover basics and important considerations, with agency- and gear-specific SOPs supplemented as needed by individual researchers. Detailed and gear-specific SOPs are outside the scope of this field manual package due to the large number of existing SOPs and the variety of gear currently employed by researchers. It is impractical that researchers would agree on detailed SOPs (and associated gear). Rather, we have developed these field manuals to find consensus about as many issues as possible, while noting the differences. These differences can then be assessed in the future (e.g. they may not correspond to large amounts of variation in data), and addressed if need be. Wherever possible, however, we have mandated or recommended specifications (e.g. imagery resolution) that should be used in future equipment upgrades or purchases.

This field manual package does not describe the decision to use a particular sampling platform, supporting previous recognition that a top-down, one-size-fits-all approach to monitoring is unlikely to be effective in systems with large environmental variability (Fancy et al. 2009). In some instances, multiple platforms will yield higher observed diversity (e.g. BRUVS + a transect-based imagery platform), while data collected among other platforms are comparable (e.g. ROV, diver-operated video, towed video, Schramm et al 2019). For a more detailed review of each sampling platform, as well as a comparative assessment among them, we refer readers to our companion reports on benthic (Przeslawski et al. 2018) and pelagic (Bouchet et al. 2018) sampling methods used in marine monitoring. These reports also relate marine sampling platforms to Essential Ocean Variables (Miloslavich et al. 2018, Muller-Karger et al. 2018). After the decision to use an appropriate sampling platform has been made, using the appropriate field manuals will help ensure that the collected data can be compared with data collected previously and in the future, thus contributing to national marine monitoring and reporting.

Format

In order to maximise uptake, methods in each field manual are usually presented as simple steps. All steps listed are considered essential unless they are clearly marked with brackets and italics as recommended (i.e. Use netsonde or bottom contact sensor to ensure sled or trawl is suitably deployed along the seafloor *[Recommended]*)

The field manual package is designed to be separated into its component chapters representing discrete sampling platforms, as needed. The component chapters themselves fit together into a cohesive whole (Figure 1.2). For this reason, the package can be downloaded in its entirety as a single pdf, or as standalone chapters representing discrete field manuals (Figure 2). References are listed accordingly at the end of each chapter.

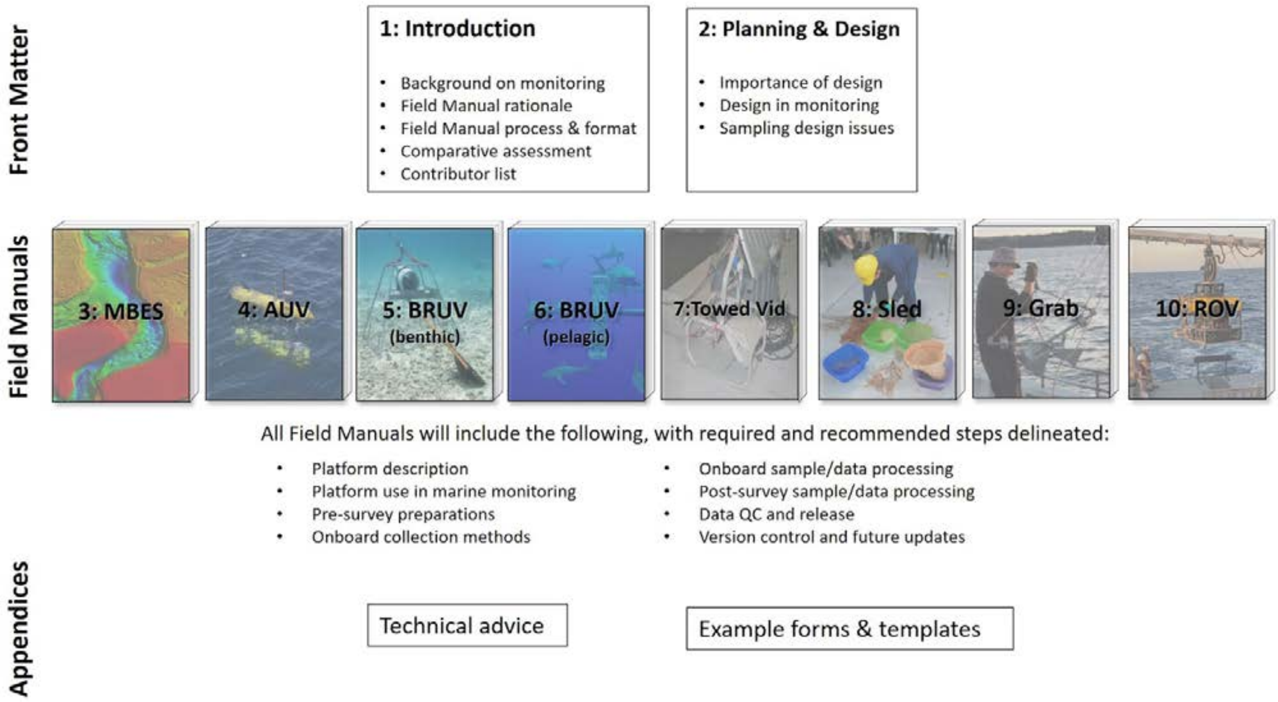

Figure 1.2: The structure and general contents of the NESP field manual package (version 2) with numbers indicating respective chapters.

Development of Field Manuals

The process of developing these field manuals has been detailed in Przeslawski et al (2019a).

The main challenge in the development of these manuals was to find a balance between being overly prescriptive (such that people prefer to follow their own protocol and ignore the manuals) and overly flexible (such that data are not consistent and therefore not comparable). A collaborative approach was therefore paramount to their development.

Ultimately, over 136 individuals from at least 53 organisations contributed to versions 1 and 2 of the field manual package (see Collaborators section in this introductory chapter). The increase in collaborators from Version 1 to Version 2 is due primarily to i) the new ROV manual, ii) expansion of the BRUV authors based on preparation of an associated manuscript to a journal, and iii) the merger of the V1 NESP field manual with AusSeabed's *Australian Multibeam Guidelines*. By engaging researchers, managers, and technicians from multiple agencies with a variety of experience, sea time, and subject matter expertise, we strove to ensure the field manuals represented the broader marine science community of Australia including real-world context, diversity of experiences, and candid acknowledgement of limitations and challenges. This not only improved the content but also increased the potential for adoption of the SOPs across multiple agencies and monitoring programs. After the release of the first version, input from additional stakeholders was actively sought and incorporated into the second version (see the section 'Version 2 - Updates and Revisions' later in this chapter).

The process used to develop each field manual included in this package is shown in Figure 1.3, and the steps are listed below:

1. For each field manual, a working group was formed in which known users of the given sampling platform were invited. To be as inclusive as possible, we also extended more general invitations through email lists (e.g. Australian Coral Reef Society, Australian Marine Science Association (AMSA), NESP) and presentations (e.g. AMSA 2017 conference). Each working group was led by a coordinator(s) to develop content. Coordinators were identified as experts in their particular sampling platform and took on the role of lead author(s) for their respective field manual (Figure 1.4).
2. Content was developed by the coordinators based on meetings with the working group and associated input, including existing SOPs.
3. A draft field manual was distributed to the working group as a strawman for further discussion and refinement.
4. A complete field manual was submitted for internal review and approval by the editors, NESP, Geoscience Australia, and IMOS.
5. A complete field manual was submitted to an external reviewer who was not previously associated with the project.
6. A final revised field manual package was released as Version 1 on the Ocean Best Practice Repository (www.oceanbestpractices.net) and the website (www.nespmarine.edu.au).
7. Feedback was solicited through a questionnaire, particularly geared towards field testers.

8. Content of field manuals was revised based on feedback and new developments (e.g. data discoverability and accessibility). This was incorporated into Version 2, with the exception of the ROV manual which was a new addition to the Version 2 field package and thus has not yet been through a process of stakeholder feedback after release.

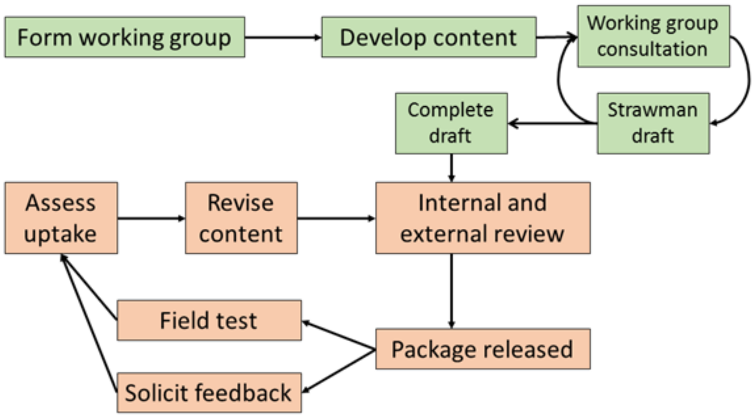

Figure 1.3: Flow chart showing the iterative process used in the initial development of this field manual package (version 1, orange and green), as well as version 2 and subsequent future versions (orange only).

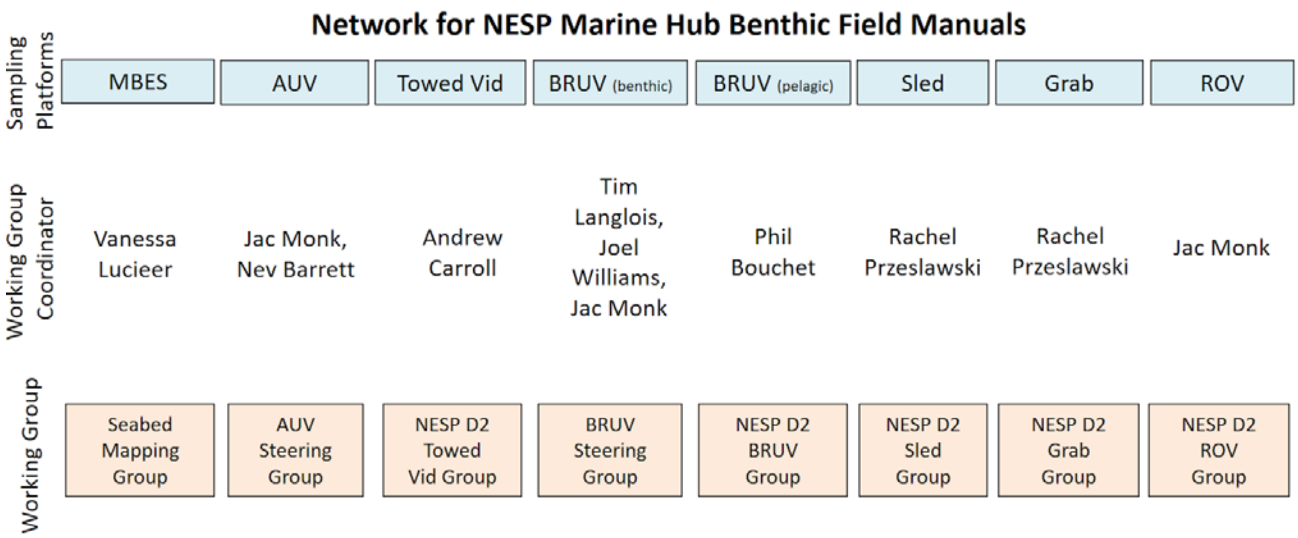

Figure 1.4: Collaborative network that developed the marine sampling field manuals. Working group members are listed in a table at the end of this chapter as authors or collaborators.

Universal Protocols

In this section, we generally describe some of the protocols that span all sampling platforms. Further detail on each of these is also provided in each chapter, as it is specifically relevant to a given sampling platform.

Sampling design

There are several overarching issues related to sampling design across all marine sampling platforms (e.g. randomisation, efficient designs, and uncertainty). We strongly encourage users of any field manual contained in this package to read Chapter 2 to familiarise themselves with these issues.

Permits

Prior to undertaking any marine survey, researchers are responsible for ensuring appropriate applications for permission are lodged, with subsequent relevant approvals obtained and documented. A list of potential permissioning documents relevant to marine sampling in Commonwealth waters are listed in Appendix A.

Risk assessments

Risk assessments not only help quantify potential risks associated with planning and field activities, they can help make fieldwork safer and reduce costs. They may also be a requirement for some organisations. It is recommended that a risk assessment is completed during the survey planning phase and again prior to the commencement of fieldwork for any of the sampling platforms included in this manual:

- Planning risk assessment. The assessment during the planning phase identifies risks and mitigation strategies associated with attaining appropriate equipment, staff, finances and other resources. In addition, it should include potential reasons survey objectives may not be met. This provides an opportunity to develop contingency plans and prioritise objectives.

- Fieldwork risk assessment. This assessment identifies risks associated with onboard activities, including safety hazards, equipment damage or loss, inclement weather, and any other aspect that may compromise budget, survey objectives, or crew health and safety. There will be some overlap with the risks identified in the planning phase, but this risk assessment should explicitly address onboard risks. This provides an opportunity to ensure the survey is compliant with workplace health and safety issues, as well as optimising the potential for successful data acquisition.

Quality assurance and control

These field manuals define quality assurance (QA) as measures adopted before and during data acquisition, while quality control (QC) are measures adopted after data acquisition. Specifically QA represents the processes necessary to support the generation of high quality data and QC represents the follow-on steps that support the delivery of high-quality data, requiring both automation and human intervention. The documentation of the QA/QC process is arguably just as important as data acquisition itself. The QA/QC process can affect data analysis and interpretation (e.g. observer bias in marine imagery in Durden et al. 2016b), and it is thus an integral part of standardisation to facilitate comparisons between datasets (Lara-Lopez et al. 2017). The appropriate methods for QA/QC depends on the data type (e.g. multibeam, underwater imagery, biological specimen). As such, further details on QA/QC are included in each field manual in the Data Release sections.

Data discoverability and accessibility

All marine metadata and data should be publicly released so that it is discoverable and accessible to the public, unless circumstances require otherwise (e.g. confidentiality clause or embargo for commercial work). Even in situations when data cannot be shared, the metadata should be made available so that future surveys are based on informed decisions about existing sampling locations. Refer to Stocks et al. (2016) for further information on appropriate information management including useful advice on data quality control and data sharing. Data can be licensed with the Creative Commons BY license which attributes the author but allows for free use of the data, including commercial applications. Some agencies may prefer to restrict commercial applications based on their data in which case Creative Commons BY-NC should be used.

Discoverable and accessible data contribute the following potential benefits to scientific, commercial, environmental, and social endeavours:

- Increased citations, media attention, and public engagement opportunities for researchers (McKiernan et al. 2016);
- More collaboration, funding, and job opportunities for researchers (Popkin et al. 2019);
- Larger and more useful datasets to address regional, national, and international issues (e.g. Cinner et al. 2020);
- Faster and more accurate development of analytical tools to inform important and emerging scientific and management questions (Zipkin 2019);
- Enabling artificial intelligence developments to improve the cost-efficiency of biodiversity monitoring (OzFish Dataset).
- Stronger capability to monitor environmental changes and develop appropriate management plans, including expedited capacity to appropriately respond to natural disasters (Donner et al. 2017);
- Increased potential for industry and commercial application of data products and information (e.g. Carroll et al. 2012);

All field manuals, excluding the manual on survey design, include a section titled "Data Release," which describes ways to ensure public discoverability and accessibility of collected data, thereby abiding by the FAIR (findable, accessible, interoperable, reusable) principles (Wilkinson et al., 2016). In the first version of the field manuals, these sections did not provide a clear national standard and instead refer to anticipated improvements in subsequent versions. This vagueness was due to the current lack of established national data infrastructure able to incorporate appropriate or comprehensive information produced from the sampling platforms.

To meet these challenges related to data discoverability and accessibility, a series of workshops were held in the months following the field manuals release (July – September 2018, July 2019), including focused workshops on bathymetry data, marine imagery, and biological specimen data. The bathymetry data release protocols are dependent on new digital infrastructure being developed as part of the AusSeabed program (www.ausseabed.gov.au). In contrast, marine imagery and biological specimen data are linked to existing digital platforms (Squidle+, GlobalArchive, OBIS Australia, Atlas of Living Australia) so priorities are to establish appropriate workflows linking these platforms with the data collection phase, and to find the resources needed to ensure they can be developed and maintained. Further recommendations the discoverability of marine imagery and biological specimen data can be found in the relevant workshop reports (Przeslawski et al. 2019c,d).

Regardless of the challenges described above, the appropriate methods for release of marine data depend on the data type (e.g. multibeam, underwater imagery, biological specimen). As such, further details on data management (including accessibility and discoverability) are included in each field manual in the Data Release sections.

Post-survey report

A post-survey report is highly recommended within a year of survey completion. Such a report is valuable documentation of the survey objectives, methods, and preliminary results. It is especially important because it is a single resource describing the multiple methods and data often acquired from a given survey, and it provides overarching context to a survey that is not found in the associated metadata or data. Many agencies have their own post-survey report template, and we have also included one with suggested headings and content in Appendix B for reference.

Outreach and Maintenance

After the release of the Version 1 of the field manual package in early 2018, efforts were focussed on outreach to increase the adoption of the field manuals by the broader marine science community in Australia, as well as industry, regulators, and policymakers. This was done initially through conference presentations and face-to-face meetings, with follow-up meetings and questionnaires to gauge the success of adoption. Outreach and engagement efforts were focussed on establishing institutional uptake of the field manuals, rather than just individual uptake. This ensures the continuity and long-term applicability of the SOPs even if advocating individuals leave an agency. Ultimately, institutional uptake will maximise the comparability of datasets from various surveys, thus increasing the amount of comparable data able to be applied to national products and syntheses.

The field manuals are not just applicable to the Australian community; they are also valuable to the international community, both regarding their content and the process used to develop them. The latter was addressed in a scientific journal paper (Przeslawski et al 2019a), while the content is available through the international searchable Ocean Best Practice Repository (www.oceanbestpractices.org) (Pearlman et al 2019).

Support was available to develop a Version 2 of this field manual package following additional community consultation and input. There will be a need to develop subsequent versions for the following reasons:

- Keeping up with technological advances to ensure uniformity of data acquisition across multiple agencies over time is a challenge for some platforms, particularly those that are based on rapidly advancing technology (e.g. AUV, MBES). In order to ensure that field manuals include relevant advances, they should be periodically checked and revised, lest they become superseded or obsolete.

- Over time, opportunities may arise for increasing the amount of standardisation between research providers. This may come from the acquisition of new sampling gear, changes in research staff, or development of new projects and monitoring programs.

- The way in which the data are stored in aggregated databases will evolve over time. Currently, for many platforms, there is a competitive environment within this area. Competition is a force for change, and so change is likely to occur. The 'Data Release' sections of each manual will almost certaintly need to be updated by 2025 to account for these developments and provide clearer and more definitive instructions (e.g. Przeslawski et al 2019d).

- Each field manual has a sub-section on uses of the sampling platform in marine monitoring. This will need to be periodically updated to include new research and monitoring outcomes.

- One of the strengths of this field manual package is the collaborative approach taken to ensure representation of a range of organisations and disciplines. As time passes, this representation will become increasingly outdated, and new and different researchers should be given the opportunity to contribute.

- Suggestions about standard vocabularies for metadata are currently lacking, and there is an opportunity to help guide the AODN and other programs regarding controlled metadata vocabularies in future versions.

- The new online platform managed through GitHub Pages was chosen partly due to the inherent version control features. Nonetheless, an update or new system to host these field manuals may be required in the future.

A long-term plan for managing the field manuals has not yet been developed, with the exception of the multibeam field manual which will be overseen by AusSeabed. Efforts are still needed to establish a high-level oversight committee to develop and implement actions needed for future versions and to strengthen institutional uptake. At the time of writing this introduction, the most likely groups for this responsibility are the National Marine Science Committee's Monitoring and Environmental Baseline working group, the AODN and/or a future iteration of the NESP Marine Hub.

Version 2 - Updates and Revisions

Version 1 of the field manual package was released in February 2018, and Version 2 was released two years later in July 2020.

All original chapters were updated in Version 2 with stakeholder feedback, corrections, and updates where applicable. The chapter 'Seafloor Mapping Field Manual for Multibeam Sonar' was substantially changed in Version 2 to amalgamate it with the *Australian Multibeam Guidelines* which were released in June 2018 by AusSeabed, a nationally seabed mapping coordination program. The unified multibeam manual in Version 2 addresses stakeholder concerns about maintaining two separate SOPs for multibeam sonar. In addition, a new manual on ROVs was developed for the Version 2 package. The ROV was chosen based on findings from a report titled Scoping of new field manuals for marine sampling in Australian waters (Przeslawski et al. 2019b).

All major changes related to a given sampling platform are logged in a version control table at the end of the relevant manual.

One of the most notable changes for Version 2 was the development of an online portal for the field manuals (https://marine-sampling-field-manual.github.io). While Version 1 was released as static pdfs through the NESP Marine Hub website, Version 2 was released through GitHub. This digital delivery system has the following benefits:

- The manuals are easily accessible in online or pdf formats, increasing the flexibility of user experiences and needs.

- The online system readily reflects minor corrections by harvesting through the source document maintained on Google docs.

- Updates and version control are easier to manage through permissions on GitHub and GoogleDocs.
- Analytics are easily generated to track downloads which can then be incorporated into impact assessments.
- A clearly documented user-friendly workflow (Figure 1.5) will help future contributors to maintain and update existing SOPs and to develop new ones.
- The online system will have more flexibility to embed imagery and other media (e.g. video tutorials) in future versions, thereby taking a much more modern approach than only static pdfs allow.

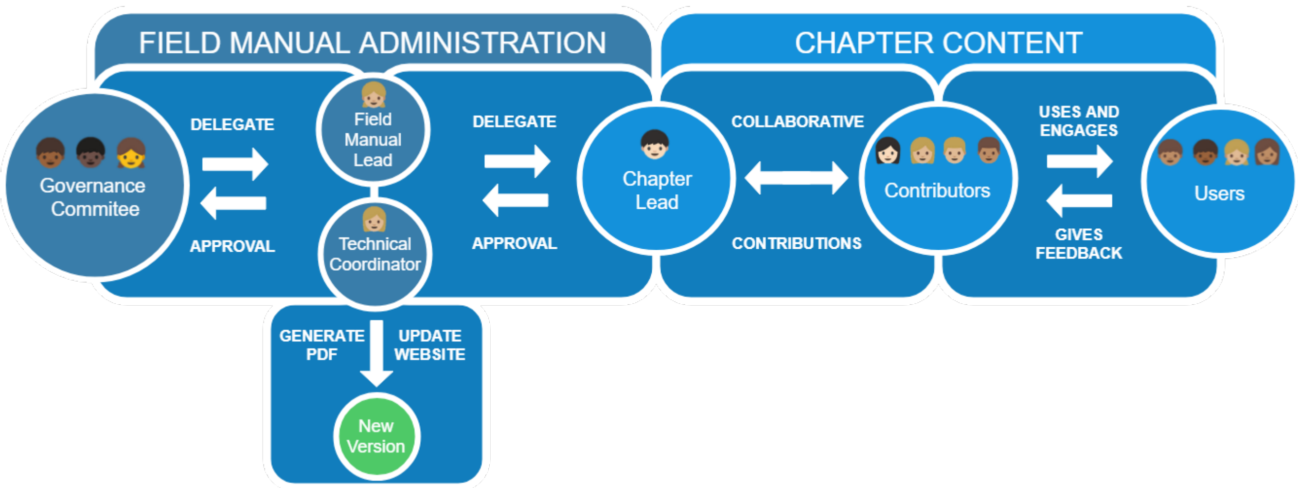

Figure 1.5: Workflow of version control and governance for the digital field manuals of Version 2 and future versions.

Collaborators

All individuals that contributed to versions 1 or 2 of this field manual package are listed below, with the following categories assigned based on their level of contribution:

- *Editors* oversaw production of the entire field manual package, ensuring fit-for-purpose content and consistent scope, style, and formatting throughout.
- *Lead authors* led working groups associated with discrete chapters or sampling platforms.
- *Authors* helped write chapters or provided crucial information to do so.
- *Contributors* participated in working group discussions.
- *Reviewers* provided assessments of draft chapters. In some cases, reviewers of Version 1 became co-authors of Version 2 due to their extensive contributions.

First name	Surname	Agency	Role	Chapter
Rachel	Przeslawski	Geoscience Australia	Editor, Lead author	All
Scott	Foster	CSIRO	Editor, Lead author	All
Neville	Barrett	UTas	Lead author	AUV, ROV, MBES
Phil	Bouchet	UWA	Lead author	P_BRUV, BRUV
Andrew	Carroll	Geoscience Australia	Lead author	Towed Vid, AUV
Tim	Langlois	UWA	Lead author	BRUV, P_BRUV, Intro
Aero	Leplastrier	Geoscience Australia	Lead author	MBES (V2)
Vanessa	Lucieer	UTas	Lead author	AUV, MBES (V1)
Jac	Monk	UTas	Lead author	ROV, AUV, BRUV, TowVid, Stats
Kim	Picard	Geoscience Australia	Lead author	MBES (V2)
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Todd	Bond	UWA	Author	ROV
Tom	Bridge	AIMS	Author	AUV
Mike	Cappo	AIMS	Author	BRUV
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Nicole	Hill	UTas	Author	AUV
Garnet	Hooper	RPS	Author	Stats, Grab
Geoffrey	Hosack	CSIRO	Author	Stats
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* An abridged version of the grab field manual was developed for the AHO for sedimentology, excluding geochemical and biological data.

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2. STATISTICAL CONSIDERATIONS FOR MONITORING AND SAMPLING

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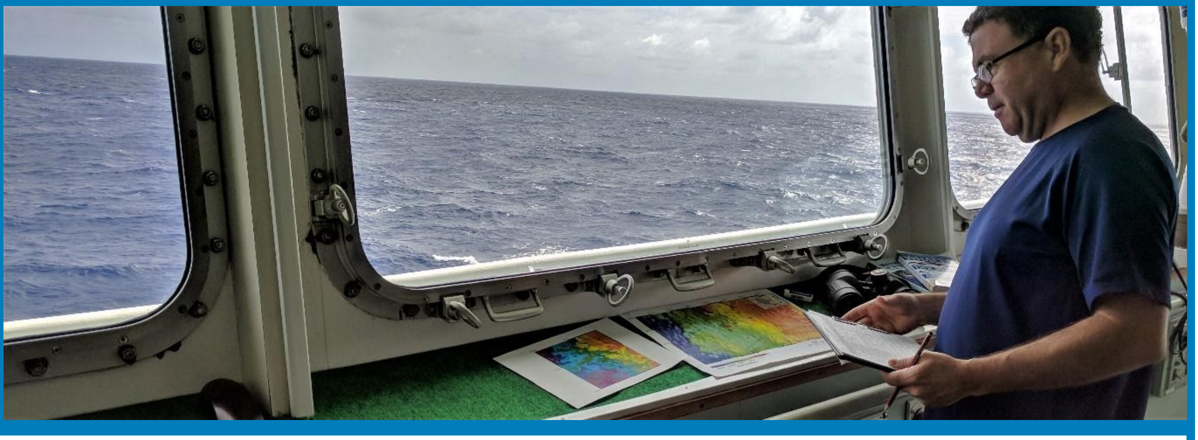

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Introduction

A rigorous scientific process is essential to forming sound conclusions that can inform evidence-based decision-making. This process starts with defining a research question, assessing what level of information is needed and then critically assessing how that information should be obtained (see Table 2.1 and Hayes et al., 2019). Evidence can be obtained from a variety of sources, ranging from expert opinion, through ad-hoc data collection, then well-designed observational surveys, and finally to randomised controlled experiments. Well-designed experiments/surveys that are targeted to the research question are often more expensive than other options, and in certain circumstances (e.g. an inabillity to randomly allocate sample units to treatment/control groups), may be unavailable. The other sources of information, however, may be adequate depending on the research question and situation (see Leek and Peng, 2015). Table 2.1 for example provides a brief overview of a hierarchy of research questions and the types of data that are appropriate to answer them.

Table 2.1: Different types of research questions (adapted from Leek and Peng, 2015 and Hayes et al 2019).

Research Type	Description	Example Question	Examples of adequate data sources	Complexity
Descriptive associations	Summaries of observed data	What is happening within our *sample?*	Expert judgement*, and all forms of controlled/uncontrolled trials, and observational studies with or without a representative sample	Simple
Exploratory	Identify trends and relationships *within the sample*[1]	What correlates with reef die-back in the sample?		↓
Inferential	Extending the patterns in the sample to the *population* from which the sample was taken	What is the status of species X in a marine protected area?	Expert judgement*, all forms of randomised controlled trials, and observational studies with a representative sample	
Predictive	Predict the values at unsampled locations based on sampled data	What assemblage is likely to be found in this location?		
Causal	Identify the reason for a particular association	Are the management actions having an effect?	Expert judgement*, all forms of randomised controlled trials and observational studies with a representative sample so long as the effects of potentially confounding variables can be controlled.	Complex

There is no way to tell if the *sample's* associations are the same as the *population's*

*Expert judgement will likely be influenced by a variety of well known heuristics biases. Attempts should be made to control for these during any elicitation exercise.

Observational studies using data from well-designed surveys (e.g. surveys that ensure samples are representative of the population of interest) are able to answer all types of research questions, and are sometimes the only source of adequate information (Table 2.1). These research questions include those concerning status and trends of biological populations and ecological metrics.

Observational data are generated by scientists observing the current state of the system, whether it be an altered system (e.g. after the establishment of a reserve or an industry) or not (e.g. a baseline survey). The key attribute of an observational study is that there is no attempt to intentionally alter parts of the system for the sole purpose of quantifying effects. Rather, the data is gathered and analysed in a manner that provides information on what the system is like (its status), how it is evolving (its trends) and what may be responsible for these trends (its causative factors). As an example, if baseline/ground-truth surveys are conducted inside and outside previously established no-take marine park boundaries, then they would generate observational data. This chapter discusses the requirements for appropriate statistical design for this observational data.

Causal research questions (attributing observed changes to specific causes) are the most difficult questions to answer. In this case (ideally randomised) controlled experiments are typically recommended, but in this context there are usually limiting factors whose discussion is beyond the scope of this manual (see Hayes et al., 2019). Causal questions require special care and are usually more demanding in terms of the resources needed to answer them. Here we focus on (marine) observational surveys, and in particular the design of surveys. Whilst the topics discussed in this section are relevant to investigating causal relationships, other considerations associated with the analysis of observational data would also be required to be addressed before undertaking causal research (and we do not deal with these issues here). For more information on the evidence hierarchy, and a more thorough description of the different design types for marine ecology, see Hayes et al. (2019).

A key concern in this scientific process is ensuring that survey data are trustworthy and fit-for-purpose (i.e. can answer the research question). To this end, it is important that surveys and monitoring programs are designed and implemented in such a way that the resulting data are: (i) appropriate for the research question under consideration; (ii) representative of the population under investigation so that (for example) the sample mean is generalisable to the population mean; and (iii) information rich so that uncertainty around inferences is reduced as much as survey budgets will allow. We focus here on survey designs that will help ensure environmental monitoring programs deliver data with these characteristics.

Scope

This chapter will not follow the usual presentation for statistical design in ecology. Rather, we will focus on what we believe to be the most important aspects from a practical (and management) viewpoint. We do not intend it to be like a 'text-book' and explicitly do not include formulae or descriptions of tangential details. Readers will want to look elsewhere for such detail (Urquhart and Kincaid, 1999; Gitzen *et al.*, 2012; Thompson, 2012, are a good start, although there are many). We hope to only introduce the relevant concepts and stress that these are the things that should be thought about by all researchers involved with survey planning. In particular, we discuss: (i) setting the research objectives, (ii) randomisation, (iii) efficiency of design, (iv) uncertainty reduction, (v) sampling in space and time, and (vi) specifics for different gear types. This all leads to an illustrative example design, using the *MBHdesign* R-package. (available from CRAN, https://cran.r-project.org/package=MBHdesign). For those readers interested in acronyms: *MBHdesign* stands for *M*arine *B*iodiversity *H*ub *design*. The goals and techniques implemented in *MBHdesign* are outlined throughout this chapter.

Research Objective(s)

The first, and most important factor in developing an appropriate statistical design, is knowing the objective(s) you're asking (your scientific hypotheses) and hence the type of question(s) you are seeking answers to. The objectives will have direct, and sometimes obvious, implications for design. As an example, if the objective is to estimate the effect of implementing a management zone (e.g. a no-take reserve) - a casual type of research question - then at a minimum samples will have to be taken from outside the reserve (a control) as well as within it. We think it useful to consider the following list of probing questions before starting the design process.

i. What is the primary research question? Is a comparison between areas of interest required (e.g. impacted/not-impacted)?

ii. What is the appropriate metric to measure (and to subsequently analyse)? Often measurements will be taken on species (e.g. biomass, size, presence-absence, and/or abundance), but analysed as a different quantity (e.g. a diversity index).

iii. What are the primary sources of potential difference, if any? This will depend on the research question (e.g. impacted/not-impacted areas) but may also include extraneous variables such as environmental conditions and human impact.

iv. Could locations with different 'treatments' also differ in other important variables, so that there is potential for confounding? An example is whether the habitats within and outside no-take reserves are different.

v. What resources are available for conducting the survey? Is there a particular type of sampling platform that should be used (see the remaining chapters)? What previously-collected information is available to aid the current survey (e.g. bathymetry or back-scatter data)? How can we use the previously collected information? Does the previously collected information make one sampling platform or unit of measurement a better candidate than another? How many samples can be taken? This last question also directly affects the *power* of the survey to detect differences in contrasts of interest. See Section 'Uncertainty, Precision and Power' for more discussion on power.

Random Sampling

In all areas of science (and where statistical methods are applied), representative samples are typically achieved by randomly selecting samples from a wider population (e.g. Thompson, 2012; Smith et al., 2017; Tillé and Wilhelm, 2017). Random sampling ensures that the information contained in the sample is generalisable to the population that it was obtained from (Fisher, 1925). Simply using some sort of random sampling ensures that the data are representative and thereby able to answer many types of research questions (see Table 2.1).

An alternative, which is unfortunately common in marine ecology, is to select sites based on other (non-random) properties. These properties could include their convenience to be sampled, or what a researcher expects to find. This is called 'ad-hoc', 'opportunistic', 'haphazard', 'judgemental', 'purposeful', or 'convenience' sampling. While at first glance this approach appears to be efficient, it in fact diminishes the ability to answer any questions about the population as a whole, which limits questions to those involving the specific sample only: descriptive and exploratory questions (unless non-testable assumptions are made). The reader is referred to Smith et al. (2017) and Dobson et al. (2020) for recent discussions on this topic in ecology.

The implication here is immediate and clear – **researchers should randomise** the sampling process if they expect the patterns observed in the sample to hold in the population. Researchers should not routinely perform haphazard sampling. Of course, there may be situations where a particular location appears so interesting that it could be *appended* to a randomised survey design, but its data can only be included into the analysis with additional (strong) assumptions and/or complexities in analysis approaches. The randomisation process is particularly important for monitoring programs where data from multiple surveys (through time and/or space) are combined.

An important side-effect of randomisation is that a researcher must specify what the statistical population under study is. Formally, for surveying geographic areas, the population is a collection of potential survey locations from which a random sample is taken, often called a *sample frame* in the literature. The formal specification of the sample frame is important as it gives the extent to which the results are legitimately generalisable. A sample frame may be delimited by some combination of: spatial extent, depth, habitat type, season and the type of sample that the selected gear can adequately collect. Generalisation beyond the sample frame requires assumptions, often quite strong assumptions, that the processes outside the sample frame are identical to those within it. It is best to try and avoid these assumptions by expanding the sample frame prior to undertaking the survey.

Efficient Designs

Simple randomisation – randomly scattering sampling locations through space – is not necessarily an efficient approach, and in many circumstances a large number of samples are necessary to obtain acceptably precise estimates of population parameters (e.g. Tillé and Wilhelm, 2017). This potential inefficiency is one of the reasons that haphazard sampling can initially although mistakenly appear quite attractive. There are, however, ways to address inefficiency, and to generate designs that require fewer samples and resources. Various researchers have proposed statistically valid restrictions on the randomisation process. In the environmental sciences this discussion has ultimately led to several forms of spatially balanced designs (Stevens and Olsen, 2004; Dobbie et al., 2008; Grafström et al., 2012; Grafström, 2012; Grafström and Tillé, 2013; Grafström, 2013; Robertson et al., 2013; Brown et al., 2015; Foster et al., 2017; Tillé and Wilhelm, 2017), with similar ideas known as 'spatial coverage designs' (Royle and Nychka, 1998; Brus et al., 1999, 2006; Minasny and McBratney, 2006; Walvoort et al., 2010) and 'even sampling designs' (Chen et al., 2012).

A spatially balanced design can be seen as an extreme form of stratification (Stevens and Olsen, 2004) that aims to reduce the frequency of placing samples close to each other (relative to simple randomisations). This process improves efficiency by reducing the amount of spatial auto-correlation between data implying that each sample is providing as much unique information as possible (Grafström and Tillé, 2013). Additionally, spatially balanced designs are more efficient than other types of randomised designs as they tend to increase balance on many environmental variables (also known as covariates), where the population's covariate mean is equal to the sample's covariate mean (Grafström, 2013). This is more than just stratifying for important environmental gradients, as that process does not ensure balance unless explicitly accounted for. Even if balance is sought in stratification, the simple randomisation process within strata lacks efficiency, can complicate analyses, and can be wasteful of 'degrees of freedom' in the analysis (reducing analytical power – where relevant). In summary, spatially balanced designs are used to enhance efficiency so that the greatest amount of information is obtained from any number of sample locations (compared to other forms of randomisation).

This type of efficiency is not the only consideration though - logistical considerations often impose practical constraints. Take for example baited remote underwater video (BRUV) surveys where there are often multiple BRUV cameras, each of which must undergo a ‘soak time’ before the data can be collected. In this case, it is inefficient to sit at a single station during the soak time of each and every BRUV deployment (not sampling and not travelling to other sample locations). Instead, it may be better to make multiple deployments in a spatial ‘cluster’ with all the available BRUVs sampling simultaneously. Similar arguments can be made for sampling gear that takes considerable time to deploy and retrieve (e.g. SCUBA), where multiple transects can be swum in a single dive. This type of design is known as a cluster design in the sampling literature (Thomson 2012) and has been successfully used for marine sampling (e.g. Lawrence et al., 2015 and Hill et al., 2018). The location of the clusters can still be spatially balanced (Lawrence et al., 2015), which gives the spatial balance over the survey area. We suggest trying to make the number of clusters as large as possible, especially if there is a trade-off between the number of clusters and the size of those clusters. In some situations, like the BRUV example, the number within each cluster may be naturally specified by the number of BRUV cameras that are available or can be safely stored on the vessel. All design decisions have implications for analysis, and using nested designs is no exception. When analysing nested data, there should be some accounting for within-cluster correlation. This can be achieved using a cluster random-effect, or by using a geostatistical model (e.g. Diggle, P. & Ribeiro, 2007 and Banerjee, et al. 2004).

Some researchers will know spatially balanced designs as ‘GRTS’ (for generalized random tessellation stratified; Stevens and Olsen, 2004), but GRTS is just one type of spatially balanced design. It is a good design approach and it is the prime reason that spatially balanced designs are gaining popularity. However, it is not the most spatially balanced design, which implies that it is also not the most efficient (Grafström et al., 2012; Robertson et al., 2013; Foster et al., 2017). Between the various spatially-balanced design types, the differences in relative performance are minor. Computational methods for GRTS, via the *spsurvey* R-package (Kincaid and Olsen, 2016), in our experience can be cumbersome, time-consuming and in some ways inflexible. Experienced GRTS users can legitimately continue using it, as the efficiency cost is not large, and they have already overcome many of the more cumbersome aspects. However, we recommend that new users start with *MBHdesign*.

While we focus here on spatial balance, many (but not all) of the algorithms for producing spatial balance can be employed to sampling situations that involve more than just 2-dimensional space. In particular, the algorithms implemented in *MBHdesign* are equally applicable to space-time scenarios and even space-depth-time ones (where a 3-dimensional volume, such as a water mass, is sampled over time). In fact, the algorithms scale well with dimensions, and there is no limiting dimensionality, except what is practical in the application.

The efficiencies of spatially balanced designs can be further improved by increasing the probability of selecting sites (sampling locations) where the sampling variable is thought to have greater variance (e.g. Godambe and Joshi, 1965; Brewer et al., 1988; Chambers, 2011; Grafström and Tillé, 2013). Here, we use the term ‘site’ to mean the location where a single deployment is made. We note that others may have slightly different definitions. This is achieved by altering the so-called inclusion probabilities of each potential site. Inclusion probabilities specify the chance of each site being randomly chosen to be part of the survey and they can be chosen on the basis of data from a pilot study or from other sources (e.g. literature on similar species and/or regions). A very low inclusion probability (near zero) will imply that the site will almost never be sampled, whereas a site with very high inclusion probability will be chosen much more often. The inclusion probabilities are prescribed by the survey designer to indicate where the sampling effort should be placed (see Grafström and Tillé, 2013, for more information on how to perform this task).

In ecology, where univariate biological variables often have an increasing mean-variance relationship (e.g. through Taylor's power law; Taylor, 1961), this equates to increasing inclusion probabilities in locations where the variable being sampled is expected to have high abundance (noting again that this often the motivation for judgemental samples but here we embed auxiliary information on abundance within a strictly probabilistic framework). If no prior knowledge exists about the variable under study, which may have been obtained from previous surveys or a pilot study, then the inclusion probabilities should be equal.

Special consideration is required in situations where there are multiple outcome variables to be measured, such as the sampling of multiple different community types or multiple species. In these cases, the inclusion probabilities should reflect 'combined usefulness'. For sampling multiple communities/species this means that each community/species should be effectively sampled and that the combined inclusion probabilities should reflect this. Whilst the 'combined usefulness' concept is vague, it should reflect the combined utility of each sampling site to each component of the multivariate observation. In situations where the multivariate observations are independent or even negatively correlated, such as communities occupying different habitats might be, then inclusion probabilities may be increased for each different habitat. The nett result of this process may be an inclusion probability surface that is quite even and so equal inclusion probabilities may be a good default..

Altering inclusion probabilities requires the identification of one or more measured covariates (available at time of design) that can be used to guide the variation in inclusion probabilities. It is beneficial only in situations where the inclusion probabilities are related to the sampling variable. When inclusion probabilities *do not* have this relationship, then this will cause a *loss* of efficiency (lower precision) than equal inclusion probabilities. We caution against using too many covariates in the design stage and point out that equal inclusion probabilities is a conservative and usually adequate approach. In fact, fewer covariates is better in many ways. The simple reason is that if they are used to define the design then they must also be used in the analysis (as the design is conditional on these covariates), see Gelman et al. (2013) and Foster et al. (2017) for discussion. This means that precious 'degrees of freedom' must then be used to estimate potentially non-helpful parameters, which has the effect of increasing analysis complexity and reducing the discrimination ability of the analysis. So, the survey designer must weigh up the anticipated reduction in variation due to incorporating the covariate against the necessity to use more terms in the model. When there are multiple sample variables of interest, altering the inclusion probabilities should be considered carefully as altering the probabilities to reduce the variation in one variable may be at the expense of others.

The concepts of stratification and altered inclusion probabilities are almost, but not quite, identical in situations where stratification is applicable. However, at the cost of being conceptually more sophisticated, the inclusion probability concept is more general and more flexible. The reasoning for the equivalence is that the inclusion probabilities can be designed to match the stratification, so that *on average* the specified number of survey sites is chosen within each strata, but this is not guaranteed for every randomised design. Contrastingly, all stratified designs will have the specified number of survey sites within each strata. To us, this is not a large difference and the ability to spatially balance the design is likely to lead to bigger benefits. We therefore recommend altering inclusion probabilities with spatial-balance in preference to formal stratification. However, stratification is not a bad option and is more efficient than simple randomisation (when the stratification is meaningful). We note that the *spdesign* software that implements GRTS allows for stratification *and* spatial balance by balancing within each spatially-contiguous strata.

When planning marine monitoring programs, the ability to incorporate any existing sites will often be advantageous, especially when those sites are part of a random sample. An example is when certain sites are mandatorily sampled to achieve regulatory compliance or where sites must be sampled in the future to demonstrate compliance. In the NESP Marine Biodiversity Hub, methodology was developed to incorporate these *legacy* sites into a spatially balanced design. Legacy sites (or historical, reference or sentinel sites) are those sites that have been sampled in the past and the researcher wants to re-visit them as part of the upcoming survey for comparability, or sites that must be sampled in the future, for example to quantify the effects of decommissioning oil and gas platforms in-situ. Readers are referred to Foster et al. (2017) for details. Briefly however, spatial-balance is achieved by setting the inclusion probability of legacy sites to one and adjusting inclusion probabilities (within the proximity of legacy sites) downwards so that new samples are less likely to be placed very near them.

Software

There are many pieces of software that will generate spatially-balanced designs, most of which are based on different algorithms. For monitoring the marine environment, we developed a specific software – the R-package *MBHdesign*. It is intended to be easy to use and tailored to common situations in marine ecology. It also has the ability to make designs spatially balanced around existing legacy sites, see Foster et al. (2017), and also for designing surveys with sampling platforms that are transect-based, see Foster et al (2019). We will use *MBHdesign* in the example to follow.

Uncertainty, Precision, and Power

It is important to consider how to reduce the uncertainty (and increase precision) in statistical analyses of survey/monitoring data. Practically, there are two components to this: 1) increasing the information content in the dataset; and 2) reducing non-relevant variation (noise) during the collection process. Addressing the first component, increasing information content, begins by using an efficient survey/monitoring design, such as a spatially balanced design. More information implies that the signal in the data can be clarified with greater ease. The second component (noise reduction) refers to that part of the variation in the data that is induced by (for example) performing assays slightly differently each time. This includes the measurement tools used (e.g. CATAMI for image classification; Althaus et al. 2015). This type of noise can be reduced by adhering to well-defined, repeatable, measurement protocols and classification schemes so that two or more measurements on the same sample will generate identical or at least very similar observations. See the gear-specific chapters in this field manual package for detailed advice on reducing measurement noise. As an example, consider the scoring of an AUV mission. Scoring more images from the mission (less subsetting) and using a higher density of points within each image will reduce measurement variation. There is diminishing returns though, with more points becoming less and less better (Perkins et al.; 2016). What constitutes irrelevant noise depends on the objectives of the study, but additional sources of noise can be subtle and can encompass issues such as taxonomic inconsistency and inclusion of non-target species or individuals of a wide variety of life-stages. The latter may occur from sampling pelagic species in transit to the targeted habitat.

For some novel measurement platforms, measurement/scoring techniques are still being assessed and these updates should be incorporated where possible. Examples of this process are Perkins et al. (2016) for scoring AUV images and Schobernd et al. (2014) for scoring BRUV deployments. We stress though, that whilst noise reduction is important, it is not the only consideration and that particular care should be taken to maintain protocols within already established monitoring programs, or calibrate new protocols with old. In addition to reducing 'noise', it will ensure that, for example, time-series do not get 'broken' and that data are directly comparable in time and space without unfortunate confounding due to a change in sampling methodology or other factors discussed above.

Most chapters in this field manual package are variations on the noise-reduction theme as they provide a foundation for reducing variation between and within surveys. In particular, if adhered to, they will help minimise, or possibly even eliminate, inherent systematic variation (bias) between different surveys or within a monitoring program. This will have the effect of increasing the utility of combining data from different surveys (as there will be minimised bias between the two sets). We have unfortunately come across long-term studies that could not be used to estimate trends in the target species because of inconsistencies in sampling design and implementation (Hosack and Lawrence, 2013).

Any approach to reducing variance in the sample statistics should be welcomed whole-heartedly, so long as there is no introduction of confounding between it and any spatial/temporal signals or other important trends. This includes processes to eliminate obvious sources of measurement variation (e.g. non-uniform gear deployment, faulty measurement equipment, poor laboratory practices) and data entry errors. In well conducted studies, under most circumstances, measurement variation is likely to be relatively small compared to the variation in the ecological processes that are being sampled. Understanding this means that exorbitant amounts of time should not be placed in perfecting each measurement – especially not if the cost of perfection is a substantial reduction in the number of samples taken. Often a much richer sample is obtained (in terms of signal to noise) by taking more, slightly noisier, samples than fewer precise ones. Unfortunately, we are aware of no rules-of-thumb to guide researchers with this issue.

In certain situations, it may be pragmatic to alter the measurement process. For example, in the rare situations where the cost of performing the measurement assay is large compared to the cost of collecting the ecological material, then it *may* be useful to combine a number of samples prior to measurement. However, it is important to realise what is being lost in this case: the ability to understand the variability between samples within the same assay group. This is often a limitation if the combined samples originated in quite different environmental conditions (for example). It should also be noted that in analyses, the combined sample is the sampling unit, not the original ones that contribute to it. Another situation where measurement variation can be reduced is when the assay is both cheap and noisy. In this situation, it can be beneficial to use sub-samples (sometimes confusingly called replicates), which are measurements on the *same* biological material. When sub-samples are utilised, the analyst can partition variation into measurement and ecological components.

Some design experts advise that a power analysis be performed before any survey effort is undertaken. Recall that a power analysis calculates the probability that the survey will be able to detect a difference if there actually is one (a true positive). This is undoubtedly a good thing to do when there is a clear hypothesis to be tested, a meaningful effect size can be stipulated and detected, and an (at least moderately) accurate estimate of variance is available prior to the study. However, this is not always the case. It has been observed that power analyses are often performed without great thought, leading to (perhaps) overly large stipulated sample sizes (e.g. Mapstone, 1995); probably larger than any reasonable budget will allow. The arguments outlined in Mapstone (1995) are, to us, quite compelling as they make a researcher undertaking a power analysis think critically about the relative environmental / economic / political costs of making a poor decision. Sometimes it will be more important to guard against making a false-negative (type II) error than false-positive (type I). Such a situation could occur if the cost of falsely declaring significance is larger than that of falsely declaring *non*-significance (e.g. declaring impact may result in closure of a factory or imposing fishing quotas). This is quite contrary to many applications of hypothesis testing in other areas of science.

If a power analysis is undertaken, then there is some general advice that we offer to marine ecologists. First, don't blindly follow text-book recipes for power analyses. They make some strong assumptions that are unlikely to be met in ecology (e.g. normality of observations, independence of observations, and constancy of variance in space and/or time). Second, be prepared to do a lot of homework about the sizes of the components of variation that you are likely to observe: "How much overdispersion is there in your study region?" "Is there any spatial autocorrelation likely?" "What analysis methods are intended to be used?"

It is our opinion that a very useful, and often not too difficult, method for assessing power is to use simulation. There have recently been attempts to provide simplified R-based tools for this process (Green and MacLeod, 2016, for mixed models), and these show promise. The simulation approach consists of a small number of steps: 1) simulate some data under the alternative hypothesis (incorporating the effect that is being considered), 2) analyse the data and see if there is a significant effect, and 3) repeat steps 1) and 2) many times. The proportion of analyses (of simulated data) that produce a significant analysis will give one minus the power of the test. The simulation approach is not without detractions though, and many of these are shared with all power-analyses. Primarily, the simulation model describes a simplified version of reality, which is likely to be less 'noisy'. The reduction in noise stems from unaccounted for events, such as storms, unusual recruitment events, and so on. Irrespectively, power analyses are widely used and the simulation approach has been used in many places, including the marine realm (Foster et al., 2014, Perkins et al., 2017). Power is not the only piece of information that can come from the simulation though. In particular, it can be used to support the evaluation of how sample size and study design impacts more general monitoring objectives (e.g., the ability to estimate parameters in a model or predict future data).

Spatio-Temporal Sampling

Sampling in space is a task that requires plenty of thought, as demonstrated by the previous sections. Sampling in space *and* time (i.e. monitoring) requires even more thought as there are even more options. Generally, if one wants to sample repeatedly then the focus will be (at least partly) on trends through time. It is commonly established in the survey literature, that the uncertainty around temporal signals is reduced by repeatedly visiting the same sites (e.g. Urquhart and Kincaid, 1999). This comes at a cost though – less sites are sampled and therefore the sample may not be as representative of the population as it could be. Extreme cases in marine sampling are when the sampling gear actively alters the population size (through extractive sampling) or its habitat (for example removal of epibenthic structure). In these cases, repeatedly sampling the same sites will not reflect the trends in the population.

Intuition tells us that, unless sampling is destructive, then you should revisit at *least some* of the sites. This is due to the reduction in variation in the temporal signal (the site-to-site variability is removed). The proportion of sites to be revisited, and the pattern of revisits (e.g. rotating panel, fixed panel, and so on – see McDonald, 2003), will depend upon the temporal (and spatial) variability of the biota under consideration (see Perkins et al., 2017, and references therein). Legacy sites, which come from a previous randomised survey, can, and should, be incorporated into a temporal monitoring program. Our advice is to try and make sure that some legacy sites get sampled during each revisit for new sites. This has the effect of ensuring 'a link back to the legacy site time-series' for each revisit. If the biota change randomly/unpredictably and rapidly, even at the same spatial location, then there is little point revisiting sites. This is especially so for monitoring programs with substantial time between revisits. In summary, think carefully about the relative importance of the temporal signal versus the generality. This will reflect the number of revisits to perform.

Gear-Specific Considerations

Some gear types need special consideration as they naturally force the survey designer into different modes of thinking and have limitations on the type of data collected. To our mind, the biggest distinction in sampling gears for marine biota, for design considerations at least, is whether the gear collects a single observation point from each deployment (e.g. a grab) or whether it collects many (e.g. an AUV). There is some grey area here: we usually class BRUVs as point collection methods and under certain circumstances (outlined below) we might also class trawls also as point source methods. BRUVs introduce uncertainty in the exact area sampled due to variation in bait plumes with different current conditions. Trawls integrate spatially contiguous locations along a transect by means of combining the catch in a cod-end (e.g. Foster et al., 2019). Trawls also introduce uncertainty in the exact area sampled due to the behaviour of the trawl ('digging in' or bouncing off the sea bed) and sometimes not knowing where the trawl has touched/left bottom or where the net is. These can be particular concerns in deeper water without a well-functioning positioning device (USBL).

When the spatial scale of the sample-frame is geographically large, in relation to the transect size (e.g. AUV or trawl) or field-of-view (e.g. BRUV), then all these methods can be treated as point collection and standard survey design principles apply. However, when the sample frame is geographically small in relation to the size of the area sampled by the sampling gear, then the position of the observation within the sampling unit becomes important as biota from two separate samples may be spatially close. The only design advice in the literature for the gear types considered in this field manual package, that we are aware of, is to try and space samples well apart in space within the objectives of the study (Foster et al., 2014). However, recent Marine Biodiversity Hub research aims to provide greater utility around this (see Foster et al. 2019). Developed methods are implemented into the R-package *MBHdesign*.

There are more considerations when designing a transect-based survey when the transect footprint is large relative to the sample frame (e.g. AUV, ROV and towed video). Chiefly, one needs to consider how long the transects are and in what direction the transects should be performed. Our intuition tells us that, logistics aside, the length of the transect should be dependent on the spatial properties of the biota being surveyed. Biota with large spatial autocorrelation should be sampled with many short transects, whereas biota with short spatial autocorrelation could be sampled with longer transects. See Foster et al. (2014) for an example of identifying length and direction of spatial autocorrelation from image-based transect data and see Foster et al. (2019) for how to randomise, with spatial balance, transect samples. Of course, it may be cheaper to deploy the image-based sampling platform for longer and then simply sub-sample or account for the autocorrelation within an analysis model, but the reasoning will still provide advantages. In any situation, care needs to be taken in the analysis to account for this autocorrelation (see next paragraph for further elaboration). The direction of the transects might be gear dependent – for example it may be 'safer' to take transects down-slope or across-slope; or more efficient to tow into the prevailing current. However, irrespective of the restrictions on direction the design should aim to cover the study area as evenly as possible. Image-based transects have further considerations – how much effort to place in scoring each image versus how much effort to place in scoring more images. Perkins et al. (2016) suggests that this too depends on the spatial properties of the biota under consideration and suggests apportioning effort according to these properties.

When designing temporal surveys, it is important to consider if you can actually perform replicates with enough geographical accuracy to be useful. If the exact transect cannot be repeated then there is a confounding of temporal and spatial variation, and if the spatial patterns are quickly changing then the temporal uncertainty will also be inflated (Perkins et al., 2017). This is particularly concerning for gear types that are located only by the location of the deployment vessel. Even for accurately re-deployable gears the spatial repeatability is sometimes not sufficient to adequately determine within-site heterogeneity and detect a prescribed temporal change (Perkins et al., 2017).

Whilst this chapter is about statistical *design*, we feel it important to briefly mention statistical *analysis* of survey data, especially that resulting from transect-based sampling platforms. These produce data that are spatially close to each other, often very close. This naturally raises concerns about spatial autocorrelation and its impact on an analysis. Our advice for these platforms is to use geostatistical models (e.g. Diggle and Ribeiro, 2007; Banerjee et al., 2004). These naturally account for the spatial dependence between observations and adjust measures of uncertainty accordingly. This is not an easy approach and involves a steep learning curve for many practitioners. However, it does circumvent the unfortunate (and dangerous) consequence of falsely considering that there is less uncertainty in the data than there actually is, which is effectively what happens when one assumes that geographically close observations are independent. Subsetting the individual observations within a transect is likely to have some beneficial effect on mitigating autocorrelation (e.g. Mitchell et al., 2017). However, doing so presupposes that the range of the autocorrelation is less than the distance between the subsetted observations.

Mapping as a Foundation

Seafloor data from multibeam sonar and sidescan sonar can cover an entire area (sampling frame) and is a real boon for efficient survey designs. In particular, multibeam data can facilitate the production of base maps covering tens or hundreds of square kilometres, with accurate geo-location. Multibeam data enables the survey design team to produce a design that picks out the major sources of variation in the ecosystem (typically depth and hard substrate), which can then be used to alter inclusion probabilities. To use these data one must consider how the multibeam data might be related to the variance in the target biota being sampled; -- under certain circumstances it is reasonable to spend greater survey effort on hard substrate to reduce variation in parameter estimates. For example, sponge abundance will have higher variance on hard bottom than on soft bottom and so a sponge survey should disproportionally target hard bottom. Once these areas have been (accurately!) identified, then the inclusion probabilities for those regions can be increased, which will increase the chance of sampling hard substrate but maintaining the ability to infer to the sampling frame. This is the intuition in the approach that was used in Lawrence et al. (2015).

Although our recommendation is to map the survey area using multibeam prior to designing biological surveys, it is not always possible. One alternative approach, which tries to leverage as much multibeam information as possible, is to stage the sampling: perform a limited amount of multibeam mapping and work within those limited areas. Done smartly, like in Lawrence et al. (2015) this approach can still offer good estimates of biota. However, it is not without difficulties (principally in the analysis stage) and these complications could be, in some cases, overly limiting. Another possible alternative is to predict the presence and location of important habitat features, such as reefs, using statistical models (!Ref) and use the resulting habitat map to guide inclusion probabilities. We would caution, however, that such an approach will only be advantageous with a well-validated model.

Case Study: Surveying a Marine Park in Tasmania

To illustrate some of the technical aspects of the design process, we plan a baseline survey design for the Governor Island Marine Reserve off Bicheno on the East Coast of Tasmania to establish the status of biota. There are no zones of interest in this example, as the survey is not designed to test a management action (or other source of variation). The marine reserve is geographically complex with boundaries governed by natural land formations. The depth profile of the reserve is decreasing away from the land-based boundary, and there are less 'shallow' regions in the reserve than 'deep' ones.

We will present three designs. The first is a plain (vanilla) spatial design where all sites within the reserve are equally likely to be sampled. The second design intentionally samples shallow sites more often on the assumption that these sites are likely to be more heterogeneous and diverse than their deeper water counterparts. The third type of design is when there are legacy (reference) sites in the area that should be resampled as it is considered important to create a time-series for this reserve. The spatial balance should then account for the locations of these legacy sites when finding the new sites. For more details on how to perform this third type of design, please see the *MBHdesign* vignette (by loading the *MBHdesign* package into R and typing vignette 'MBHdesign'). Another good place to look is the paper describing the method: Foster et al. (2017). The inclusion of legacy sites in this example is somewhat artificial, as we have to first choose the legacy sites to incorporate. However, we hope that the process is illustrative, and stress that it mimics the consequences of real sampling with legacy sites – first the legacy sites are chosen randomly and then the new sites are chosen randomly around them (with spatial balance).

The example here is performed in R, an open source statistical platform. Importantly, there are other free and licensed software and programming languages that can also be used, depending on your proficiency and what is available to you. Some of the code may, at first glance, look a little daunting. Well, that's R for you. Most of the lines written here are for plotting purposes and for reading in data. Since this is a document, we have taken some care with how the plots appear. This produces pretty(er) pictures but it also produces longer and more detailed code. Users should feel free to use the code below as a template, but please don't blindly do so without thinking if the actions of the code are appropriate for your data. If you do re-use code, then please run checks to see if the code has done what you think that it ought to.

If you are new to R, then you could try to get an introduction by one of the many online tutorials (e.g. https://cran.r-project.org/doc/manuals/R-intro.html). That particular one is likely to be like R helpfiles (helpful but takes time) and it could be quite *dense*. Another option is the excellent book Venables and Ripley (2002), which introduces you to R *and* gives a good introduction to some types of data analysis. Other recommended introductions to R include: Crawley (2007); de Vries and Meys (2015). However, these are just suggestions, you should shop-around until you find a reference/tutorial that is at-your-level and in no time at all you will be reading in data, analysing it, plotting it, and summarising results.

Set Up R to Generate Design

To start we have to set up R for generating designs. This should not be onerous in this case. The most difficult thing is in setting up the data file in the first instance (usually through a GIS).

Here we have used an asc file as this is relatively easy to read into R. This file is included in the field manual package, along with the R code to create the output below.

This document was created using the R-package *knitr* (Xie, 2014). It is a wonderful tool, but like any tool it requires interpretation. Most notable here is that the R-code is placed in a grey box, to enable readers to highlight the code versus the document text. Within the code sections, anything that comes after a '#' symbol is a comment that is not interpreted by R (most of these are a brown colour). Bold dark blue words are function names. Dark blue words are argument names. Green is for text and light blue for numbers.

```
##########################################################################
#
####    Read in Data from spatial data (.asc here) and
Organise        ####
####    Foster et al. NESP Biodiversity Hub Field
Manuals              ####
##########################################################################
#

##if you don't have MBHdesign installed, please do so using
# install.packages( "MBHdesign")

#Load required packages
library(MBHdesign) #For spatial sampling
library(fields)  #for lots of things, but for plotting in this example
library(sp)  #for reading the ascii file of cropped depths for the reserve

#Set a seed for reproducability
set.seed(666)

#Read in depth as an ESRI asc file as requested by the sp package.
#This file contains long, lat and depth
#This path/file only exists on the first author's system
#   you will need to change it if running this code
#the projection will need to be changed for each region too
#bth.orig.grid <- read.asciigrid("./ExampleGovIsland/gov_bth.asc",
proj4string = CRS("+proj=utm +zone=55 +datum=WGS84"))
bth.orig.grid <- read.asciigrid("gov_bth.asc", proj4string = CRS("+proj=utm
+zone=55 +datum=WGS84"))

#convert to a data.frame for ease
DepthMat <- as.matrix( bth.orig.grid)
bth.orig.grid <- as.data.frame(
  cbind( coordinates( bth.orig.grid), as.numeric( DepthMat)))
colnames( bth.orig.grid) <- c("Easting", "Northing", "Depth")
bth.orig.grid <- bth.orig.grid[order( bth.orig.grid$Northing,
  bth.orig.grid$Easting),]
#Setting up plotting for now and later
uniqueEast <- unique( bth.orig.grid$Easting)
uniqueNorth <- unique( bth.orig.grid$Northing)
ELims <- range( na.exclude( bth.orig.grid)$Easting)
NLims <- range( na.exclude( bth.orig.grid)$Northing)
```

```
#Fix up ordering issue
DepthMat <- DepthMat[,rev(1:ncol(DepthMat))]
#plot it to see what we are dealing with.
image.plot( uniqueEast, uniqueNorth, DepthMat,
    xlab="Easting", ylab="Northing", main="Governor Island Reserve",
    legend.lab="Depth (m)", asp=1, ylim=NLims, xlim=ELims,
    col=rev(tim.colors()))
```

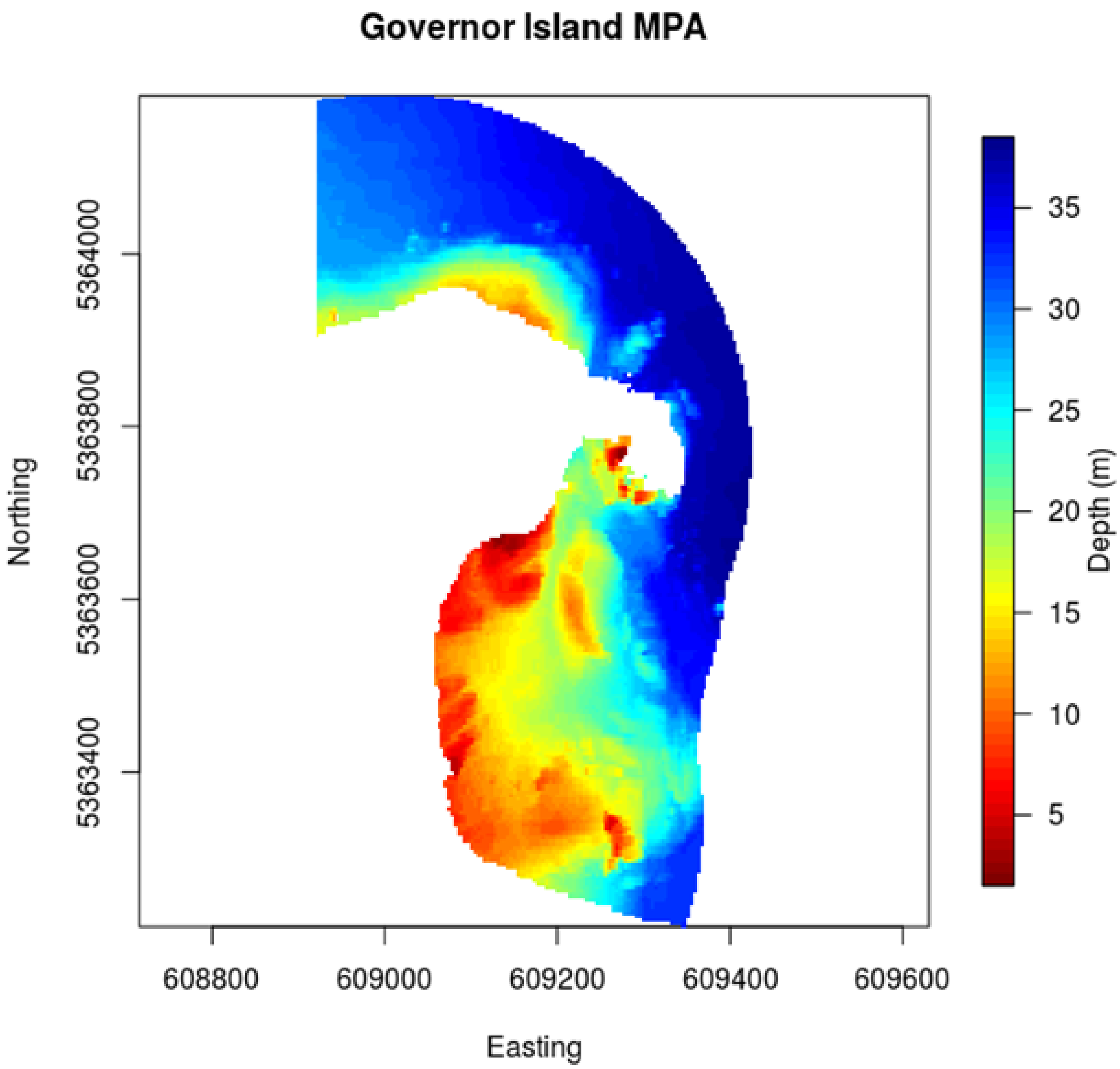

Figure 2.1: Map of Governor Island study region with depths. Note the non-regular shape and the non-uniformity of the region's depth profile.

Generate a spatially balanced design

Generating a spatially balanced design within the reserve is quite straight-forward using *MBHdesign*. Here we do it for 30 sampling sites spread throughout the reserve (Figure 2.1). Note that designs will vary from one realisation to the next, unless the random number generating seed is fixed (like we did in the previous subsection). Try it a few times, if you like, and see what happens between the realisations. Note that *on average* (over all realisations) the spatially balanced designs will have good spatial coverage.

```
###########################################################################
#
####    Spatially balanced design -- uniform inclusion
probs           ####
####    Foster et al. NESP Biodiversity Hub Field
Manuals              ####
###########################################################################
#

#number of samples
n <- 30
#take the sample
samp_spatialOnly <- quasiSamp( n=n, dimension=2,
    potential.sites = bth.orig.grid[,c("Easting","Northing")],
    inclusion.probs=!is.na( bth.orig.grid$Depth))
with( bth.orig.grid, image.plot( uniqueEast, uniqueNorth, DepthMat,
    xlab="Easting", ylab="Northing", main="Spatially Balanced Sample",
    legend.lab="Depth (m)", asp=1, ylim=NLims, xlim=ELims,
    col=rev(tim.colors())))
points( samp_spatialOnly[,c("Easting","Northing")], pch=20, cex=2)
write.csv(samp_spatialOnly, file="spatialOnly.csv", row.names=FALSE)
```

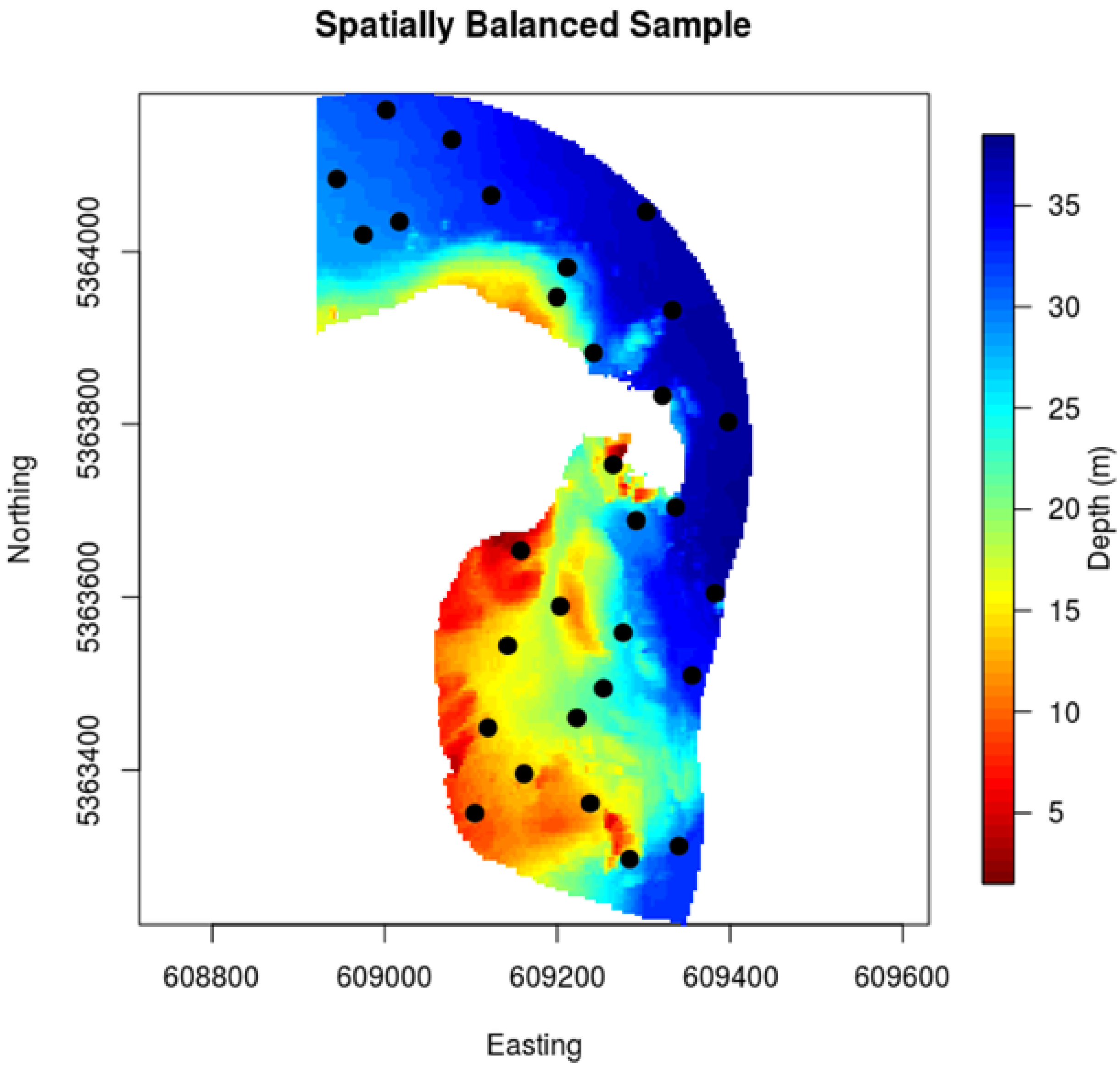

Figure 2.2: A uniform inclusion probability sample for Governor Island.

Preference shallow environments

The equal inclusion probability design (Figure 2.2) assumes that all sites are equally advantageous to sample. Previously, we mentioned that this may not be an efficient approach to sampling. In particular, it can be advantageous to over-sample sites/regions that have greater variability. In the Governor Island reserve, this corresponds to the shallower depths as these typically are more heterogeneous and biodiverse on the east coast of Tasmania. We can design a survey with this in mind by increasing the probability that shallow sites will be sampled (i.e. by increasing their inclusion probabilities). This has the obvious effect of also decreasing the probability that deeper sites will be sampled (Figure 2.3). The code below shows how this can be done. It is a little more involved, but most of the complexity comes from detail. The approach is simple though: 1) find the empirical distribution of depths in the reserve; 2) define the inclusion probabilities based on this empirical distribution; and 3) sample according to those inclusion probabilities. We will sample a few more sites (n = 100), just to make the effect of the depth adjustment clear.

```
################################################################################
#
####    Spatially balanced design -- Depth biased inclusion probs     ####
####    Foster et al. NESP Biodiversity Hub Field Manuals             ####
################################################################################
#

par( mfrow=c(1,3), mar=rep( 4, 4))
n <- 100
#The number of 'depth bins' to spread sampling effort over.
nbins <- 4
#force the breaks so R doesn't use 'pretty'
breaks <- seq( from=min( bth.orig.grid$Depth, na.rm=TRUE),
   to=max( bth.orig.grid$Depth, na.rm=TRUE), length=nbins+1)
#Find sensible depth bins using pre-packaged code
tmpHist <- hist( bth.orig.grid$Depth, breaks=breaks, plot=FALSE)
#Find the inclusion probability for each 'stratum'
tmpHist$inclProbs <- (n/(nbins)) / tmpHist$counts
#Matching up locations to probabilties
tmpHist$ID <- findInterval( bth.orig.grid$Depth, tmpHist$breaks)
#A container for the design
design <- data.frame( siteID=1:nrow( bth.orig.grid),
   Easting=bth.orig.grid$Easting, Northing=bth.orig.grid$Northing,
   Depth=bth.orig.grid$Depth, inclProb=tmpHist$inclProbs[tmpHist$ID])
#Plot the depths and the inclusion probabilties
with( design, plot( Depth, inclProb, main="Inclusion Probabilities",
   ylab="Inclusion Probabilities", xlab="Depth (m)", pch=20, cex=1.4))
#Plot the inclusion probabilities in space
with( design,
   image.plot( uniqueEast, uniqueNorth,
      matrix( inclProb, nrow=length( uniqueEast), byrow=FALSE),
      xlab="", ylab="", main="Inclusion Probability", asp=1,
      ylim=NLims, xlim=ELims))
#Take the Sample using the inclusion probabilities
samp <- quasiSamp( n=n, dimension=2,
   potential.sites = design[,c("Easting","Northing")],
   inclusion.probs=design$inclProb, nSampsToConsider=100*n)
#Plot the design
with( design, image.plot( uniqueEast, uniqueNorth, DepthMat,
   xlab="", ylab="", main="Spatially-Balanced Sample", asp=1,
   ylim=NLims, xlim=ELims,
      col=rev(tim.colors())))
points( samp[,c("Easting","Northing")], pch=20, cex=2)
write.csv( design, file="design.csv", row.names=FALSE)
```

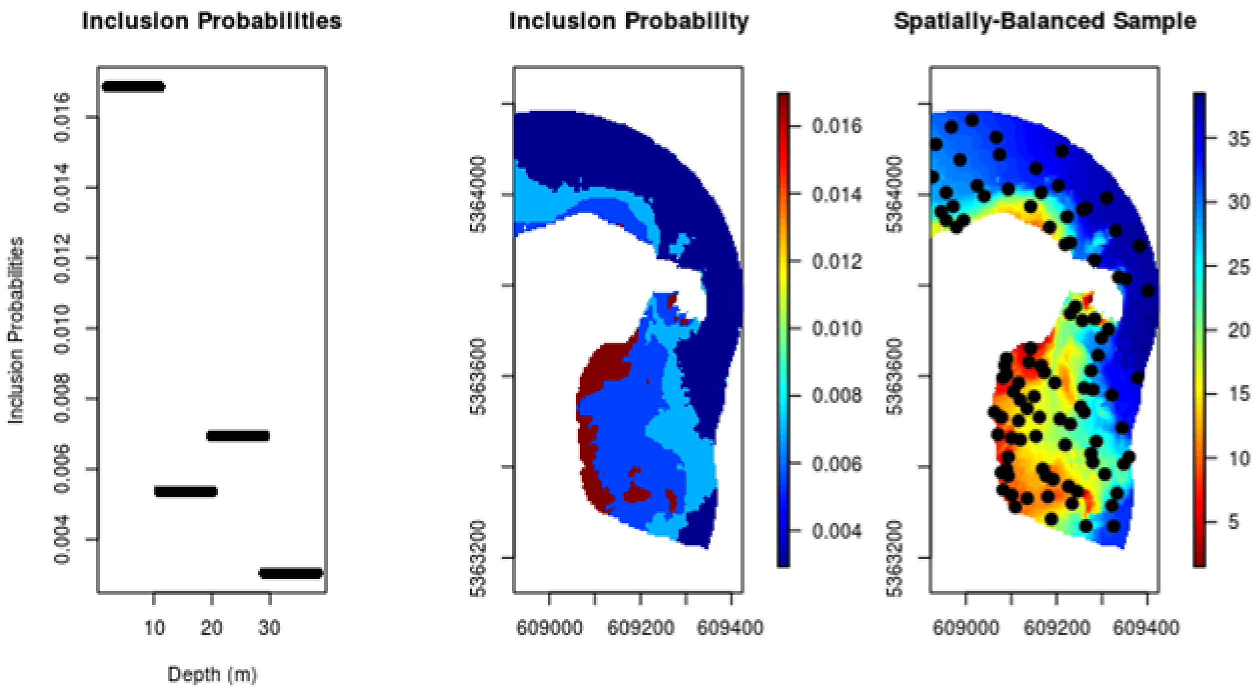

Figure 2.3: (Left panel) The empirical distribution of the 4 different depth bins. (Middle panel) The spatial distribution of the depth bins. (Right panel) A non-uniform spatially balanced sample, with inclusion probabilities based on the distribution of depths throughout the region. Shallow sites have been over-represented in the sample.

Incorporate legacy sites

Here, for edification purposes, we provide an illustration of how to design a spatially-balanced survey that accounts for the locations of legacy sites, which are those sites that we wish to include in the survey. The most likely reason for including legacy sites is that they have been sampled before as part of a previous randomisation process. Various names exist for legacy sites, including ‘reference sites’, and perhaps even ‘sentinel sites’ in some situations.

In our example, we first generate legacy sites and then generate more sites around them. To provide a little extra spice to the design we try to mimic the learning process: the n = 6 legacy sites are chosen with uniform probabilities (as we would do when there is no information about the area) and then the n = 15 new sites are chosen with a depth gradient altering the inclusion probabilities (Figure 2.4). This example therefore incorporates elements of the previous two examples.

```
##########################################################################
#
####    Spatially balanced design -- Legacy Sites (biassed incl probs)
####
####    Foster et al. NESP Biodiversity Hub Field
Manuals              ####
##########################################################################
#

#set up the plotting structure
par( mfrow=c(2,2), mar=c(3,3,3,3))
#number of samples
```

```
n_l <- 6
##Take the sample for the legacy sites.
#Here they are a spatially balanced sample but in practice
# they would be supplied from a previous randomisation process
samp_legacy <- quasiSamp( n=n_l, dimension=2,
    potential.sites = bth.orig.grid[,c("Easting","Northing")],
    inclusion.probs=!is.na( bth.orig.grid$Depth))
#plot the legacy sites
with( bth.orig.grid, image.plot( uniqueEast, uniqueNorth, DepthMat,
    xlab="Easting", ylab="Northing", main="Legacy Sites",
    legend.lab="Depth (m)", asp=1, ylim=NLims, xlim=ELims,
    col=rev(tim.colors()), legend.mar=8.1))
points( samp_legacy[,c("Easting","Northing")], pch=17, cex=2)
#plot the depth-based inclusion probabilities
# scale first to sum to n=15
n <- 15
design$inclProb <- n * design$inclProb / sum( design$inclProb, na.rm=TRUE)
with( design,
    image.plot( uniqueEast, uniqueNorth,
        matrix( inclProb, nrow=length( uniqueEast)),
        xlab="", ylab="", main="Inclusion Probability", asp=1,
        ylim=NLims, xlim=ELims, legend.mar=8.1))
##Depth-based inclusion probabilities
#Alter the inclusion probabilities for the next sample
# inclusion probs taken from previous example
p2 <- alterInclProbs( legacy.sites=as.matrix(
    samp_legacy[,c("Easting","Northing")]),
    potential.sites=bth.orig.grid[,c("Easting","Northing")],
    inclusion.probs=design$inclProb)
#plot the altered inclusion probabilities
with( design,
    image.plot( uniqueEast, uniqueNorth,
      matrix( p2, nrow=length( uniqueEast)), ylim=NLims, xlim=ELims,
      xlab="", ylab="", main="Altered Inclusion Probability", asp=1,
legend.mar=8.1))
##Take the new sample, spatially balanced around the legacy sites
samp <- quasiSamp( n=n, dimension=2,
    potential.sites = design[,c("Easting","Northing")],
    inclusion.probs=p2, nSampsToConsider=100*n)
#plot legacy sites and new sample sites.
with( design, plot( Easting, Northing,
    col=c('white',grey(0.9))[1+!is.na(inclProb)], ylim=NLims, xlim=ELims,
    xlab="", ylab="", main="Combined Sample Locations", asp=1))
points( samp_legacy[,c("Easting","Northing")], pch=17, cex=2, col='red')
points( samp[,c("Easting","Northing")], pch=20, cex=2)
legend( "bottomleft", c("Legacy Sites", "New Sites"), pch=c(17,20), pt.cex=2,
    col=c('red','black'), bty='n')
```

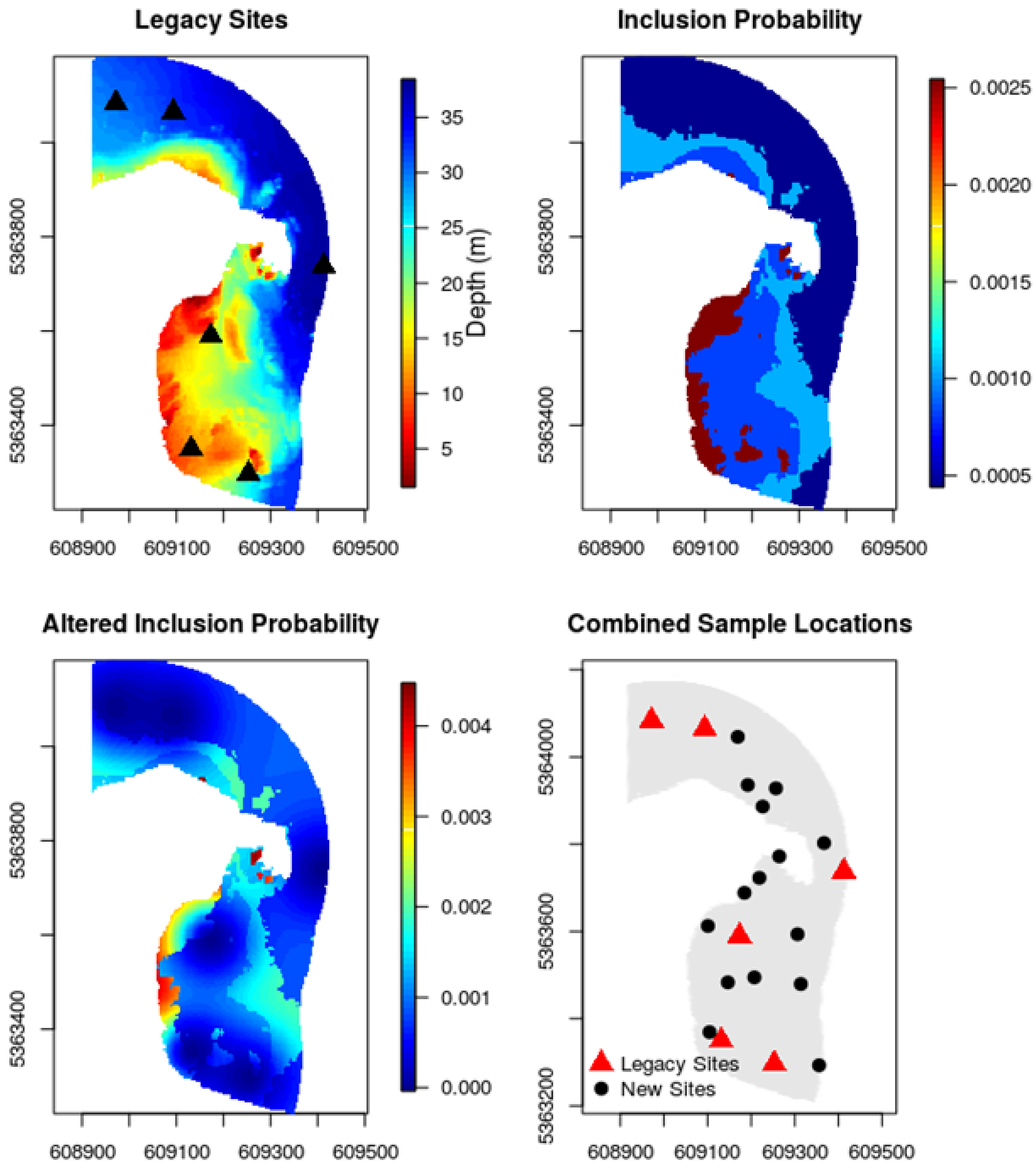

Figure 2.4: A spatially balanced design for Governor Island that incorporates legacy sites and has depth-varying inclusion probabilities (shallow sites are over-represented).

Case study summary

We have now seen how to generate three different kinds of designs: 1) a spatially balanced design with equal inclusion probabilities for when little is known about the sources of variation of the system; 2) a spatially balanced design with unequal inclusion probabilities for when we think we know where the locations with higher variance are likely to be; and 3) a spatially balanced design for when we have legacy sites that we want to take a repeat sample.

If future researchers wish to re-survey the area at some point in the future, then they have a choice to make: (i) Do they wish to revisit the same sites (to get a good temporal estimate)? (ii) Do they choose a new set of sites (to get a good spatial estimate)? Or (iii) Do they assume that the temporal change is not important and include the previous survey as part of the sample? This last scenario would be performed efficiently by using the original sample locations as legacy sites and spatially balance the new sample locations around those (as was done in the example). It will usually be sensible to combine these objectives by repeating some (not all) of the samples but choosing some new locations as well.

Field Manual Maintenance

In accordance with the universal field manual maintenance protocol described in Chapter 1 of the Field Manual package, this manual was updated in 2020 as Version 2. Updates reflect user feedback and new developments. There is currently no long-term plan or support for future updates. See Chapter 1 (Introduction to field manual package) for further details.

The version control for Chapter 2 (survey design) is below:

Version Number	Description	Date
0	Submitted for review (NESP Marine Hub, GA, external reviewers as listed in Chapter 1.	22 Dec 2017
1	Publicly released on www.nespmarine.edu	28 Feb 2018
2	Minor corrections, updates, added references and clarifications.	July 2020

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AUS SEABED

Australian Multibeam

GUIDELINES

2020

with contribution from the National Environmental Science Programme

Marine Biodiversity Hub

Australian Multibeam Guidelines

AusSeabed

GEOSCIENCE AUSTRALIA
RECORD 2018/19

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1. Introduction

High-resolution seafloor mapping has developed into a significant component of the marine surveying industry in the past few decades, with a rapid growth in demand for this fundamental marine geospatial data. There is a large and increasing number of drivers and applications for this data, including:

- navigation and safety of life at sea
- environmental assets management (including fisheries management)
- ocean and climate modelling
- hydrodynamic modelling
- coastal and nearshore sediment mapping
- resource development
- aquaculture planning
- oil and gas subsea assets integrity
- telecommunication cable deployment
- renewable energy assessments
- marine spatial planning
- territorial claims
- demonstration of Antarctic presence
- underwater cultural heritage management
- artificial reef development.

These applications have resulted in seafloor mapping in locations from the upper reaches of estuaries to the abyssal plains from the tropics as far north as Papua New Guinea to the Southern Ocean to the waters of the Australian Antarctic Territory.

In Australia, apart from port and harbour surveying, much of the focus has been on mapping areas of the continental shelf and slope at varying levels of coverage and resolution, which reflect the drivers for mapping, vessel and gear availability, and the combination of targeted and opportunistic data collection. However, despite a significant increase in survey coverage in the past decade, less than 25% of the seafloor in Australia's maritime jurisdiction has been mapped to a relatively high-resolution.

Since only the narrow coastal margin of the seafloor can be detected by airborne or satellite sensors (e.g. lasers; multi-spectral scanners), swath acoustic mapping systems, principally multibeam echosounders (MBES) and bathymetric sidescan sonars (interferometric sonar), are used to map Australia's seafloor. These systems measure water depth, seabed backscatter (commonly known as seabed hardness), and in some cases with MBES, water-column backscatter. Multibeam sonar data is acquired by a wide range of organisations.

However, to better realise the value of these data, collaboration is needed to build broad regional and national seabed data sets. Key to this is the development of common standards for data acquisition, processing and reporting. This data needs to be openly available, and easily accessible for reuse to benefit the wider community (Table 1)

The primary objective of this guideline is to establish standardised approaches to the acquisition and processing of MBES data. Use of these guidelines will improve consistency in the collection and description of the data, enhancing its quality and utility for uptake.

To achieve this objective, AusSeabed was formed, a national seabed mapping coordination program run by a consortium of representatives from Commonwealth and State governments, universities and industry. AusSeabed's role is to encourage and facilitate the acquisition of seabed mapping data and make it available for use by all stakeholders. As such, the program runs a series of coordinated initiatives, including:

- the production of maps identifying completed surveys and priority areas for Commonwealth and State Government agencies
- maintenance of the Australian Multibeam Guidelines (this document)
- the AusSeabed website hosting various resources including survey planning and data management tools, and a data portal providing a gateway to existing data coverage and custodians.

Table 1 Key stakeholders benefiting from better coordination and availability of seabed mapping data and the type of data they preferentially use (note the list is not exhaustive, but intended to give examples)

Stakeholder	**Preferred data type**	
	Source data (raw or processed files)	Products (e.g. maps of seabed depths, habitat, morphology)
Department of Defence (e.g. Hydrography, Mine warfare)	X	X
Marine parks (Australia or States Marine Parks)		X
Department of Industry, Innovation and Science (e.g. NOPSIMA)		X
Industry (Oil & Gas; Infrastructure)	X	X
State coastal planning and management groups		X
Maritime Jurisdiction (Geoscience Australia)	X	
Australian Tsunami Advisory group		X

State and Commonwealth research institutions (e.g. CSIRO, Geoscience Australia, State environment and fisheries agencies)	X	X
Universities	X	X

Overall these initiatives aim to achieve a number of specific objectives, including:

- collation of a historically sorted dataset at an identified level of quality available to all stakeholders within Australia and beyond
- identification of areas where new data collections are prioritised
- enabling stakeholders to better leverage Australia's seabed mapping expertise and capabilities
- providing tools to allow efficient and consistent pre-survey planning
- promote data availability, collaboration and innovation with stakeholders
- utilising national resources in a coordinated effort to map Australia's seabed
- providing clear guidelines that aim to improve data acquisition methods and compliance with recognised standards
- ensuring better informed management of Australian waters through easy access standards-compliant seabed data

1.1 Scope

The Australian Multibeam Guidelines were established by the AusSeabed consortium. The guidelines provide recommended procedures for survey planning, data acquisition and submission. They are designed for a range of audiences, from those experienced in seafloor mapping using multibeam sonar systems, non-experts who are developing mapping capabilities, and those contracting seafloor mapping surveys using swath systems.

These guidelines aim to improve interoperability, discoverability and accessibility of MBES system data, and encourage improved acquisition standards to better meet end-user requirements. We acknowledge that to achieve such an aim, adaptation of the project might be necessary and could impact time and cost. However, in most cases, the inconvenience of varying parameters will be outweighed by the increased utility of the data to a wider user base.

These guidelines aim to provide a standard set of requirements for seafloor mapping activities conducted in Australian waters and comply with international initiatives (such as Seabed2030) to ensure that national efforts can provide global impact. They are designed to complement the purpose-based requirements and associated documentation related to specific survey requirements (e.g., hydrographic surveys; seabed infrastructure planning or installation) (Figure 1).

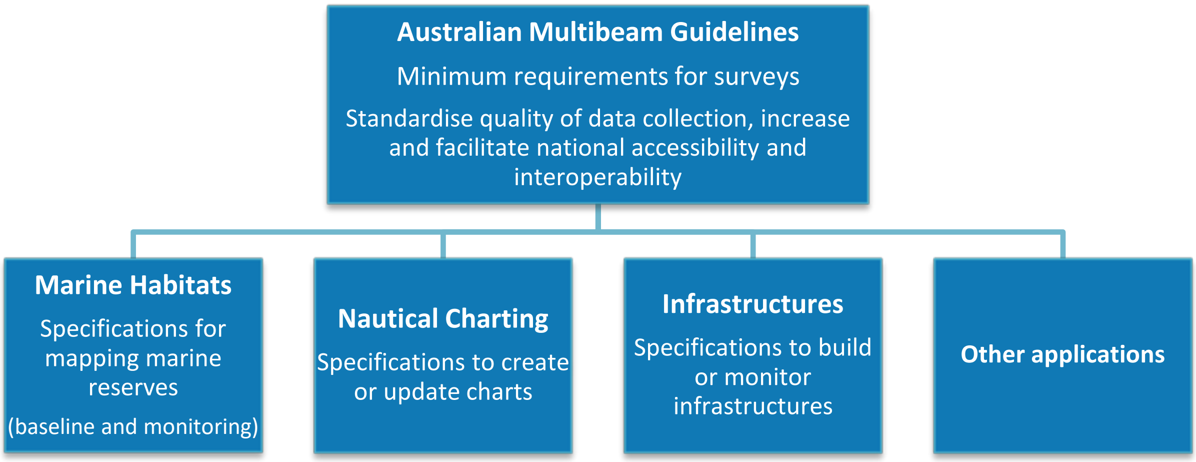


Figure 1 Anticipated key areas of relevance for the Australian Multibeam Guidelines.

The guidelines include a broad examination of data processing and guidance for data submission with recommendations for all three types of swath acoustic data (bathymetry, backscatter and water column backscatter) relevant across all water depths and adopt international guidelines where appropriate. They do not include instrument preparation activities such as bench/workshop tests, personnel requirements, or provide survey costing information (see section 5.3.4 of Przeslawski et al. 2018a for MBES Costing). This revision of the Australian Multibeam Guidelines (version 2) contains information previously published in the *Seafloor Mapping Field Manual for Multibeam Sonar* (Lucieer et al., 2018) as chapter 8 (*Multibeam acoustics for marine monitoring*) and, as such, will also succeed the *Seafloor Mapping Field Manual for Multibeam Sonar* as chapter 3 in the second release of the National Environmental Science Program (NESP) *Field manuals for Marine Sampling to Monitor Australian Waters* (Przeslawski and Foster, 2018). The decision to make this extension to the guidelines and inclusion in the NESP suite of Field Manuals was made by AusSeabed and the NESP to allow both initiatives to continue with a single reference document to inform seabed mapping and eliminate the complications and community confusion associated with the maintenance of two reference documents with extensive overlap.

1.2 How to use these guidelines

To help navigate these guidelines, Table 2 identifies sections that are more relevant to various user-groups. Glossaries of abbreviations and terms are included in appendices A and B, and a variety of tools and resources available are included in Table 3. Some tools are still under development and will be shared through the AusSeabed website.

These guidelines do not include a full and comprehensive technical description of MBES systems, but rather, provide a list of pertinent references, such as Hughes-Clarke (2017a). They also refer to related guidelines where relevant.

Table 2 Relevance to the various user groups by document section number. However, all stakeholders will find useful information in all sections

Section	Non-expert groups	Expert groups
1 Introduction	All	All

2 Pre-survey planning	All	2.1; 2.2; 2.4; 2.5; 2.6
3 Mobilisation, calibration and validation	3.1; 3.9	All
4 Acquisition	4.1; 4.6	All
5 Data processing	5.3	All
6 Reports	All	All
7 Data submission and release	All	All
8 Multibeam acoustics for marine monitoring	All	All

1.3 Related standards and publications

The following publications and resources provide information to underpin the collection of geospatial data and augment these guidelines. The complete references can be found in section 9, but the most recent published versions of key documents are:

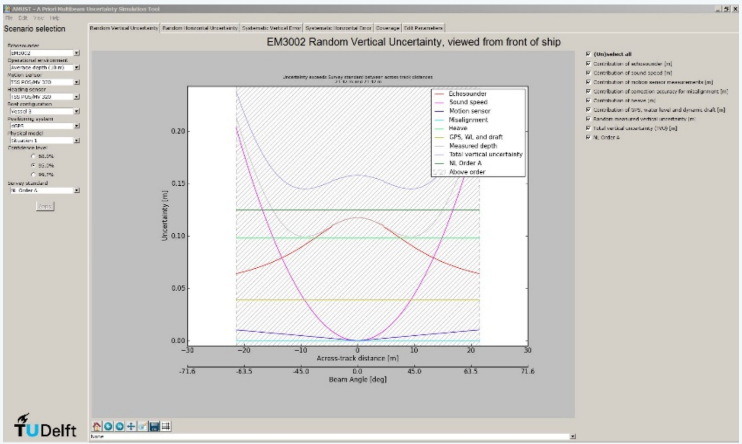
1. AHO, 2018. Hydroscheme Industry Partnership Program - Statement of Requirements
2. AHO. Hydrographic Note, Australian Hydrographic Office
3. AHO. Seafarer's Handbook for Australian Water (AHP20)
4. CHS, 2013. Hydrographic survey management guidelines
5. Mills J. and Dodd D., 2014. Ellipsoidally Referenced Surveying for Hydrography. FIG Publication No. 62
6. GeoHab Backscatter Working Group, 2015. Backscatter measurements by seafloor-mapping sonars: Guidelines and Recommendations.
7. Godin, A., 1998. The Calibration of Shallow Water Multibeam Echo-Sounding Systems, Technical Report No. 190.
8. Hughes-Clarke, J.E., 2003. A reassessment of vessel coordinate systems: what is it that we are really aligning?
9. ICSM, 2018. Geocentric Datum of Australia Technical Manual.
10. ICSM, 2004. Australian Tides Manual (SP9).
11. ICSM, 2014a. Guidelines for Control Surveys by GNSS (SP1).
12. ICSM, 2014b. Guidelines for Control Surveys by Differential Levelling (SP1).
13. ICSM, 2014c. Standard for the Australian Survey Control Network (SP1).
14. IHO, 2008. IHO Standards for Hydrographic Survey, (S-44)
15. IHO, 2013. Manual on Hydrography (C-13).
16. IHO, 2015. INT1 Symbols, Abbreviations and Terms used on Charts.
17. IOGP, 2018. Seabed Survey Data Model (SSDM)
18. Lamarche G. and Lurton X., 2017. Recommendations for improved and coherent acquisition and processing of backscatter data from seafloor-mapping sonars.
19. LINZ, 2016, Contract Survey Specifications for Hydrographic Surveys, Vers. 1.3
20. Lucieer V. et al., 2017. Seamap Australia
21. Przeslawski R. et al., 2018. NESP field Manual for grab and box core sampling

2. Pre-survey planning

The acquisition of data is the most expensive element of a seabed mapping project. Therefore, it is essential that this phase of a survey is optimised by undertaking adequate pre-survey planning. This section of the guidelines identifies key aspects of the planning phase that can be improved for more efficient and effective surveys. They also present tools and resources available that can help (Table 3). These resources are also hosted on the AusSeabed website, and we encourage using the website to discover the full breath of available resources and future updates. The IHO C-13 Manual on Hydrography also provides an appendix on planning considerations and how to best calculate survey timings.

Table 3 Summary list of pre-survey planning tools proposed in the section

Tool or Resource	Description
Upcoming Survey Register	Register the survey to encourage collaboration and contribute to national coverage
AusSeabed Bathymetry Holdings	Coverage of MBES dataset by various agencies.
Seabed Survey Data Model	The SSDM is a GIS model that has been developed since 2010 by the International Association of Oil & Gas Producers (IOGP) to facilitate management, integration and sharing of survey data at all levels, i.e. international, national, local, etc. (IOGP, 2017).

A priori tools	These tools help to determine expected uncertainties for a system.
1) Amust	Amust link points to a registration page on the Rijkswaterstaat (Dutch Hydrographic Service) website. See also Appendix E for a list of possible errors to take into account.
2) Hydrobib	 Hydrobib provides integrated utilities for survey planning. It is more specific to R2Sonic echosounder, but can be adopted for other echosounders.
Datum tools **1) VDatum** **2) AusCoastVDT**	1) Designed to vertically transform geospatial data among a variety of tidal, orthometric and ellipsoidal vertical datums. 2) A vertical datum transformation tool for the Australian coast.
Line planning tool	Most survey acquisition software packages (QPS, EIVA, HYPACK) have line planning capability built into them. See also **Hydrobib** above

2.1 National coverage consultation and upcoming survey register

AusSeabed is currently developing a suite of pre-survey tools to view the current extent of national bathymetry data holdings, consult a map of national seabed mapping priority areas, and utilise a survey coordination tool to register and query upcoming surveys. These tools are aimed at providing seabed mappers with information to promote collaboration in areas of common interest and eliminate effort duplication. This initiative is likely to benefit all parties by reducing overall costs and facilitating more efficient data collection in Australian waters.

Seamap Australia is a complementary mapping and analysis service that provides information about the Australian shelf collated from data providers (e.g. seafloor imagery, habitat classification) that may also inform proposed mapping areas (Lucieer et al., 2017).

2.1.1 Existing data coverage

Before planning a survey we recommend consulting the Bathymetry coverage layer hosted on the AusSeabed website to avoid the collection of duplicate data. The identify tool in this portal provides metadata information for each coverage polygon submitted to AusSeabed and a URL to the location where the high resolution data can be downloaded if it is available. This ensures that users are able to find existing data, or data custodian and contact details for surveys already conducted that might meet some or all of their needs. The layer contains the spatial extents and metadata of all surveys submitted to Geoscience Australia (GA) by AusSeabed collaborators and external third-parties. It is being continually developed to display national data coverage, with input from an increasing number of organisations.

The GA MARS database contains information on seabed sediment samples collected in Australian waters, analysed, and provided to GA. Links to other data samples collected by different entities is acknowledged as an item for future development.

2.1.2 National Bathymetry priorities

The AusSeabed website also hosts an interactive map of national bathymetry priorities that show areas that are considered important to government in terms of safety of life at sea, conservation, and environmental monitoring. It is recommended that this tool be consulted in the early stages of survey planning to promote collaboration amongst stakeholders with interests in specific areas.

2.1.3 AusSeabed Coordination Tool

It is also highly recommended that the upcoming survey layer is consulted on the AusSeabed portal in the early stages of survey planning to look for collaboration opportunities should there be other organisations planning to carry out work in areas of close proximity. Upcoming survey plans can be registered using the AusSeabed Coordination Tool to enable further collaboration and future tracking of new data. The tool allows users to display the planned extent and details of an upcoming survey and collects a set of metadata that are considered a minimum for any seabed mapping activity (section 2.3.1.3) that can be utilised for the survey report and data submission following the survey. If desired, a more detailed planning document can also be attached. The AusSeabed Coordination Tool also hosts the online forms for submissions to the Hydroscheme Industry Investment Program, run by the AHO. To request a user log in for access to the survey coordination tool email ausseabed@ga.gov.au.

2.2 Research and survey permits

Various permissions are required to undertake research in Commonwealth, State and Territory waters. Due to the complexity of laws and intersecting jurisdiction's, information on this page should be treated as a guide only and information from the relevant governing bodies should be consulted to ascertain that the correct permissions have been acquired prior to any research undertaking.
Operators should contact and inform relevant national and local authorities well in advance of any intended survey work ashore and afloat. These include the local harbour authority that should be consulted at all stages of the planning and execution of any harbour surveys, marine reserves, etc. Be mindful that approvals and permits (e.g. Environment Protection and Biodiversity Conservation, Environmental Plan, local marine parks permits, etc.) may be needed before undertaking a survey. Legislation for approvals is slightly different in each state. More information regarding legislation and permitting can be found on the AusSeabed website. Appendix A (https://marine-sampling-field-manual.github.io/files/Appendix_A_Permissions.docx) provides a list of authorities that may need to be consulted and some links to general research permits for state waters.

2.3 Seabed mapping data collection considerations

The **objectives** of MBES surveys conducted by mapping programs are to collect seafloor data to identify, delineate and map biogenic, anthropogenic and geological features. This objective requires particular data to be collected that can a) chart the water depths creating a high resolution bathymetric map at an appropriate resolution in regards to the target habitat or feature and b) be able to differentiate boundaries between different substrate and/or habitat types.
This national guideline provides the minimum requirements for all seabed mapping activities to enable national coordination and compilation. It is thus designed as an overarching document that can be complemented by more specific requirements. If data collection is for charting purposes, consult the Australian Hydrographic Office and the Hydroscheme Industry Partnership Program (HIPP) Statement of Requirements (SOR) available at www.hydro.gov.au/NHP.

The application of these guidelines to marine monitoring has been included as a case study in Section 8 that outlines the mandated best practice data and metadata requirements, QA/QC and data submission practices for baseline surveying or more targeted feature monitoring. Appendix D provides some approximate planning timeframes as a guide for the various activities related to seabed mapping surveys.

2.3.1 Data type, formats, and metadata

In 2019, AusSeabed held a workshop on data formats and metadata attributes to establish an agreed set of preferences for the delivery and acquisition of seabed data. The outcomes of that workshop underpin the information presented in the following sections, as a set of best practice policies to maximise the utility of collected open data.

2.3.1.1 Data type

The types of data derived from a MBES survey are:

- bathymetry: essential
- seabed backscatter: essential
- water column backscatter: encouraged

The minimum essential requirements of any seafloor mapping survey are the bathymetric data and seabed backscatter data (the collection of which may require manual activation). Water column backscatter data acquisition is encouraged if the system can collect it. In addition to scientific benefits (such as identifying gas flares and vegetation mapping), water column data is a common method used to confirm least depth over features and to identify bathymetric artefacts. It is both used in terms of 3D visualisation of the seabed and in observing oceanographic turbulence, such as internal waves, which may result in bathymetric artefacts (Hughes-Clarke, 2017b).

2.3.1.2 Data levels and file formats

Consistent definitions of data levels allow the community to reduce ambiguity when discussing, delivering, processing or describing data. The AusSeabed definitions of data levels has been modelled on those prescribed by NASA for Earth Observations data products (Table 6).

Table 4 AusSeabed Data Level Definitions

Level	Definition	Examples			
		MBES	Navigation and attitude	Ancillary files	
				SVP	Tide
L0	**Unprocessed instrument data** Unprocessed/raw instrument data at full resolution as received from the sensor. Includes MBES and ancillary files as well as all artefacts.	Observed by sensor	Observed by sensor POSMV	Observed by sensor	Observed by sensor, proprietary formats
L1	**Data merged with ancillary information** Reconstructed L0 data undergoes correction with ancillary information, either from within the L0 data itself or separately collected ancillary files (e.g., delayed heave and svp). This level may include radiometric and geometric correction and calibration, but not cleaning. This level may not exist for all data types and may depend on the software used.	Processed depth Integration with ancillary information	N/A: Data proceeds straight to L2		
L2	**Cleaned and/or derived variables** L1 data undergoes cleaning and filtering to create the first 'usable' data.	Bathymetry product Cleaned & filtered	Processed to SBET	Processed to *.txt	Processed to *.txt

L3	**Variables mapped on a grid** L2 data undergoes additional processing/value-adding to create L3 products. Variables mapped on uniform grid scales, with some consistency to produce derived products. L3 products cannot be backwards engineered into L2.	Additional value added, or data sampled (e.g. grid, DEM)	For the majority of commercial software available, backscatter data is progressed automatically through the L1 and L2 stages and saved directly as an L3 final product. Note: L2 is the final 'product' for ancillary data types.

A set of data formats has been recommended for each of the data levels and types described above based on community consultation (Table 5). Data submission to AusSeabed requires that the required data follow the formats and specifications outlined in this table. For submission of data it is required that all Priority 1 formats that are possible to be provided are provided. If this is not possible then the next highest priority format should be provided. AusSeabed strongly supports open source technology and formats, therefore open formats (when available) are the preferred option over proprietary formats, for any sensor and at any data level. For L3 Bathymetry data provided to the AusSeabed Data Hub it is required that both Priority 1 BAG formats and the 32-Bit Floating Point GeoTIFF files detailed in the specifications column are provided.

Table 5 Preferred data formats by data type and level.

Level	Preferred formats				Specifications
	Bathymetry	**Backscatter**	**Navigation**	**Ancillary data**	
L0	**Priority 1** • .all, .s7k, .kmall, .xse, .mbXX equivalent mbsystem formats **Priority 2** • .gsf **Priority 3** • .xtf	**Priority 1** • .all, .s7k, .kmall, .xse, .mbXX equivalent mbsystem formats **Priority 2** • .gsf **Priority 3** • .xtf	**Priority 1*** • Any proprietary formats that contain navigation and attitude (*.000) since no open formats exist yet.	**Priority 1** • ASCII (txt, csv) **Priority 2** • Proprietary	Bathymetry and backscatter should contain all necessary datagrams required for processing, including raw backscatter per beam (and time series), and all required ancillary data. Water column data is recommended and if possible should be stored in a separate file. Navigation and Ancillaries should contain date and time (calendar or UTC, specify otherwise) and geodetic reference system (geographic WGS84 or GDA2020 with an ellipsoidal height datum).
L1	**Priority 1** • .gsf,	**Priority 1** • .gsf **Priority 2** • Proprietary	**N/A**	**N/A**	Not Compulsory for data submission L1 should also include all raw data as required in L0 that allow for processing at any stages if required. Header information and sign convention are required to accompany ASCII point cloud.
L2	**Priority 1** • .gsf, .las/laz	**Priority 1** • .gsf	SBET data + RMS (for generation of TPU)	**Priority 1** • Text files: (ASCII .txt, NetCDF, .csv) **Priority 2** • Proprietary	When L2 data are provided, also include all L0 data to allow for reprocessing at any stages, if required. L2 should contain data that enable reproduction of L3. **Bathymetry and Backscatter** Variables: coordinates, depth (m, neg value) or intensity (dB), uncertainty, flag. Coordinate system: Geographic (GDA2020 or WGS84) Precision: Metric variables with minimum of 2 decimals; Angular variables degree decimals with minimum of 6 decimals

					Navigation and Ancillaries Date and time: Calendar and UTC or specify otherwise Coordinate system: Geographic WGS84 or GDA2020 with an ellipsoidal height datum
L3	**Priority 1** • BAG single-resolution • BAG multi-resolution • 32-bit floating point GeoTIFF (.tiff) **Priority 2** • .las/.laz	**Priority 1** • BAG single-resolution **Priority 2** • 32-bit floating point GeoTIFF (.tiff)	**Priority 1** • Sensor trackline (GeoJSON)	**N/A**	**Bathymetry and Backscatter** Vertical datums: both Ellipsoid and MSL Resolution as per Table 9 Variables: coordinates, depth (m, neg value) or intensity (dB), density (sounding/cell), uncertainty, flag (bathymetry in GeoTIFF format requires three separate files: depth, density, uncertainty). Coordinate system: Geographic GDA2020 or WGS84 Precision: Metric variables with minimum of 2 decimals; Angular variables with deg decimals and 6 decimals **Navigation and Ancillaries** Date and time: Calendar and UTC or specify otherwise Coordinate system: Geographic WGS84 or GDA2020 with an ellipsoidal height datum

2.3.1.3 Metadata

Metadata consistency is an essential aspect of data management and a key step in the move to coordinate a comprehensive national repository of seabed data in the Australian marine estate. The following list of metadata outlines the minimum set to meet ISO 19115.3 standards. The AusSeabed community propose that best efforts are made by collecting and processing institutions to utilise these fields. Appending organisation specific fields is acceptable but such fields should not be used in place of the fields below (Table 6). An example template with descriptions of the metadata fields to assist organisations in "mapping" metadata information is included in appendix H.2.

Table 6 Overview of required metadata.

Metadata Category	General	Citation	Survey	Technical
Metadata Fields	• Survey Title • Survey ID • Abstract • Lineage	• Data Owner • Custodian • Country (data ownership) • Collecting Entity • Attribution Licence • Legal Constraints • Access Constraints • Use Constraints	• Survey Area (general) • Bounding Box • Coordinate reference system-bounding Box • Coordinate reference system– Survey Data • Geodetic Datum of the survey • Horizontal datum • Vertical datum	• Instrument type • Sensor type • Sensor Frequency • Platform type • Platform name

This set of metadata is not exhaustive, and a large number of specific survey, calibration and acquisition parameters need to be recorded in addition to the above information to ensure complete documentation of the survey process. These are categorised and detailed in the section 6.1 which outlines the Mobilisation, Calibration and Validation reports.

2.3.2 Survey area characterization

Operational requirements, gear availability and technical capacity will determine the most appropriate type of MBES system to use. The characteristics of the survey area and mapping requirements are also key issues to consider, including:

- survey duration and size of the area
- anticipated depth range as this will affect line planning (section 2.5.5) and acquisition parameter settings (section 4.3)
- wind and wave conditions and seasonal weather changes
- tidal regime and tidal infrastructure

- feature detection and sounding density requirements; reflected in required pulse repetition (ping rates), swath width and survey speed
- the nature of the seabed, which is important for seabed backscatter data acquisition (section 4.3.2). If one of the objectives of the mapping is to understand the nature of the seabed and to predict it over the area of interest, seabed sediment sampling/imaging needs to be considered (section 2.5.6). See also the NESP field manuals for standard operating procedures on sediment sampling and underwater imagery.
- water column anomalies and feature anomalies, which may benefit from recording seabed water column backscatter (section 4.3.2)
- the time of year and relevance to whale migrations for low frequency instruments
- potential interactions with surface fishing gear

2.3.3 Data representation (seafloor coverage and resolution)

Data representation, with respect to seafloor coverage, depends primarily on the MBES system utilised. For MBES systems, data representation will be dependent on the beam width of the system and the associated footprint on the seafloor (Table 4). It is important to consider that the data representation of the final output has to be greater or equal to the beam footprint. For bathymetric sidescan, however, the sounding interval on the seafloor is constant.

Horizontal and vertical accuracy are two key factors of resolution that should also be taken into consideration when choosing the right equipment or designing a survey plan (sections 3.3 and 3.4). These can be assessed by listing all sources of error and calculate interactively the total propagated uncertainties of a sounding (TPU; section 5.2). The Total Vertical Uncertainty (TVU) must not exceed the depth accuracy, and total horizontal accuracy (THU) actually refers to the accuracy of the position of sounding on the seafloor and not the accuracy of the GPS [GNSS] position of the survey vessel alone. Survey speed can also affect the data representation and accuracy (Hughes-Clarke, 2017b).

If data representation is not the primary driver in the choice of the system to use, it is recommended that data be collected at the best resolution achievable by the system.

Table 7 MBES footprint (m) at nadir and beam width (deg). The beam footprint for a MBES increases in the outer beams.

		Beam Width (deg)					
		0.5	**0.7**	**1**	**2**	**3**	**4**
DEP	**10**	0.09	0.12	0.17	0.35	0.52	0.70
	25	0.22	0.31	0.44	0.87	1.31	1.74
	50	0.44	0.61	0.87	1.74	2.62	3.49

T H (m)	**75**	0.65	0.92	1.31	2.62	3.92	5.23
	100	0.87	1.22	1.75	3.49	5.23	6.97
	250	2.18	3.05	4.36	8.72	13.08	
	500	4.36	6.11	8.73	17.45		
	1000	8.73	12.22	17.45			
	1500	13.09	18.33				
	2500	21.82					

It is important to highlight that identification of features of specific sizes rely on a combination of parameters. It is generally accepted that when using side scan sonar as the feature detection tool, that a minimum of five boresight hits are made on the feature target. When using MBES as the feature detection tool, the common requirement is to achieve a minimum 3 along track hits and 3 across track hits on the feature target. The above requirements are to be considered conservative and in line with accepted sampling theory. Refer to section 7.5 from AHO (2018) for further information.

The general formula to calculate the depth at which five pulses should ensonify a target of a given size at different speed is (GBHD, 1996):

$$D = \frac{\left(Sx\left(\frac{1852}{3600}\right)x\left(\frac{5}{prr}\right)\right) - t}{2\tan\left(\frac{\phi}{2}\right)}$$

Where:

D = least depth of detection (metres below transducers)

S = speed in knots

t = along track dimension of target to be detected (metres)

ф= echo sounder's beam width (fore and aft) in degrees.

prr = pulse repetition rate (pulses per second (Hz))

2.3.4 Quality assessment / uncertainty scheme

The International Hydrographic Organisation (IHO) publishes a document for hydrographic standards – IHO Special Publication (SP-44). Appendix G of this publication details a range of survey standards for varying purposes. By surveying and providing data to these minimum standards, a collaborative approach to providing safe maritime navigation in future surveying areas can be assured in areas where there may be a future need to conduct operations.

However, these standards may not fit the purpose of the survey or be flexible enough (Figure 1). Therefore, it is recommended that each parameter be evaluated separately when planning a survey. Consideration should be given to other user specifications or requirements, such as Port Authorities and Marine Parks, as these could also be met with little additional time, effort or cost (e.g. PPA, 2017, Lucieer et al., 2018). The data would then benefit more users and contribute to the National Seabed Mapping effort.

Regardless of the standards used, it is important to provide quality and uncertainty statements based upon calibration and validation evidence to ensure consistency. These should be quantitative statements where numerical analysis is conducted e.g. TVU = +/-0.1m, THU = +/-1.0m.

2.3.5 Platforms & systems

Seabed mapping can be conducted from a variety of platforms, including ships, which can have hull or pole-mounted systems, towed-platform or automated underwater and remotely operated vehicles (AUV and ROV respectively). While this guideline provides information that applies to any platform, this section only provides general information on the various platforms and does not address the specific requirements of each. Refer to the material referenced for more information.

2.3.5.1 Hull or pole-mounted systems

A hull-mounted system refers to a system fixed to the vessel, and is the most robust way to mount a transducer. However, due consideration must be given to the effects of acoustic interference and bubble sweep down over the face of the MBES transmit and receive arrays.

A pole-mounted system refers to a system fixed to the end of a pole, which is commonly mounted to the side or the bow of the vessel. They are commonly used for smaller installations, allowing for permanent or deployable mounting. Rigidity and minimisation of the vibration of the pole are key to acquiring good quality data. It is also recommended that where possible, the motion reference unit (MRU) be installed and 'tightly coupled' on the pole at the transducer.

For deployable pole-mounted systems, it is important to consider that every time the system is deployed, there should be assurance that the system returns to exactly the same position in order to negate the requirement for another patch test. An operating check, which is less robust than a patch test but verifies the mount is returned to the correct position, should be conducted if the pole is reset. This may be as simple as performing cross perpendicular lines over a significant feature and analysing for incorrect alignments.

Regardless of which method is used to deploy the swath system, it is important to understand the negative impact of vessel hull, machinery noise and bubble sweep-down on the system. Care should be taken to install the transducers as far away from acoustic noise sources as possible and to ensure a smooth flow of water over the sonar(s) when the vessel is underway at the planned survey speed. Clients should be made aware that it is rarely possible to guarantee an acoustically silent installation on any vessel being used for the first time. Unfortunately, it is often a case of undertaking the installation and subsequently testing, before the suitability of the vessel and installation can be known.

This website provides additional information on various possible mounts and considerations. Note that the working group is not endorsing the company that this information is taken from.

2.3.6 Dimension control of sensor offsets

Dimensional control, otherwise known as a sensor offset survey, is essential to any seafloor mapping survey and needs to be reported (see section 3.2).

2.4 Project team

The project team should include personnel with relevant and adequate experience in swath acoustic instrumentation and survey requirements. These may consist of qualified people from various backgrounds, such as geophysicists, geologists, engineers, and hydrographic surveyors, but also increasingly includes marine ecologists and spatial analysts that manage seafloor mapping programs.

It is recommended that for all survey reports each team member should be identified. This provides traceability for decisions and the data acquired. It is also highly recommended that a member of the team has completed professional training in the principles and operation of swath systems and provides evidence of recent field experience with swath acoustic systems.

2.5 Field survey instructions

2.5.1 Geodetic control and horizontal datum

Seabed mapping surveys conducted within the Australian EEZ shall be referenced to a geodetic reference frame based on the International Terrestrial Reference System (ITRS), e.g. ITRF 2014 (GRS80 Spheroid) during collection.

Data should be processed on the Geocentric Datum of Australia 2020 (Figure 2; GDA2020) which is being implemented to modernise the geodetic positioning, based on 1994 models (ICSM, 2018). Stage 1 of GDA2020 will be fixed to the epoch 2020.0 and Stage 2 (anticipated in 2020) will transition to a time dependent reference frame and will be known as the Australian Terrestrial Reference Frame (ATRF). Specific information regarding GDA2020 can also be found on GA's website.

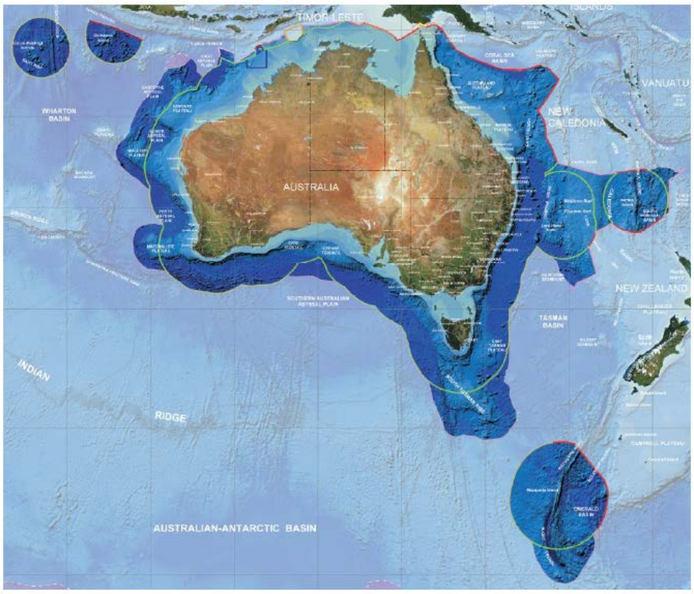


Figure 2 Extent of GDA2020 on the Australian continental shelf (Geoscience Australia)

Proposed Horizontal control should be reviewed for accuracy and if local control such as RTK base stations are to be used, then sites for local positioning systems should be determined. To establish shore-based geodetic control, refer to the procedures described in Intergovernmental Committee on Surveying and Mapping (ICSM, 2014a-c).

Grid positions shall be referenced to the Universal Transverse Mercator (UTM) Grid.

2.5.2 Tidal or ellipsoidal datum

The datum to which depths are to be reduced is fundamental to any seafloor mapping survey. Many datums can be used (Figure 3), but the common datums are the ellipsoidal or tidal chart datums (sections 2.5.2.1 and 2.5.2.2). While mapping however, the sounding datum should be used.

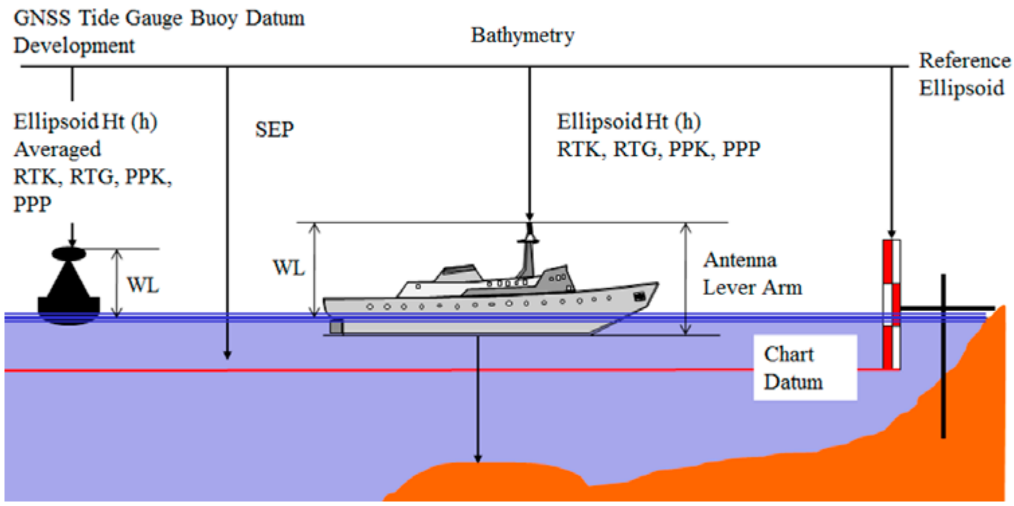


Figure 3 Schematic of datum and associated reduction information (Mills & Dodd, 2014)

Regardless of the datum used for the final products, the following points need to be considered:

- direct tide from the GNSS (GPS tide) should be recorded
- all data should be acquired and processed in WGS84 or ITRF if available
- all raw GNSS observations should be kept to allow post-processing
- all efforts should be made to improve positions to the highest accuracy possible, and post-processing will usually also improve horizontal positioning and minimise heave artefacts.

Typically, post-processing would involve:

- offshore: Precise Point Positioning (PPP) corrections using the final International GNSS Service (IGS) products
- coastal regions: kinematic post processing against land based fixed GNSS base stations, either permanent or deployed.

Transformation to the required 'publication datum' can be made after this process but retains the benefits of being connected to the global datum. These transformations can be done using AusCoastVDT, which is a free software tool with a blanket accuracy of ± 0.5 m for MSL to LAT reductions. AusCoastVDT was developed by the Intergovernmental Committee on Surveying and Mapping, a collaboration between the Australian states, Defence Force and New Zealand.

2.5.2.1 Ellipsoidal datum

With the advancement of modern GNSS positioning systems and post-processing methods, ellipsoidal datum connections can be employed as an alternative to the Lowest Astronomical Tide (LAT) or chart datum (CD) connections. The GRS80 ellipsoid vertical reference surface has benefits to scientific and environmental disciplines with a consistent surface separation of seafloor features globally, please confirm that this ellipsoid is being used by your geodetic coordinate system.

When used in conjunction with GNSS connected/levelled tide gauge data, connections to CD/LAT can be estimated where required. For details on the issues of this method see “Ellipsoidally Referenced Surveying for Hydrography” (FIG, 2014).

2.5.2.2 Tidal Datum

When surveying for the purposes of nautical charting, it is essential to have knowledge of local tides. In many areas around Australia, the tidal network infrastructure is sparse and additional temporary tidal infrastructure will be required. To acquire ‘observed tide’ from a tide gauge, a number of tide gauges will need to be installed depending on the tidal complexity of the environment, albeit it is desirable to have at least one gauge installed.

For specific advice regarding recommended tidal infrastructure for your survey area, please contact the Australian Hydrographic Office (tides.support@defence.gov.au).

2.5.3 Sound velocity profiling

Sound Velocity Profiling (SVP) of the water column is essential to the acquisition of swath mapping data, and is used for ray tracing through the water column. SVP influences directly the accuracy and uncertainty of both the horizontal and vertical position of each sounding and its impact is greatest towards the outer beams of the swath (farthest sounding).

Physical processes such as fresh water influx, solar warming of the upper water column, presence of mesoscale currents, and storm mixing can affect the temperature and salinity profile, and hence the SVP. These changes can occur at various spatial and temporal scales and can sometimes be observed in the water column backscatter data.

Acquisition of SVPs must be planned to identify the relevant number and distribution of profiles, and monitored carefully during the survey. It is recommended to commence a survey area with frequent SVPs until the behaviour of the water column is understood and then reduce the time and spatial interval as required to maintain best quality depth data. It is recommended that SVPs are conducted with a minimum interval of 6 hours. If sounding is restricted to the daytime only then SVPs should be conducted at the beginning and end of the day as the absolute minimum, but this is not recommended. The SVP can be determined using one of the following methods:

1. direct observation via deployment of a SVP measuring device
2. calculation of the SVP through deployment of an expendable bathy thermograph (XBT)
3. bar check
4. calculation of the SVP using CTD (Conductivity/Temperature/Depth) data and applying the UNESCO formula

2.5.4 Time and date

All digital data, field notebooks (logs) and samples should be set and recorded using the Coordinated Universal Time (UTC) and associated date.

For descriptive text used in reporting, the time zone should be clearly specified (AWST, ACST, and AEST).

2.5.5 Line planning

Survey line planning will vary based on the seafloor mapping objectives. However, the following minimum recommendations have to be taken into consideration:

1. Seabed topography: lines should be designed parallel to the general direction of seabed contours as much as possible for swath systems.

2. Depth range: the depth of the survey area changes the swath width and consequently the line spacing. Large areas should be divided into similar depth ranges so that the requirement to run in-fill lines is reduced.

3. Swath width (angle): depends on what type of swath system is used for the project (e.g. dual versus single-head MBES system), and hence the line spacing will differ. It is nearly always necessary to operate the swath system at less than published 'maximum' swath angles in order to improve the quality of the data collected and to improve the sounding density of the data collected.

4. Overlap: for full (100%) seabed mapping coverage, a minimum of 10% overlap of the good data swath (data meeting the 95% uncertainty level) is recommended. This will enable validation by comparison of the data acquired at the edge of each swath. For partial coverage, where possible, it is recommended to use line spacing that will enable a subsequent in-fill mapping effort to complete the mapping of the area.

5. Other requirements: acquisition of other sonar data, seabed and water column backscatter data (see below), etc. may dictate a different line spacing.

6. Regular checks: where there is an object of interest on the seabed detected in the survey, additional lines should be run to better delineate the feature and overall area.

7. Crosslines: crosslines are essential quality indicators, especially for data uncertainty management, and hence it is **highly recommended** to plan multiple crosslines.

   As a minimum, one cross line per "block" of data mapped should be acquired. Crossline(s) should normally be run last so that the cross line can be run perpendicularly across the whole extent of the data block collected.

8. Turn data: consists of data that is recorded during a vessel turning from one survey line to the next. While data quality may not be at its best during turns due to poor MRU stabilisation, this data nevertheless provides new information that can be useful for some users. BUT, it is strongly recommended to record turns as a **separate file** (i.e. stop recording before the turn, record the turn, and start recording new line.) so that the data can easily be removed if the artefacts outweigh the benefits of coverage.

9. Transit data: consists of data generally acquired between port and the primary survey area and is used as "discovery" data. Data from transit or passage sounding, contributes significantly to the national good by increasing knowledge of our seabed, and oceanography.

   Transit data should be:

   a. logged whenever possible unless the sea conditions are deemed too bad
   b. collected over new ground, i.e. not where previously mapped
   c. recorded and identified as a separate file to the primary survey lines

10. File length: depending on the system used, the rate of data acquisition and data type being collected, the size of the digital file recorded will vary. To avoid data loss and facilitate data management, it is recommended that file size be managed and data collected as smaller files in preference to large continuous files (an upper limit of 500 MB is suggested).

Where **seabed backscatter data is the primary objective** of the survey, the same recommendations as above apply with the following exceptions:

11. Incidence angles: overlap should be as the swath coverage but limited to incidence angles between 20 and 60 degrees (Figure 4; Lamarche and Lurton, 2017). This angle requirement is needed in order to compensate for the high variability of individual backscatter intensities (Gavrilov and Parnum, 2010; Kloser, 2017).

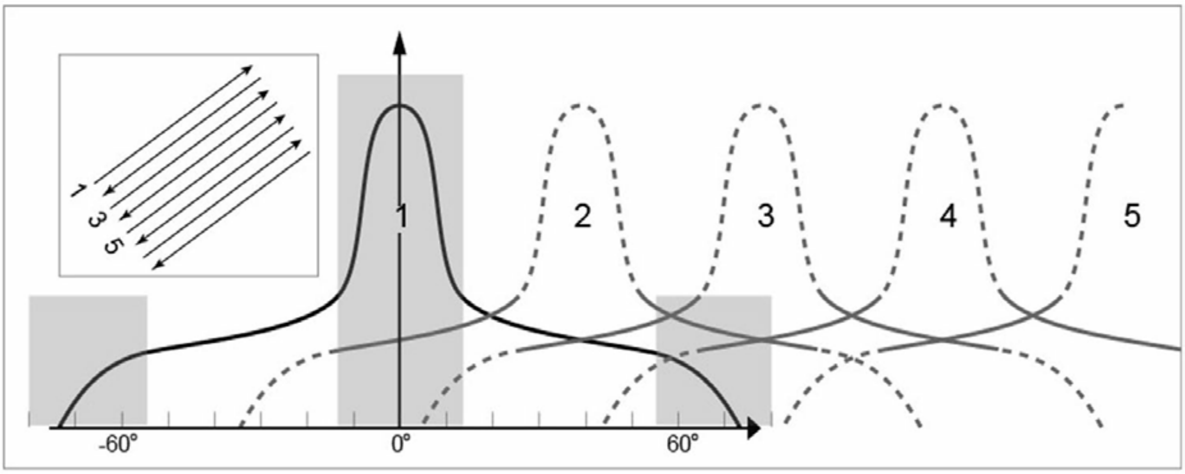


Figure 4 Diagram of ideal swath overlap (After Lamarche and Lurton, 2017).

12. Repeated seabed backscatter survey: For survey using the same swath system, it is recommended that the survey strategies, such as survey direction and orientations, and the system settings are kept identical. Frequency should also not be changed.

See section 4.2 which provides information regarding the project structure and nomenclature

2.5.6 Seabed samples

Seabed samples are often acquired during a seafloor mapping survey for various purposes, including seabed characterisation and seafloor backscatter data calibration. It is thus recommended that procedures outlined in the relevant chapters of the ‘Field manuals for marine sampling to monitor Australian waters’ (Przeslawski and Foster 2018) are followed.

This manual recommends sending the samples to Geoscience Australia for analyses, such as grain-size, carbonate content, and results will be delivered in MARS public database. This analysis of samples contributes significantly to the knowledge of our seabed.

2.6 Submission of plan, data and notifications

See sections 2.1.3, 7 and 4.6.

3. Mobilisation, calibration and validation

Mobilisation refers to the process of combining multiple equipment sets (echo sounder, positioning system, motion reference unit & sound velocity instrumentation) into a single functioning high precision and accurate system. Calibration refers to the measurement and removal of systematic errors in all installed sensors. For most installations, errors mainly consist of small offsets and rotations between system components. Validation refers to testing calibrated systems against known controls by conducting multiple observations in order to provide an analysis of the repeatability, precision and accuracy of an individual or combined system.

3.1 Overview

Mobilisation must be done with care since compromise to any part of the integrated equipment set will increase the risk of degrading the whole system and can result in no capacity to correct or post-process the problem. Calibration and validation are vital to assess the performance of the installed system against survey specifications, particularly TVU, TPU and datum control, as elaborated throughout this section.

The mobilisation, calibration and validation process will vary between vessels. For example, a 'vessel of opportunity' commonly involves significantly more planning and setup time than permanently configured survey vessels. The steps below generalise the detailed processes outlined in the hardware and software manufacturer's instructions for the deployed equipment. Specific information on some of the steps of the mobilisation, calibration and validation are included as a brief glossary in the following subsections.

Generalised steps for mobilising a vessel of opportunity:

1. During the pre-survey planning phase, attempt to source previous mobilisation reports for the planned survey vessel and equipment (even if from another vessel). This information will assist in understanding any engineering requirements or complications, thus saving downtime during mobilisation.

2. Ensure adequate resources are assigned for mobilisation of the swath acoustic system on the vessel of opportunity, which typically requires days (2-3 days), not hours.

3. Confirm the vessel reference frame to be used along with offsets and keep records and diagrams by either organising a survey of the vessel or re-use the results of a recent one. This establishes the spatial layout of equipment and sensors relative to each other. The responsible seabed mapper should conduct QC on any offset report received from a third party or conducted by the team.

4. Make equipment structures as rigid as possible to ensure stable geometry. E.g. moon-pool, and/or over the side rigid mounts should return to exactly the same location when deployed.

5. Take care with the physical installation, particularly cable runs and joins to limit electrical interference/noise, and account for vessel vibrations, vessel thoroughfares, water ingress, power-stability (pure sine wave for inverters, earthing), etc. Consider under-keel and overhead clearances. Vessel stability should be considered on smaller vessels to ensure safe manoeuvrability around equipment.

6. Minimise acoustic and vibration noise sources to acoustic sensors, IMU and electronics.

7. Check vessel sounder or engine vibration and noise over engine revolution range. Test a range of survey speeds for noise changes. Where possible check the swath systems performance at desired survey speed and sea state.

8. Check sky view of observed GNSS satellites in positioning system and minimise radio interference on GNSS antennas. Lost GNSS observations cannot be recovered.

9. Perform all manufacturer's self-tests and calibrations (positioning system, swath sonar, sound velocity instruments) to ensure validity of entire system. This includes a patch test (section 3.5)

10. Record all sign conventions and calibrated geometries of installed sensors (screen captures and reports; section 6.1).

11. Backup system and parameter files on a separate location. This is also important for rolling back configurations when accidental, unknown system changes are made.

12. Preferably complete mobilisation and testing before leaving port for the survey area.

13. Check tidal observation equipment for connections to local tidal datum if required.

14. Double check all geodetic parameter settings in positioning and acquisition systems for consistency. Ensure no undesired/undocumented transformations are taking place.

15. Consider processing capability on the vessel for near real-time assessment of acquired data.

16. Confirm on-board vessel storage has enough capacity to capture all required raw data, including backup strategy.

17. Discuss planned survey lines with vessel master, survey ground sea-states, forecast weather and implication for survey plan. Communication strategies between MBES system operator and helm (including installing swath system helm display).

18. Describe the equipment and actions undertaken on the vessel before, during and after the survey to form part of a 'mobilisation and calibration' report to be submitted along with the data (section 6.1).

3.2 Dimensional control

This is the process of establishing the spatial relationships of the mounted equipment locations on the vessel. This includes the physical vessel offsets (section 3.2.1) and angular rotational offsets (section 3.2.2) of the installed equipment, and the integration of them into the complete swath acoustic system. All recommended calibration and alignment procedures specified in the manufacturer's equipment manuals should be carried out. These measurements are validated and refined during the patch test process.

3.2.1 Physical offset survey

Establish the physical offsets of the installed equipment to permanent locations or marks on the vessel (Figure 5). This is achieved by adding equipment specific offsets to the previously carried out static (slipped) vessel system offsets survey or via surveyed measurements to the installed equipment. Preferably offsets should be known with centimetre level uncertainties, or better, to establish spatial relationships between soundings and external earth reference frames (WGS84, ITRF) via the GNSS equipment installed on the vessel.

It is important to note that the systematic errors and uncertainties associated with this control will feed directly into the overall quality of the data and will greatly increase with water depth. Acquiring accurate data ensures the long term benefits that accompany the "collect once, use many times" mantra. For more information, refer to Hughes-Clarke (2003).

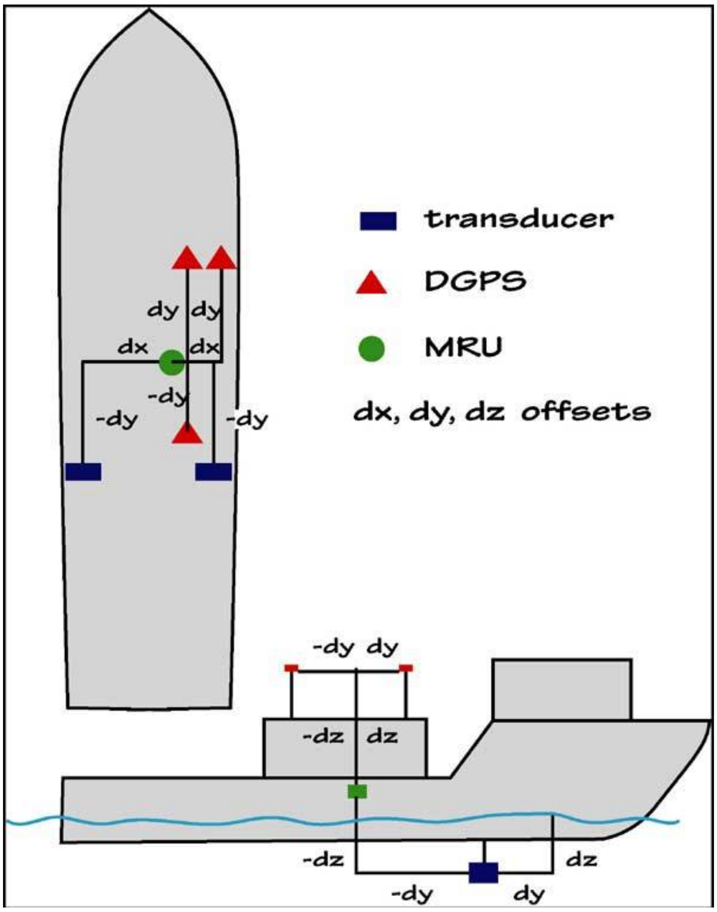


Figure 5 Diagram of dimensional control for MBES system (After Gardner et al., 2002)

3.2.2 Rotation offset survey

A rotation offset survey checks the alignment of individual equipment relative to the vessel's reference frame.

Establish all known rotations (angular offsets between the vessel and the reference frames of the installed equipment) for each equipment set. The offsets between rotational frame conventions (if any) of each equipment set should be accounted for as part of this process and recorded in the mobilisation, calibration and validation report (section 6.1). If equipment rotations (physical measurement) are known separately to calibrated rotations (patch test) and applied as such in the acquisition software, these details should also be included in the report.

Rotation offset survey is normally associated with permanently-installed systems.

3.3 Horizontal positioning

It is recommended to use a tightly coupled GNSS-Inertial system consisting of dual GNSS antennae and IMU integrated system that is tested. The GNSS-Inertial system has to be calibrated and validated prior to the commencement of the survey as this is critical to detect and correct setup errors, and estimate uncertainties. This process involves both static and dynamic validation if possible:

Static validation of GNSS positioning equipment involves verifying the performance of the system against a known reference position. This should be preferably done using land survey methods, however should a known reference point not exist near the point of mobilisation, points may be established and should be in accordance with ICSM (2014a-c).

Dynamic validation or confidence checks involves carrying out dynamic comparisons between positioning systems (where more than one system is mobilised). These dynamic calibrations should be performed regularly and whenever any component or changes to the vessel positioning systems or setup are made.

Validations may include:

- alongside checks using baseline and offset measurements to vessel datum points while logging on the acquisition system.
- check of independent positioning system mounted on vessel with known offset to transducer and on-board primary positioning system. Vessel records of all systems while conducting a box, then perform comparative analysis between logged system data and the independent positioning system. The least preferred method is to conduct this while static, but this may be the only operational option.

Setting up positioning systems to transmit data to the swath system topside at a frequency of 1 Hz is adequate for most scenarios.

3.4 Vertical positioning

3.4.1 Depth validation

Depth validation should be done once the patch test (section 3.5) has been performed. The system should be used to run a series of parallel and perpendicular sounding lines over a reference bottom surface where the depths have been previously determined and verified with an independent system of known accuracy.

If none of these comparative methods are available, then a “bar check” can be undertaken understanding that the results will not be as accurate as the precedent methods. The results obtained by any of the methods should compare favourably and be within the accuracy requirements of the survey.

Prior to sailing, a lead line observation may also be conducted.

3.4.2 Settlement and squat

Settlement occurs once the vessel is in a constant transit and is a vertical displacement which is constant at a given speed through water. Squat is a relationship between depth of water and speed through water.

All vessels are subject to settlement and squat, and measurements of these parameters should be made wherever practically possible by the most appropriate validation method. Ideally tests should be performed at various vessel speeds over a flat bottom using RTK GNSS or orthometric levelling heights at the transducer location. The heights should be measured at rest and then in increments of vessel speed with RPM noted, and then used to derive an appropriate squat/settlement table. A squat table is not necessary when using ellipsoidal reduction methods, however, should you need to revert to sounding reduction by tide, a table is best practice.

3.4.3 Vessel draft

Vessel draft may be difficult to measure. However, it is possible to approximate distance from arbitrary reference points to the waterline before and after a survey as this is likely to change with fuel consumption. For validation, the vessel draft should be derived using quantitative measurement methods as for section 3.4.2 (Settlement and squat).

3.4.4 Sound velocity

To ensure proper calibrated sound velocity reading, at least one probe (SVS or SVP) needs to be independently calibrated. Use a comparative method to validate other sensors (SVS at head and SVP). Assess speed of sound at the swath sonar head against SVP at same depth below surface. Where possible, compare SVP readings with external sensors (e.g. derived sound velocity from CTD).

3.4.5 Tidal station

For shallow inshore work (<30m), water level tidal observations, including local environmental effects, should be conducted for a minimum period of 35 days. If this is not possible, predictions based on tidal constituents may be used and in this instance tidal stations should be installed and calibrated as directed by ICSM (2004).

3.5 Patch test

The patch test confirms timing and alignment of the MBES sensor, vessel and IMU reference frames. It is essential to execute the standard patch test method as appropriate for sensor type (single or dual- head) and vessel (Appendix F). A patch test should be conducted at the beginning of the field season or whenever a piece of equipment is replaced or repaired and has to be undertaken once the calibration for the GNSS inertial system is complete (section 3.3). The results of the patch test should be reported in the Mobilisation and Calibration Report (Appendix H).

3.6 Seafloor backscatter calibration

Lamarche and Lurton (2017) provide a comprehensive review of seafloor backscatter from data acquisition to processing. Calibrated seafloor backscatter is essential to enable comparison of data acquired by various systems. There are two types of calibrated backscatter: absolute and relative backscatter.

Calibration is executed through the use of reference areas of known seabed types (preferably flat, smooth, and geologically and acoustically homogeneous areas). Use roll lines of the patch test (no need to rerun for backscatter) and list overlap (for backscatter quality survey). For systems with multiple transmitting sectors it is recommended that the average backscatter level be consistent across all sectors and for different modes.

It is also recommended that sediment samples and/or imagery samples be taken from the area to ground truth and calibrate backscatter data. As part of a sea-acceptance test practice, an overall calibration must be performed once the sonar system has been installed on the vessel. This involves both the customer’s technical team and operators.

3.7 Water column backscatter calibration

Calibration of water column data is desirable into the future and is best acquired if available on system. The same procedure for seabed backscatter calibration should be applicable for the water column backscatter calibration. While it is not practical to use the sphere calibration technique, inter-calibration with a calibrated fisheries single-beam echo sounder through the use of reference areas (Demer et al. 2015; Foote et al. 1987) may be employed. This at least provides assurance of self-consistency.

3.8 Built-in systems test

Built-in tests, such as built-in systems test (BIST) or built-in test environment (BITE) are a test of sonar head communication with software controllers and are useful for the validation of communication between systems. They becomes integral when troubleshooting and should be logged. It is recommended that, at a minimum, a BIST be done at the start and end of the mapping. The results should be reported in a Mobilisation and Calibration Report (section 6.1).

3.9 Final acceptance test

A final check should be performed to ensure that all the equipment is working properly and that the logging systems are operating correctly. Care should be taken to ensure depth, position and if necessary water level values are being logged correctly. The positioning system should be checked for operation and periodically throughout the survey.

4. Acquisition

4.1 Survey plan

Acquisition of the MBES data should follow the pre-survey plan discussed in section 2, unless the on-board seabed mapping lead decides otherwise based on the environmental situation and new information at-hand, which are difficult to account for in the planning stage. It is recommended that any changes to the acquisition plan are captured in the Report of Survey (section 6.2.2). Wherever possible, nearing the conclusion of data acquisition, a review of data coverage is highly recommended and infill lines conducted to ensure there are no gaps in the bathymetry, as this impacts the suitability of the data for end use. Additional lines over significant shoal features are also recommended to ensure good density of soundings and determination of least depth. For efficiency, such lines may be conducted concurrently to other activities such as during transits or seabed sampling. Emphasis here is put on the system settings and other specifics that were not recommended in section 2, especially section 2.5.

4.2 Project structure and nomenclature

Although the project structure and nomenclature is specific to the project, it is recommended that the following conventions be considered to facilitate data submission and interoperability:

- project structure:
    a. reports
    b. tides
    c. QA DataPack
    d. products
    e. raw data (see 2.3.1)
    f. processed data
    g. backscatter
    h. WC data
- file naming convention should be sequential, include timestamp and system type, e.g. nnnn_yyyymmdd_hhmmss_system, where: nnnn is the sequential number; yyyymmdd is the date; hhmmss is the time

4.3 Systems settings

System settings should depend on the purpose of the seafloor mapping and the data types that are being recorded.

4.3.1 Bathymetry

While acquiring data, the power, pulse width and gain need to be monitored and adjusted during the course of the survey to ensure good bathymetry. For high resolution/high frequency operations a short pulse width is desirable. As water depth increases, longer pulse widths will become necessary.

4.3.2 Backscatter

If the MBES system is capable, it is required that you ensure backscatter data (both the Beam Average Backscatter and the Time Series "Snippets" Backscatter data) are being logged and stored with the bathymetry data files. It is imperative that the Range (R), intensity (I), angle (ϴ) information are all recorded. Collecting these data may require custom settings to be applied during the initial set up of the acquisition software.

When acquiring data, it is essential that a log is kept of all settings and changes made to settings during acquisition (section 6.2.1). Do NOT run the MBES system on auto mode as this will make it very difficult to normalise the backscatter data due to the dynamic changes in the pulse length. If possible:

- avoid changes to the pulse length and pulse type or keep to a minimum
- collect in equidistant mode
- stop logging at the end of the line and apply new settings before starting to next line if changes are made (capturing changes in the log accordingly)
- minimise constant saturation of the seabed backscatter signal.

At the end of a survey, an **additional backscatter calibration test is essential** if you have used pulse lengths that differ from your original patch test and backscatter calibration**.** This calibration test is made up by running the same line once for each pulse length that was used during the survey. It is important that enough space is given for the turn so that the line can be intersected straight on because the calibration requires the lines to directly overlap for at least 500 m. Please record which pulse length coincides with which line number for each calibration run.

4.3.3 Transit data

It is recommended that the system settings during transit data acquisition be set to maximise data quality by considering the overall characteristics of the transit rather than maximise data coverage or swath width. Refer also to section 2.5.5.

Unless a deep water CTD or XBT cast is available throughout the transit and when water depth is greater than 200m, a generic SVP tool, such as the Hydroffice Sound Speed Manager tool can be used to improve profiles. Should no SVP option be available, the sound velocity should be set to 1500m/sec.

4.4 Ancillary systems

4.4.1 Sound velocity profile

It is recommended that:

- for shelf waters (< 200m water depth), at least one SVP be conducted every 24 hours. However, every 6 hours would better align with Bureau of Meteorology (BOM) weather reporting requirements
- for "off the shelf" surveys (> 200 m), SVP may not be necessary daily, but monitoring of the SVP is still recommended as per point below.

- SV be constantly monitored and SVP be collected if visual changes are observed in the acquired swath (e.g. frown or smiles), or the SV vessel probe indicate greater changes than 2 m/s at the sonar head for a consistent period of time.

Note that SVP for all depths are also highly valued by other types of users, such as oceanographers and ecologists. To further accommodate such users it is recommended that SVPs are also collected during deployment and retrieval of deep-tow systems, ROVs and AUV.

4.4.2 Tides

During a survey, acquisition of GNSS tide (ellipsoidal height of the vessel minus the geoid model at the same location) can be monitored; however, it is difficult to monitor tide gauges unless regular download of the data is undertaken. Therefore, for GNSS tides acquisition, it is recommended to:

- ensure that all the bathymetry files include GNSS height, otherwise GNSS tides will be computed to less than 10 cm vertical accuracy.
- use an updated Geoid model (e.g. AUSGeoid2020) keeping in mind that this model is unsuitable offshore.
- acquire the delayed heave from the MRU without gaps and ensure that the bathymetry data has a complete delayed heave coverage applied.
- compute GNSS tide for all the files.

During the survey, data QC should be done using predicted tides from the Bureau of Meteorology (BOM) for standard ports or AusTides for secondary ports. Refer also to section 2.5.2.

4.5 Monitoring, QA/QC & data backup

During a survey the following information should be constantly monitored, including:

- depth
- vessel draft
- GNSS (see section 4.5.1) or subsea positioning for sub-sea platform
- motion sensor
- sound velocity
- backscatter consistency and saturation
- overlap
- data density

To ensure safe data transport it is recommended that multiple copies of the data be made and transported separately in the time between data collection and submission (section 7).

4.5.1 GNSS positioning

Most seafloor mapping and GNSS software provide real-time monitoring capabilities. The quality of the GNSS data should be monitored while mapping to ensure that the horizontal positioning falls within the seafloor mapping specification. Any deviations outside of the survey specification should be noted and included within the Report of Survey (section 6.2). Maintaining a minimum QC requirement will provide data that is interoperable with many providers and uses. This integrity information includes (LINZ, 2016):

- sigma values or semi-major axis of the positional error ellipse are not to exceed 3.5m at the 95% confidence level
- the DGNSS correction age is not to exceed 10 secs
- PDOP is not to exceed 6 for recording and continued sounding. If PDOP is greater than 7 then surveying is to be halted until it improves.
- the minimum number of observable healthy satellites being tracked during survey operations is to be 5
- the minimum elevation for SVs is to be 10° above the horizon.

4.6 Mandatory notifications

4.6.1 Dangers found – hydrographic notes

It is **imperative** that any feature found, which may be a potential navigational hazard to vessels, **is reported to the Australian Hydrographic Office (datacentre@hydro.gov.au)** by hydrographic note (AHO, AH102) and if an immediate danger exists, **the Joint Rescue Coordination Centre (JRCC) Australia (AMSA)**. Once danger is reported and received by these agencies, the agencies noted assume responsibility for further reporting to mariners. Should reports not be lodged and an incident occurs, liability may be passed on to operators who failed to notify dangers during operational activities.

4.6.2 Underwater cultural heritage notification

Thousands of historic ship and plane wrecks are known to exist within Australian waters, although the locations of many of these remain unknown. Information about known shipwrecks can be found using the Australian National Shipwreck Database. Notifying relevant State and Commonwealth management agencies, when underwater cultural heritage sites are discovered, will greatly assist these organisations to manage fragile and irreplaceable resources (Table 8). Notification of underwater cultural heritage finds is also a legal requirement under the *Historic Shipwrecks Act 1976* (Cth) (HSA) and state heritage protection legislation (see section 17 (1) of the Act).

A notification report should include a snapshot of the scan image, coordinates, water depth and a brief description of the site giving dimensions of the object. It is requested that the Australian Hydrographic Office (datacentre@hydro.gov.au) is included as an information addressee on all notification reports to the relevant authorities.

Table 8 Contact details of management agencies to notify for wrecks

Commonwealth		
Marine Information Services Australian Hydrographic Office 8 Station Street WOLLONGONG NSW 2500 Tel: (02) 4223 6500 Email: hydro.mail@defence.gov.au (*for any Information Requests relating to charted features*) Email: datacentre@hydro.gov.au (*request cc on all Notification Reports*) Website: www.hydro.gov.au	Historic Heritage Section Department of Agriculture, Water and Environment GPO Box 787 CANBERRA ACT 2601 Tel: (02) 6274 2116 Website: www.environment.gov.au/heritage/historic-shipwrecks	Additionally (if in the Coral Sea Marine Park): Great Barrier Reef Marine Park Authority Heritage, International and Governance Project Manager, Maritime Cultural Heritage GPO Box 1379 TOWNSVILLE QLD Tel: (07) 4750 0618 Email: info@gbrmpa.gov.au Website: www.gbrmpa.gov.au/

State	
Queensland: Heritage Branch Department of Environment and Heritage Protection GPO Box 2454 BRISBANE QLD 4001 Tel: 13 74 68 Email: info@ehp.qld.gov.au Website: www.qld.gov.au/environment/land/heritage/archaeology/maritime/	**Northern Territory**: Heritage Branch Department of Lands, Planning and the Environment GPO Box 1680 DARWIN NT 0801 Tel: (08) 8999 5039 Email: heritage@nt.gov.au Website: www.dlp.nt.gov.au/heritage/maritime-heritage

New South Wales: Heritage NSW Community Engagement Group NSW Department of Premier and Cabinet Locked Bag 5020 PARRAMATTA NSW 2124 Tel: (02) 9873 8500 Email: heritagemailbox@environment.nsw.gov.au Website: https://www.heritage.nsw.gov.au/about-our-heritage/maritime/	**South Australia:** State Heritage Unit Department for Environment, Water and Natural Resources GPO Box 1047 ADELAIDE SA 5001 Tel: 08) 8124 4960 Email: DEWNRheritage@sa.gov.au Website: www.environment.sa.gov.au/our-places/cultural-heritage/Maritime_heritage
Norfolk Island: Norfolk Island Museum Kingston NORFOLK ISLAND 2899 Tel: (0011) 672 323 788 Email: admin@museums.gov.nf Website: http://norfolkislandmuseum.com.au/exhibitions/hms-sirius/	**Tasmania:** Historic Heritage Parks and Wildlife Service GPO Box 1751 HOBART TAS 7001 Tel: 1300 827 727 Email: mike.nash@parks.tas.gov.au Website: www.parks.tas.gov.au/index.aspx?base=1729
Western Australia: Western Australian Museum Maritime Archaeology Department 45-47 Cliff Street FREMANTLE WA 6160 Tel: (01) 300 134 081 Email: reception@museum.wa.gov.au Website: http://museum.wa.gov.au/research/research-areas/maritime-archaeology	**Victoria:** Heritage Victoria Department of Planning and Community Development GPO Box 2392 MELBOURNE VIC 3001 Tel: (03) 9938 6894 Email: heritage.victoria@delwp.vic.gov.au Website: www.dtpli.vic.gov.au/heritage/shipwrecks-and-maritime

5. Data processing

5.1 Data processing considerations

5.1.1 During survey

Processing during a survey should at a minimum be done to QC the data, both bathymetry and backscatter data. QC includes:

- checking for artefacts
- consistency of seabed backscatter
- meeting the required specifications, e.g. data density

A processing log should be kept and is required to be submitted alongside the survey reports (section 6).

5.1.2 Post-survey

Post-survey processing should include:

- reduction of soundings to appropriate vertical datum (observed or post-processed GNSS tides).
- application of SVPs and refraction correction applied (where allowed).
- data cleaning, which may vary depending on the purpose of the survey (see 5.1.2.1)
- elimination of surface artefacts, e.g. resulting from calibration errors.
- removal of random errors (ambient noise) using filters/CUBE or manual techniques
- data QA using crosslines (if collected). If specific crosslines are not collected, consider using transit lines that cross main survey lines (e.g. data acquired while going to a sampling location).
- TPU calculation for each sounding (section 5.2).
- surface (grid) creation as per 5.1.2.1 if submitting to AusSeabed Data Hub
- all interventions should be noted in a processing report, including parameters or techniques used.

See also section 10 of AHO, 2018 for more information on processing.

5.1.2.1 AusSeabed data cleaning and creation of surfaces (grids)

AusSeabed aims to have as few as possible manual interventions in the cleaning and processing of data to optimise delivery, and importantly, create reliably reproducible outputs with a clear provenance. As such, process automation is being adopted wherever possible.

AusSeabed has adopted a banded depth approach for creating gridded products (L3) and optimising the horizontal resolution delivered from acquired multibeam data (table 8).

Table 9 Matrix of depth range used to guide horizontal resolution of bathymetry grids. Modified from NOAA (2019)

Normal depth band			Steep slope depth band[1]			Res (m)	Ratio[2]
D_s (m)	D_d (m)	Range Interval (m)	D_s (m)	D_d (m)	Range Interval (m)		
0	20	20	0	20	20	0.5	0.0250
18	40	22	16	40	24	1	0.0250
36	80	44	32	80	48	2	0.0250
72	160	88	64	160	96	4	0.0250
144	320	176	128	320	192	8	0.0250
288	640	352	256	640	384	16	0.0250
576	1280	704	512	1280	768	32	0.0250
1152	2560	1408	1024	2560	1536	64	0.0250
2304	5120	2816	2048	5120	3072	128	0.0250
4608	12000	7392	4096	12000	7904	210	0.0175[3]

[1]In cases of steep slopes, the overlap between grids of different resolutions may need to be increased to prevent gaps in their junction. In these cases, the coarser resolution grid should have its shoaler extent modified to prevent this coverage gap.

[2]Highest resolution at which the dataset can support a minimum of five soundings per node (ideally, twice the maximum standard required survey resolution for the depth of the area, i.e. 2.5 % of water depth) (NOAA, 2019).

[3]Based on 1° beamwidth (highest resolution that the current technology of shipborne systems can effort) because of the constraint in the minimum capture distance in CUBE to a maximum of 100.

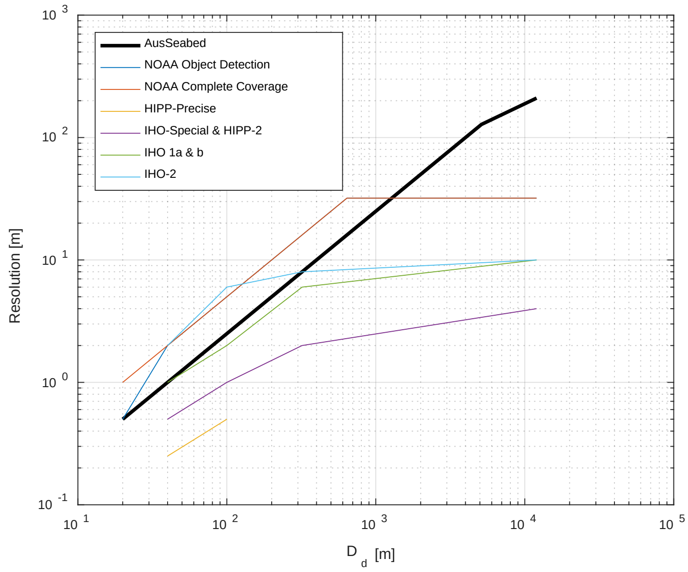


Figure 6 Horizontal resolution according to depth range for various existing standards.

5.1.3 Backscatter processing requirements

Please keep a processing log that records what processing software and settings are used to prepare the backscatter mosaic. When you process, it is important to specify the imagery type (Beam Average/Time Series); Beam Pattern Correction (yes/no); and Anti-aliasing (yes/no) selection.

Mandatory information to record for the backscatter data processing is:

- the AVG window size
- AVG method
- beam Pattern Correction (yes/no – if yes, please provide the beam pattern file)
- the imagery type (Beam Average/Time Series)
- gain (yes/no)
- time varying gain (yes/no)

Other image processing information that is useful but not mandatory:

- the speckle option (to remove noise)
- anti-aliasing (yes/no)

Further details about best-practice for backscatter data acquisition can be found in Lamarche and Lurton (2017).

Acquisition and processing logs should be delivered alongside all raw data (including calibration test) and processed mosaics in accordance with Section 7.

5.2 Total propagated uncertainties (TPU)

The total propagated uncertainty (TPU) for each sounding should be computed and included in the data submission (Section 7).

The TPU is the combination of the total horizontal uncertainties (THU) and the total vertical uncertainties (TVU) of that sounding (Appendix E). THU is a 2-dimensional quantity in the horizontal plane and is assessed only after the GNSS-Inertial system has been calibrated. TVU is a 1-dimensional quantity in the vertical dimension. TPU is not a linear addition of uncertainties in each system's component. It is a propagated combination of uncertainties for the non-linear set of equations comprising the integrated swath acoustic-GNSS Inertial system.

Uncertainty calculation is best addressed using most internationally accepted statistical models for determination of TPU, which are derived from Hare et al. (1995). Current international best-practice statistical model for resolving the system of equations is the Combined Uncertainty Bathymetric Estimator (CUBE). The average horizontal and vertical TPU estimates determined by the software for a range of water depths is provided with respect to the IHO S-44 standard for position and depth accuracy in Table 6.

Table 10 Example Sounding Accuracy - TPU (calculated at 1σ, but most software computes at 2σ)

Depth band (m)	0-5	5-20	20-50	50-100	100-200
Position Accuracy (m)					
IHO Standard	5.25	5.50	6.00	6.50	7.25
TPU Estimate	0.27	0.27	0.30	0.34	0.42
Depth Accuracy (m)					
IHO Standard	0.38	0.39	0.44	0.50	0.63
TPU Estimate	0.27	0.27	0.28	0.31	0.35

6. Reports

To ensure consistent documentation of all aspects of survey planning, mobilisation, calibration and acquisition, all information (reports and logs) should be recorded throughout the process. At a minimum, metadata (section 2.3.1.3), records for Mobilisation, Calibration and Validation (section 6.1), and the records proposed in section 6.2 are recommended. The proposed templates for these reporting requirements can all be found in Appendix H.

6.1 Mobilisation, calibration and validation records

Methodology and results of the mobilisation and calibration should be outlined in a mobilisation and calibration report, and the associated records. At a minimum, it is recommended to include the following information, modified from AHO (2018). Report templates meeting these requirements are included in Appendix H.

6.1.1 Logs

Mobilisation and calibration logs should include:

- tests survey lines, including patch test and final acceptance test
- SVP deployments: filename, time, lat, long, depth, SV sonar head reading (used for comparison)
- squat and draft tables

6.1.2 Report

Mobilisation and calibration report should document the integrated survey system, methodology, raw results and processed results, i.e. once the calibration is accepted.

Report Heading:

- seabed mapping survey title and associated reference number
- mapped by (agency/company/etc. and Seabed mapping lead)
- dates of mapping
- mobilisation, calibration and validation report
- version
- date of the report

Introduction: includes an overview of the procedures conducted for the installation and calibration of equipment that comprise the seabed mapping system (SMS).

- Background and outline of events: a narrative giving an overview and timeline for the set-to-work of the survey platform(s).
- Platforms: a description of, and justification for, the survey platforms chosen to undertake the survey.

- Geodetic controls: geodetic parameters for the control survey, station diagrams and descriptions outlining the geodetic control utilised for the survey.

Equipment: summary of equipment that forms the SMS as installed on the survey platforms, including all relevant offsets and calibrations.

- Hardware: summary of the hardware relating to data acquisition including manufacturer, model and serial number is to be tabulated.
- Software: summary of the acquisition and processing software, including version numbers is to be tabulated.
- Sensor mounting systems: a description of the mounting system utilised for data acquisition is to be provided, e.g. pole mount, gondola, moon pool etc.
- Sensor offsets: the measurement method and results for the dimension control that determine the relationship between the measurement sensors and the platform CRP are to be provided. Sensor offsets may be annexed to the report.
- MRU heading checks.
- Built-in test results (e.g., BIST, BITE).

Underway calibration: outline the checks and calibrations of platform when underway. These may include:

- acoustic sensor bar checks
- draft, settlement and squat
- primary and secondary positioning
- patch test; the method undertaken, and results of the patch test for the pitch, roll and heading bias are to be calculated and rendered
- reference surface (if performed): difference statistics between manoeuvring lines and the reference surface are to include; beam number; mean, maximum and minimum differences and standard deviation
- target detection (if performed): the ability of the SMS to meet the target detection criteria of the specified order are to be demonstrated
- acoustic interference check (if performed): results of the pre-survey acoustic interference check are to be rendered

6.2 Records of survey

This section includes logs that should be used during acquisition of data as well as information required in the Report of Survey provided at the end of the survey. This section also points to legal notification requirements in regards to Dangers found (section 4.6.1) and Underwater Cultural Heritage (section 4.6.2). Templates of the reports and logs can be found in Appendix H for a summary of minimum requirements and in the IHO M-13 Manual on Hydrographic Surveying for a comprehensive report.

6.2.1 Logs

Survey logs should include:

- relevant information on survey lines, including data types recorded and daily events. Minimum parameter requirements found in Appendix H.
- system parameters relevant to backscatter data acquisition include:
  - environmental parameters controlling sound speed and absorption within the water column
  - weather and sea conditions
  - backscatter intensity
  - source level
  - pulse length
  - transmit beam patterns
  - receive beam patterns
  - receiver time varying gain functions
  - path length attenuation characteristics (spherical spreading and absorption coefficient)
  - seabed grazing angle
- SVP deployments (filename, time, lat, long, depth, SV sonar head reading (used for comparison)
- log for additional data collected, such as seabed samples (section 2.6)

Processing logs should include detailed changes made to any variables not captured in the datagram. For example:

- SVP refraction correction
- Surface artefact correction.

6.2.2 Report of Survey

The Report of Survey (ROS) should give a comprehensive account of how the seabed mapping survey was carried out, the results achieved, and any difficulties encountered. A template can be found in Appendix H, but at a minimum, it is recommended to include the following (modified from AHO, 2018):

Report heading:

- seabed mapping survey title and associated reference number
- mapped by (agency/company/etc. and seabed mapping lead)
- dates of mapping
- report of seabed mapping
- version
- date of the report

Introduction:

- dates: give start and end dates with activities that took place during the survey, especially where swath acoustic data was acquired while executing other activity (transit and sampling)
- map: give general map of where the data was collected, including coordinates of coverage
- setting conditions: general statement on weather and sea conditions as these are essential to understand data quality. Provide also information on oceanographic conditions which explain SVP frequency
- completion: comment on completeness of the survey, including opinion in regards to coverage and line spacing, and MBES data type recorded

Standards:

- local datum epoch and transformation parameters: provide a table with the relevant information that was used within the acquisition software. In addition, all software used on the survey must contain the correct datum parameters and this should be checked independently and evidenced here.
- horizontal and vertical accuracy: the following section confirms that the horizontal and vertical accuracy of soundings acquired during the *Survey Name* seabed mapping survey are compliant/non-compliant with the (IHO/LINZ/Other) standard for position and depth accuracy
- TPU: comment on TPU in reporting relative to various industry standards and provide a Table (see example Table 5 from section 5.2) with a detailed analysis of the TPU estimates for the relevant depth bands mapped for the project, using *name of software*

Seabed sampling:

- method: describe method used and problems with equipment or recovery of the samples, state sampling interval and any particular samples obtained from interesting features, state the number, plan for analysis and submission of samples

Tides and sounding datum (see section 13.4.1.9 in AHO, 2018)

Wrecks and danger found:

- Provide a table with any notifications made in accordance with legislation (section 4.6)

7. Data submission and release

The AusSeabed Data Hub is the national repository for all seabed mapping data collected within the legal boundaries of the Australian Continental Shelf and the Australian Charting Area and any data that lies outside this region but is considered of value to the Australian marine community or was commissioned by Australian entities. Data submitted and distributed through the hub, in accordance with the AusSeabed Data Submission and Distribution policies, will be made publicly available through the AusSeabed Marine Data Portal under a Creative Commons Attribution 4.0 International licence. Data Distributed through the AusSeabed Marine Data Portal are done so under the proviso that they are not used for navigational purposes. Data subjected to embargos or confidentiality agreements will not be considered. It is worth noting that this infrastructure is undergoing development to function as a federated hub, whereby, organisations can emulate the architecture of the AusSeabed Data Hub, retaining custodianship over their data while making it discoverable and accessible through the AusSeabed Portal. Institutions wishing to pursue this path are encouraged to contact ausseabed@ga.gov.au for more information.

7.1 Data submission to AusSeabed

Data submitted to the AusSeabed Data Hub needs to comply with the following final QA/QC checklist:

- Ensure that calibration values have been applied adequately, i.e. not doubled up through the various software used (e.g. applied by the acquisition software and again by the processing software). See section 3.
- Data should be delivered according to formats and specifications listed in Table 5 of section 2.3.1
- Where processing or cleaning has been applied it has been done according to section 5.

Data can be transferred to AusSeabed using any one of a number of secure online data transfer mechanisms (Google Drive, One Drive, Cloudstor, Drop Box, directly through the National Computing Infrastructure, by sharing permissions to Amazon S3, etc.). If no online data transfer method is possible, data can be sent to Geoscience Australia using a hard drive. Please follow the steps outlined below to ensure efficient delivery of data and contact ausseabed@ga.gov.au if unsure during any stage of the process:

1. Ensure that data meet the Final QA/QC requirements above and that all files outlined in Table 11 have been prepared for submission.
2. Contact AusSeabed (ausseabed@ga.gov.au) and AHO (datacentre@hydro.gov.au) to inform of the intention to submit data. This communication with AusSeabed can be used to determine the most convenient method for file transfer. If hard drives are used, they will be returned to sender. If your submission is a requirement of your funder or regulator (e.g. permit provider) please include the funder or regulator in your correspondence.
3. Send data and associated files to AusSeabed.
4. Provide access to the data's metadata record by either:

    a) publishing the metadata record(s) to the Australian Ocean Data Network (AODN) catalogue as soon as possible after metadata has been quality controlled and pass the publication details of the metadata record on to ausseabed@ga.gov.au. Publishing the record with AODN can be done in one of two ways:

i. If metadata from your agency is regularly harvested by the AODN, follow agency-specific protocols for metadata and data release.

ii. Otherwise, metadata records can be created and submitted via the AODN Data Submission Tool. Note that user registration is required, but this is free and immediate.

b) providing the metadata record with the data for AusSeabed to assume custodianship of the data and exclusive publication through the AusSeabed Data Hub and associated services.

Please note that other funder, or regulator metadata requirements may apply.

Table 11 Data required for submission to AusSeabed

Deliverable item	Specifications
Sonar file L0, L2 and L3	Table 5
Navigation, Heave and Attitude files L0 and L2	Table 5
Ancillary files L0 and L2 (Tide, SVP, etc.)	Table 5
Backscatter L3	Table 5
Records (Reports and logs)	Section 6
Metadata	Section 2.3.1.3
Two visual images of the bathymetric surface for manual inspection of data quality (one with sun illumination from two orthogonal directions and the other with five time's vertical exaggeration.)	

In the future, a data submission portal will be integrated with the Survey Coordination Tool and the QC tools suite (both currently being developed by AusSeabed). This will make the provision of data to the AusSeabed Data Hub a seamless and efficient user experience, utilising metadata captured during earlier stages of the surveying process and providing automated quality assurance of collected data.

8. Multibeam acoustics for marine monitoring

This section is particularly relevant to the acquisition of MBES data within the Australian Marine Parks (AMPs), but can be used for any surveys where habitat monitoring is a key focus. The principles presented in the preceding sections of the Australian Multibeam Guidelines should still inform and influence the planning through to acquisition phases of MBES work undertaken in AMPs and the requirements detailed in this section should be seen as a complementary lens used to refine effort for the particular needs of benthic habitat monitoring.

The AMPs were established to protect and conserve areas of ecological significance within the Australian marine estate and cover 36 per cent of our oceans, or around 3.3 million square kilometres. To ensure adequate and appropriate management of these areas, the National Environmental Science Program Marine Biodiversity Hub, AusSeabed Community and Parks Australia have defined the requirements of MBES acquisition carried out within Australian Marine Parks. These requirements will maximise the environmental and societal benefits of any MBES data collection done in these areas.

There are two particular needs for mapping habitats in AMPs: 1) baseline surveys or monitoring surveys, which are first—time acquisition of high-resolution data for exploratory purposes; and 2) monitoring surveys, which consist of repeat mapping for monitoring benthic habitat change. MBES can be used for both survey types, however, they have different acquisition and post-processing specifications.

Baseline surveys are used to map the distribution of marine benthic habitats at a particular spatial scale and provide information necessary for more targeted field surveys using such tools as towed video, AUVs and stereo baited remote underwater video stations (BRUVs) (Lucieer et al. 2013, Monk et al. 2016, Wines et al. 2020). In contrast, monitoring surveys are used to assess change in distribution and extent of targeted habitats or features (such as rocky outcrops) identified during previous baseline surveys (Rattray et al. 2009, McGonigle et al. 2010). This type of survey requires MBES data to be collected at a higher resolution and with a greater degree of positional accuracy. The survey specifications and requirements needed to meet the aims of each survey type are presented in Table 12.

Table 12 Standard Operating Procedures for MBES surveys aimed for benthic habitat mapping according to purpose: Baseline surveys or Monitoring surveys

Specification	Baseline surveys	Monitoring surveys
Purpose	• Used to identify seafloor habitats and potential biodiversity hotspots. • Used for discovery purposes in regions that have had no baseline mapping conducted.	• Used to ensure spatio-temporal assessment of the seabed and habitat through repeat mapping of targeted key benthic habitats. • The survey accuracy standard is very high to ensure reproducibility over time.
Pre survey preparation	• as per section 2	In addition to baseline survey specifications: • Synthesis of all pre-existing survey data into survey region database • Identification of locations of seafloor targets to be monitored
Mobilisation and calibration	• As per section 3	
Data Logging	• Bathy: Mandated • Seabed Backscatter: Mandated • Water column backscatter: Recommended (if available)	• Bathy: Mandated • Seabed Backscatter: Mandated • Water column backscatter: Mandated (if available)
Acquisition setting	• As per section 4 • Set to equidistant mode and minimise setting changes	
Sound Velocity Profiles (SVP)	• Min of 1 per day, but should be monitored. • If sound speed at the transducer varies by > 2m/s another SVP should be collected	• Min of 2 per day (beginning and end of survey), but should be monitored. • If sound speed at the transducer varies by > 1m/s another SVP should be collected
Geodetic Parameters	• WGS 84 (ITRF); GDA2020 • Horizontal accuracy: 5m + 5% of water depth. Vertical accuracy: 1% water depth	• WGS 84 (ITRF); GDA2020 • Horizontal accuracy: absolute positioning to be < 2 m. Vertical accuracy: < 0.5 m
Mapping Coverage & Overlap	• 100% Coverage with 30% overlap between survey lines of data with 95% confidence level.	• 100% coverage with 60% overlap between survey lines of data with 95% confidence level.
Resolution	• 1 m resolution in < 50m depth ; 5% of depth beyond 50 m	• 1 m resolution
Tides and GPS Tide	• Record GPS tides. All soundings shall be reduced to the ellipsoid.	• Record GPS tides. All soundings shall be reduced to the ellipsoid.
Point data attribution	• All data should be attributed with its uncertainty estimate at the 95% confidence level for both position and, if relevant, depth.	• All data should be attributed with its uncertainty estimate at the 95% confidence level for both position and, if relevant, depth.

Metadata and Reports	As per section 2.3.1.3 and section 6
Data Release	As per Section 7. Until further notice, a metadata record should also be filled with AODN for archiving. For agencies with regular metadata harvest by the AODN, follow agency-specific protocols for metadata, otherwise create and submit metadata records via the AODN Data Submission Tool. Note that user registration is required, but this is free and immediate.
Notification	After the data has been successfully received by AusSeabed and metadata uploaded to the AODN, please contact marineparks@awe.gov.au to confirm delivery of data.

9. References

AHO, 2018. Hydroscheme Industry Partnership Program - Statement of requirements. (Last accessed 07 July 2020) www.hydro.gov.au/NHP

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Appendix A – Abbreviations

Table A13Abbreviations used in this document

AHO	Australian Hydrographic Office
AMP	Australian Marine Park
AUV	Autonomous underwater vehicle
BIST	Built-in Systems Test (Kongsberg specific)
BITE	Built-in test environment (Reson specific)
BM	Benchmark
CD	Chart Datum
CTD	Conductivity / Temperature / Depth
CRP	Common Reference Point
DGNSS	Differential Global Navigation Satellite System
DGPS	Differential Global Positioning System
DOP	Dilution of Precision
GA	Geoscience Australia
GDA2020	Geodetic Datum of Australia 2020
GNSS	Global Navigation Satellite System
GPS	Global positioning system
HAT	Highest Astronomical Tide
HIPP	Hydroscheme Industry Partnership Program
ICSM	Inter-Governmental Committee on Surveying and Mapping
IHO	International Hydrographic Organisation
IMU	Inertial motion unit
ISO	International Organisation for Standardisation
ITRF	International Terrestrial Reference Frame
LAT	Lowest Astronomical Tide
LINZ	Land Information New Zealand
MBES	Multibeam Echo Sounder (inclusive of interferometric bathymetric swath systems)
MHHW	Mean High Water
MHWS	Mean High Water Springs
MLWS	Mean Low Water Springs
MRU	Motion Reference Unit
MSL	Mean Sea Level
NESP	National Environmental Science Program

NM	International Nautical Mile
PPK	Post Processed Kinematic
PPS	Pulse Per Second
QA	Quality Assurance
QC	Quality Control
ROS	Report of Survey
ROV	Remotely operated vehicle
RTK	Real Time Kinematic
SD	Sounding Datum
SIC	Seabed mapper in Charge
SMS	Seabed Mapping System
SO	Special Order
SV	Sound Velocity
SVP	Sound Velocity Probe or Sound Velocity Profile
SVS	Sound velocity sensor
THU	Total Horizontal Uncertainty
TPU	Total Propagated Uncertainty
TVU	Total Vertical Uncertainty
UTC	Coordinated Universal Time
UTM	Universal Transverse Mercator
WGS-84	World Geodetic System 1984
XBT	Expendable Bathythermograph

Appendix B – Glossary

Below are some of the terms used in these guidelines. A more extensive list of hydrographic terms and definitions can be found in Table 2.1.2 of AHO (2018).

% Overlap: refer to the amount of overlap between adjacent swaths. 0% overlap means that the ship tracks are run so that the outer beams of the swath meet the outer beam of the adjacent swath, which is not recommended, 10-20 % overlap is recommended (Figure B1). 100% overlap means that the adjacent ship track is run along the outer beam edge (meeting the required specification) of the previous swath (Figure B2). Refer to section 7.4 of AHO (2018) for more details

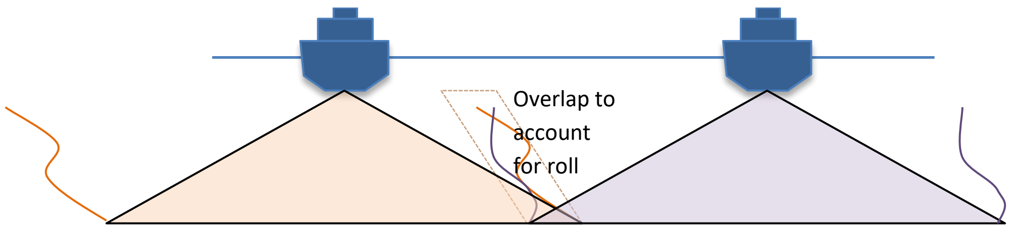

Figure B1 100% swath coverage with 10-20 % overlap to account for ship role and line keeping (AHO, 2018)

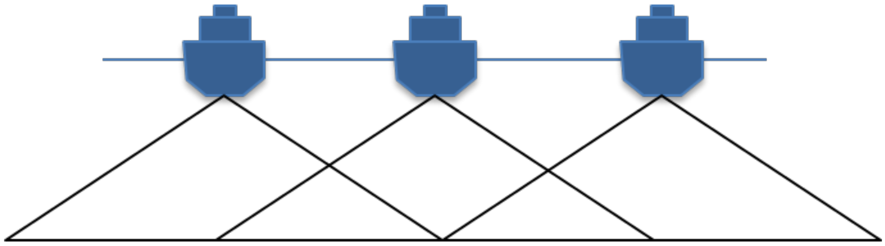

Figure B2 200% swath coverage with 100 % overlap (AHO, 2018)

Blunders: See Error, gross.

Checkline: Sounding lines that are run perpendicular to the main survey lines and used to QA the soundings.

Coverage: portion of the seabed cover by the multibeam swath. 100% coverage refers to 100% of the seabed covered by the swath without any overlap (Figure B1), while 200% coverage refers to 100 % overlap (Figure B2). Partial coverage refers to a seabed coverage that is less than 100%.

Crossline: also known as checkline

Depth: Depth is a vertical distance from a given vertical datum. Depths are derived by MBES from measurements of angles and ranges corrected for environmental factors. Horizontal Position is provided to derived depth by GNSS-Inertial system thus providing an xyz value. GNSS Inertial system derived vertical position from measurements of angular rates and acceleration.

Dimension control: consists of determining the relationship between the measurement sensor and the platform Common Reference Point.

Error: The difference between an observed or computed value of a quantity and the ideal or true value of that quantity.

Error, gross: The result of carelessness or a mistake; may be detected through repetition of the measurement. Also called *blunder.*

Error, random: remaining uncorrelated noise in the system, or noise, also known as accidental error.

Patch test: A patch test is a specific survey performed prior to principal survey to allow adjustments of the MBES data for parameters such as transducer error (pitch, roll and yaw), and navigation latency. This test is done since the MBES has no reference to external fixed frame of reference (satellite constellation isn't visible underwater), the MBES receives its "frame" from GNSS-Inertial system. These adjustments are entered in the acquisition software. For patch test patterns see Appendix F.

Seabed backscatter: Defined as the amount of acoustic energy being received by the sonar after a complex interaction with the seabed. Measured as the ratio between the intensity of the acoustic pulse scattered back by the seafloor and the incident intensity, this information can be used to determine bottom type, knowing that the different bottom types "scatter" sound energy differently. The intensity of the backscatter received at the transducer depends on the transmitted source level, the transmission loss (absorption in the water column and geometrical spreading), and the target strength. Many multibeam sonar systems offer two types of seabed backscatter data namely "one-per-beam" backscatter (either beam average or max intensity) and "time series" backscatter. For further information on backscatter refer to Lamarche and Lurton, 2017

Sounding datum: This datum is used while mapping. It is a low-water plane to which soundings are reduced and above which drying heights are given on the Standard Sheet and in other survey records. However, for chart datum, tidal reduction is essential (Figure 3).

Swath system: Current swath sounding systems utilize two differing technologies to achieve bathymetry measurements across a "swath" of the sea floor: 1) Beam forming (multibeam echo sounders), and 2) interferometric or phase discrimination sonars, also known as bathymetric sidescan. Both of these techniques have their merits; however, the same end results are achieved.

Systematic error: see error.

Transit data: Transit data include any data collected outside the survey specific area, e.g. data collected between port and survey area or between sampling sites. In hydrographic terms, this is referred to as passage soundings.

Water Column backscatter: Recently developed multibeam sonars have the capability to record the sonar time series for each beam, which maps the water column in addition to the seafloor. Water column data could be used for direct mapping of fish and marine mammals, the mapping of plumes and vents, the location of mid-water targets, and a wide range of physical oceanographic processes.

Appendix C – Legislation and permitting

Table C1 List of documents relevant to multibeam activities in the Commonwealth waters (defined as 3 nautical miles seaward to the outer boundary of the EEZ, 200 nautical miles). Extracted from Marine Sampling Field Manuals (Przeslawski and Foster, 2018). Similar issues should be considered when working in coastal waters of States and the Northern Territory.

Activity	Activity Type	Jurisdiction	Responsible Agency	Legislation/Treaty/ Documents	Requirements for approval	Link
Research and monitoring	All activities	Australian Marine Parks	Department of Agriculture, Water and Environment (DAWE)	*Environment Protection and Biodiversity Conservation Act 1999 (Cth)* (EPBC Act)	Authorisation is required for all zones	https://parksaustralia.gov.au/marine/contact/
	Activities with potentially significant impact on a matter of national environmental significance	Commonwealth	DAWE	Australian Marine Park Management Plans EPBC Act	EPBC Act referral Public consultation, including indigenous stakeholders	http://www.environment.gov.au/protection/environment-assessments/ http://www.environment.gov.au/epbc/what-is-protected
	All activities	Heard Island and McDonald Islands	DAWE	Environment Protection and Management Ordinance 1987 (HIMI) EPBC Regulations 2000	Permit required	*https://www.antarctica.gov.au/living-and-working/travel-and-logistics/cargo-and-freight/types-of-cargo/scientific-samples/environmental-approvals/*
	All activities	Antarctica (south of 60°S)	DAWE	Antarctic Treaty (Environment Protection) Act 1980 *Antarctic Marine Living Resources Conservation (AMLRC) Act 1981*	Authorisation ***and*** permit required *AMLRC Act permit required if carrying out research with respect to marine living organisms in the CCAMLR Convention Area*	*https://www.antarctica.gov.au/environment/environmental-impact-assessment-approvals-and-permits//*

Interactions with Cetaceans	Acoustic equipment with received exposure level 160dB re 1 µPa2.s for 95% of shot at 1km range (seismic)	Commonwealth	DAWE	EPBC Act Policy Statement 2.1	EPBC Referral and comply with Policy Statement 2.1	http://www.environment.gov.au/resource/epbc-act-policy-statement-21-interaction-between-offshore-seismic-exploration-and-whales
	Vessel interaction	Commonwealth	DAWE	*EPBC Act. Regulations 2000* (Cth) (EPBC Regulations) part 8	Report death, injury, stranding or entanglement of whales and dolphins to DoEE. Specific requirements for vessels	https://www.legislation.gov.au/Details/F2016C00914
Interaction with Heritage	Historic Ship wrecks	Continental shelf waters (incl. some areas > 200 nm)	DAWE	*Historic Shipwrecks Act 1976 (Cth)*	Ship wrecks and relics older than 75 years and lying within protected zones.	http://www.environment.gov.au/heritage/historic-shipwrecks
Restricted vessel movement and moored scientific equipment that create navigation hazards			Australian Hydrographic Service AHS Australian Marine Safety AMSA		Notice to mariners 2-3 weeks prior to survey commences. Vessel to RCC to update NAVAREA X alerts	https://www.amsa.gov.au/safety-navigation/navigation-systems/maritime-safety-information-database datacentre@hydro.gov.au rccaus@amsa.gov.au
Research in the Great Barrier Reef Marine Park GBRMP	Research, except for limited impact research.	GBRMP	Great Barrier Reef Marine Park Authority GBRMPA	*Great Barrier Reef Marine Park Act 1975 (Cth)* *EPBC Act*	Limited impact research may be conducted under a letter of authority issued by an accredited educational or research institutions All other research requires permission	http://www.gbrmpa.gov.au/zoning-permits-and-plans/permits http://www.gbrmpa.gov.au/zoning-permits-and-plans/permits/research-permissions
Research around petroleum and other infrastructure		Commonwealth	National Offshore Petroleum Safety and Environmental Management Authority (NOPSEMA)	*Sea Installations Act 1987*	Vessels prohibited to go within a safety zone of 500m	http://www.environment.gov.au/topics/marine/marine-pollution/sea-dumping/sea-installations

Accessing areas where a Native Title determination exists	All activities	Commonwealth	National Native Title Tribunal	Native Title Act 1993 *(Cth)*	Refer to National Native Title Tribunal registers.	http://www.nntt.gov.au/Pages/Home-Page.aspx
Activities within Defence Offshore Training Areas or Restricted Airspace	All activities	Commonwealth	Department of Defence (DoD)		Refer to NOTAMs, NTMs and AUSCOAST or NAVAREA X warnings	http://www.hydro.gov.au/factsheets/WFS_Firing_Practice_And_Exercise_Areas.pdf https://www.airservicesaustralia.com/aip/aip.asp https://nationalmap.gov.au/#share=s-wMPX5gwlZcPGccu8ijiVrF4RFIx *offshore.petroleum@defence.gov.au* *ADF.Airspace@defence.gov.au*
Impact on the commercial fishing industry	Activities with potentially significant impact fish stocks or habitat	Commonwealth	*Commonwealth Fisheries Association (CFA)*	*Fisheries Management Act 1991 (Cth)*	Consultation	https://www.afma.gov.au/sustainability-environment/petroleum-industry-consultation (List of regional bodies on website) *ceo@comfish.com.au*

Laws and regulations regarding multibeam sonar acquisition in State and Territory waters (less than 3 nm from the coast) vary slightly across jurisdictions, but they are generally not restricted or subject to permit requirements, with the exception of:

- Survey undertaken in Marine Protected Areas (for guidance see Marine Protected Areas section above).
- Survey carrying out extractive work (marine biota) or work that could be considered destructive to marine habitats.
- Surveys undertaken across areas with access restrictions (e.g., naval waters, commercial ports, or shipping channels).
- Surveys carried out In New South Wales for the purposes of resource exploration (permission through NSW Resources and Energy - Environment and Planning).

Table C2 Weblinks to state and territory permits

VIC Research	SA Research	NSW Research	NT Research	TAS Research	QLD Research	WA Research

Appendix D – Guideline on timeframe for actions

Table D15Estimated time frame required to perform some of the swath system related tasks. These estimates are to assist in survey planning, but note that they can vary considerably depending on the difficulty or the issues arising from the task performed.

Action	Timeline to be expected
Authorisation/permits from authority	Months
Mobilisation, calibration, validation (does not include time to manufacture mounts to fit the system)	3-5 days
Patch test	2 hrs to 0.5 day
Self-system test	2-5 minutes
SVP cast (depends on water depth and device)	20 min plus deployment time of the SVP, which depends on water depth (based on SVP not XBT device)
Crossline	0.5 day (depends on survey area)
Acquisition vs Processing ratio (depends on the quality of the input data and the level of cleaning)	1:1 to 1:3

Appendix E – Total Propagated Uncertainties

Table E16Sounding Accuracy - Example MBES Total Propagated Uncertainty Estimates to a 95 % CL

Uncertainty Source	Value	Reference to Accuracy Value for Total Propagated Uncertainty Computation
Heading (degrees)	0.05	(Make/Model) – Manufacturer Accuracy Value
Smart Heave (Amplitude %) Real-Time Heave (Amplitude %)	2.5 5.0	(Make/Model) – Manufacturer Accuracy Value
Smart Heave (m) Real-Time Heave (m)	0.025 0.05	(Make/Model) – Manufacturer Accuracy Value
Roll (degrees)	0.01	(Make/Model) – Manufacturer Accuracy Value
Pitch (degrees)	0.01	(Make/Model) – Manufacturer Accuracy Value
Navigation (m)	0.10	(Make/Model) – Manufacturer Accuracy Value
Transducer Timing (s)	0.001	Estimated – 1PPS (Make/Model)
Navigation Timing (s)	0.001	Estimated – 1PPS (Make/Model)
Heading Timing (s)	0.001	Estimated – 1PPS (Make/Model)
Heave Timing (s)	0.001	Estimated – 1PPS (Make/Model)
Pitch Timing (s)	0.001	Estimated – 1PPS (Make/Model)
Roll Timing (s)	0.001	Estimated – 1PPS (Make/Model)
Offset X (m)	0.02	Estimated – (Description of Dimensional Control method)
Offset Y (m)	0.02	Estimated - (Description of Dimensional Control method)
Offset Z (m)	0.02	Estimated - (Description of Dimensional Control method)

Speed (knots)	0.10	Not Applicable
Loading (m)	0.02	Estimated
Draft (m)	0.05	Estimated – (Description of measurement)
Delta Draft (m)	0.02	Estimated - Vessel Dynamic Draft (Squat/Settlement) Calibration
MRU Heading Alignment (degrees)	0.05	Estimated - Multi-beam Patch Test Calibration
MRU Pitch/Roll Alignment (degrees)	0.05	Estimated - Multi-beam Patch Test Calibration
Tidal Measurements (m)	0.02 0.02 0.03 0.05	(Make/Model) TG – Manufacturer Accuracy Value (Make/Model) Barometer – Manufacturer Accuracy Value Estimated - GNSS Buoy TG calibration Estimated – Accounting for above Contributions
Tidal Zoning (m)	0.10	Estimated - Co-Tidal Model
SVP Profile Measurement (m/s)	0.02 0.50	(Make/Model) – Manufacturer Accuracy Value Estimated - Temporal and Spatial Variation
SVP Surface Measurement (m/s)	0.017	Make/Model) - Manufacturer Accuracy Value
Sonar Measurement		MBES Device Models File

Appendix F – Patch test

The figures below shows the pattern to use for the patch test of a MBES system with one (Figure F1) or two (Figure F2) sonar head configurations.

For **backscatter calibration** see section 4.3.2

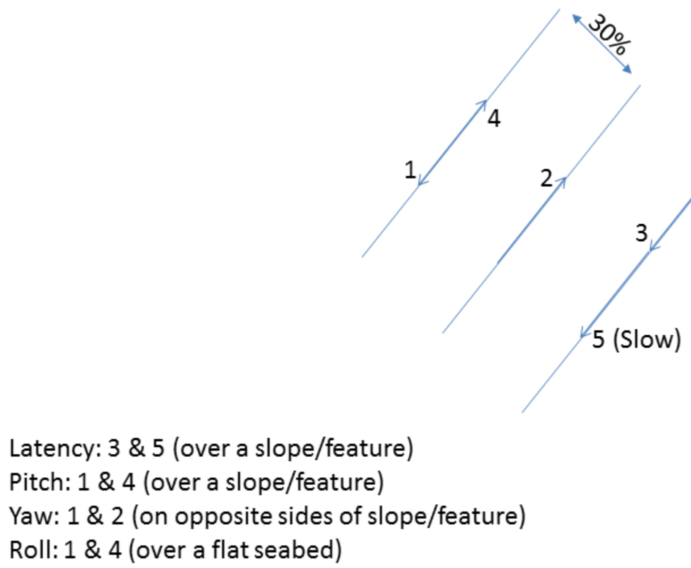

Figure F1 Proposed line pattern for single head sonar patch test

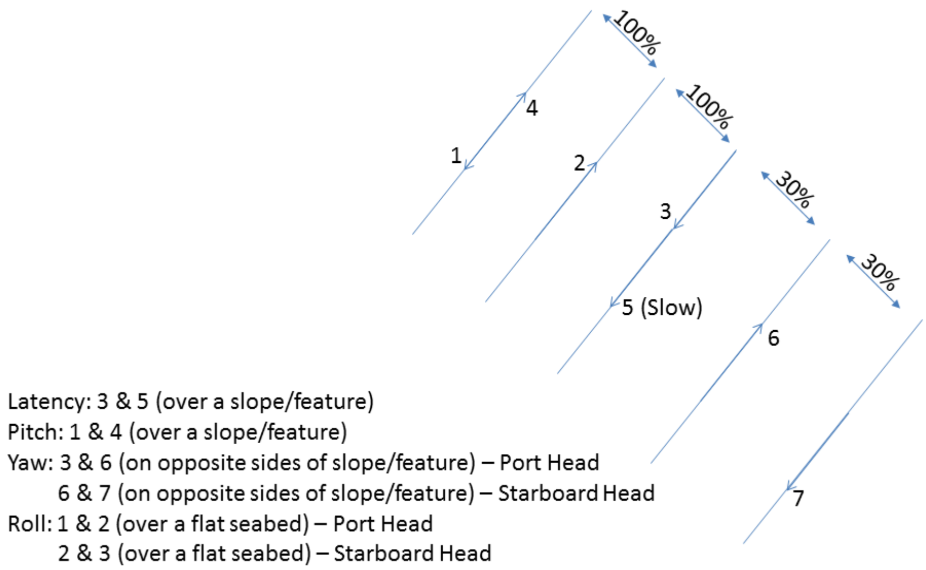

Figure F2 Proposed line pattern for **dual-head** sonar patch test

Appendix G – IHO Standards

Table G17IHO standards for hydrographic surveys (S-44). Read in conjunction with document (IHO, 2008). These are presently in review by the IHO.

Reference	Order	Special	1a	1b	2
Chapter 1	**Description of areas.**	Areas where under-keel clearance is critical	Areas shallower than 100 metres where under-keel clearance is less critical but *features* of concern to surface shipping may exist.	Areas shallower than 100 metres where under-keel clearance is not considered to be an issue for the type of surface shipping expected to transit the area.	Areas generally deeper than 100 metres where a general description of the sea floor is considered adequate.
Chapter 2	**Maximum allowable THU 95% *Confidence level***	2 metres	5 metres + 5% of depth	5 metres + 5% of depth	20 metres + 10% of depth
Para 3.2 and note 1	**Maximum allowable TVU 95% *Confidence level***	a = 0.25 metre b = 0.0075	a = 0.5 metre b = 0.013	a = 0.5 metre b = 0.013	a = 1.0 metre b = 0.023
Glossary and note 2	***Full Sea floor Search***	Required	Required	Not required	Not required
Para 2.1 Para 3.4 Para 3.5 and note 3	***Feature Detection***	Cubic *features* > 1 metre	Cubic *features* > 2 metres, in depths up to 40 metres; 10% of depth beyond 40 metres	Not Applicable	Not Applicable
Para 3.6 and note 4	**Recommended maximum Line Spacing**	Not defined as *full sea floor search* is required	Not defined as *full sea floor search* is required	3 x average depth or 25 metres, whichever is greater For bathymetric lidar a spot spacing of 5 x 5 metres	4 x average depth
Chapter 2 and note 5	**Positioning of fixed aids to navigation and topography significant to navigation. (95% *Confidence level*)**	2 metres	2 metres	2 metres	5 metres
Chapter 2 and note 5	**Positioning of the Coastline and topography less significant to navigation (95% *Confidence level*)**	10 metres	20 metres	20 metres	20 metres
Chapter 2 and note 5	**Mean position of floating aids to navigation (95% *Confidence level*)**	10 metres	10 metres	10 metres	20 metres

Table G2 HIPP standards for hydrographic surveys (AHO, 2018)

HIPP ORDER		HIPP - Precise	IHO – Special	IHO - 1a	IHO - 1b	HIPP - 2	IHO - 2	HIPP-Passage
TOTAL HORIZONTAL UNCERTAINITY (THU)								
TOTAL HORIZONTAL UNCERTAINITY (95% Confidence Level)		1m	2m	5m + 5% of depth	5m + 5% of depth	5m + 1% of depth	20m + 10% of depth	5m +5% of depth
SEAFLOOR SEARCH REQUIREMENTS (COVERAGE)								
Swath Systems (1)		Full Seafloor Coverage (FSC)	Full Seafloor Coverage	Full Bathymetric Coverage (FBC) (LIDAR – 200% Coverage)(2)	Full Seafloor Ensonification (FSE)	Full Bathymetric Coverage	Not Required	Offset tracklines (if applicable)(3)
FEATURE DETECTION								
Water Depth <40m	Swath	50cm	1m	2m	As Specified	As Specified	Not Applicable	4m
Water Depth >40m	Swath	1m	2.5% of depth	5% of depth	As Specified	2% of depth	Not Applicable	10% of depth
TOTAL VERTICAL UNCERTAINITY (TVU) (4)								
TOTAL VERTICAL UNCERTAINITY (95% Confidence Level)		a = 0.15m b = 0.0075	a = 0.25m b = 0.0075	a = 0.5m b = 0.013	a = 0.5m b = 0.013	a = 0.6m b = 0.0085	a = 1.0m b = 0.023	a = 0.5m b = 0.023

Appendix H – Records templates

The following appendix provides suggested templates for records that should be produced during a seabed mapping survey. These templates can also be downloaded on the AusSeabed website.

H.1 Mobilisation, calibration and validation report

The following link provides you with the template.

H.2 AusSeabed minimum required metadata

Below is a table with specific field definitions and examples for each metadata field expected to accompany data submitted to AusSeabed in order for AusSeabed to assume custodianship of, and to exclusively publish the data. The fields specified are considered a minimum set that can be extended to include fields outlined in section 2.3.1.3, but should not be deviated from, replaced, or altered. Note that on submission it is only required to provide the Field column and the associated survey metadata, the other columns in the table are provided for illustrative purposes only.

Table H19Required Metadata for data submitted to AusSeabed

Category	Definition	Fields	Specific Field Definitions	Example Data
General	Basic information about the data package being submitted.	Survey title (full)	A short phrase or sentence describing the dataset. In many discovery systems, the title will be displayed in the results list from a search, and therefore should be human readable and reasonable to display in a list of such names.	*MH370 Phase 1 150m Bathymetry datasets*
		Survey ID	The ID assigned to the survey, relevant especially when an ID may be how the survey is more widely referenced.	*GA-4421, GA-4422, GA-4430*
		Abstract	A paragraph describing the dataset, analogous to an abstract for a paper.	*“On behalf of Australia, the Australian Transport Safety Bureau (ATSB) is leading search operations for missing Malaysian airlines flight MH370 in the Southern Indian Ocean. Geoscience Australia provided advice, expertise and support to the ATSB to facilitate bathymetric surveys …* [for full abstract visit http://pid.geoscience.gov.au/dataset/100315]

Category	Definition	Fields	Specific Field Definitions	Example Data
		Lineage	Information about the events or source data used in constructing the data specified by the scope or lack of knowledge about lineage. Lineage can be complex to record, so can be actively linked within a metadata record either to a file within the dataset being submitted or to a hosted location where the lineage statement may be found. If neither of these options are preferred, a full narrative may also be provided.	*"link-to-lineage-statement" OR* *Full text:* *"The MH370 Search bathymetry Surveys, GA-4421 GP1483 was acquired by the Australian Government through ATSB/GA on-board the MV Fugro Equator from the 05th of June to the 30th of July 2016, GA-4422 through the Chinese Navy Vessel Zhu Kezhen 872 from the 3rd June to 31 August 2014 and from the 5th January to the 30 April 2015 for the MV Fugro Supporter………"*
Contact for the Data	Information that is related to contacts for the data	Data Owner	. The person and/or organisation that owns the submitted data for the purpose of empowering AusSeabed to act as a custodian	*Commonwealth of Australia*
		Custodian	The person and/or organisation that accepts, archives and disseminates the data	*Commonwealth of Australia*
		Point of Contact	The person and/or contact details for initiating contact regarding the data	*Commonwealth of Australia (Geoscience Australia)* *clientservices@ga.gov.au (Manager Client Services)* *Cnr Jerrabomberra Ave and Hindmarsh Dr GPO Box 378, Canberra, ACT, 2601, Australia* *Call 1800 800 173,02 6249 9960*
		Collecting Entity	The organisation that was responsible for collecting the data being described.	*Australian Transport Safety Bureau (ATSB)*

Category	Definition	Fields	Specific Field Definitions	Example Data
Citation	Information that is collected to ensure appropriate credit is assigned for the data being provided, and ensuring the data's intended use of the data is clear.	Attribution Licence (citation)	Statement of attribution that must be included whenever the data being provided is distributed/redistributed or used by another organisation.	*2017. MH370 Phase 1 150m Bathymetry datasets (GA-4421, GA-4422 & GA-4430). Geoscience Australia, Canberra. http://pid.geoscience.gov.au/dataset/100315*
		Legal Constraints	Restrictions and legal prerequisites for accessing and using the resource or metadata	*Creative Commons Attribution 4.0 International Licence http://creativecommons.org/licenses/*
		Access Constraints	Details of any constraints that are not determined under the licence constraints regarding the access to the information being provided. Access constraints are applied to assure the protection of privacy or intellectual property, and any special restrictions or limitations on obtaining the resource or metadata	*As per licence*
		Use Constraints	Details of any constraints that are not determined under the licence constraints regarding the use of the information being provided.	*As per licence*
		Country (of data ownership)	Country of the owner of the data.	*Australia*
	The information provided in the	Survey area (general)	Plain English description of the location of the survey.	*Indian ocean approximately 1100nm off the coast of Perth Australia.*

Category	Definition	Fields	Specific Field Definitions	Example Data
Survey Positioning Data	positioning data provides for both an overview of the survey's coverage, and the primary coordination reference system that was used to collect/prepare the survey data.	Survey bounding box coordinates	The detailed coordinates of the survey. This may be provided in a variety of formats, however full positioning information is required.	*78.00, -42.00, 116.00, -12.00*
		Coordinate reference system - Bounding Box	The coordinate reference system used to define the survey bounding box.	*"WGS 84 / UTM zone 44S (EPSG:32744)","WGS 84 / UTM zone 46S (EPSG:32746)","WGS 84 / UTM zone 47S (EPSG:32747)","WGS 84 / UTM zone 48S (EPSG:32748)","WGS 84 / UTM zone 49S (EPSG:32749)","WGS 84 / UTM zone 50S (EPSG:32750)"*
		Coordinate reference system - Survey Data	The coordinate reference system used for data collection.	*"WGS 84 / UTM zone 44S (EPSG:32744)","WGS 84 / UTM zone 46S (EPSG:32746)","WGS 84 / UTM zone 47S (EPSG:32747)","WGS 84 / UTM zone 48S (EPSG:32748)","WGS 84 / UTM zone 49S (EPSG:32749)","WGS 84 / UTM zone 50S (EPSG:32750)"*
Reference System	The finer details of the reference system used for data collection.	Geodetic datum of the survey	The reference datum of the data collected	*WGS 84*
		Horizontal Datum	The horizontal reference datum for data collection	*UTM*
		Vertical Datum	The vertical reference datum for data collection	*MSL*

Category	Definition	Fields	Specific Field Definitions	Example Data
Survey Configuration	The configuration of the survey as it ran.	Instrument type	The type of instrument used to capture the data. Suggested values are: - Multi-beam - Single-Beam - Bathy LiDAR - Airborne Imagery - Satellite - Side-Scan - Sub-Bottom profiler	*Multi-beam Sonar*
		Sensor type	The type of sensor used to collect the data being provided.	*EM2040*
		Sensor Frequency	Frequency at which the survey was conducted. This may be provided as multiple values based on the sensor's capabilities.	*200-400kHz*
		Platform type	The platform hosting the instruments and sensors used to collect the data.	*Ship, AUV*
		Platform Name	The name of the platform used to collect submitted data	*RV Investigator*

H.3 Survey log sheet templates

MBES LOG SHEET						
SURVEY NAME:			**VESSEL:**		**JULIAN DAY:**	**UTC OFFSET:** / **PAGE:**
OPERATOR					**GENERAL DESCRIPTION:**	
Name:		**Signed:**				
WEATHER:						
Local Time		**Line Name**	**Heading**	**Speed**	**Event (e.g. settings, SVP, Transit, Turn, etc.)**	**Comments (e.g. mode, frequency, pulse length, etc.)**
Start	**Stop**					

SVP LOG SHEET

SURVEY NAME:	VESSEL:	LOCAL DATE:	UTC OFFSET:	PAGE:

OPERATOR		GENERAL DESCRIPTION:
Name:	Signed:	

LOCAL TIME	POSITION		WATER DEPTH	SURFACE SV (SVS)	WEATHER			COMMENTS
	DEPLOY	RECOVER			WIND SPEED	DIRECTION	SEA STATE	

H.4 Report of Survey template

The following minimum template has been modified from AHO AH68 Survey Summary Template, which can be found in full here. A full Report of Survey format can be found in IHO publication C13. Guidance on Confidence Levels and Error Ellipse scaling is contained in ICSM (2014a), uncertainties from IHO publication S-44 or by contacting the Bathymetric Data Assessment Section at the Australian Hydrographic Office on 02 4223 6500.

Introduction

Survey Title and ID	**Locality**
Survey Authority	**Survey Sponsor/Custodian**
Surveyor in Charge and qualification	**Date this Survey Summary was completed**
Start Date of Survey	**End Date of Survey**
Survey Platform/Vessel Name	**Survey Platform/Vessel Name**
Purpose of the Survey	

Horizontal Control

Soundings are on the following datum (WGS84 preferred but not essential)	
Datum	
Spheroid	
Projection and Zone	
Was the positioning system validated?	
Were laybacks applied?	
Estimated horizontal accuracy of soundings at 2 Sigma (95%) confidence level (Calculations can be included as an	

attachment. Don't know? Enter "Not Known")	

Vertical Control

Tides Applied	
Soundings Datum	
Tide Station 1 Details	
Benchmark (BM) used and Datum connection	
Geoid details if using GPS tides	
Tide Station 2 Details	
Benchmark (BM) used and Datum connection	
Geoid details if using GPS tides	
Tide Station 3 Details	
Benchmark (BM) used and Datum connection	
Geoid details if using GPS tides	
Tide Model comments (if applicable)	

Were soundings corrected for draught?	
Were the soundings corrected for sound velocity?	
Estimated vertical accuracy of soundings at 1.96 Sigma (95%) confidence level (Calculations can be included as an attachment. Don't know? Enter "Not Known")	

The following positioning systems were used:	
Positioning System 1	
Positioning System 2	
Base station (If applicable)	
The following sounding systems were used:	
Model / System Details	**Frequency (kHz)**
Echosounder 1	
Echosounder 2	
Logging and Processing Systems used, and Versions:	
Logging	
Processing	
Was the survey systematically controlled with planned survey lines or methods?	
Was full feature detection achieved as defined in IHO publication S-44, Edition 5, February 2008?	
If feature detection was achieved, what Order of features is applicable?	
Feature detection comments (if applicable)	

Were all shoal depths systematically investigated and their least depths determined?	
Has data been thinned from that collected?	
If thinned, what thinning method and bin size was used?	

Remarks (If applicable)

Shoals and Dangers

This section seeks comments on any features that may be dangerous to surface navigation. (Comments as required. General location and depth references, pictures, screen dumps, etc. will assist. Has a Hydrographic Note or Danger to Navigation Report been submitted?)

Wrecks

This section seeks comments on any wrecks detected during the course of survey. (Comments as required. General location and depth references, pictures, screen dumps, etc. will assist.)

National Environmental Science Programme

4. MARINE SAMPLING FIELD MANUAL FOR AUVS (AUTONOMOUS UNDERWATER VEHICLES)

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Platform Description

Autonomous Underwater Vehicles (AUVs) are untethered robotic platforms that operate independently to complete pre-determined surveys. The endurance of AUVs typically range from hours to several days (Huvenne et al. 2018). However, with the rapid development of battery technology long-period deployments ranging from weeks to months are now possible (Furlong et al. 2012; Hobson et al. 2012). Maximum operational depths range from a few hundred metres for the smaller vehicles (Wynn et al. 2014) to over 6000 m for larger units (Huvenne et al. 2009).

Huvenne et al. (2018) classify AUVs as either "cruising" or "hovering" vehicles (Figure 4.1). Cruising AUVs are traditionally torpedo-shaped, driven by a single propeller at speeds up to 2 ms^{-1}, and are optimised to cover large distances along pre-designed survey tracks (Wynn et al. 2014). These cruising AUVs are usually not well suited to photographically surveying high-relief seabed terrain due their lack of vertical agility. Traditionally, cruising AUVs are the main type of AUVs used in the commercial world, with prominent scientific examples including the Autosub series from the National Oceanography Centre (UK), the AsterX and IdefiX from French Research Institute for Exploitation of the Sea (IFREMER; France) and the Dorado series from Monterey Bay Aquarium Research Institute (USA) (Furlong et al. 2012; Rigaud 2007). By contrast, hovering AUVs are equipped with several propellers, which facilitate multi-directional manoeuvrability capabilities, similar to a remotely operated vehicle (ROV). Hovering AUVs are designed for precision operations, slow motion surveys (e.g. seabed photography) and work in distinctly 3-dimensional terrains, such as around high-relief reefs (Williams et al. 2012). Among the best-known scientific examples of hovering AUVs are ABE and Sentry from Woods Hole Oceanographic Institute (USA) (e.g. Tivey et al. 1998; Wagner et al. 2013) and Sirius from Australian Centre for Field Robotics (Australia) (e.g. Bewley et al. 2015; Williams et al. 2016; Williams et al. 2012).

Depending on the size of an AUV they can be equipped with a range of sensors such as conductivity, temperature, depth, acoustic doppler current profilers, chemical sensors, photo cameras, sonars, magnetometers and gravimeters (Connelly et al. 2012; Sumner et al. 2013; Williams et al. 2010). Importantly, on-board battery capacity is the primary limitation to the number of sensors and survey duration for AUVs. Furthermore, AUVs are currently not yet equipped for extensive physical sampling of seabed or fauna, although sampling of the water column can be achieved (Pennington et al. 2016). Overall, AUVs are more suited for survey operations, acquiring sensor data along pre-programmed transects, while ROVs are optimal for high-resolution, highly detailed and interactive work, including high-definition video surveying and physical sampling. An extensive review of the use and capabilities of AUVs for geological research was recently published by Wynn et al. (2014). There is, however, no equivalent review discussing the capabilities of AUVs for ecological research (but see section 3.3 in Wynn et al. 2014; Durden et al. 2016).

This document focuses on hover class AUVs can control their position and heading at very low speeds, which makes them suitable for operations over rough terrain while maintaining an appropriate altitude for imaging small scale targets. When equipped with navigational sensors such as GPS, Ultra Short Baseline Acoustic Positioning System (USBL), acoustic doppler profiler, and forward-looking obstacle avoidance sonar, hover class AUVs enable precise tracking along the pre-programmed routes. These characteristics make them particularly suited to collecting highly detailed sonar and optical images over high-relief seabed terrain, which can be geo-referenced with high precision. These can then be stitched together into photomosaics to focus on large features or specific details on the seafloor.

While most of the well-known AUVs used in scientific research are custom built, technological developments over the last five years have seen a number of ready-built, commercial units becoming available, with examples such as the cruising Iver and hovering Subsea 7 AUVs. The release of these units into the market will likely increase the uptake of AUVs for scientific research.

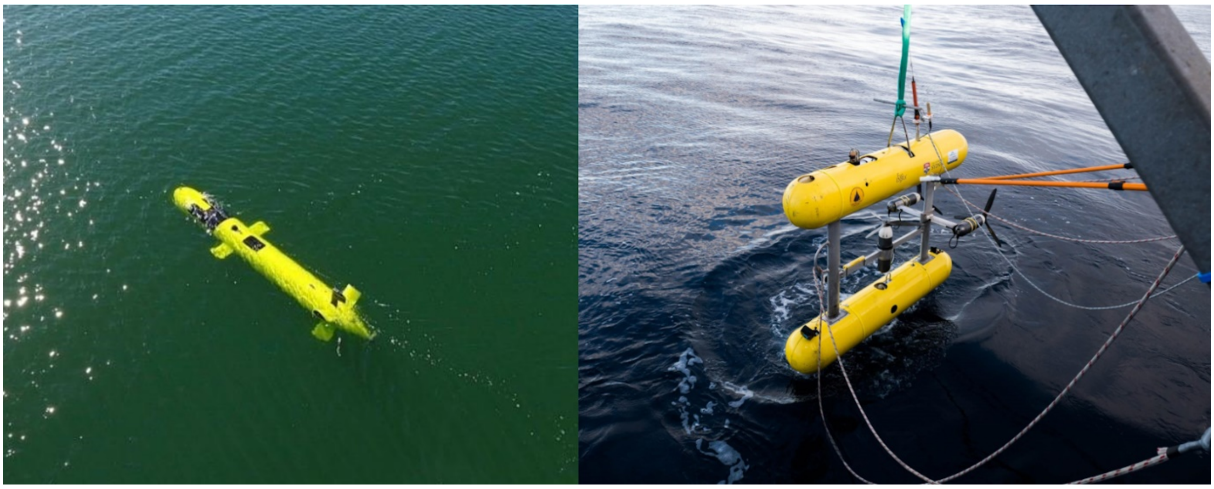

Figure 4.1: Examples of AUV classes. Left: an example of the cruising class AUV *Nupiri muka* operated by the University of Tasmania (photo credit: Damien Guihen). Right: an example of the hovering class AUV *Sirius* operated by Australian Centre for Field Robotics for Integrated Marine Observing System (Photo credit: Asher Flatt).

Scope

The primary aim of this field manual is to establish a consistent approach to marine benthic sampling using AUVs and facilitate statistically sound comparisons between studies. This manual will focus on hover class AUVs designed to survey the seabed due to their proven use in marine benthic monitoring compared to other marine imagery platforms (described in the next section of this chapter). It will not consider cruising class AUVs. The scope of the manual is to cover everything required from equipment, pre-survey preparation, field procedures and post-survey procedure for using hover class AUVs to photographically survey seabed assemblages found on Australia's continental shelf regions. Deep-sea environments are currently excluded from this field manual as we do not currently have an AUV in Australia capable of image-based surveys at these depths. Although it should be noted that AUV-based photographic surveys of the deep-sea benthos have been successfully undertaken internationally (e.g. Morris et al. 2014; 2016; Milligan et al. 2016).

For further information on the advantages and disadvantages of AUVs compared to other benthic imagery and sampling platforms, refer to *Comparative assessment of seafloor samping platforms* (Przeslawski et al 2018).

AUVs in Marine Monitoring

Application of AUVs for monitoring benthic marine ecosystems has experienced a rapid increase over the past two decades. Researchers have used hover class AUVs in monitoring the impacts of invasive species (Ling et al. 2016; Perkins et al. 2015), for ecosystem-based fisheries management (Smale et al. 2012), assessing population trends in demersal fishes (Clarke et al. 2009; Seiler et al. 2012), mapping of benthic habitats (Lucieer et al. 2013), examining diversity in reef communities (Bridge et al. 2011; James et al. 2017; Monk et al. 2016), changes in structural complexity of coral reefs (Ferrari et al. 2016a, b), and mapping the spatial and depth extent of kelp forests (Marzinelli et al. 2015).

Compared to other marine imagery platforms (e.g. towed systems), hover class AUVs have several strengths applicable to marine monitoring:

- They navigate precisely defined flight paths and the geolocation of individual images along this path. The geolocation of imagery and flight paths allows relatively precise repeat transects to be conducted, and also for the imagery to be used to ground-truth multibeam sonar (Lucieer et al. 2013) as well as for modelling the environmental factors driving species' distributions (Hill et al. 2014).
- The time-gain it provides over an ROV. This particularly the case if the AUV system can be left alone (i.e. that are truly autonomous).
- An AUV will follow the set path, will not slow down or divert for something pretty, exciting or scary in the water: something that tends to happen to humans when piloting an ROV.
- They generate spatially accurate photomosaics and finescale digital elevation models. Multibeam data which is often available with accurate georeferencing can provide important information regarding habitat types and structural complexity but is often limited to cell resolutions of 50 cm to 5 m. Finescale digital elevation models from AUV photomosaics can be done at 1-10cm cell resolution, thus enabling extremely detailed structural information to be extracted (Ferrari et al. 2016a,b). Additionally, and perhaps more importantly, the benefits of using AUV to provide digital elevation models is that the AUVs also provide colour information (via the photomosaics), which is crucial for species identification and the evaluation condition (e.g. live vs. dead coral).

The manner that data is extracted from imagery (i.e. image annotation) is context-dependent and ranges from the simple scoring of presence-absence of indicator organisms or habitats within individual images (e.g. Perkins et al. 2016) to automated habitat classification that uses sophisticated algorithms (e.g. Friedman et al. 2011). Random point count is one of the commonly employed approaches in the quantification of the cover of benthic habitats or organisms (e.g. James et al. 2017; Monk et al. 2016; Perkins et al. 2016). Whilst pattern recognition annotation has the potential to substantially speed up the image scoring process, it is not a point yet where it is accurate enough to replace manual point-counts. Accordingly, this manual will focus on point-count annotation approaches.

Pre-Survey Preparations

Ensure all permits, safety plans and approvals have been obtained. Any research undertaken within Australian Marine Parks (AMPs) requires a research permit issued from Parks Australia. See Appendix A for a list of potential permits needed.

Define question/aim of project.

Confirm sampling design is statistically sound with adequate spatial coverage and replication, and addresses the initial question/aim. This is generally achieved through the use of an explicit randomization procedure to ensure that independent replicates are obtained (Foster et al. 2017; Smith et al. 2017). See Chapter 2 for further details on sampling design.

Select appropriate transect design for AUV deployment. Two AUV transect designs are recommended for marine monitoring: 1) broad grids and 2) dense grids. Foster et al. (2014) evaluated a number of broad grid designs and determined that a grid consisting of three long parallel transects, with each transect separated by ~150-200 m (each generally covering a total of 2000-4000 m) was generally the most optimal design for monitoring purposes (Figure 4.2). The dense grid transects are used to get a complete coverage photomosaic that covers a 25 x 25 m scale (Figure 4.2). Combinations of both within a survey can be applied if required (e.g. Morris et al. 2016). Essentially, broad grids cover more ground but are less repeatable, whereas dense grids are more repeatable but less general (essentially you get more information about less).

The decision to which transect design is most appropriate is driven by the question being addressed, as well as the environment, available time and logistics of AUV deployment and retrieval. For example, in the deeper regions (> 100m) within the AMPs that are exposed to strong currents, dense grids are not recommended for temporal monitoring purposes because the challenges with maintaining physical position in these conditions make it difficult to successfully repeat the same 25 x 25 m grid. This ultimately results in limited temporal overlap between sampling points over time (Figure 4.3). Where inference is the primary objective of the study it is recommended that broad grids are used to increase sampling power (Chapter 2). Conversely, if the physical structure of the seafloor or biota (e.g. corals; Ferrari et al. 2016a) are the focus then dense grids are best suited.

Broad grids are generally used in mid-outer continental shelf Tasmanian waters as a result of strong currents. Conversely in Western Australia, the patchy nature of inshore reefs, coupled with a lack of shelf slope to encompass a wide depth range along broad grid designs meant that dense grids surveys undertaken within each of a replicate number of patch reef systems and depths was the most pragmatic solution. In southern Queensland, dense grids were the primary method used due to the initial process-based research focus, however, the missions are time intensive, as is post processing and analysis, and could readily be modified to a broad grid design in the future to simplify analysis. In NSW a combination of both broad and dense grids has been conducted at most sites over several time periods, although more recent surveys in the Sydney region have just used broad grids.

Stereo-cameras must be pre- or post-calibrated in shallow water using the techniques similar to those outlined in Boutros et al. (2015).

Decide on appropriate navigational systems (e.g. USBL). Accurately geo-referenced imagery is crucial to the success of any AUV deployment, and appropriate effort must be given to this during the survey planning phase.

Ensure appropriate software is installed on onboard laptops (e.g. AUV navigation software platform, GIS, etc), and potential users are familiar with it so that the AUV can be tracked and its mission success monitored while underway.

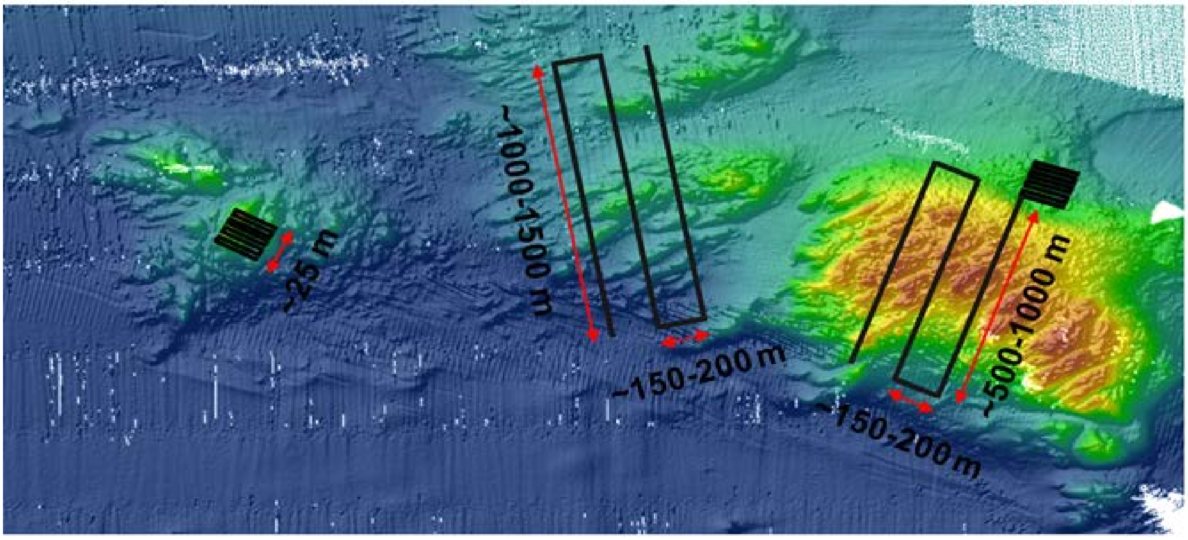

Figure 4.2: Examples of AUV transect designs over multibeam mapped reef features. Left: stand-alone 25 x 25 m dense grid transect. Middle: stand-alone broad grid. Right: combination of broad grid with a dense grid embedded. Note with this design broad grid transects are usually shorter due to the time required to complete both grid types.

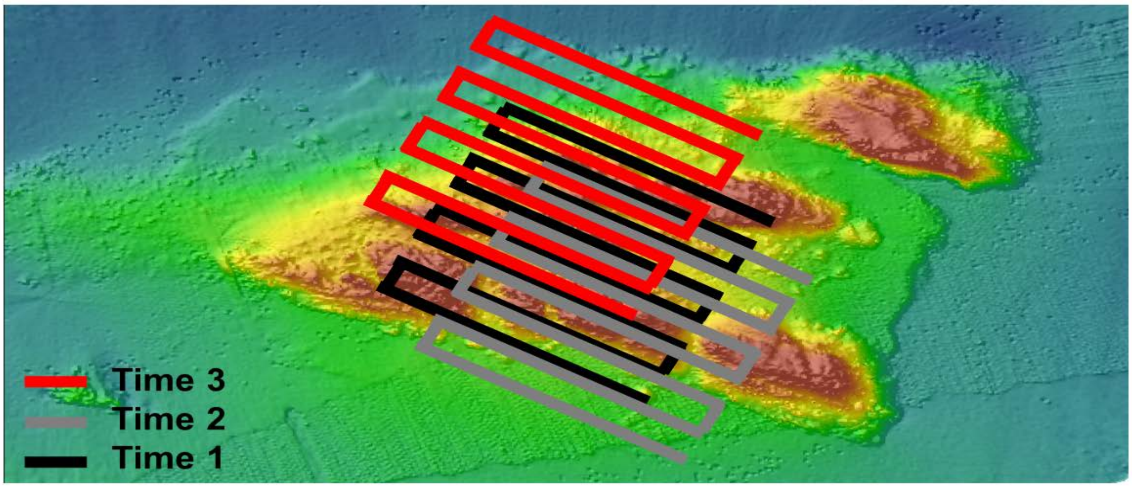

Figure 4.3: Example of spatial mismatch between sample time points for a 25x25 m grid in a high current/wave action environment. Note the limited overlap between all three sampling points.

Field Procedures

Onboard sample acquisition

Complete an on-site briefing.
Prior to deployment, a deployment briefing should always be completed to ensure the operation can be completed safely. Always take a precautionary approach to risks associated with vehicle deployment. See Chapter 1 for further information about risk assessments.

Set up and test the AUV system.
Allow sufficient time during survey mobilisation to undertake system checks, calibrations and testing of equipment and account for unforeseen problems; in most cases it will be possible to complete all system setup and tests within half a day. The conduct of pre-start checks should be noted in the trip log and any test failures specifically recorded for later-reference. Detailed settings for each component should be made using relevant operations manuals (e.g. USBL operations manual etc.).

On-deck tests should include, but not limited to, the following checks:

- on-board data storage
- on-board power
- cameras
- strobe lighting
- iridium beacon, RF and emergency strobes
- propellers
- all blanking plugs are installed
- correct and new corrodible link attached emergence ascent drop weight
- crane and associated shackles are working order
- check all seals/o-rings and blanking plugs are good working order
- check all surface communications

Wet testing should include checks of the following:

- USBL and internal navigation (e.g. compass and avoidance sonar)
- cameras and strobes
- through-water communications

Acoustic tracking setup

- Set position of GPS receiver. *Differential GPS is mandatory for repeat site monitoring.*

- Deploy USBL transceiver (e.g. pole or vessel mounted).
- Measure offsets of USBL transceiver head to GPS receiver and put offsets into navigation system.

Conduct AUV transects

Pre- deployment

- Transects should only be undertaken in areas where the substratum is known/mapped (often in the form of multibeam mapping) as to avoid entrapment and potential loss of AUV. Do not deploy blind, as this increases the risk of equipment loss and damage, as well as unnecessary impact on potentially vulnerable ecosystems.
- Once final transect locations have been determined, provide the locations of the transects (usually in ESRI shapefile format) and associated multibeam maps (in geotiff format) to the AUV engineers responsible for uploading missions. Cross-check the uploaded transect corresponds to the correct area on the geotiff (i.e. ensure the geographic coordinates are defined for all spatial data).
- The flight elevation of AUV should be set and maintained at ~ 2m from the seafloor to facilitate a consistent field of view. General sampling methodology can be found in Williams et al. (2012). Although this needs to be informed by 'survey question', camera type and performance, illumination type and output power, etc.
- Prepare for AUV launch and recovery on deck, and ensure only essential personnel participate in its preparation and deployment.
- Place USBL transceiver in water and ensure functionality.
- Correctly insert the deployment release pin.

AUV deployment and retrieval

1. Disconnect any power or data cables, ensuring any blanking plugs are fitted prior to deployment.
2. Install sacrificial ballast weights. Ensure that there is sufficient time allocated to transect when selecting a corrodible link.
3. Vessel master must ensure the vessel is positioned at the start of the transect start location.
4. Following the signal to deploy from the vessel Master, use the crane and/or A-Frame to lift and guide the AUV from the deck into the water.
5. Minimise the time taken from when the AUV is let out of reach, to when it is lowered in the water, so as to reduce potential swing and impact against the vessel.
6. Using appropriate software (see Pre-Survey Preparations), monitor the AUVs progress to the seabed and start of transect location. Note the start time of transect using a timer as this will be used to determine when the sacrificial weight will be automatically released (if fitted) in the case of an emergency.

7. Confirm data are being recorded where possible (e.g. recording indicators, hard drive operating).

8. Ask the vessel's Master to follow the AUV during transects, to maintain USBL communication and AUV tracking.

9. Monitor weather forecast conditions prior to and during deployment to maintain a safe working environment. Consider aborting operations if local weather and forecast conditions are marginal.

10. When the transect is complete or if the transect is being aborted, advise the vessel Master of the intention to retrieve the AUV.

11. Watch for the AUV to resurface, ensuring only required personnel are near open transom. Avoid approaching the AUV looking into the sun as this increases the risks of collision.

12. Use a grapple hook to connect the lift line to the AUV for retrieval. At least three personnel should be present with hooks to avoid the AUV colliding with the vessel [Recommended].

13. Shut down the AUV and connect relevant power or data cables.

14. Remove the sacrificial ballast weights.

15. For the last transect of the day, wash down the AUV with freshwater, unplug the USBL and turn off emergency beacons.

16. Raise the USBL transducer (if pole mounted) before moving the vessel to the next location.

Procedures for seabed entanglement or loss of communications with AUV

Potential entanglement of the AUV is always a possibility. The following procedures should be followed upon entanglement:

1. Log the last known position of the AUV.

2. Send an abort code to AUV to manually end the transect.

3. If the AUV appears entangled (i.e. not moving), a mini remotely operated vehicle (ROV) should be used to locate and retrieve the unit. If the AUV is trapped under a ledge/cave, or ensnared in fishing line or kelp, the automatic release of the sacrificial weights may cause issues with recovery of the unit. Under such circumstances it is recommended that a ROV is deployed to recover the AUV.

4. If the AUV is fitted with a sacrificial dump weight, which automatically releases after a user defined period, it may surface on its own. Once it's on the surface, use the fitted iridium beacon, RF, GPS and emergency strobes to locate the unit.

5. Ensure that you check AUV thoroughly for damage before redeployment.

Completion of operations

Prior to any vessel movement or engine start-up, operators should check the following:

- All equipment is clear of the water, including the USBL transducer pole.
- AUV is shut down.
- All gear is safely stowed.
- All power and data cables are connected.
- An "All Clear to Move" command is given to vessel Master when the AUV team is satisfied it is OK for the vessel to move on.

Onboard data processing and storage

1. Once the AUV transect is complete, it is good practice to download associated raw imagery and associated positional data. Imagery and associated positional data should be checked to ensure no failures have occurred, including but not limited to the following:

    - Miss-timing between image capture and strobes (i.e. dark/black imagery)
    - Failure of one of the stereo cameras
    - Failure of positional logging

2. Name data files according to established conventions. File naming conventions are important for ensuring both efficient and effective management of field data and its integration into appropriate data management repositories. It is important to note that these conventions will differ among agencies and academic institutions.

3. Ensure accurate recording of metadata. Metadata are descriptive data sources composed of information that may be used to process the images or information therein Durden et al. (2016). While it is important to follow agency specific protocols for capturing metadata, it is also essential that metadata are sufficient enough in detail to satisfy conformance checks for subsequent data release via AODN. Minimum data for each transect should contain as follows:

    - Campaign (i.e. Survey identifier)
    - Station/event number
    - Platform
    - Latitude and longitude (WGS 1984 in decimal degrees with a minimum of 6 decimal places *[Recommend]*)
    - Altitude in m
    - Depth in m
    - Time and date stamp in UTC
    - AUV orientation (roll, pitch, heading) in degrees
    - Precision details (e.g. type of navigation system used and its associated errors)
    - Data provenance

4. Backup data. This is necessary to ensure all data collected in the field is safely returned and securely backed-up at host facilities, prior to quality control and public release. Onboard copies of data should be made as soon as practical following acquisition. When operating external to a network, it is recommended that all data be backed up on a RAID or a NAS that contain built-in storage redundancy in case of hard-drive failure. A duplicate copy of all data onto external hard drives for transportation back to host facilities is *[Recommended]*.

Post-Survey Procedures

Data processing

A general workflow for data processing methodology can be found in Williams et al. (2012). Key requirements for raw image processing and positional data are as follows:

- It is recommended that at least one of the stereo images is in colour and enhanced following similar procedures as outlined by Bryson et al. (2016).
- All stereo images should be georectified following Williams et al. (2012). If not stereo then processing routines can be found in Morris et al. (2014).
- Positional data should be post-processed using Simultaneous Localisation and Mapping (SLAM) as demonstrated in Barkby et al. (2009) and Palomer et al. (2013)

Data annotation

Scoring of individual images can be done using a number of annotation software tools. Examples include, Transect measure, Coral Point Count, CoralNet and Squidle+. For national consistency Squidle+ (https://squidle.org) is recommended as it is free and allows for different approaches in image subsampling, which appears to influence inferences from data (Monk et al. unpublished data), as well as stratified and random point count distribution on images. It also automatically imports the collected AUV data once it is uploaded to the AODN making it ready for analysis, and has tools for exploring survey data as well as analysis. In addition, it supports multiple annotation schemes, and will provide consistency through translation between schemes, which is an important point that differentiates Squidle+.

There are three approaches recommended for annotating georeferenced imagery from AUVs:

- Annotation of individual images
- Annotation of photomosaics
- Extracting structural complexity from orthomosaics

Annotation of individual images or photomosaics can be undertaken using three methods:

- Full assemblage scoring of imagery across space and time. It is important to note that this is a time-consuming process, requiring a lot of replicate images to be scored to enable sufficient power to detect biologically meaningful change as most morphospecies are < 10 % cover within images. This approach appears to be good for delineating bioregional and cross-shelf patterns at a morphospecies (Monk, et al. unpublished data) and CATAMI (Althaus et al. 2015) level (James et al. 2017; Monk et al. 2016). This approach will no doubt be effective in choosing an initial suite of indicators for national level monitoring and reporting.

As a general guideline, and dependent on the survey question, we recommend that 25 random points per image from at least 50 images per transect leg are a good starting point for recording most morphospecies present within images (based on Perkins et al. 2016). It is important to note that the properties of the organism themselves will also influence the number of points/images to score. Obviously morphospecies that are less abundant require more effort, but also the 'clumpiness' of species will affect the scoring effort needed (Perkins et al. 2016). Van Rein et al. (2011) and Perkins et al. (2016) suggest that, while a higher number of points per image can increase the detection rate of more organisms within an image, increasing the number of scored images using fewer points is likely to have a similar (or greater) effect. Ideally, increasing both the number of images scored and the number of points scored within an image would result in greater power (Roelfsema et al. 2006), but preference is usually for increasing the number of images (Perkins et al. 2016). Unfortunately, the adoption of this approach is likely to result in substantial increases in processing time and thus cost.

- Targeted scoring of indicators or proxies (such as grouping fine level morphospecies into broader level CATAMI classes; Monk et al. unpublished data). This approach has been shown to work very well at an indicator morphospecies level for detecting change at a regional level (Perkins et al. 2017) as well as for detecting invasive species trends (Ling et al. 2016; Perkins et al. 2015). More recently this approach has been extended to mobile species, such as fish (Seiler et al. 2012) and lobster (Bessell et al. unpublished data). Care needs to be taken if length data (using photogrammetry or structure from motion) is extracted from stereo pairs from Sirius data as both Seiler et al. (2012) and Bessell et al. (unpublished data) found precision can be poor for mobile species if camera separation is inadequate (see Boutros et al. 2015)

  Since this approach requires substantially less effort to score each image, more images (i.e. often all images) can be scored and, thus, increased statistical power. The drawback is that narrower understanding of the environment is produced.

- Automated analysis of imagery potentially provides a cost-effective alternative to annotating imagery from AUVs. It is important to note that automated imagery analysis is a relatively new, and largely developmental, way of annotating images. Despite this some studies suggest that coral and macroalgae can be reliably identified using automated image analysis (Table 7).

The last approach to annotating AUV imagery involves the extraction of 3D structural information from stereo images using structure from motion techniques outlined in Ferrari et al. (2016) and Pizarro et al. (2017). This approach works particularly well too for sessile species to track changes in growth form through time at a 25 x 25 m scale (Ferrari et al. 2016).

Table 4.1: A brief summary of methods for automated benthic image classification. The number of classes and the main taxa included in the respective studies are also shown.

Authors	Classes	Main Species
Marcos et al. (2005)	3	Corals
Stokes & Deane (2009)	18	Corals, Macroalgae
Pizarro et al. (2008)	8	Corals, Macroalgae
Beijbom et al. (2012)	9	Corals, Macroalgae
Denuelle & Dunbabin (2010)	2	Kelp
Bewley et al. (2012)	19	Corals, Algae and Kelp
Bewley et al. (2014)	19	Corals, Algae and Kelp
Beijbom et al. (2016)	10	Corals, Macroalgae
Mahmood et al.(2016a)	9	Corals, Macroalgae
Mahmood et al. (2016b)	2	Corals, Macroalgae

Data curation and quality control

A national AUV steering group has been set up to oversee a nationally coordinated AUV benthic monitoring program which is supported by the Integrated Marine Observing System (IMOS) (Table 4.2). Any new AUV deployments should be discussed with this steering group to ensure that, wherever possible, they can be integrated within the national program *[Recommended]*.

Table 4.2: Key contacts in national AUV steering group as of Jan 2018

Name	State	Organisation
Neville Barrett*	Tasmania	IMAS
Craig Johnson	Tasmania	IMAS
Jacquomo Monk	Tasmania/Victoria	IMAS
Peter Steinberg	New South Wales	SIMS
Alan Jordan	New South Wales	NSW DPI
Stefan Williams	New South Wales	USyd
Gary Kendrick	Western Australia	UWA
Russ Babcock	Western Australia	CSIRO

Paul Van Ruth	South Australia	SARDI
Hugh Sweatman	Queensland	AIMS
Tom Bridge	Queensland	JCU/QLD Museum
Daniel Ierodiaconou	Victoria	Deakin

* Chair

Data quality control at both the collection and annotation stage is critical. Most importantly, the annotation schema needs to be consistent between studies. Morphospecies and associated CATAMI parent classes be used *[Recommended]*. An initial morphospecies catalogue for southeastern shelf waters is currently held and maintained at the Institute for Marine and Antarctic Studies (IMAS) (contact Dr Neville Barrett or Dr Jacquomo Monk).

Other annotation schema are available, and can be applied. In such situations where an alternative schema are used to annotate AUV imagery, it must be able to be mapped to CATAMI so that comparisons can be made with previous studies or between regions. Translations between schema can be readily applied within Squidle+. The quality control of all annotations undertaken by novice scores should be assessed against an experienced analyst (e.g. using confusion matrices; Figure 4.4). Logically, it is important to correct any discrepancies between annotators. This can be done by re-examining the images to ensure an agreement can be reached between annotators. Alternatively, if an agreement cannot be reached, then the miss-classified morphospecies could be potentially grouped into a higher level CATAMI class.

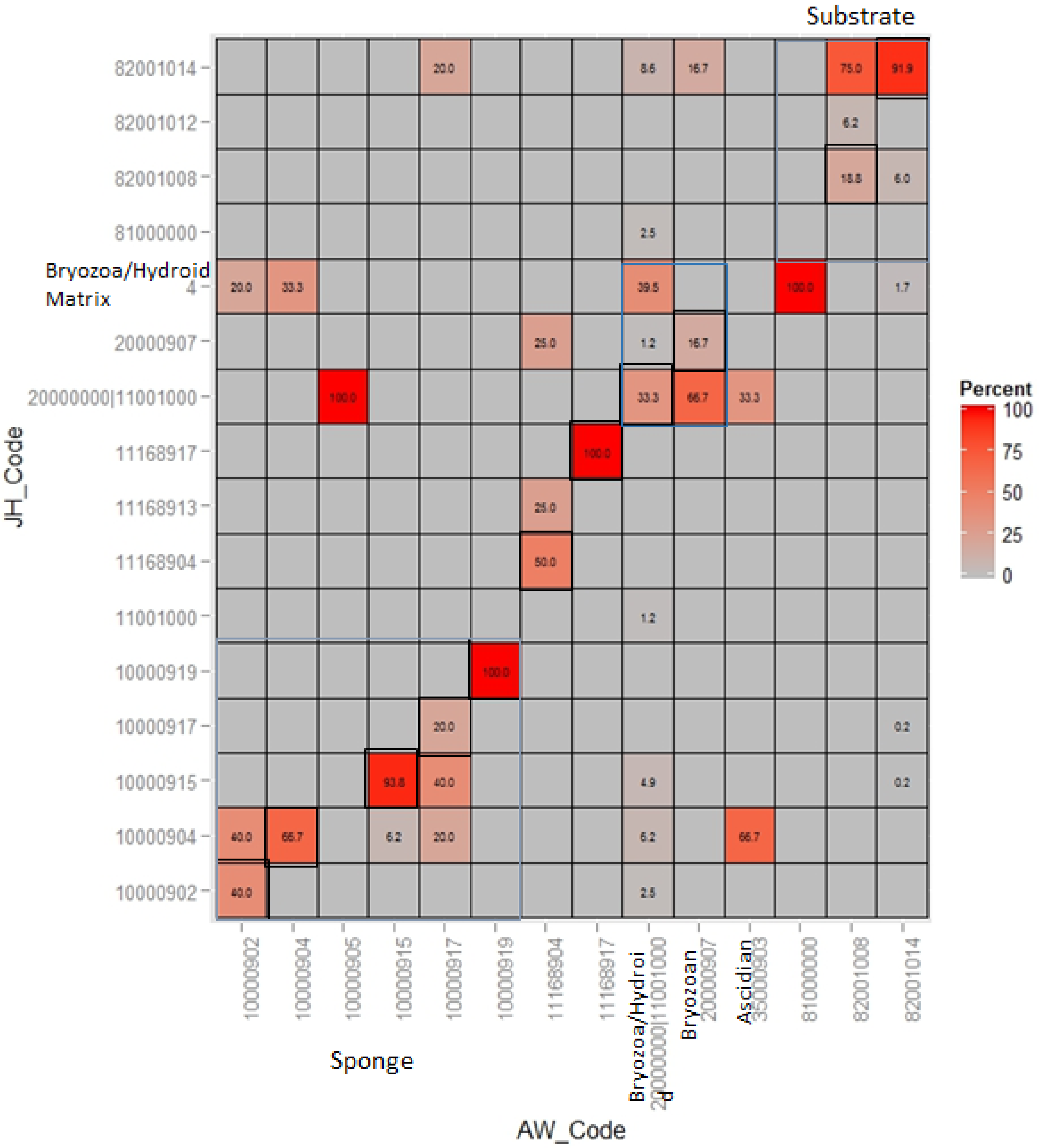

Figure 4.4: Confusion matrix showing the CATAMI classes scored by novice 1 (AW) and experienced (JH) for 30 co-scored images. Black outlined boxes indicate consistent classification between scorers, the percent of all points scored as any particular class are shown in each box and colour coded. Blue outlined boxes indicate sponge, bryozoan/hydroid and substratum respectively moving from left to right across the image.

Data release

Squidle+ is a centralised online platform for standardised analysis and annotation of georeferenced imagery and video. Many national marine observing programs (for example IMOS through the Australian Ocean Data Network (AODN) or the Marine Geoscience Data System (MGDS) in the USA) routinely store imagery data online in an openly accessible location. Squidle+ operates based on flexible distributed data storage facilities (i.e. imagery can be stored anywhere in an openly accessible online location) to reduce data duplication and inconsistencies, and provides a flexible annotation system with the capability to translate between different annotation schemes.

Following the steps listed below will ensure the timely release of imagery and associated annotation data in a standardised, highly discoverable format.

1. Create a metadata record describing the data collection. Provide as much detail as possible on the deployment (either directly in the metadata record itself, or in the form of attached field sheets as .csv, .txt or similar). Details of minimum metadata requirements are provided in Onboard Data Processing and Storage section above.

2. Publish metadata record(s) to the Australian Ocean Data Network (AODN) catalogue as soon as possible after metadata has been QC-d. This can be done in one of two ways:

   - If metadata from your agency is regularly harvested by the AODN, follow agency-specific protocols for metadata and data release.

- Otherwise, metadata records can be created and submitted via the AODN Data Submission Tool. Note that user registration is required, but this is free and immediate.

  Lodging metadata with AODN in advance of annotation data being available is an important step in documenting the methods and location of acquired imagery and enhancing future discoverability of the data.

3. Upload raw imagery from the survey to a secure, publicly accessible online repository (contact AODN if you require assistance in locating a suitable repository).

4. Create a Squidle+ campaign as soon as possible after imagery is uploaded, choose the most appropriate annotation schema, and commence annotation of imagery.

5. Add links to the location of the Squidle+ campaign to the previously published metadata record. You may also wish to attach or link a copy of the annotation data directly to the record.

6. Produce a technical or post-survey report documenting the purpose of the survey, sampling design, sampling locations, sampling equipment specifications, annotation schema (e.g. morphospecies, CATAMI, etc.), whether the survey was assemblage-based or targeted towards key (morpho)species, number of points, interval between images (e.g. every 50th image), and any challenges or limitations encountered. Provide links to this report in all associated metadata. See Appendix B for a suitable template *[Recommended].*

Data analysis

The breadth of research questions precludes any detailed advice on the analysis of data from AUV transects. However, one common attribute of the image-based data that will have to be contented with for all analyses is spatial proximity. The closeness of images, within and sometimes between transects, means that image data are unlikely to be independent (due to spatial autocorrelation). Yet, this is an assumption that many statistical methods rely upon. The failure to meet this assumption means that the inferences from the statistical analysis may be: (i) over-confident, e.g. having a p-value that is too small; (ii) biased, i.e. the estimates do not reflect the truth; (iii) both, or; (iv) no effect. Obviously, the fourth category is what a researcher hopes for, but it is improbable and must be validated. However, if it is known that the study organism exhibits particularly low autocorrelation then the analysis need not consider it explicitly.

Methods to analyse data, accounting for autocorrelation are available. These include geostatistical models (see Foster et al. 2014 for AUV-based examples). However, in certain situations subsampling images will help (see Mitchell et al. 2017 for a marine based example), but not necessarily alleviate completely. Further, if the study is for a broad area, where transects are small and are well-separated, then amalgamating data to transect level may also be appropriate.

Field Manual Maintenance

In accordance with the universal field manual maintenance protocol described in Chapter 1 of the Field Manual package, this manual was updated in 2020 as Version 2. Updates reflect user feedback and new developments. There is currently no long-term plan or support for future updates. See Chapter 1 (Introduction to field manual package) for further details.

The version control for Chapter 4 (field manual for AUVs) is below:

Version Number	Description	Date
0	Submitted for review (NESP Marine Hub, GA, external reviewers listed in Chapter 1.	22 Dec 2017
1	Publicly released on www.nespmarine.edu	28 Feb 2018
1.1	Link to Squidle+ corrected	March 2018
2	Relevant updates, including Data Release sections based on NESP, AODN, IMOS, GA, and CSIRO projects	July 2020

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5. A FIELD AND VIDEO-ANNOTATION GUIDE FOR BAITED REMOTE UNDERWATER STEREO-VIDEO SURVEYS OF DEMERSAL FISH ASSEMBLAGES

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Platform Description

Stereo-BRUV systems consist of two convergent video cameras inside waterproof housings, attached to a base-bar (Figure 5.1b), held in a frame (Figure 5.1a), with some form of baited container in front of the cameras (Figure 5.1e). Systems are generally tethered by rope to surface buoys (Figure 5.1c). Ballast can be added to frames for use in deep-water or areas of strong current (Figure 5.1f).

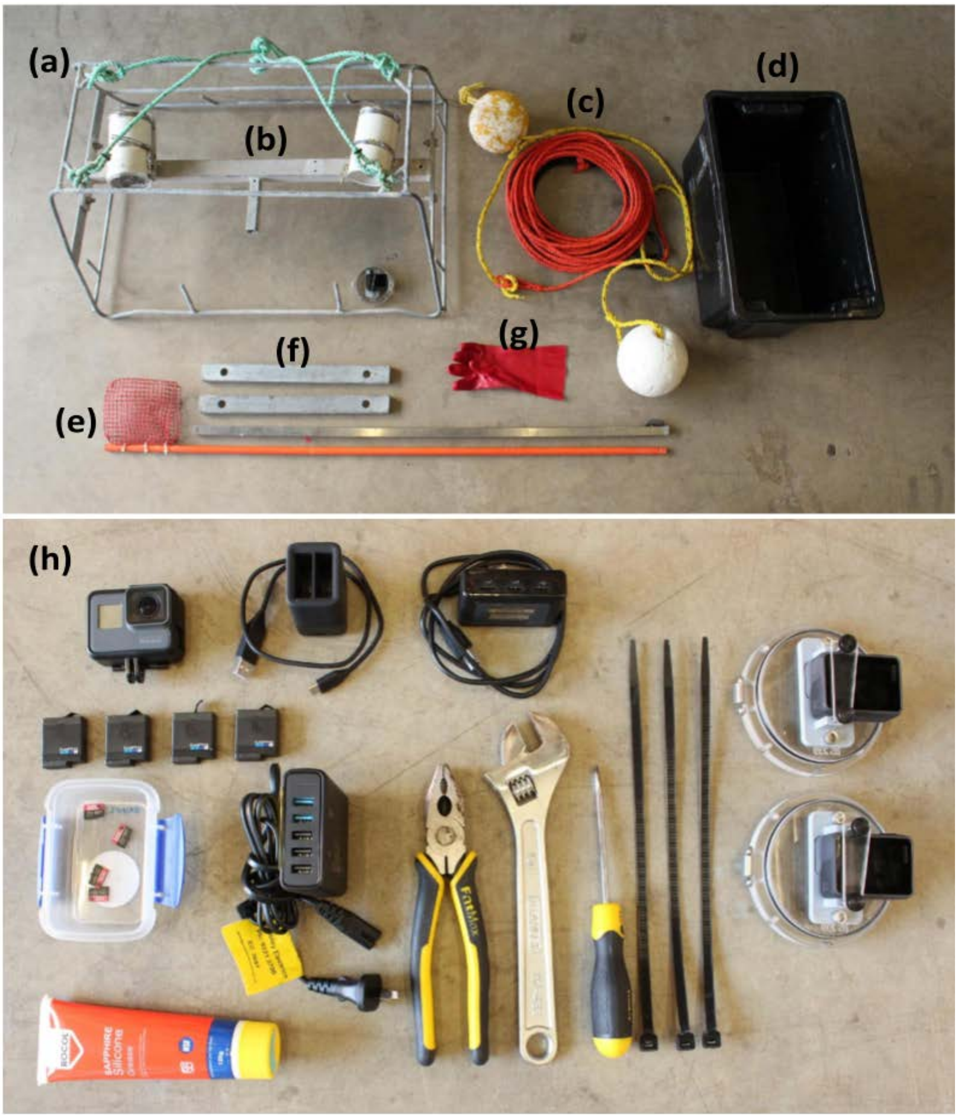

Figure 5.1: Equipment required for stereo-BRUV surveys, including (a) mild-steel galvanized frame and bridle, (b) stereo base-bar and camera housings, (c) rope with detachable float line and two floats, (d) storage container for equipment and bait, (e) PVC bait arm (reinforced with fiberglass rod) with mesh bait bag and supporting metal diode arm, (f) metal weights for deep-water or strong current, (g) long-armed glove for handling bait, and (h) dry kit including calibrated cameras fixed to face plates, spare cameras, spare batteries, battery charger, micro-sd card reader, micro-sd cards, standard tools, cable ties to secure bait bags, and silicone grease for o-rings.

Cameras and photogrammetry

We recommend cameras with full, high-definition resolution of at least 1920 x 1080 pixels (Harvey et al. 2010) and a capture rate of at least 30 frames per second (note some models of action cameras can overheat at high resolution e.g. 4K). Higher camera resolution will improve identification of fish, and the pixel selection required for measurement. Higher frame rates reduce blur on fast-moving species. To maintain stereo-calibrations, cameras must have video stabilisation disabled, and a fixed focal length can facilitate measurements both close to and far from the camera systems when correctly calibrated (Shortis, Harvey & Abdo 2009; Boutros, Shortis & Harvey 2015). The field of view should be standardised and chosen to limit distortion in the image (e.g. no more than a medium angle, ~95° H-FOV). When sampling demersal fish assemblages at typical maximum range (8 m) from the cameras, Boutros et al. (2015) suggested a separation < 500 mm will result in a decrease in the accuracy of measurements, with measurement precision being a function of 1/(camera separation). Cameras are fixed to a rigid base bar to preserve the stereo-calibration required to calculate accurate length and range measurements (Harvey & Shortis 1995, 1998; Shortis & Harvey 1998; Shortis et al. 2009; Boutros et al. 2015). The system pictured in Figure 5.1 uses GoPro Hero 5 Black cameras, with camera housings separated by 700 mm with 7° convergence angle on a steel base bar, although 500 mm with a 5° convergence angle is also common.

Stereo-calibrations must be made both prior to and following a field campaign. Given the required tolerances involved with stereo-BRUV construction, we recommend seeking manufacture and calibration advice from recognised providers or adhering to strict specifications. Any changes in camera positioning (e.g. if a camera is dismounted during battery replacement) will disrupt the stereo-calibration, resulting in measurement error. For this reason, most "off-the-shelf" housings remain unsuitable for stereo-BRUVs. Figure 5.1h provides an example of a camera that is secured to the housing faceplate to ensure stability. Each housing and camera should be uniquely identified, ensuring the latter are only used on the system they are calibrated for. A flashing LED may be added to the end of the diode arm to aid synchronisation of imagery from the left and right cameras when submerged (Figure 5.1).

Bait

As a general rule, locally sourced, sardine-type oily bait is recommended (Dorman et al. 2012), as the oil disperses to attract fish. Sourcing sardine bait locally from factory discards (e.g. fish heads, tails and guts) will reduce the survey's ecological footprint, cost of sampling and potential for disease translocation. We recommend 0.8–1 kg of roughly crushed bait, positioned between 1.2 m and 1.5 m in front of the cameras with the mesh bait bag as close to the benthos as possible. Positioning outside of this range will reduce the ability to identify and measure individuals.

Deployment time

Benthic stereo-BRUVs should be deployed for a standard duration. We recommend deployments of 60 min, to allow species detection (Currey-Randall et al. 2020), and facilitate comparison with historical data. Deployments of 30 minutes have been demonstrated to be sufficient for sampling particular species of finfish on shallow temperate reefs (Bernard & Götz 2012; Harasti et al. 2015).

Scope

BRUV systems with stereo-video cameras (stereo-BRUVs) enable precise measurements of body size (Harvey, Fletcher & Shortis 2001), which surpass estimates made by divers (Harvey et al. 2001). Both length and biomass distribution data are recognised as essential metrics for biodiversity conservation and fisheries management reporting (Langlois, Harvey & Meeuwig 2012b). Importantly, stereo-BRUVs provide comparable body-size distribution data to fisheries-dependent methods such as trawls (Cappo, Speare & De'ath 2004), hook and line (Langlois et al. 2012a), and trap fishing (Langlois et al. 2015). Despite being considered unsuitable for estimating density, stereo-BRUVs provide a cost-effective and statistically powerful method to detect spatio-temporal changes in the relative abundance, length, and biomass distribution of fish assemblages (Harvey et al. 2013; Malcolm et al. 2015; Bornt et al. 2015). However, in over 260 studies using stereo-BRUVS for a range of objectives (Supp 1), Whitmarsh, Fairweather & Huveneers (2017) found widespread variation in methodology, which may prevent interoperability of the data.

Sampling Design

Sampling strategies should be designed to ensure valid inferences and interpretations of resulting data (Smith, Anderson & Pawley 2017). We recommend spatially balanced statistical routines, such as R package MBHdesign (Foster et al. 2019), which can incorporate environmental information and legacy sites to create sampling designs with known inclusion probabilities (Foster et al. 2017, 2018). Due to the need to revisit each site to retrieve stereo-BRUVs after deployment, spatially balanced designs may be inefficient for sampling large regions (>10 minutes transit time between samples), and clustered sampling designs may be preferred (Hill et al. 2018).

Individual stereo-BRUV samples should be separated to reduce the likelihood of non-independence due to individuals being concurrently sampled by adjacent stereo-BRUVs. Separation distance will depend on the mobility of the species and the habitat being studied, for typical demersal fish assemblages a minimum of 400 m for one-hour deployments is recommended (Bond et al. 2018b) or 250 m for 30 minute deployments (Cappo, Speare & Wassenberg 2001).

Field Logistics

Vessels fitted with a swinging davit arm, or pot-tipper and winch are ideal for deploying and retrieving stereo-BRUVs in deeper waters (Figure 5.2), however, light-weight stereo-BRUVs (Supp. 2) can be retrieved by hand. Comparable trap fishing retrieval methods are generally the most efficient. Each retrieval design remains dependent on the type of vessel used, stereo-BRUV weight and size, and prevailing sea conditions. Local fishers familiar with a study location can provide valuable advice on sampling logistics. Multiple stereo-BRUVs can be deployed concurrently, with ~10 stereo-BRUV systems providing optimum logistical efficiency for 60 minute deployment times. Crepuscular periods should be avoided due to demonstrated changes in fish behaviour during these times (Myers et al. 2016; Bond et al. 2018a). When sampling in low light conditions, both blue (450-465 nm) and white (550–560 nm) lights can be used. White can provide the best imagery for identification (Birt et al. 2019), but blue has been found to avoid potential behavioural biases and reduce backscatter from plankton at night (Fitzpatrick, McLean & Harvey 2013). Field methodology checklists are provided in Supp. 3.

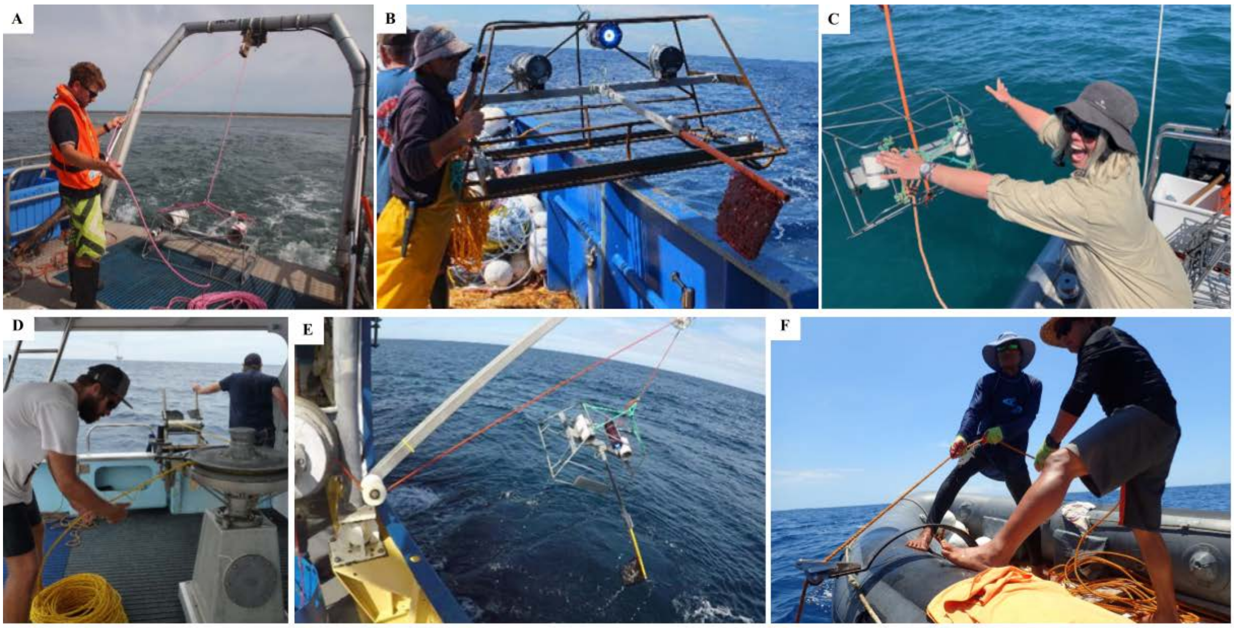

Figure 5.2: Methods to safely deploy and retrieve BRUVs from different size vessels using different equipment. A: deploying a stereo-BRUV using an A-frame and pulley at the vessel's stern; B: deploying a stereo-BRUV with weights and a light from the side of a vessel; C: deploying light-weight stereo-BRUV from a small rigid inflatable (see Supp. 2); D: using a 'pot winch' and 'pot tipper' to quickly retrieve stereo-BRUVs in deep water; E: retrieving a stereo-BRUV using a davit arm from the side of a vessel; F: retrieving stereo-BRUVs by hand using an repurposed anchor hauler in the Philippines.

Image Annotations

Software

Software specifically designed to annotate and measure fish from stereo-video will substantially increase the cost-efficiency and consistency of image annotation (Gomes-Pereira et al. 2016). For stereo-video the challenge is not the annotation by the calibration of imagery to provide accurate length and range measurement. Annotation software and packages with measurement capabilities include Vision Measurement System (Harman, Harvey & Kendrick 2003), NIH Image (Dunbrack 12/2006), SEBASTES package in Python (Boldt et al. 2018), StereoMorph package in R (Olsen & Westneat 2015), and EventMeasure from SeaGIS (seagis.com.au). We recommend EventMeasure due to its established workflow, ability to create 3-D stereo-calibrations, and active development, which enables cost-effective and consistent point and stereo annotation of video imagery. Manual image annotation and measurement can be time consuming, but the emerging field of automated image annotation provides promise of increased cost efficiency and collection of novel metrics (Marini et al. 2018).

Annotation metadata

Field metadata (Supp. 4) should be used to populate a unique sample code for each sample and annotation set. Time on the seabed should be annotated to provide a start time for the stereo-BRUV deployment period. It is important that the link between annotations and imagery are maintained.

Abundance estimates

We recommend all fish be identified to the lowest taxonomic level possible. The standard metric of abundance is MaxN, the maximum number of individuals of a given species present in a single video frame (Priede et al. 1994). MaxN is widely used for BRUVs (Whitmarsh et al. 2017) conservative, and ensures that no individual is counted more than once (Schobernd, Bacheler & Conn 2013) It has frequently been suggested that MaxN underestimates both small and large-bodied individuals, whereas the only study so far to evaluate this has found MaxN provides a representative sample of size-distributions (Coghlan et al. 2017). Syncronise left and right cameras to allow the analyst to determine the range of fish in the field of view and ensure they are within a predefined distance from the cameras. Typically, fish are counted within a maximum distance of 8 m, beyond which length estimates are likely to be inaccurate unless specialist calibrations have been conducted. Annotations of the current MaxN may be updated when individual fish are more clearly visible, and therefore easier to measure, by taking photogrammetric measurements of individual body length at the last MaxN annotated.

Body-size measurements

Synchronised and calibrated stereo-video streams are used to accurately measure body size. All individuals of each species should be measured at their MaxN. We recommend measuring fork length rather than total length, as it is more easily definable across a range of species. Biomass estimates typically rely on total length, but fork length to total length conversions can be used to complete these calculations (Froese & Pauly 2019). For species where total length can be unreliable or there is no definable fork, body size is estimated using other measures (e.g. disk length for rays). Photogrammetric length measurements are typically made with some degree of error, which can be minimised by measuring individuals when they are as close to cameras as possible with both the nose and the tail-fork clearly visible, still or slowly moving, at an angle less than 45° perpendicular to the cameras. Defining cut-offs for measurement error across projects will help to maintain accurate and precise body-size estimates, we provide recommended stereo-measurement length rules for EventMeasure in Supp. 5. If fish cannot be measured within these parameters, a '3D point' may be used for annotation, which records the 3D location of the fish to ensure it is within the sampling area (Harvey et al. 2004). To create a relative abundance metric standardised to a consistent sample area, abundance should be summed from the lengths and 3D points at the MaxN for each species. For biomass estimates, 3D points provide a basis for extrapolating a median length value to fish that could not be measured (Wilson et al. 2018). When large tightly packed schools are encountered, fish that cannot be measured should have 3D points. When lengths or 3D points are not possible for every fish, multiple individuals can be assigned to a single length or 3D point, but care should be taken to represent the range of body sizes within a school.

Behaviour

A range of behavioural observations, including time of first arrival, time to first feed, and minimum approach distance may also be calculated (Goetze et al. 2017; Coghlan et al. 2017).

Interoperable and reproducible annotations

Video imagery enables annotators to work collaboratively to ensure identifications are consistent. A library of reference images, such as that supported by EventMeasure, will assist with identification and training. It is acknowledged that some genera cannot be consistently identified to species level from imagery, so individuals are recorded at genus-family levels (e.g.

flathead: *Platycephalus spp*). For unidentified individuals, a common convention is that fish that are potentially identifiable at a later date are annotated to Genus sp1–10, this permits a batch-rename at a later stage if the species is successfully identified. Individuals that are clearly unidentifiable to species are annotated as *Genus sp*.

Habitat classification

Information on relief, habitat types, and benthic composition (e.g. percent cover of benthos types) should be recorded from each deployment (Bennett et al. 2016; Collins et al. 2017), to facilitate investigation of fish-habitat relationships and to enable the sampling field of view to be standardised or controlled for in subsequent data analysis (McLean et al. 2016). It is important that these data are annotated consistently and it is recommended that they are mapped to the CATAMI classification scheme (Althaus et al. 2015) and a 0-5 estimate of benthic relief (Polunin & Roberts 1993; Wilson, Graham & Polunin 2007). An example of habitat composition and relief annotation schema are provided in a GitHub repository (Langlois 2017). Forward facing imagery can be annotated in a range of software, including TransectMeasure from SeaGIS (seagis.com.au), BenthoBox (https://benthobox.com), CoralNet (https://coralnet.ucsd.edu/), and Squidle+ (https://squidle.org).

Quality control and data curation

Quality control and data curation are vital to ensure FAIR data workflows (Wilkinson et al. 2016). All corrections should be made within the original annotation files to ensure data consistency over time. We recommend the following approaches to ensure quality control:

- Annotators should complete “training” videos where species IDs and MaxN are known and can be used to assess competency.
- A different annotator should complete the MaxN and length measurement annotations to provide an independent check of the species identifications.
- Quality assurance should be carried out by a senior video analyst or researcher and involve a random review of 10% of annotated videos and data within a project. If accuracy is below 95 % for all identifications and estimates of MaxN, reannotation should be undertaken.
- Unique identifiers of annotators and dates of when imagery was annotated should be maintained to provide a data checking trail (see Supp. 4).

R workflows and function packages are provided in a GitHub repository (github.com/GlobalArchiveManual/globalarchive-query) to enable validation with regional species lists and likely minimum and maximum sizes for each species.

Data storage, discoverability and release

We encourage open data policies and recommend archiving and sharing stereo-BRUV annotations on global biodiversity data repositories, such as OBIS (Ocean Biogeographic Information System), GBIF (Global Biodiversity Information Facility) and the recently developed GlobalArchive (globalarchive.org). GlobalArchive is a centralised repository that allows open access and private sharing of fish image annotation data from stereo-BRUVs or similar imagery-based sampling techniques. GlobalArchive allows users to store data in a standardised and secure manner and makes meta-data discoverable, thus encouraging collaboration and synthesis of datasets within the community of practice. We recommend all quality controlled annotation data and any associated calibration, taxa and habitat data should be uploaded to GlobalArchive and we encourage that all data should be made publicly available via the public data option. As an example, the Australian standards for data management, discoverability and release are provided in Supp. 6.

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Supplementary material 1: BRUV Studies by Topic.

Appendix II: 259 studies found using baited underwater cameras showing the purpose of the study. Papers were included in the analysis if published in peer-reviewed literature, bait was used in one or more replicates and if video footage was used rather than still images. The last search (finding 254 studies) was conducted on the 27/05/2019 using the keywords 'baited' and 'video' or 'BRUVS', on Google Scholar, Scopus, Proquest (Aquatic Sciences and Fisheries Abstracts), Biological Abstracts. Extra studies known to the authors were added. The Other category includes studies focusing on anthropogenic stressors, artificial structures, and diurnal changes. Number below show the total number of studies in that category. Individual studies may be included in more than one category.

Behavioural (63 studies) (Ellis & DeMartini 1995; Willis & Babcock 2000; Willis, Millar & Babcock 2000; Collins *et al.* 2002; Denny, Willis & Babcock 2004; Jamieson *et al.* 2006; Bailey *et al.* 2007; Stoner, Laurel & Hurst 2008; Jamieson *et al.* 2009; Broad *et al.* 2010; Fujii *et al.* 2010; McLean *et al.* 2010; Ryer, Laurel & Stoner 2010; Brooks *et al.* 2011; Dunstan, Ward & Marshall 2011; Gutteridge *et al.* 2011; McLean, Harvey & Meeuwig 2011; Robbins, Peddemors & Kennelly 2011; Zintzen *et al.* 2011; Bond *et al.* 2012; Misa *et al.* 2013; White *et al.* 2013; Barord *et al.* 2014; Dunlop *et al.* 2014; Espinoza *et al.* 2014; Harasti *et al.* 2014; Klages *et al.* 2014; Santana-Garcon *et al.* 2014b; Udyawer *et al.* 2014; Barley *et al.* 2015; Bornt *et al.* 2015; D'Onghia *et al.* 2015b; De Vos *et al.* 2015; Malcolm *et al.* 2015; Ryan *et al.* 2015; Stobart *et al.* 2015; Terres *et al.* 2015; Harasti *et al.* 2016; Kempster *et al.* 2016; Spaet, Malcolm HA 2016; Nanninga & Berumen 2016; Acuña-Marrero *et al.* 2017; Cullen & Stevens 2017; Duffy, Letessier & Irving 2017; Kilfoil *et al.* 2017; Roberson *et al.* 2017; Wellington, Wakefield & White 2017; Alós *et al.* 2018; Benjamins *et al.* 2018; Devine, Wheeland & Fisher 2018; Fetterplace *et al.* 2018; Hammerschlag *et al.* 2018; Harasti *et al.* 2018b; Irigoyen *et al.* 2018; Jabado *et al.* 2018; Mensinger, Putland & Radford 2018; O'Connell *et al.* 2018; O'Driscoll *et al.* 2018; Radford, Putland & Mensinger 2018; Sherman *et al.* 2018; Chapuis *et al.* 2019; Juhel *et al.* 2019; Rolim, Rodrigues & Gadig 2019; Thompson, Bouchet & Meeuwig 2019)
Fishing impacts (80 studies): (Willis & Babcock 2000; Willis, Millar & Babcock 2000; Westera, Lavery & Hyndes 2003; Cappo, Speare & De'ath 2004; Denny & Babcock 2004; Denny, Willis & Babcock 2004; Cappo, De'ath & Speare 2007; Heagney *et al.* 2007; Malcolm *et al.* 2007; Watson *et al.* 2007; Kleczkowski, Babcock & Clapin 2008; Svane & Barnett 2008; Svane, Roberts & Saunders 2008; Watson *et al.* 2009; McLean *et al.* 2010; Goetze *et al.* 2011; McLean, Harvey & Meeuwig 2011; Bernard & Götz 2012; Bloomfield *et al.* 2012; Bond *et al.* 2012; Dorman, Harvey & Newman 2012; Harvey *et al.* 2012b; Langlois, Harvey & Meeuwig 2012; Fitzpatrick, McLean & Harvey 2013; Gardner & Struthers 2013; Goetze & Fullwood 2013; Moore *et al.* 2013; Poulos *et al.* 2013; Rees *et al.* 2013; Sackett *et al.* 2013; White *et al.* 2013; Wraith *et al.* 2013; De Vos *et al.* 2014; Dunlop, Barnes & Bailey 2014; Espinoza *et al.* 2014; Hill *et al.* 2014; Kelaher *et al.* 2014; Lindfield, McIlwain & Harvey 2014; Peters *et al.* 2014; Rizzari, Frisch & Connolly 2014; Santana-Garcon *et al.* 2014c; Stevens *et al.* 2014; Whitmarsh *et al.* 2014; Bornt *et al.* 2015; Bouchet & Meeuwig 2015; Coleman *et al.* 2015; Fitzpatrick *et al.* 2015; Goetze *et al.* 2015; Harasti *et al.* 2015; Howarth *et al.* 2015; Kelaher *et al.* 2015a; Kelaher *et al.* 2015b; Malcolm *et al.* 2015; McLaren *et al.* 2015; Roberson *et al.* 2015; Schultz *et al.* 2015; Stobart *et al.* 2015; Tanner & Williams 2015; Terres *et al.* 2015; Colefax, Haywood & Tibbetts 2016; Gilby, Tibbetts & Stevens 2016; Heyns-Veale *et al.* 2016; Jaiteh *et al.* 2016; Ochwada-Doyle, Johnson & Lowry 2016; Parker *et al.* 2016; Walsh, Barrett & Hill 2016; Barley, Meekan & Meeuwig 2017a; Díaz-Gil *et al.* 2017; Harasti *et al.* 2017; Tickler *et al.* 2017; Goetze *et al.* 2018; Harasti *et al.* 2018b; Hill *et al.* 2018; Juhel *et al.* 2018; Malcolm *et al.* 2018; Mensinger, Putland & Radford 2018; Rees *et al.* 2018; Speed, Cappo & Meekan 2018; Harasti *et al.* 2019; Henderson *et al.* 2019; Juhel *et al.* 2019; Ortodossi *et al.* 2019; Prior *et al.* 2019
Spatial and habitat associations (79 studies): (Cappo, De'ath & Speare 2007; Heagney *et al.* 2007; Malcolm *et al.* 2007; Gomelyuk 2009; Watson & Harvey 2009; Westera *et al.* 2009; Chatfield *et al.* 2010; McLean *et al.* 2010; Moore, Harvey & Van Niel 2010; Ryer, Laurel & Stoner 2010; Cappo *et al.* 2011; Jeffreys *et al.* 2011; Malcolm, Jordan & Smith 2011; McIlwain *et al.* 2011; Merritt *et al.* 2011; Moore, Van Niel & Harvey 2011; Colton & Swearer 2012; Fitzpatrick *et al.* 2012; Harvey *et al.* 2012a; Harvey *et al.* 2012c; Langlois *et al.* 2012b; Schultz *et al.* 2012; Zintzen *et al.* 2012; Harvey *et al.* 2013; Poulos *et al.* 2013; Rees *et al.* 2013; Espinoza *et al.* 2014; Morton & Gladstone 2014; Schultz *et al.* 2014; Bacheler & Shertzer 2015; Pearson & Stevens 2015; Schultz *et al.* 2015; Scott *et al.* 2015; Tanner & Williams 2015; Andradi-Brown *et al.* 2016; Gilby *et al.* 2016; Hesse, Stanley & Jeffs 2016; Heyns-Veale *et al.* 2016; Lindfield *et al.* 2016; McLean *et al.* 2016; Vargas-Fonseca *et al.* 2016; Vergés *et al.* 2016; Walsh, Barrett & Hill 2016; Yates *et al.* 2016; Asher, Williams & Harvey 2017; Babcock *et al.* 2017; Barley, Meekan & Meeuwig 2017a; Benzeev, Hutchinson &

Friess 2017; Borland *et al.* 2017; Ford, Stewart & Roberts 2017; Galaiduk *et al.* 2017a; Galaiduk *et al.* 2017b; Galaiduk *et al.* 2017c; Henderson *et al.* 2017; Lavaleye *et al.* 2017; Linley *et al.* 2017; Logan *et al.* 2017; Oh *et al.* 2017; Schmid *et al.* 2017; Tickler *et al.* 2017; Zintzen *et al.* 2017; Abesamis *et al.* 2018; Alós *et al.* 2018; Esteban *et al.* 2018; Ferrari *et al.* 2018a; Ferrari *et al.* 2018b; Ford & Roberts 2018; Galaiduk, Radford & Harvey 2018; Goetze *et al.* 2018; Hammerschlag *et al.* 2018; Harasti *et al.* 2018a; Irigoyen *et al.* 2018; Kiggins, Knott & Davis 2018; Rees, Knott & Davis 2018; Wellington *et al.* 2018; Bach *et al.* 2019; Clarke *et al.* 2019; Gilby *et al.* 2019; Hale *et al.* 2019; Reis-Filho *et al.* 2019; Schultz *et al.* 2019; Williams *et al.* 2019)
Methods (within BRUVS)(40 studies): (Watson *et al.* 2005; Harvey *et al.* 2007; Stobart *et al.* 2007; Lowry, Folpp & Gregson 2011; Bernard & Götz 2012; Dorman, Harvey & Newman 2012; Gladstone *et al.* 2012; Harvey *et al.* 2012a; Ebner & Morgan 2013; Fitzpatrick, McLean & Harvey 2013; Hardinge *et al.* 2013; Letessier *et al.* 2013; Taylor, Baker & Suthers 2013; Wraith *et al.* 2013; De Vos *et al.* 2014; Hannah & Blume 2014; Santana-Garcon, Newman & Harvey 2014; Unsworth *et al.* 2014; Anderson & Santana-Garcon 2015; Campbell *et al.* 2015; Harasti *et al.* 2015; Letessier *et al.* 2015; Rees *et al.* 2015; Stobart *et al.* 2015; Tanner & Williams 2015; Trobbiani & Venerus 2015; Ghazilou, Shokri & Gladstone 2016b; Ghazilou, Shokri & Gladstone 2016a; Misa *et al.* 2016; Walsh, Barrett & Hill 2016; Watson & Huntington 2016; Cundy *et al.* 2017; Kilfoil *et al.* 2017; Schmid *et al.* 2017; Trave *et al.* 2017; Benjamins *et al.* 2018; Sherman *et al.* 2018; Whitmarsh, Huveneers & Fairweather 2018; Clarke *et al.* 2019; Whitmarsh, Fairweather & Huveneers 2019; Wong *et al.* 2019)
Methods (comparisons to other methods)(45 studies): (Ellis & DeMartini 1995; Willis & Babcock 2000; Willis, Millar & Babcock 2000; Cappo, Speare & De'ath 2004; Watson *et al.* 2005; Stobart *et al.* 2007; Colton & Swearer 2010; Langlois *et al.* 2010; Watson *et al.* 2010; Brooks *et al.* 2011; Lowry *et al.* 2011; Pelletier *et al.* 2011; Colton & Swearer 2012; Harvey *et al.* 2012c; Langlois *et al.* 2012a; Lowry *et al.* 2012; Ebner & Morgan 2013; Gardner & Struthers 2013; Wakefield *et al.* 2013; Rizzari, Frisch & Connolly 2014; Santana-Garcon *et al.* 2014a; Ebner *et al.* 2015; Goetze *et al.* 2015; Langlois *et al.* 2015; McLaren *et al.* 2015; Stobart *et al.* 2015; Andradi-Brown *et al.* 2016; Ochwada-Doyle, Johnson & Lowry 2016; Parker *et al.* 2016; Pejdo *et al.* 2016; Spaet, Nanninga & Berumen 2016; Bacheler *et al.* 2017; Barley, Meekan & Meeuwig 2017b; Bosch *et al.* 2017; Bradley, Papastamatiou & Caselle 2017; Galaiduk *et al.* 2017a; Logan *et al.* 2017; Roberson *et al.* 2017; Boussarie *et al.* 2018; Davis, Larkin & Harasti 2018; Enchelmaier, Babcock & Hammerschlag 2018; Goetze *et al.* 2018; Hale *et al.* 2019; Stat *et al.* 2019; Wong *et al.* 2019)
Other (e.g. diel variation)(41 studies): (Yau *et al.* 2002; Smale *et al.* 2007; Svane & Barnett 2008; Svane, Roberts & Saunders 2008; Bassett & Montgomery 2011; Craig *et al.* 2011; Marouchos *et al.* 2011; McIlwain *et al.* 2011; Aguzzi *et al.* 2012; Birt, Harvey & Langlois 2012; Harvey *et al.* 2012a; Harvey *et al.* 2012b; Fitzpatrick, McLean & Harvey 2013; Folpp *et al.* 2013; Ruppert *et al.* 2013; Anderson & Bell 2014; Lowry *et al.* 2014; Peters *et al.* 2014; Unsworth *et al.* 2014; Anderson & Santana-Garcon 2015; D'Onghia *et al.* 2015a; Kelaher *et al.* 2015a; Kelaher *et al.* 2015b; Scott *et al.* 2015; Ghazilou, Shokri & Gladstone 2016b; Griffin *et al.* 2016; Roberts, Pérez-Domínguez & Elliott 2016; Vargas-Fonseca *et al.* 2016; Benzeev, Hutchinson & Friess 2017; Díaz-Gil *et al.* 2017; Nagelkerken *et al.* 2017; Bond *et al.* 2018; Florisson *et al.* 2018; Irigoyen *et al.* 2018; Mensinger, Putland & Radford 2018; Olds *et al.* 2018; Radford, Putland & Mensinger 2018; Reynolds *et al.* 2018; Chapuis *et al.* 2019; Henderson *et al.* 2019; Whitmarsh, Fairweather & Huveneers 2019)

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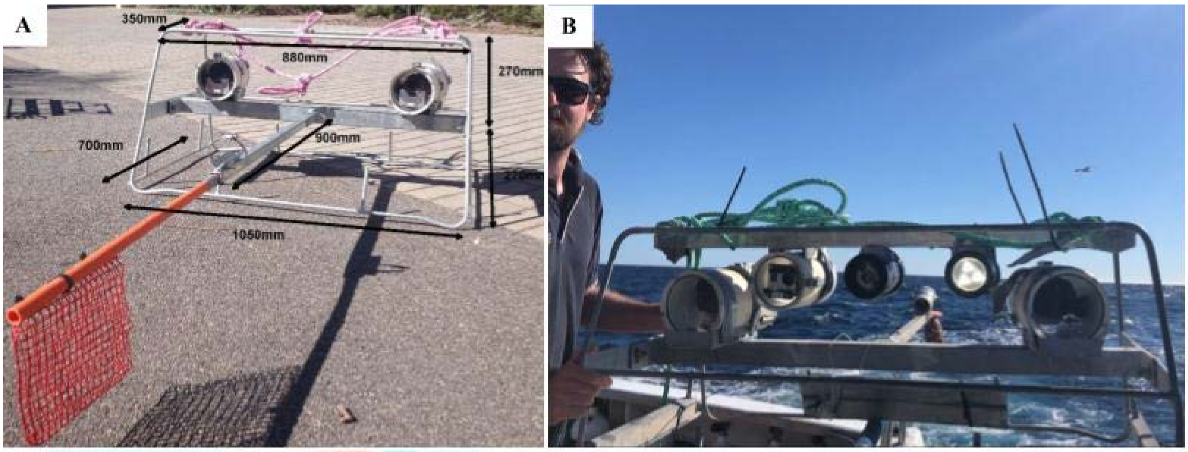
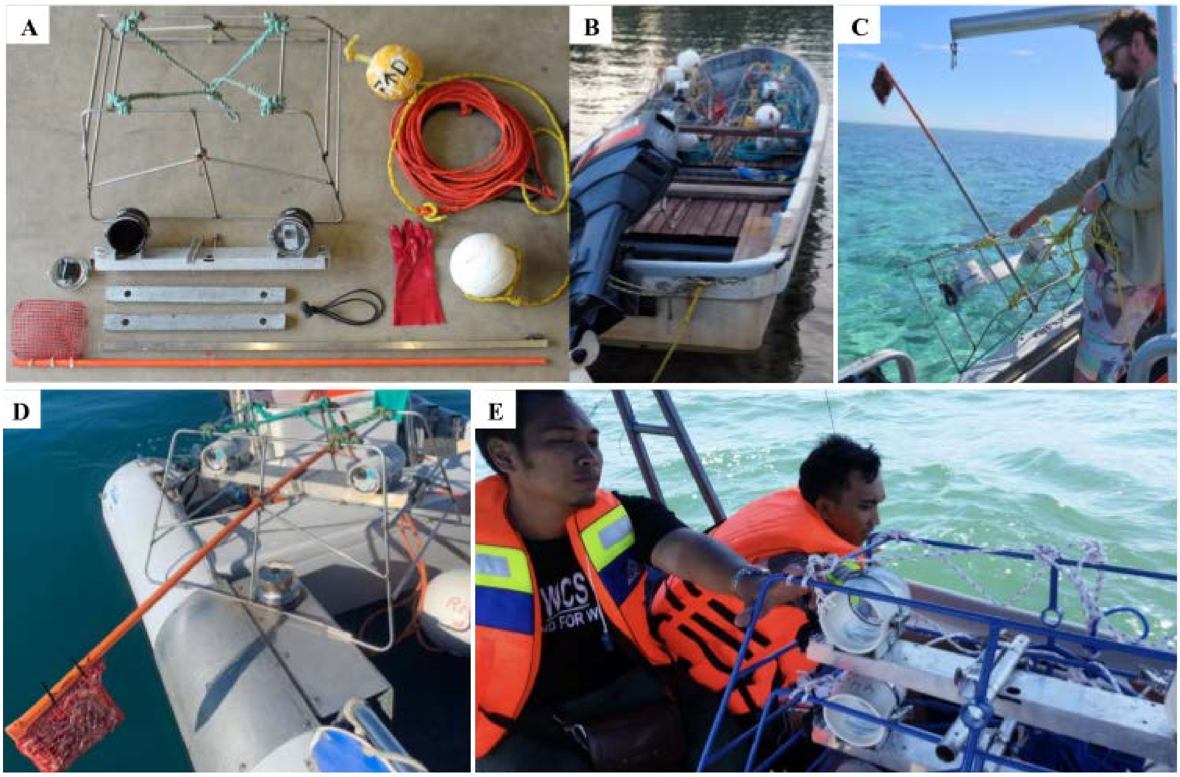
Supplementary Material 2: Stereo-BRUV Design Variations

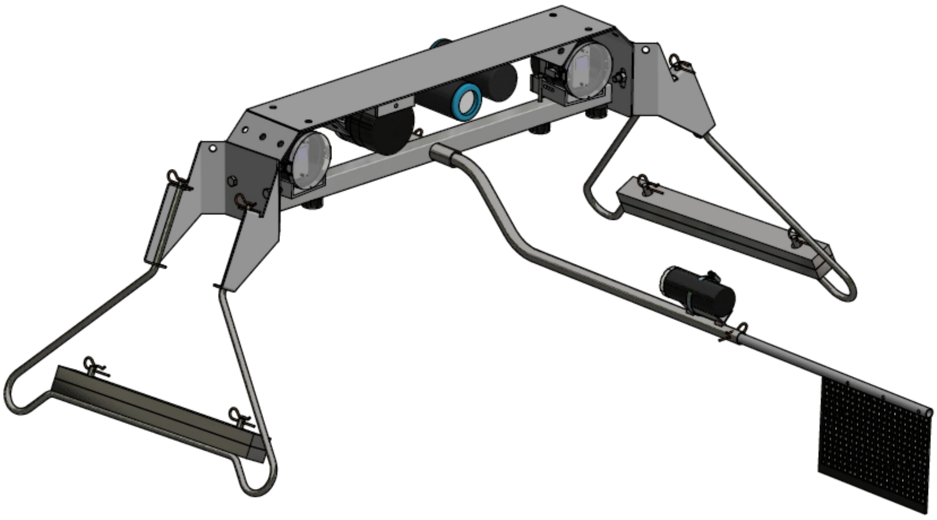


Supp 2 Figure 1: Stereo-BRUV systems, including (A) standard dimensions, and (B) addition of weights for deeper water deployment and added forward and rear facing lights and rear facing stills camera to collect habitat imagery.



Supp Figure 2: Light weight stereo-BRUV. (A) Frame made of thin gauge stainless steel. Diode arm is passed through the back and front of the frame and not attached to the base bar. This reduces strain to the base bar during retrieval and allows the base bar to be made of light-weight hollow aluminum rectangular section (D). Base bar uses hooks and bungee cords to attach to the frame. The separation of cameras has been reduced to 500mm, with camera convergence of 5 degrees, to decrease the size of systems and making them easier for (B) travel with and use on smaller vessels and can be (C) hand-hauled. For research projects led by partners without expertise in stereo calibrations, (E) frames can be manufactured locally and pre-calibrated light-weight base bars can be sent to study site. See this video example of deploying light weight stereo-BRUV

Supp Figure 3: Stereo-BRUV systems developed by the Australian Institute of Marine Science (AIMS). Designed to be easily assembled and packed down with detachable legs that occupy minimal space when shipping. The cameras are inwardly converged at 5 degrees and separated by 650mm. Camera cradles are precision machined and have a locating pin that aligns with the back of the camera housing which allows for housings to be easily removed from the frame (for battery change, downloading etc.) and put back in the exact same position, maintaining camera calibration. A plate across the top of the frame allows for additional backward facing cameras or lights to be attached. The lack of rails along the front and back of the frame footing reduces potential for seabed snags and minimises contact with seabed habitats.



Supplementary Material 3: Field Methodology Checklist

Pre-field work

Check equipment as shown in Figure 5.1.

1. Conduct 3D calibration of stereo-camera pairs. We recommend an enclosed pool environment with good visibility. This must be repeated at the end of the field campaign, or if any camera or housing positions have changed.
2. Ensure sampling design can be imported to the research vessel navigation system, or bring a standalone navigation and sounding system for the skipper.
3. Ensure sufficient data storage capacity for downloading all video imagery collected, and for back-up copies.
4. Ensure sufficient spares for stereo-BRUVs (Figure 5.1).
5. Purchase bait and ensure it can be stored appropriately for the duration of fieldwork.
6. Create a metadata sheet or preferably using a capture device (e.g. Collector for ArcGIS or QGIS, tablet computer with GIS) to record the sample, stereo-camera pair and memory card unique identifier in addition to other essential field data (Supp. 4). By capturing metadata digitally transcription errors and post-field work time are reduced.

Pre-deployment

1. Set up stereo-BRUVs, including ropes and floats.
2. Check camera batteries are charged and memory cards are formatted.
3. Check the batteries in lights and synchronising devices if applicable.
4. Defrost enough bait the night before sampling.
5. Discuss deployment, retrieval procedures and safety with skipper and crew.

Deployment

See this video example of [deploying light weight stereo-BRUV]

1. Fill bait containers with ~1 kg of crushed bait.
2. Turn cameras on and ensure there is sufficient battery life and storage space.
3. Check camera settings are consistent.
4. Film the metadata sheet or capture device with each camera so information can be attributed to the video footage.
5. Check the camera housings are dry and clean before aligning and inserting cameras. Check o-rings are not pinched or dirty.
6. Attach the bait arm and turn on exterior lights (if applicable).

7. Ensure a means of synchronising cameras such as a flashing diode, a stopwatch, slow clapper board or hand clap is recorded within view of both cameras simultaneously.
8. Once on site, and at the command of the master, experienced personnel or deck hands should physically deploy stereo-BRUV, ropes, and floats clear of the vessel. Ropes and floats may need to be streamed in advance if operating in deepwater.
9. It is important the vessel remains directly over the site whilst deploying. In shallow water, it may be necessary to arrest the deployment of the stereo-BRUV above the bottom to ensure it maintains orientation. In water depths >30 m and when using ballast, rope drag through the water is often enough to maintain orientation and the system can be left to freefall from the surface.
10. When the stereo-BRUV lands on the seafloor a waypoint should be taken.
11. Ensure all field metadata and comments are collected (as in Supp 4).

Retrieval

1. Once deployment (sampling) time is complete, vessels should manoeuvre alongside the surface floats heading upwind or upcurrent.
2. Crew gaff or grapple the rope between the floats and retrieve slack rope as the vessel manoeuvres over the system.
3. Stereo-BRUVs should only be retrieved once the vessel is directly above the deployment site. Stereo-BRUVs retrieved at an angle are prone to being dragged and caught on the benthos.
4. Once the stereo-BRUV is on deck, dry the housings and remove cameras and their memory cards and change bait. Check battery life is sufficient for another deployment and turn the cameras off to preserve battery life.
5. Ensure all field metadata and comments are collected (as in Supp 4).

End of day checks

Review, download, and backup all footage during or at the end of each day. Save separate samples in a folder structure with clear naming conventions (see Jordan S. Goetze et al. 2019). Format memory cards for the next day once the videos have been checked, downloaded, and backed-up. Ensure all field metadata and comments are collected (as in Supp 4).

Supplementary Material 4: Example Field and Lab Sheet

Please download this Excel file at https://benthic-bruvs-field-manual.github.io

Supplementary Material 5: Recommended Stereo-measurement Length Rules for EventMeasure

Name	Data	Units
Use lengths rules	True	Boolean
Apply range rule	True	Boolean
Minimum range	0.0000	mm
Maximum range	8000.0000	mm
Apply RMS rules	True	Boolean
Maximum RMS	20.0000	mm
Apply precision to length ratio rules	True	Boolean
Maximum precision to length ratio	10.0000	%
Apply precision rule	False	Boolean
Maximum precision	10.0000	mm
Apply direction rule	False	Boolean
Maximum direction	45.0000	Degrees
Apply horizontal direction rule	False	Boolean
Maximum horizontal direction	45.0000	Degrees
Apply vertical direction rule	False	Boolean
Maximum vertical direction	45.0000	Degrees
Apply x coordinate range rule	False	Boolean

Minimum x coordinate	-2500.0000	mm
Maximum x coordinate	2500.0000	mm
Apply y coordinate range rule	False	Boolean
Minimum y coordinate	-2500.0000	mm
Maximum y coordinate	2500.0000	mm

Supplementary Material 6: Australian Standards for Data Management, Release, and Discoverability of Stereo-BRUV Data

Quality control and data curation

Quality control and data curation are vital, but are potentially time consuming. These time considerations (and associated costs) should be considered during the survey planning stages.

All data corrections should be made within the original annotation files (i.e. within EventMeasure) to ensure data consistency over time. Four complementary approaches for QAQC of data are recommended:

- Analysts should first be adequately trained by completing deployments for which a species composition and density are known to which they can be compared.
- Once the first annotation for a deployment is completed, a different analyst should view each MaxN annotation to double check the species ID and abundance estimates.
- Footage from any previously unrecorded (i.e. range or depth extensions) or unidentifiable species should be sent to the project taxonomist for formal ID. It is important to send footage clip rather than still images.
- R workflows are provided in a GitHub repository to enable comparison with regional species lists and likely minimum and maximum sizes for each species (Langlois et al. 2017).

It cannot be stressed enough that any corrections should be made to the annotation files before data is exported to GlobalArchive or other repositories (i.e. only QA/QC and validation annotations should be publicly released).

A national stereo-BRUV steering group has been set up to oversee a nationally coordinated BRUV monitoring program (Supp. 7). Any new stereo-BRUV deployments should be discussed with this steering group to ensure that, where possible, they can be integrated within the national program.

Data release

GlobalArchive (www.globalarchive.org) is a centralised repository for stereo- and single-camera image annotation of mobile fauna, in particular from Baited Remote Underwater stereo-Video (stereo-BRUVs) and Diver Operated stereo-Video (stereo-DOVs). A user manual for GlobalArchive is available in an open-access GitHub repository. Metadata should be made publicly available via GlobalArchive as soon as possible after survey completion and data QA/QC and validation. This should include positional data, as well as the purpose of the sampling campaign, the survey design, all sampling locations, equipment specifications, and any challenges or limitations encountered. Annotations can also be uploaded once complete. Spatial metadata from GlobalArchive data will in the future be harvested by the Australian Ocean Data Network, and the metadata will accordingly be available on their national portal.

Until this is done, metadata should be published on both GlobalArchive and AODN to ensure data discoverability.

There is currently no national repository for BRUV imagery so we recommend following agency-specific protocols to ensure public release. A national marine imagery repository (including for BRUV imagery) will be scoped in 2020 and updates provided in this field manual.

If desired by the researcher or requested by the funding agency all quality controlled annotation data and any associated calibration, taxa and habitat data should be uploaded to GlobalArchive (www.globalarchive.org) and made publicly available via the public data option. Other funding agency requirements may apply.

Immediate post-trip reporting should be completed by creating metadata records. This can be done far in advance of annotation (scoring) of raw video which is time-consuming and often does not occur for some time following completion of sampling.

ISO 19115 records should be generated at both the Project[1] and Campaign(s)[1] level. For Project records, the ScopeCode element should be set to “fieldSession”. Accompanying Campaign metadata record(s) should use the ScopeCode element “dataset” and be linked to the Project record by adding the Project record identifier (the UUID) into the parentIdentifier element of the Campaign record. An example of a Project record with linked Data records (equivalent to Campaign records) in AODN is here. This approach improves discoverability, provides context to datasets, and aligns with the schema used by services like Research Data Australia.

The Project metadata record should document the project name, purpose, description, location, dates/times, and relevant contacts. The Campaign metadata record(s) should document the purpose of the BRUV sampling campaign, the survey design, all sampling locations, equipment specifications, and any challenges or limitations encountered.

[1] See Global Archive definitions here.

Data discoverability

Following the steps listed below will ensure the timely release of video and associated annotation data in a standardised, highly discoverable format.

1. Immediate post-trip reporting should be completed by creating a metadata record documenting the purpose of the BRUV sampling campaign, the survey design, all sampling locations, equipment specifications, and any challenges or limitations encountered. This can be done far in advance of annotation (scoring) of raw video which is time-consuming and often does not occur for some time following completion of sampling.

2. Publish metadata record to the Australian Ocean Data Network (AODN) catalogue as soon as possible after metadata has been QA/QC. This can be done in one of two ways:

    - If metadata from your agency is regularly harvested by the AODN, follow agency-specific protocols for metadata and data release.

- Otherwise, metadata records can be created and submitted via the [AODN Data Submission Tool](). Note that user registration is required, but this is free and immediate.

Lodging metadata with AODN in advance of annotation data being available is an important step in documenting the BRUV campaign and enhancing future discoverability of the data.

1. Annotate video (fish counts and length) using EventMeasure or similar software.
2. Upload annotation data and any associated calibration, taxa and habitat data to GlobalArchive.
3. Upload raw video data to a secure, publicly accessible online repository (contact AODN if you require assistance in locating a suitable repository for large video collections).
4. Add links to GlobalArchive campaign and raw video storage location to previously published metadata record. You may also wish to attach or link a copy of the annotation data directly to the published metadata record.
5. Produce a technical or post-survey report documenting the purpose of the survey, sampling design, sampling locations, sampling equipment specifications, annotation schema, and any challenges or limitations encountered. Provide links to this report in all associated metadata.

Supplementary Material 7: Australian National BRUV Working Group, as of May 2020.

Name	State	Organisation
Euan Harvey*	Western Australia	Curtin
Tim Langlois	Western Australia	UWA
Neville Barrett	Tasmania	IMAS
Jacquomo Monk	Tasmania/Victoria	IMAS
Nathan Knott	New South Wales	NSW DPI
Hamish Malcolm	New South Wales	NSW DPI
Daniel Ierodiaconou	Victoria	Deakin
Charlie Huveneers	South Australia	Flinders University
Daniel Brock	South Australia	SA DEWNR
Leanne Currey	Queensland	AIMS

* Chair

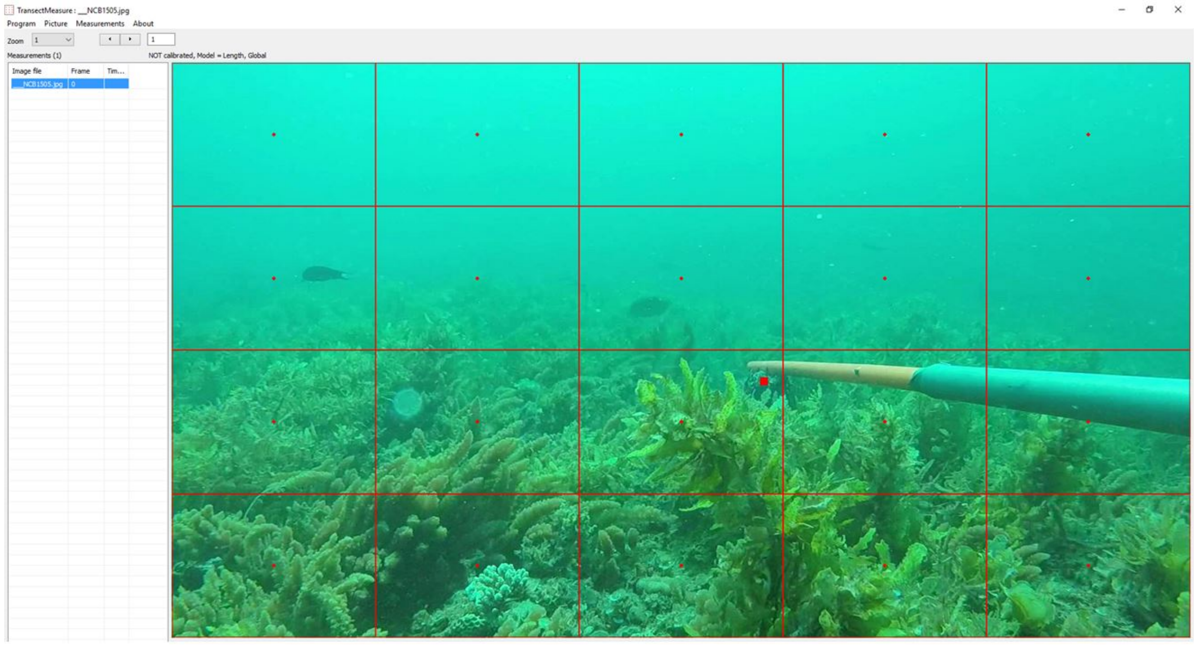
Supplementary Material 8: Habitat Annotation of Stereo-BRUV Imagery

We have developed a simple approach to characterise the composition and complexity of habitats from stereo-BRUV imagery, adapting existing standardised schema for benthic composition (CATAMI classification scheme) and benthic complexity, with the addition of a class to quantify the percent cover of benthos versus open water within the horizontally facing image.

The annotation approach is rapid and produces percent composition and mean and standard deviation estimates of complexity, which enable flexible modelling of habitat occurrence and fish-habitat relationships.

Methods

To simplify the annotation process and still represent multiple scales of habitat in stereo-BRUV imagery, a 5 x 4 grid is overlaid on a high definition image (Supp 8 Figure 1). Each of the 20 ‘rectangle’s are annotated for dominant *Benthic Composition*, *FieldOfView* and *Relief*. See this github repository for examples of annotations.



Supp 8 Figure 1: Screen capture from TransectMeasure (seagis.com.au)

Benthic composition

The annotation schema is made up of nested *Benthic Composition* classes taken from the CATAMI schema (“*BROAD*” > “*MORPHOLOGY*” > “*TYPE*”, e.g. “Macroalgae” > “Erect coarse branching” > “Brown”).

For detailed information on the particular taxonomic levels within the “*BROAD*” > “*MORPHOLOGY*” > “*TYPE*” classifications provided in this annotation schema, please consult the CATAMI visual guide.

To the “*BROAD*” class, we have added additional levels of "Open water" (to calculate the percentage of benthos within each image) and "Unknown" (to account for the frequent issues of limited visibility typical for forward facing imagery).

NOTE: Any ‘rectangle’ that has some form of habitat visible should be classified for *Benthic Composition* (even if open water makes up the majority of the grid).

Field of view

The *FieldOfView* class assesses how the BRUV is positioned when it lands on the substrate. Definition of *FieldOfView* options:

- Facing Down: No open water visible and the system is facing the benthos. This deployment would most likely be removed from analysis due to atypical field of view.
- Facing Up: No substrate visible and the system is facing towards the surface. This deployment would most likely be removed from analysis due to atypical field of view.
- Limited: BRUV landed on its side, upside down or the field of view is badly obstructed by benthos or substrate within ~1m of the camera that would limit the number of individuals observed. This deployment may be removed from analysis due to atypical field of view.
- Open: BRUV landed upright and level on the substrate and there is an adequate amount of habitat available for classification.

Relief

The Relief class uses a 0-5 quantification of relief and includes an "Unknown" level to account for ‘rectangle’s with limited visibility. *Relief* class is representative of complexity or the height and angle of substrate.

When the *Benthic Composition* is “Open Water”, *Relief* should be classified as “Unknown”. Distinct categories have been adapted from Wilson et al. (2006):

0. Flat substrate, sandy, rubble with few features. ~0 substrate slope.

1. Some relief features amongst mostly flat substrate/sand/rubble. <45 degree substrate slope.

2. Mostly relief features amongst some flat substrate or rubble. ~45 substrate slope.

3. Good relief structure with some overhangs. >45 substrate slope.

4. High structural complexity, fissures and caves. Vertical wall. ~90 substrate slope.

5. Exceptional structural complexity, numerous large holes and caves. Vertical wall. ~90 substrate slope.

NOTE: Any ‘rectangle’ that has some form of habitat visible should be classified for Relief (even if open water makes up the majority of the grid).

Recommended approaches

For standard (rapid) assessment of *Benthic Composition*, *FieldOfView* and *Relief* we recommend using ONLY the: "*BROAD*" classification within the *Benthic Composition* and *FieldOfView* and *Relief*. An experienced analyst would be able to annotate this schema to over 200 images a day.

OR

For detailed assessment of *Benthic Composition* (where coral bleaching or macroalgae composition was of interest), *FieldOfView* and *Relief* we recommend using all the classes in *Benthic Composition* ("*BROAD*" > "*MORPHOLOGY*" > "*TYPE*" and *FieldOfView* and *Relief*. An experienced analyst would be able to annotate this schema to over 120 images a day.

Forward facing imagery can be annotated in a range of software, including TransectMeasure from SeaGIS (seagis.com.au), ReefCloud (reefcloud.ai), CoralNet (coralnet.ucsd.edu), and Squidle+ (squidle.org). See this github repository for an example of how to annotate imagery using TransectMeasure (github.com/GlobalArchiveManual/forward-facing-habitat-annotation).

Annotation summary and quality control

All corrections should be made within the original annotation files to ensure data consistency over time. We recommend the following approaches to ensure quality control:

- Check that *FieldOfView*, *Relief* and *Benthic Composition* have been entered for every grid that contains habitat (see R script below).
- Check that the image names match the metadata sample names (see R script below).
- Check all successful deployments have habitat data (see R script below).

See this github repository for an example R script to check and summarise annotations (github.com/GlobalArchiveManual/forward-facing-habitat-annotation).

6. MARINE SAMPLING FIELD MANUAL FOR PELAGIC STEREO BRUVS (BAITED REMOTE UNDERWATER VIDEOS)

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Photograph: Pelagic stereo-BRUV in French Polynesia. Manu San Felix, National Geographic Society 2014

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Platform Description

Underwater videography has become a staple of observational studies in both tropical and temperate environments, where the technique offers a robust, non-invasive, and affordable means of monitoring marine species _in situ_ (Mallet & Pelletier 2014). Initially pioneered for applications in the abyssal zone (Priede et al. 1994), benthic BRUVs (see [https://benthic-bruvs-field-manual.github.io/](Chapter 5)) have been extensively used in shallow, inshore environments (e.g. McLean et al. 2011, Langlois et al. 2012, Zintzen et al. 2012, Oh et al. 2017, Juhel et al. 2018).

However, a growing international commitment to expand the world's marine protected area coverage in recent years (Pala 2013) has motivated efforts to adapt BRUVs to pelagic, open ocean habitats away from coasts (Bouchet & Meeuwig 2015) (Table 6.1). Multiple research groups and organisations have concurrently developed several pelagic BRUV designs (Figure 6.1), most of which share similar elements, namely (i) one (monocular) or a pair (stereo) of cameras in appropriate underwater housings, (ii) a base frame on which the camera(s) is/are mounted, (iii) an attractant, usually olfactory in the form of bait, (iv) a synchronisation device (e.g. diode, clapperboard) and (iv) a suspension system (consisting of weights, ropes, and floats).

Pelagic BRUVs retain all the qualities that have made camera-based sampling a flexible and effective approach to non-destructive marine monitoring, as:

- They are suitable in areas where fishing or other extractive activities are prohibited.
- They are straightforward and relatively quick to operate.
- They have little direct impact on wildlife and ecosystems, other than through bait use.
- They present a safety advantage over diver-based methods and overcome some of their limitations and biases (e.g. depth and time constraints, avoidance behaviour in fishes).
- They produce accurate body length measurements when configured in stereo.
- They yield a permanent archive of high-definition footage.
- They generate quantitative data, while also documenting behaviour.
- They are viable in a range of depths, underwater terrains and ocean conditions.

Importantly, the use of one or more attractants substantially increases the likelihood that nearby animals enter the field of view of the cameras for digital capture (Rees *et al.* 2015). Extensive collective experience in the deployment of pelagic BRUVs across a range of habitats, climates, and conditions indicates that the instruments are capable of detecting a large suite of taxonomic groups (including many of interest to fisheries), from teleost fishes to elasmobranchs, marine mammals, molluscs, crustaceans, and reptiles (Figure 6.2).

In spite of their performance, pelagic BRUVs suffer from a number of limitations, many of which apply equally to demersal videography, including:

- Footage quality is affected by high turbidity and low visibility.
- Correct identification of some species can be difficult for small, shy or morphologically similar species and individuals.

- Bait dispersal is a complex, dynamic process likely to fluctuate spatio-temporally. Quantifying the size of the effective area being sampled and its variation remains an unresolved challenge.
- Bait elicits diverse animal behavioural responses whose strength, timing and duration often relate to many unknown parameters (e.g. olfactory performance, prey search strategy, human presence etc.).
- Numerous species may also respond to non-olfactory cues in ways that have seldom been quantified (but see Rees *et al.* 2015).
- The nature and magnitude of observation biases arising from the presence of conspecifics (and other species) are largely unknown (Dunlop *et al.* 2014, Coghlan *et al.* 2017).
- Counts of wildlife on BRUVs reflect measures of *relative* rather than *absolute* abundance and can be biased, e.g. by screen saturation (Lowry *et al.* 2011, Schobernd *et al.* 2013).
- Detection/attraction probabilities likely vary by time of day, habitat, bathome, and species.
- Zero-inflation is common and may undermine the statistical power needed to identify patterns and changes in pelagic communities (Santana-Garcon *et al.* 2014b).
- Benthic "species contamination" can occur wherever the ratio between suspension and seabed depths approaches one (e.g. pelagic BRUVs suspended at 10 m in a total of 15 m of water) (Letessier *et al.* 2013b), but see Clarke *et al.* (2019) for a comparison of benthic and pelagic assemblages and their overlap at different depths.

Further discussion of some of these caveats can be found in Bouchet & Meeuwig (2015), Santana-Garcon *et al.* (2014b) and Espinoza *et al.* (2014), among many others.

Table 6.1: Summary of studies using pelagic video systems in marine monitoring. Orientation refers to the angle of the camera(s), and can be either horizontal (forward-facing) or vertical (downward-facing). Deployments can be conducted with instruments either moored to the seafloor ('anchored'), linked to a vessel via a coaxial cable or similar ('tethered), or free drifting (as individual units or in a longline configuration). NSW: New South Wales. WA: Western Australia. Due to differences in local supply, it is difficult to identify a standardised type of baitfish. As a rule, small pelagic species with soft, oily flesh are usually recommended. For instance, sardines/pilchards (*Sardinops sagax*) have been a staple of BRUV research in Australia and New Zealand, as evidence suggests they result in consistent numbers of fish among samples (less variation), exhibit higher mean abundance among sites and are more persistent (i.e. longer time to depletion) (Dorman *et al.* 2012). MW = mid-water. P = pelagic. S = Stereo.

Authors	Location	Stereo	Orientation	Method	Attractant type	Bait type	Instrument name
Heagney *et al.* (2007)	Lord Howe Island (NSW, Australia)	×	Horizontal	Anchored	Olfactory (dead bait)	Mixture of minced pilchards, bread and tuna oil (8:1:1), combined in matrix of vegetable meal (falafel) [100g]	MW BRUVs
Letessier *et al.* (2013)	Shark Bay (WA, Australia)	✓	Horizontal	Anchored	Olfactory (dead bait)	Pilchards, squid, and combination (slurry, 1:1)	MW camera rigs
Santana *et al.* (2014a)	Ningaloo Reef (WA, Australia)	✓	Horizontal	Anchored	Olfactory (dead bait)	Mullets (cut in halves) [1kg]	PS BRUVs
Santana *et al.* (2014b)	Coral Bay (WA, Australia)	✓	Horizontal	Anchored	Olfactory (dead bait)	Pilchards [800g]	PS BRUVs
Santana *et al.* (2014c)	Western Australia (several locations)	✓	Horizontal	Anchored	Olfactory (dead bait)	Crushed pilchards [800g]	PS BRUVs
Santana *et al.* (2014d)	Houtman Abrolhos Is. (WA, Australia)	✓	Horizontal	Anchored	Olfactory (dead bait)	Crushed pilchards [800g]	PS BRUVs
Schifiliti *et al.* (2014)	Ningaloo Reef (WA, Australia)	✓	Vertical	Tethered	Olfactory (dead bait)	N/A	RemORA
Bouchet & Meeuwig (2015)	Perth Canyon (WA, Australia)	✓	Horizontal	Drifting	Olfactory (dead bait)	Crushed pilchard heads, guts and tails [2-3kg]	PS BRUVs
Fukuba *et al.* (2015)	Mariana Trench (Western North Pacific)	×	Vertical	Drifting	Olfactory (live bait)	Live matured eels	Una-Cam
Rees *et al.* (2015)	Jervis Bay (NSW, Australia)	×	Horizontal	Anchored	Olfactory, visual, acoustic	Visual: Spearfishing 'swivel flasher'. Acoustic: Playback recording of bait fish.	MW RUVs

						Olfactory: Mixture of white bread and pilchards.	
Scott *et al.* (2015)	Sydney Harbour (Australia)	×	Horizontal	Anchored	Olfactory (dead bait)	Mixture of minced pilchards, bread, and tuna oil, in an (8:1:1) [100g]	P BRUVs
Kempster *et al.* (2016)	Mossel Bay (South Africa)	✓	Vertical	Tethered	Olfactory (dead bait)	Sardines and fish heads [0.5kg]	RemORA
Vargas *et al.* (2016)	Australian east coast (several locations)	×	Horizontal	Drifting	Olfactory (dead bait)	Chopped pilchards and squid [500g]	Surf-BRUVs
Acuña-Marrero *et al.* (2018)	Galapagos Islands, Ecuador	✓	Horizontal	Anchored	Olfactory (dead bait)	Yellow-fin tuna [800g]	P BRUVs
Caselle *et al.* (2018)	Tristan da Cunha (British Overseas Territory)	✓	Horizontal	Drifting	Olfactory (dead bait)	Crushed fish [800g]	MW BRUVs
Ryan *et al.* (2018)	Mossel Bay (South Africa)	✓	Vertical	Tethered	Olfactory (dead bait)	Crushed sardines [0.5kg]	N/A
Clarke *et al.* (2019)	Gulf St Vincent (SA, Australia)	×	Horizontal	Anchored	Olfactory, visual	Visual: flasher. Olfactory: minced sardines [1kg]	P BRUVs

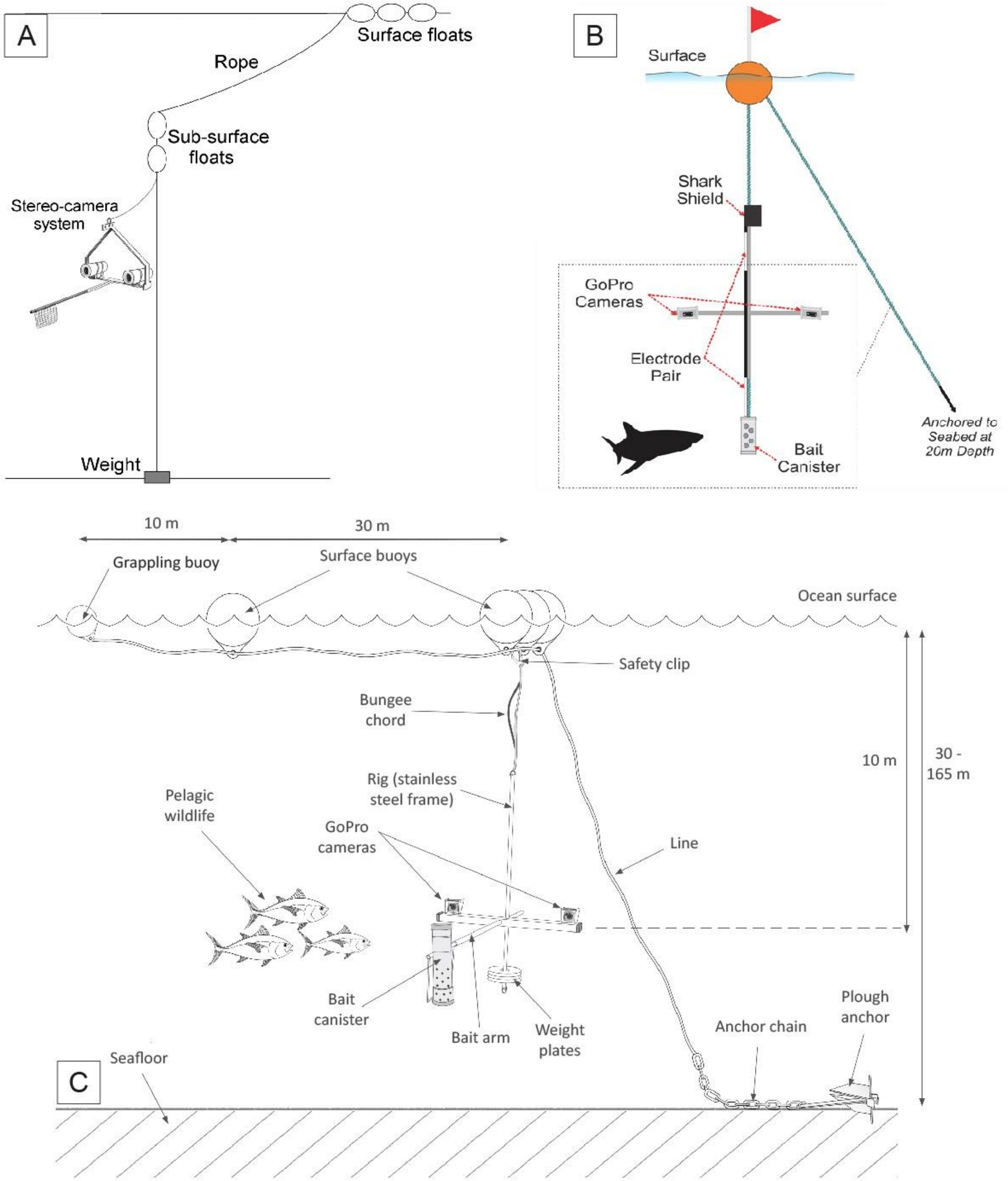

Figure 6.1: Examples of possible deployment configurations for pelagic BRUV sampling. Schematics extracted from or as used in (A) Santana-Garcon *et al.* (2014b), (B) Schifiliti *et al.* (2014) and Kempster *et al.* (2016), (C) Letessier *et al.* (2013b). Cameras can be either forward-facing (A, C) or downward-facing (B). The anchored design shown in C was adapted in Bouchet & Meeuwig (2015) to let BRUV units drift freely.

Figure 6.2: Example species observed on pelagic BRUVs. (A) Bryde's whale *Balaenoptera brydei*, (B) Manta ray *Manta birostris*, (C) Dusky dolphin *Lagenorhynchus obscurus*, (D) Whale shark *Rhincodon typus*, (E) Dolphin fish *Coryphaena hippurus*, (F) Atlantic horse mackerel *Trachurus trachurus*, (G) Blue shark *Prionace glauca*, (H) Shortfin mako shark *Isurus oxyrinchus*, (I) Sea snake *Hydrophiidae sp.*, (J) Green turtle *Chelonia mydas*, (K) Krill *Euphausia sp*., (L) Loggerhead turtle *Caretta caretta*, (M) Atlantic spotted dolphin *Stenella frontalis*, (N) Longfin yellowtail *Seriola rivoliana*, (O) Sub-Antarctic fur seal *Arctocephalus tropicalis*, (P) Yellowfin tuna *Thunnus albacares*, (Q) Pilot fish *Naucrates ductor,* (R) Blue marlin *Makaira nigricans*, and (S) Unicorn leatherjacket *Aluterus monoceros*.

Scope

This manual relates to gear designed to acquire digital video imagery of macro-organisms living in the ocean's water column, from small zooplankton (Letessier *et al.* 2013a) to marine mega-vertebrates (Letessier *et al.* 2014). A sister chapter on benthic BRUVs is included in the field package and addresses sampling protocols for demersal fish and shark assemblages (Chapter 5). The document aims to span everything from pre-survey planning to equipment preparation, field procedures, and on-board data acquisition to guarantee the efficient and correct use of pelagic BRUVs as monitoring tools in Australian Marine Parks (AMPs) and other Commonwealth waters. Such information is critical for supporting the development of consistent, concise, transparent and standardised guidelines in the collection and processing of pelagic BRUV data that can allow statistically robust comparisons between studies, sites, projects, and institutions.

Here, we consider both mono- and stereo-BRUVs[7]. While the latter can be calibrated to allow measurements of individuals' body lengths and animal positions in three-dimensional space (Letessier *et al.* 2015), the former seems to remain a more prevalent approach in the literature due to lower costs and personnel/labour requirements (Whitmarsh *et al.* 2017). It is worth noting that other imagery-based methods such as mid-water towed video transects (Riegl *et al.* 2001), in-trawl cameras (Underwood *et al.* 2014), drop cameras (Friedlander *et al.* 2014), infrared thermography (Zitterbart *et al.* 2013), unmanned aerial vehicles (Kiszka *et al.* 2016), or diver operated videos (Goetze *et al.* 2015) are also available for monitoring pelagic environments and wildlife. These would each warrant a field manual in their own right (Mallet & Pelletier 2014), and are thus not included here (for further information, see Bouchet *et al.* 2017).

Pelagic BRUVs in Marine Monitoring

The need for pelagic monitoring programs is becoming increasingly urgent as the diversity and abundance of pelagic species decline and the pressure to meet global conservation targets rises (Letessier *et al.* 2017). While pelagic baited video techniques remain in their infancy, they show promise as efficient and affordable tools for monitoring wildlife communities and characterising biodiversity patterns at a range of spatial and temporal scales. For instance, Letessier *et al.* (2013b) and Heagney *et al.* (2007) were able to detect regional differences in the structure of pelagic fish assemblages, whilst Santana-Garcon *et al.* (2014b) reported changes in species diversity with water depth. Pelagic BRUVs may therefore be useful for providing rapid assessments of the effects of spatial closures, particularly as they are equally as efficient as benthic BRUVS in reducing overall costs and sampling footprint (Clarke *et al.* 2019). Although neither Heagney *et al.* (2007) nor Santana-Garcon *et al.* (2014c) found significant differences in species composition and relative abundance between fished and protected areas within their respective study sites, their data represent valuable baselines for future surveys. Knowledge of pelagic species distributions and habitat preferences are also critical to successful management, and pelagic BRUVs can yield geo-referenced data with sufficient replication to support the development of predictive statistical models (Bouchet & Meeuwig 2015). Lastly, pelagic BRUVs allow cost-effective observations of behaviour in free-ranging animals that might otherwise be difficult to obtain outside laboratory settings (Santana-Garcon *et al.* 2014a, Kempster *et al.* 2016, Ryan *et al.* 2018). Many aspects of the behaviour and basic biological requirements of pelagic fishes remain largely unknown, and pelagic BRUVs can thus be a powerful way of filling these knowledge gaps, for example by documenting biologically important areas like spawning (Fukuba *et al.* 2015) and nursery grounds (A. Forrest, unpublished data).

In brief, BRUV sampling (and by extension pelagic BRUV sampling) generates quantitative, monitoring-relevant data on:

- The extent and magnitude of anthropogenic impacts (e.g. fishing, climate change, oil and gas exploration, novel ecosystems such as man-made structures).
- Temporal and spatial variability in the relative diversity, abundance, and size structure of fish assemblages (when used in stereo).
- Behaviour observed *in situ*.
- Species-habitat relationships.

For a detailed overview of observational methods used in the spatial monitoring of fishes, with notes on baited videography, see Murphy & Jenkins (2010) and Mallet & Pelletier (2014). Struthers *et al.* (2015) offer additional insights into the value and limitations of action camera technology for field studies and education/outreach.

Equipment

It is crucial that equipment be appropriately set up to ensure maximum consistency among surveys and to facilitate gear replacement where/when necessary. Key components for a pelagic BRUV are listed in Table 6.2.

Equipment configurations can vary among terrains, bathomes and as a function of study objectives (Figure 6.1). For instance, Santana-Garcon *et al.* (2014b)'s design is remarkably stable compared to Letessier *et al.* (2013b) but is constrained by the need to moor, which Bouchet & Meeuwig (2015)'s design bypasses. Likewise, bait arm length is usually variable, and may be reduced under turbid conditions to optimise species identification capacity.

Table 6.2: Example packing list. The list reflects the equipment needed to deploy pelagic BRUVs in an adaptation of Bouchet and Meeuwig (2015)'s protocol, whereby 3-5 camera units are tethered to each other on a longline (ca. 250 m) and drift with prevailing currents.

Item description	Quantity
BRUV units	
Rig frames	As required
Rig uprights + lynch pins (stainless steel ~ 5cm) + shackles	1 / rig + spares
Bait arms (stainless steel, 1.8m)	1 / rig + spares
Dumbbells (rubberised 2.5kg)	2 / rig + spares
Bait canisters (PVC tubes ~ 50cm)	1 / rig + spares
Rope (8mm or thicker – silver rope preferable for hauling)	1 / longline
Rubber rope bin	10m / rig / flag buoy + 200m / longline + spare
Double action clips (stainless steel ~10cm)	2 / rig + spares
Shark clips for bait arms (~10cm) + longlines (~7cm)	2 / rig + 1 / longline + spares
Buoys (orange, soft plastic, approx. 300mm x 400mm)	3 / rig
Sub-surface buoys	1-2 / rig
Flag buoys	1 / longline
Bait (pilchards/mulies/bonito whole fish frozen)	~1kg / drop + spare
GPS loggers and VHF transmitter	4
CAMERA EQUIPMENT	
Cameras (e.g. GoPro Hero 3+ Silver)	2 / rig / drop + spares

Camera battery extension packs (e.g. GoPro Battery BacPac)	1 / camera + spares
Spare internal camera batteries	10
Memory cards (e.g. micro SD 64GB)	1 / camera + spares
Camera housings	2 / rig +spares
DATA RECORDING	
Laptops (HP Probook 450 G2 + power cable)	2
Hard drives (2TB Seagate portable hard drives)	~1 / 100 hours of footage + spares
Magnadoodle / slate / white board and marker / pen and paper (metadata recording)	1
Power adapters + power boards	~4
USB hubs	8
USB2 cables	50
SD card adapters	3
Clipboard	1
Waterproof paper (for datasheets) + pencils	1 ream + 1 box
Handheld GPS	1
GENERAL	
Toolbox	1
Socket set	1
Power drill and charger (battery operated)	1
Hot knife (for cutting and sealing rope)	1
Gloves (full fingered sailing gloves for hauling)	1 pair / person
Safety boots	1 pair / person
Air compressor hose and nozzle	1
Tupperware tubs (to store cameras in the field)	2 boxes
Dry bag (to store cameras in wet conditions)	1
Nuts and bolts (Phillips head stainless steel bolts with nylon locking nuts 3/16" x 25mm)	2 / rig + spares
Screwdriver set (assorted flathead and Phillips head)	1
Hex (Allen) key set	1
Wrench set (150mm, 200mm and 250mm adjustable)	1
Spanner set (14mm and 10mm for BRUVS)	1
Wire cutters	1
Cable ties (assorted, for repairs etc.)	500
Packing tape (e.g. duct tape)	10 rolls
Plastic packing film	1 large roll
Laminated packing labels (premade for shipping out and back)	3 / item

Pre-Survey Preparations

Methodology

<u>A statistically robust sampling design must be chosen,</u> allowing for adequate spatial/temporal coverage and replication whilst meeting the overall survey objectives, given available equipment and vessel time. Santana-Garcon *et al.* (2014b) recommend a minimum of 8 replicates per experimental treatment in warm-temperate and tropical coastal environments, although this may be dependent on the geographic distribution and abundance of species. The final design should be communicated to all personnel before the survey to maximise clarity and efficiency during field operations. As a rule, pelagic BRUVs should be deployed a minimum of 200-500 m apart to reduce the likelihood of bait plume overlap and inter-camera animal movements (Santana-Garcon *et al.* 2014b, Bouchet & Meeuwig 2015), but further field testing

is required to determine if this separation is sufficient to consistently guarantee independence between replicates when sampling large, mobile vertebrate species. See Chapter 2 for additional details.

The timing and duration ("soak time") of BRUV deployments should be determined. Deployments conducted 30-60 min after sunrise and before sunset should abate the effects of differential crepuscular behaviour in fishes (Axenrot *et al.* 2004, Potts 2009). If BRUVs are only one part of a larger research program, it is important to think carefully about the timing of BRUV operations, as bait use may bias subsequent observations at that same site (e.g. if diver surveys were to follow). Optimal soaking time is likely to vary across habitats and represent a practical compromise between increasing sample size and making the best use of available vessel time in light of the target level of replication. Previous studies have reported soaking times of 45 min (Rees *et al.* 2015), 120-135 min (Letessier *et al.* 2013b, Santana-Garcon *et al.* 2014c), 165 min (Bouchet & Meeuwig 2015), or 180 min (Santana-Garcon *et al.* 2014b). Santana-Garcon *et al.* (2014b) suggested a soak time of 120 min. In cool-temperate waters, Bouchet & Meeuwig (2015)'s species accumulation curves failed to plateau after 3 hours. Although some attempts have been made to develop a range of plausible bait plume dispersal models (e.g. Olsen & Laevastu 1983; Sainte-Marie & Hargrave 1987), further on bait diffusion in the mid-water is needed to confirm the minimum distance that should be allowed between deployments, estimate the effective sampling area in a range of conditions, and better understand the dynamics bait flushing across different levels of fish activity. Lastly, careful thought must be given to the choice of suspension depth, as different assemblages may vary along depth gradients away from the surface (Santana-Garcon *et al.* 2014b).

Consideration must be given to the location of BRUVs during deployment. Instruments should not be deployed where there is a risk of entanglement (e.g. near fishing gear) or where they are likely to constitute or become a navigational hazard (e.g. inside shipping lanes, where trawlers are operating). At a minimum, deployment and retrieval locations should be recorded, with vessel location monitored at regular time intervals as a back-up. GPS loggers can be mounted on flag poles or buoys when deploying free-drifting BRUVs and are advised for capturing the exact spatial trajectories of the units (Bouchet & Meeuwig 2015). VHF radio beacons are also recommended to avoid gear loss in adverse weather conditions. Geofencing technology could be used (as it has been with fish aggregation devices) should the user need to be alerted when BRUVs exit a predefined area.

Appropriate approvals must be obtained. All research activities within Australian Marine Parks are to be undertaken under permit, and most institutions will also require Animal Ethics approval, even if the proposed methods are non-invasive. All institutional health and safety requirements must also be satisfied (e.g. travel risk assessment, volunteer insurance proposal). See Appendix A for a list of potential permits required at the Commonwealth level).

Appropriate camera settings must be selected (e.g. frame rate, video resolution, field of view mode, action cams vs camcorders, see Table 6.3) in light of their performance relative to the study goals and market availability. Correct date/time settings are particularly crucial for file management during subsequent analyses. When using GoPro cameras, note that standard and dive housings are rated to 40 m and 60 m respectively. Special backdoors must be also fitted if battery packs are considered. All equipment must be carefully checked prior to deployment, including that cameras have been serviced, cleaned, and calibrated (if using stereo-BRUVs). Spares (batteries, memory cards, cameras, Table 6.2) are essential as a contingency plan against equipment failure/damage/loss or adaptive changes in the sampling plan (e.g. additional deployments).

Table 6.3: Example camera settings for a pelagic BRUVs. Values reflect the use of GoPro Hero3 cameras. Options may differ in other camera models.

Settings	Value
Camera	
Resolution	1080
Frame Rate	25 fps
Field of View	Medium
Capture	
Upside Down	Up
Spot Meter	Off
Looping Video	Off
Set up	
Default Mode at Power Up	Video (default)
One Button	Off
NTSC/PAL	PAL
Onscreen Display	ON
Camera Status Lights	2
Sound Indicator	Off
Manual Power Off	Manual

Bait must be ordered ahead of time in sufficient quantities. Sourcing bait locally from factory discards (e.g. fish heads, tails and guts) is an attractive option for reducing costs and the ecological footprint of sampling. For some applications, bait balls comprising minced fish, oil, and/or meal, may also be appropriate, though care should be taken to standardise bait mixtures across deployments. Between 800g-3kg of bait is generally adequate for deployments of up 3 hours (Letessier *et al.* 2013b, Santana-Garcon *et al.* 2014b), though having extra supplies (e.g. 20%) may be useful if extra/longer deployments can/must be undertaken. Ultimately, the choice of bait quantity should be informed by consideration of the desired soaking time, expected flushing rate, and likely level of fish activity. Sufficient freezer space must be made available on-board accordingly. Debate is still ongoing over the most efficient way to prepare bait, although crushed/slurried mixtures seem more likely to disperse well into the water column. Presentation is also important, with wire mesh baskets (Santana-Garcon *et al.* 2014b) and perforated PVC tubes (Bouchet & Meeuwig 2015) being two popular options, despite the lack of comparative studies of their relative efficiencies. Critically, recent research demonstrates that bait alone may be a biased/poor attractant for pelagic fishes, and that consideration should be given to combinations of multiple attractants associated with sight, sound, and scent to help generate more effective abundance estimates for some species (Rees *et al.* 2015).

Rig set up should reflect the chosen BRUV design, and may need to be adapted in response to vessel constraints (e.g. available deck space). It is critical to check that the correct amount of weight, length of ropes, number of buoys etc. are available before the survey begins (Figure 6.1). Spare units and parts are essential in all circumstances.

Sampling gear specifications should always be fully documented to achieve maximum transparency and comparability. Over a third of studies fail to report on basic methodological choices (Whitmarsh *et al.* 2017), including rigging plans, camera orientation, spacing, convergence angle, field of view, inter-BRUV distances, soak time, bait choice and quantity, bait preparation technique, bait dispenser type, suspension depth, deployment configuration (Figure 6.1), number of replicates, among others.

Data storage needs must be anticipated. 2TB portable hard drives will typically provide enough storage space for 100 hours of high-resolution video footage, though this may vary by camera model/make. Equally important is making sure that enough power boards, adapters, USB hubs, data cables, etc. are purchased, and can be configured safely for use at sea, so that data offload and backup following each deployment can occur. Planning for double copies of each hard drive and for offline storage on institutional servers is highly recommended to avoid data loss in the event of hardware failure.

Pre-survey checklist

	Task	Description/comments
□	Sampling design chosen and coordinates of sampling sites calculated and checked for safety hazards	
□	Pelagic BRUV design and configuration determined	
□	Deployment protocol determined, including methods for locating/tracking gear	
□	Appropriate permits obtained and printed copies made (on waterproof paper if necessary)	
□	Bait (and/or other attractants) ordered in adequate quantities	
□	Camera settings determined, and cameras calibrated as appropriate	
□	Data storage needs identified and hardware purchased accordingly	
□	Metadata sheet prepared	
□	Gear shipment arranged	

Field Procedures

A visual summary of the key steps to follow when deploying pelagic BRUVs is shown in Figure 6.3.

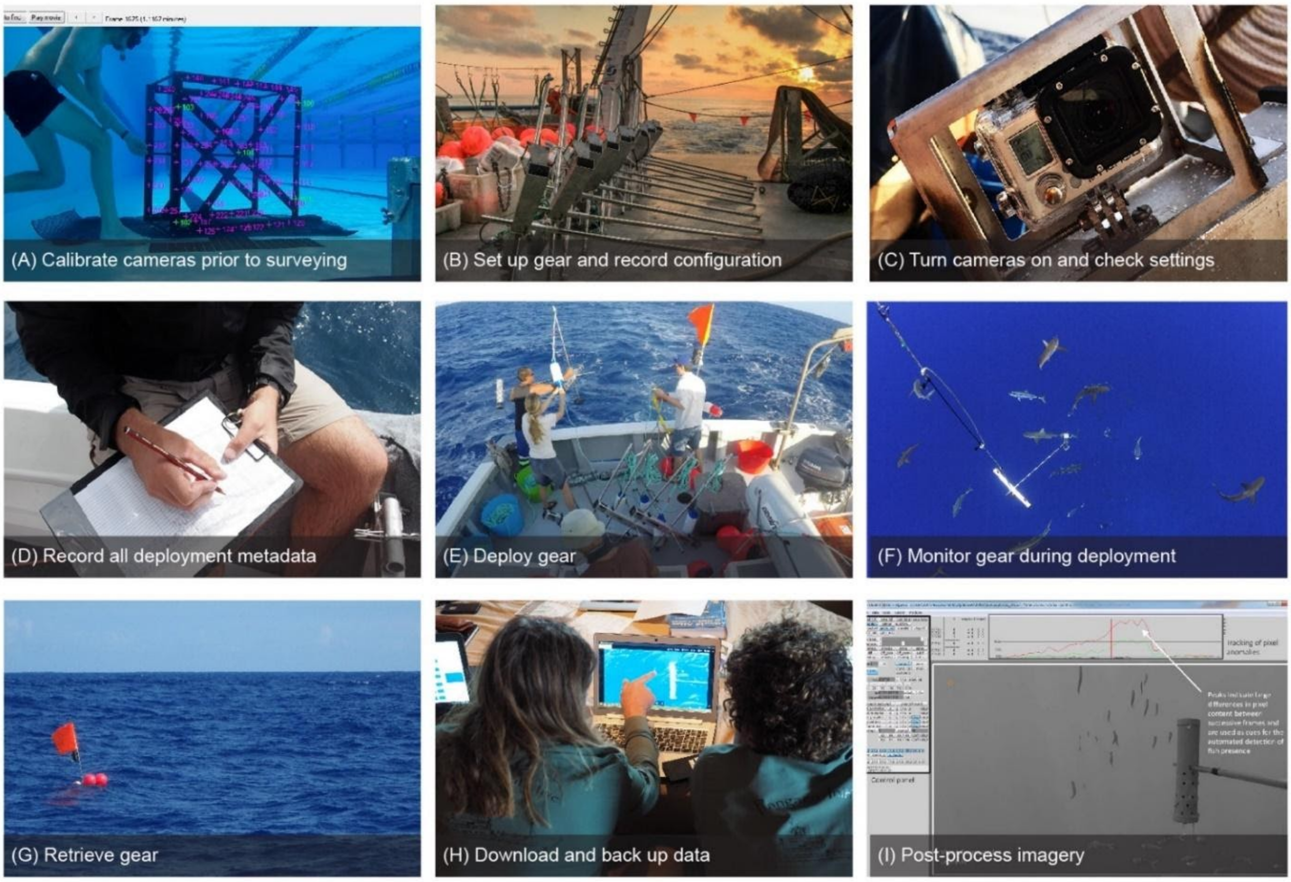

Figure 6.3: Images from key steps involved in the use of pelagic BRUVs for marine monitoring. (A) Using a calibration cube in an enclosed pool environment. (B) Once set up, the gear can be easily stacked and stowed on deck. (C) Example of a GoPro camera turned on before deployment. (D) Relevant metadata can be recorded on waterproof paper. (E) Pelagic BRUVs are versatile and can be deployed manually from a variety of platforms ranging in size from small rigid inflatables to large research vessels. (F) Maintaining visual contact with the gear is key to avoiding equipment loss. Should the deployment vessel need to leave the site (e.g. to support additional activities), a VHF transmitter can be used to re-locate the gear. (G) Flags and brightly coloured buoys help locate the equipment for recovery. (H) Videos are typically downloaded and backed up at the end of each sampling day. (I) Processing and analysis of the imagery occur in a computer lab post-survey.

Calibrations

Stereo-BRUVs require calibration to ensure accurate length measurements. Calibration frequency will ultimately depend on the hardware used and recommendations from the manufacturer. Calibrations are best carried out prior to surveying and commonly take place in enclosed pool environments. Additional post-survey calibrations are also advantageous, particularly following long sampling campaigns where the risk of camera displacement during operation or transport is higher. The calibration process takes into account the base separation, camera angle and lens distortion, all of which are unique to each BRUV (Harvey & Shortis 1998), meaning that individual units must hence be calibrated separately, and cameras should not be swapped between units. In addition, if a camera is damaged or knocked out of position during field work, calibrations will need to be repeated post-survey. While some studies show that purpose-built three-dimensional calibration cubes yield maximum accuracy (Boutros *et al.* 2015), recent evidence suggests that planar checkerboards may be equally accurate, at a fraction of the cost (Delacy *et al.* 2017). Where possible, carrying out 'mock deployments' of a single unit may be useful to ensure the BRUV units sit correctly and consistently in the water column.

SeaGIS have long been the primary provider of third-party calibration hardware and software, yet alternative open-source packages have now also begun to emerge, including the MATLAB Calibration Toolbox or the StereoMorph R package (Olsen & Westneat 2015, Díaz-Gil *et al.* 2017).

Arrival on site

1. Unpack equipment and check for any damage that may have occurred during transport.
2. Check that all camera settings are correct (Table 6.3), batteries are full and memory cards formatted.
3. If not already done, number each individual camera and memory card using a permanent marker, and make a note of which card is used in which camera on the data sheet. It may be useful to also number batteries and battery extension packs, to facilitate the troubleshooting of any hardware malfunctions.
4. Lubricate the cameras' O-rings and check them for cuts or nicks. Replace damaged O-rings as appropriate.
5. Set up pelagic BRUV unit(s) (see Table 6.4 for an example). Attach bait containers to bait arms and securely stack/stow equipment on deck.
6. Discuss deployment and safety plans with captain/crew/team and deliver a copy of sampling site coordinates to the skipper.

Table 6.4: Example instructions for setting up a pelagic BRUV. Note that BRUV components are often made of stainless steel to prevent rusting in the marine environment. All replacement parts (e.g. spare bolts, nuts etc.) must therefore also be marine grade stainless (316).

Order	Action
Rigs	
Step 1	Attach camera housings to the mounts on the crossbar using a stainless steel nylon locking nut and bolt (Phillips head 3/16" approx. 25mm). Ensure they are tightly in place and will not move if bumped. **Do not remove** after attachment to ensure calibration accuracy.
Step 2	Place the upright through the hole in the centre of the rig and secure with locking nut.
Step 3	Weight rigs by placing 2 x 2.5kg dumbbell weights (rubber coated preferable) on the base of the vertical pole in the centre and secure with a stainless steel lynch pin.
Step 4	Place the loop of the 10m rig line into the shackle on the top of the rig upright, and ensure the shackle is done up tight (use mousing wire to ensure the shackle does not come loose with the movement of the rig in situ).
Step 5	Fix the bait arm in place with a shark clip.
Bait canisters	
Step 6	Take a ~50 cm length of PVC pipe, glue a cap on one end and a screw cap on the other. Once dry, use a power drill to drill small ~1-2 cm holes in the end without the screw cap and one large hole all the way through in the centre to allow the bait arm to fit through. Drill small holes in the cap at the holey end and cable tie a dive weight to the inside of the canister.
Lines	
Step 7	Equip each rig with 10 m of rope. Note: The length of rope can be adapted depending on the suspension depth relevant to the project.
Step 8	At one end of the loop, make a small (~15cm) eye by splicing the rope back on itself. This end will be attached to the rig upright.
Step 9	At the other end, pass the line through the eyelet of a double action clip and splice it back on to itself to create a loop with the clip on the end. This will be attached to the longlines and buoys.

Step 10	Close to the top of this line (~2 m down), tie on a short length of shock cord (~1 m), to create a D-shape with the shock cord making the short side. At the top of this tie using a small length of line to attach a small buoy.
Step 11	Cut four 200 m lines for each set of 5 rigs (or 9 for sets of 10) to act as the long lines between rigs.
Step 12	Splice small loops at the ends of each of these lines (~15 cm).
Step 13	Store on a winch clipped together with shark clips to make one line. If a winch is not available, coil the lines into separate nelly or rubber rope bins, keeping the ends free and easily accessible for deployment.
Buoys	
Step 14	Inflate buoys using a compressor and needle.
Step 15	Take a length of line (1.5-2 m works well) and thread through the eyelets of three buoys and splice it back on to itself, leaving about 1 m free.
Step 16	Pass the free end through the eyelet of a double action clip and splice it back on itself to create a small loop with the clip on the end. You should be left with a loop with the three buoys and a 1m length with a clip at the end. **Note:** Smaller sub-surface buoys can also be added to the suspension line and will generally help stabilise the rig, thereby facilitating species identification and length measurements.
Step 17	To deflate the buoys at the end of the expedition, simply unscrew the bung (some are flat head and some are Phillips head).
Step 18	Inflation and deflation of buoys should be considered for storage and mobilisation (i.e. whether an air compressor is on board the work vessel and what attachment is required).
Cameras	
Step 19	Two [insert model name, e.g. GoPro Hero 3] are required per rig plus spares. The night before field work is conducted, ensure that the camera settings are correct (Table 6.3) and that the cameras and battery packs are charged (power-boards, USB hubs and USB2 cords are the easiest way to do this) NOTE: adapters may be required if working overseas.
Step 20	Once the cameras and battery packs are charged, store them in a Tupperware container lined with a layer of foam padding above and below (or a specifically fitted Pelican case) to keep them from moving around in transit.
Step 21	Store in a cool dry place until needed.
Step 22	Camera housings should be attached to rigs permanently. Consider the depth ranges being sampled and choose housing types accordingly. Standard GoPro housings are rated to 40 m while dive housings are rated to 60 m. This may vary amongst manufacturers and brands. External battery packs must be used to ensure that the cameras run for the required time.
Flag/GPS/VHF buoy	
Step 23	Assemble using socket and spanner sets.
Step 24	Make sure tension wires are tight.
Step 25	Splice a 10 m length of line to the buoy, pass the opposite end through the eyelet of a double action clip and splice back on itself to fix in place.

Deployment

1. Take bait out of the freezer before sampling and place it in a rubber bin (empty or filled with seawater) to allow it to thaw. This can be done anywhere between 1 and 12 hours beforehand. Note that in tropical countries, bait loses texture and quality if thawed too early. It is also generally easier and cleaner to crush half-frozen bait than bait that has thawed fully.

2. When on route to the drop location, rigs can be laid out in order with the first rig to be deployed closest to the stern (along with corresponding lines if a winch is not being used).
3. Prepare bait (e.g. mince, slice or crush) and fill bait bags/canisters with desired weight.
4. Seal bait canister (e.g. tighten screw caps) and store upright in a plastic container until use.
5. Check that metadata sheets are ready (see Table 6.5). These sheets should be printed on waterproof paper before leaving for the expedition. Fill in drop numbers, camera numbers and memory card numbers when preparing cameras for the day's work. Follow this in the field and fill in the other information as available.
6. Attach lights and sensors, if available.
7. If using a VHF transmitter, remove the magnet and note the device's frequency, checking it is working correctly and a signal can be heard/detected. Place it in a small pelican case attached to the flag buoy, along with one GPS logger (turned on by holding down the middle button) and close tightly.
8. Insert cameras into housings and check that the housings are dry and sand-/hair-free, without any other objects obstructing the O-rings to ensure a good seal.
9. Turn the cameras on (e.g. for GoPros, by pressing the front button until the red light starts flashing and the timer starts), check there is battery and storage space available.
10. Place the data sheet (or Magnadoodle/slate/white board/paper sheet) showing drop number, date, rig number and location in front of each camera and in the centre over the bait arm so that it is clearly seen in the fields of view of both cameras. Verbal logs are an alternative/complementary option, as modern cameras are usually sufficiently sensitive to record spoken instructions/information.
11. Attach a diode to the bait arm if using stereo-BRUVs. If a diode is not available, clap slowly 3-4 times in front of the cameras (using a clapperboard or bare hands) over the bait arm in clear view to allow synchronisation during video analysis.
12. Attach the flagpole, one cluster of buoys and the first of the rigs to be deployed to the end of the first longline via double action clips. Ensure the rope is free, coiled, and facing the correct direction to un-coil without hindrance
13. At the captain's go-ahead (i.e. vessel in position and stationary), drop the flagpole into the water.
14. Once the flagpole is clear, push or throw the first rig so that it clears the side of the boat, ensuring all lines are clear of feet and untangled. Drop the cluster of buoys over first, followed by the rig ensuring not to drop the rig on any of the other lines in the water. This works best if one person handles the buoys and another the rig. Note that this sequence differs slightly for moored BRUVs, which require the ballast/anchor to be dropped first, followed by the rig and the floats in this order.
15. Mark a GPS waypoint when the unit is deployed and record both deployment time and site coordinates on the data sheet, which will have been pre-populated with location, rig number, camera numbers, memory card numbers etc. Include comments where necessary e.g. issues, weather conditions.

16. For single-rig designs, travel to the next site. For multi-rig designs, repeat until all units are in the water, making sure the captain moves forward slowly to pay out the lines.

Table 6.5: Example metadata sheet for pelagic stereo-BRUV fieldwork. Left and right memory card numbers must be recorded for each camera pair.

Date	ID	Rig	Left cam	Left card	Right cam	Right card	Time in	Location in	Time out	Location out	Comments (e.g. wildlife, behaviour, habitat etc.)
2017-10-25	SITE-A	15	12	05	10	02	08:00	(115.1252E; 32.5437S)	10:15	(115.2411E; 32.5008S)	Seabird aggregation observed near deployment site

Retrieval

1. Manoeuvre the vessel alongside the flag/grappling buoy, heading upwind of the current towards the BRUV.
2. Either gaff or grapple the rope joining to flag buoy to the first cluster of buoys.
3. Haul the line in and retrieve the flag buoy, taking care not to knock the tension wires on the stern of the boat. Remove and store the VHF transmitter and GPS logger when convenient. Wear gloves when hauling and coiling. Pelagic BRUVs are relatively light so manual handling is generally possible, however use a winch or pot hauler if available and warranted.
4. Unclip buoys and coil rope to facilitate future deployments.
5. Turn off the cameras, rinse them with freshwater, dry the seals around the housings with a towel and carefully remove the cameras from their housings when convenient. If conducting surveys over multiple days, it is good practice to clean and re-grease the O-rings with silicone at regular intervals.
6. Store the rig and buoys out of the way.
7. Repeat until all units are retrieved.
8. Remove memory cards.
9. If required, charge or change camera batteries.
10. Either setup the equipment for redeployment or securely stow on deck.

Post-Survey Procedures

Data management and quality assurance/control are crucial for monitoring and comparisons between studies within a given area. Following simple steps and using easily understandable and transferable metadata (see Table 6.5) will enable efficient harmonisation between studies.

Data management

Store used cards separately from unused cards.

1. Download the video data onto a portable hard-drive using a card reader or equivalent.
2. Save the files from each camera in a separate folder named using the unique site/drop identifier and L for left side or R for right side (e.g. CH001L).
3. Use multiple laptops or extra card readers to speed up the process.
4. During downloads, check that the videos are of good quality and note any interesting species etc. If any issue occurred with a camera, rig etc. attempt to rectify the issue before the next day's sampling.
5. At the end of each day, make a backup of the day's videos to two hard-drives stored in separate locations.
6. Transcribe the data from the data sheets into an expedition spreadsheet updated and backed up daily. The spreadsheet should also include the hard drive number where each sample is saved.

Note: It is important that all hard drives be clearly labelled – e.g. with the date, project name, contents and hard drive number. Ideally, files should also be labelled according to a standardised and unambiguous naming convention. All memory cards should be stored in waterproof containers. They should not be re-used or reformatted until data has been download and a backup created.

Pelagic BRUVs typically generate large volumes of data, including video imagery, field data sheets and software outputs. Consistently labelling folders and files is therefore essential to easily locating information and simplifying analyses. An example folder name is "176022_Groote_Island_stereo-BRUV_HD1", which concatenates the deployment date, study location/name, and hard drive number. Similarly, an appropriate file name could reflect the following structure: OpCode_year_month_day_study_cam1_cam2_L (folders on hard drives should follow a naming convention so that programs like Bulk Rename Utility can be easily used to rename all files with OpCode and camera number in the correct format). Template folder/file structures and further details on data management and quality control are provided in Chapter 5.

At this stage, there are no online video file storage databases, however the GlobalArchive platform has been created to store metadata (see 'Data Release' section). Refer to the software's website for instructions on metadata and data recording instructions.

Quality control

Quality assurance/quality control (QAQC) is an equally vital but potentially time-consuming undertaking for organisations and individual researchers. Following straightforward steps and using easily understandable and transferable metadata will enable harmonisation between studies.

It is important that any data corrections are made within the original annotation files to ensure consistency over time. Four complementary QAQC approaches are recommended:

- Analysts should first be adequately trained by processing videos for which species composition and density are known, and to which their results can be compared.
- Once the first annotation (fish counts and lengths) for a deployment is completed, a different analyst should view each MaxN annotation to double-check the species ID and abundance estimates.
- Footage from any previously unrecorded (i.e. range or depth extensions) or unidentifiable species should be sent to the project taxonomist for formal ID. It is important to send footage clip rather than still images.

R workflows are provided in a GitHub repository to enable comparison with regional species lists and likely minimum and maximum sizes for each species (Langlois 2017).

Importantly, any corrections should be made to the annotation files before data are exported to GlobalArchive or other repositories.

Video processing

Trained analysts/fish biologists/taxonomists must be engaged to ensure that all footage can be appropriately processed and species can be correctly identified. Care must be taken to ensure that a consistent nomenclature is used, with FishBase, the World Register of Marine Species (WoRMS) and the Codes for Australian Aquatic Biota (CAAB) being popular, authoritative sources of taxonomic information. Undescribed or unnamed species (e.g. defined operational taxonomic units, OTUs) must also be meticulously documented. Archives of reference images from previous sampling campaigns have been established by numerous agencies across Australia and can serve as a useful benchmark for problematic sightings. The Collaborative and Annotation Tools for Analysis of Marine Imagery and Video (CATAMI) Project offers a framework for the cataloguing, annotation, classification and analysis of underwater imagery (Althaus et al. 2015).

A number of software tools are currently available for image analysis, with SeaGIS EventMeasure being arguably the most widespread but also the costliest. Advanced packages such as Image-Pro Plus, SigmaScan, or simpler programs such as ScreenCalipers can also be used to make measurements calibrated by scale bars. The StereoMorph R package (Olsen & Westneat 2015) is an open-source alternative that additionally allows the reconstruction of 3D objects. Irrespective of the approach chosen, it is critical that any output be produced in a format comparable to other studies to facilitate comparison of data between campaigns and organisations.

Overestimates of abundance can occur as a result of double counting, for instance when the same individual/s is/are viewed at different time points throughout a deployment. To overcome this challenge, counts of the maximum number (MaxN) of individuals of any one species seen over the recording period have been used. In a monitoring context, comparative studies have suggested that the use of MaxN may be “hyper-stable” (i.e. underrepresents the magnitude of changes in true abundance) when fish abundance is high due to saturation of the field of view

(Schobernd *et al.* 2013) and have suggested alternative metrics (e.g. MeanCount). However, MaxN remains the most widely accepted metric, and provides the best option for standardisation between sampling programs.

The essential information produced by annotation software should include three main outputs:

- Point information
- Length measurements
- 3-D point information

Point information is typically used to calculate MaxN values, while length and 3D point information is used to calculate length and biomass metrics. EventMeasure-Stereo has established queries built-in that produce a number of chosen metrics over a user defined period within the footage. In addition, EventMeasure-Stereo annotation datasets held within GlobalArchive can be queried in a similar fashion to produce such metrics. While there are a number of relative abundance metrics available, MaxN is the most widely accepted (Harvey *et al.* 2007).

The type of fish length measured (e.g. fork length or total length for fish and disc length for rays) should be clearly indicated as part of the annotation information for each sampling campaign.

Data release

GlobalArchive is a centralised repository for fish image annotation data, particularly those collected using Baited Remote Underwater Video (mono- and stereo-BRUVs) and Diver Operated Video (DOVs). A user manual for GlobalArchive is available in an open-access GitHub repository. Metadata should be made publicly available via GlobalArchive as soon as possible after survey completion and data QA/QC and validation. This should include positional data, as well as the purpose of the sampling campaign, the survey design, all sampling locations, equipment specifications, and any challenges or limitations encountered. Annotations can also be uploaded once complete. Spatial metadata from GlobalArchive data will be harvested by the Australian Ocean Data Network in the future, and the metadata will accordingly be available on their national portal (and possibly on partner portals, such as the web interface of the Integrated Marine Observation System, IMOS). Until this is done, metadata should be published on both GlobalArchive and AODN to ensure data discoverability *[Recommended]*.

There is currently no national repository for BRUV imagery so we recommend following agency-specific protocols to ensure public release.

Following the steps listed below will ensure the timely release of BRUV imagery and associated annotation data in a standardised, discoverable format.

1. Immediate post-trip reporting should be completed by creating a metadata record documenting the purpose of the BRUV sampling campaign, the survey design, sampling locations, equipment specifications, and any challenges or limitations encountered. This can be done far in advance of annotation (scoring) of raw video, which is time-consuming and often does not occur for some time following completion of sampling.

2. Publish metadata record to GlobalArchive and the Australian Ocean Data Network (AODN) catalogue as soon as possible after metadata has been quality controlled (see 'Quality Control' section).

This can be done in one of two ways:

- If metadata from your agency is regularly harvested by the AODN, follow agency-specific protocols for metadata and data release.
- Otherwise, metadata records can be created and submitted via the GlobalArchive upload page and the AODN Data Submission Tool. Note that user registration is required, but this is free and immediate.

Lodging metadata with the AODN prior to making annotation data available is an important step in documenting the BRUV campaign and enhancing future discoverability of the data.

3. Annotate video (fish counts and length) using EventMeasure or similar software.
4. Upload annotation data and any associated calibration, taxa and habitat data to GlobalArchive.
5. Upload raw video data to a secure, publicly accessible online repository (contact AODN if you require assistance in locating a suitable repository for large video collections).
6. Add links to GlobalArchive campaign and raw video storage location to previously published metadata record. You may also wish to attach or link a copy of the annotation data directly to the published metadata record.
7. Produce a technical or post-survey report documenting the purpose of the survey, sampling design, sampling locations, sampling equipment specifications, annotation protocol, and any challenges or limitations encountered. Provide links to this report in all associated metadata. See Appendix B *[Recommended].*

Forthcoming developments

The development of novel methods combining pelagic BRUVs with ancillary data streams from other sampling platforms is currently underway. This includes, for instance, the integration of species size distributions as observed on BRUVs with active acoustics (echosounder data at 38 kHz) as a means of improving estimates of fish biomass. See the following publication for more details:

Letessier TB, Proud R, Meeuwig JJ, Cox M, Cattaneo Fernandes M, Brierley AS. (Submitted) A protocol for estimating fish biomass using echosounders and baited stereo-videography. Methods in Ecology & Evolution.

Field Manual Maintenance

In accordance with the universal field manual maintenance protocol described in Chapter 1 of the Field Manual package, this manual was updated in 2020 as Version 2. Updates reflect user feedback and new developments. There is currently no long-term plan or support for future updates. See Chapter 1 (Introduction to field manual package) for further details.

The version control for Chapter 6 (field manual for pelagic BRUVs) is below:

Version Number	Description	Date
0	Submitted for review (NESP Marine Hub, GA, external reviewers as listed in Chapter 1.	22 Dec 2017
1	Publicly released on www.nespmarine.edu	28 Feb 2018
2	Minor corrections, updates and clarifications.	July 2020

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Marine Biodiversity Hub

National Environmental Science Programme

7. MARINE SAMPLING FIELD MANUAL FOR TOWED UNDERWATER CAMERA SYSTEMS

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Platform Description

Towed underwater camera systems, of various configurations, have been used since the turn of the 20th century to acquire video and photographic still images of the seafloor (Bicknell et al. 2016) They are deployed on a cable from a surface vessel, have no propulsion mechanisms, and generally have forward-looking oblique and/or downward-looking cameras that either record images which are stored and subsequently downloaded, or transmit data directly to the surface in real-time via a coaxial or fibre optic cable (Bowden and Jones 2016, Durden et al. 2016a). Towed underwater cameras not only augment data from collected specimens (Chapter 8, 9); they also provide an important non-invasive sampling alternative where extractive methods are either unnecessary or unsuitable, such as in sensitive deep-sea habitats (e.g. Althaus et al. 2009, Williams et al. 2015, Sherlock et al. 2016), or for repeated sampling in marine reserves (e.g. Lawrence et al. 2015). Towed platforms also have the added advantage of providing cost-effective permanent data capture along transects that can be up to several kilometers in length and can be used to traverse highly heterogeneous seafloor topography (Shortis et al. 2007, Sheehan et al. 2016). The quality of imagery acquired by towed systems depends largely on sea conditions and water clarity, both of which may vary considerably depending on geographic location, season of sampling and extent of tidal influence. In depths greater than around 30 m, lighting and camera specifications become increasingly important to image quality. The quality and versatility of equipment and the maintenance of a consistent flying altitude above the seabed are also critical factors affecting image quality and usability.

Conventional underwater still photography and video imagery were initially applied by marine ecologists to collect basic qualitative data (e.g. simple visual assessment of seabed conditions to assess habitat type or dominant species), or often low-accuracy quantitative data estimated through the use of parallel lasers to define the scale of the images (see Harvey et al. 2002, Shortis et al. 2008, Durden et al. 2016a). Recent technological advancements have emerged that permit collection of high-resolution benthic imagery using versatile multifunctional towed platforms carrying a variety of camera systems (e.g. stereo-image measurement systems) and a range of other sensors (e.g. high-resolution multibeam and side-scan sonars, motion sensors, conductivity temperature and depth sensors, and subsea acoustic positioning systems) (Kocak et al., 2008, Rattray et al. 2014, Bowden and Jones 2016, Durden et al. 2016a, Logan et al. 2017). This technology, coupled with advances in camera resolution, positional accuracy, digital data processing and visualisation techniques, has enabled more quantitative and spatially-referenced studies of the seafloor. Calibrated stereo-imaging in particular has facilitated more reliable length measurements of mobile species, such as epibenthic invertebrates and demersal fish, and more accurate estimates of biomass and population distributions (Harvey et al. 2002, Shortis et al. 2009). Towed underwater imaging systems can be applied to acquire baseline data, evaluate benthic diversity, map benthic habitats, identify vulnerable communities, assess changes in biota, and support spatial and ecological modelling/monitoring.

For further information on the advantages and disadvantages of towed camera systems compared to other benthic imagery and sampling platforms, refer to *Comparative assessment of seafloor samping platforms* in Przeslawski et al. 2018).

Scope

As still and video cameras can be mounted to tow bodies in a variety of ways (Figure 7.1, Table 7.1), this field manual does not mandate specific gear types. Rather, it provides recommendations for future updates or replacement of existing platforms. It targets the suite of towed camera platforms currently being used to acquire quantitative imagery of benthic habitats in Australian waters, and seeks to standardise monitoring efforts by recommending standard operating procedures (SOPs) for survey planning, field acquisition and post-survey data processing, description, and storage for public accessibility (Figure 7.2).

The primary aim of this field manual is to establish a consistent approach to marine benthic sampling using towed camera systems that will facilitate statistically sound compilation between studies. Note that hybrid towed systems and other video-based monitoring platforms (e.g. dropped video cameras, or video and still cameras mounted on sleds or trawls) that are commonly used to gather qualitative sample data (e.g. general animal behaviour) fall outside the scope of this manual.

Figure 7.1: Types of towed camera systems deployed in Australian waters. a) MNFs Deep Towed Camera platform; b) and c) AIMS towed camera platform being deployed off RV Solander; d) towed camera platform being trialled by Geoscience Australia off RV Southern Surveyor; e) and f) Deakin University towed video system.

Table 7.1: Types of towed camera systems deployed in Australian waters and their main characteristics. Note this list is not comprehensive. See reviews on towed cameras and perspectives in visual imagining for information about gear deployed elsewhere in the world (Durden et al. 2016a).

Towed Platform	AIMS Towvid	CSIRO - MNF Deep Towed Camera	CSIRO – MRITCO&A Deep Towed Camera	NSW OEH	Deakin
Dimensions (W x H x L mm)	400 x 350 x 600	1200 x 1300 x 2000	1200 x 1300 x 1700	1100 x 900 x 500	400 x 600 x 300
Weight (kg)	15	490	340	15	20
Max depth (m)	150	2500	2500	200	120
Camera system (video) & orientation	SD video forward facing Additional forward facing GoPro (HD) (optional)	Canon C300 high definition video camera with a Canon EFS 10-18mm f4.5-5.6 lense at 45 deg. Hitachi – HV-D30P forward facing camera	Canon ME20F-SH high definition video camera with a Zeiss Distagon 18mm f3.5 lense at 45 deg.	Forward looking GBO Technology 1080 IP video camera in central pressure housing (CSIRO) camera at 30 degrees through Fibre Optic Cable	SD video oblique facing Additional oblique facing STEREO HD GoPro with 400mm base bar
Camera system (stills) & orientation	12MP downward stills	Canon 1DX stills camera with a Zeiss Distagon 18mm f3.5 lens set at 45 deg.	2 x Canon 1DX MKII stereoscopic stills cameras with Zeiss Distagon 18mm f2.8 lens set at 45 deg.	Downward looking stills Canon EOS450D	12MP downward stills with strobe
Illumination	Keldan 8M 8000 lumen floodlights (video) Inon D2000 strobe (still camera) synced to camera hotshoe by LED trigger and optic slave cable	4 x Deep Sea Power and Light – 3150 Sea Light Sphere	4 x Deep Sea Power and Light – LSL-2000 LED Sealite for video 2 x Customized Quantum Qflash Trio for stills	2 Keldan LUNA 8 CRI lamps	Video ray lights for oblique view and strobe for down facing imagery

Laser(s)	In development	2 x Laserex 10 mW (red) 16-laser array unit for stereo video calibration A pair of lasers with a known separation distance (10cm) is used as a reference for scaling objects and aligning video and stills in time.	2 x Teledyne Bowtech Ocealaser-D-5 at 300mm spacing	A pair of 5mw green-light laser pointers (100 mm separation) for downward looking camera	
Sensors	Nil	Pressure: Druck PMP 5074 IMU (pitch, roll and yaw) : Lord – 3DM-GX3-25 Altimeter : Kongsberg Mesotech – 1007D CTD : Seabird SBE 37 Position: Sonardyne USBL WMT	Pressure: Digiquartz 9000-10K-10 IMU (pitch, roll and yaw) : Lord – 3DM-GX5-25 Altimeter : Datasonics PS900 CTD : Seabird SBE 37 Position: Sonardyne USBL WMT	Pressure, Camera Temperature, Applanix POS MV providing 100 Hz Roll/Pitch/Yaw and positioning (G2 GNSS), sounder depth, camera angle from horizontal, USBL 1500	HOBO Pendant temperature/light data loggers (UA-002-08) recorded mean light (lum/ft²) and temperature (˚C) at ten-second intervals for the duration of each deployment
Suitable terrain	All, but steep inclines are best surveyed downslope; rugged terrain in low visibility is also risky.	The Deep Towed Camera can only be deployed on a downhill/flat gradient and travelling towards deeper/open water to mitigate against winch failures	The Deep Towed Camera can only be deployed on a downhill/flat gradient and travelling towards deeper/open water to mitigate against winch failures	All but relatively steep terrain – always planned downslope; usually <100m water depth, turbidity, wind waves and strong currents in nearshore limiting factor – small vessel ops	
Example Reference	(Nichol et al. 2013)	(Sherlock et al. 2016)	(Marouchos et al. 2017)	(Ingleton et al. 2018)	(Logan et al. 2017)

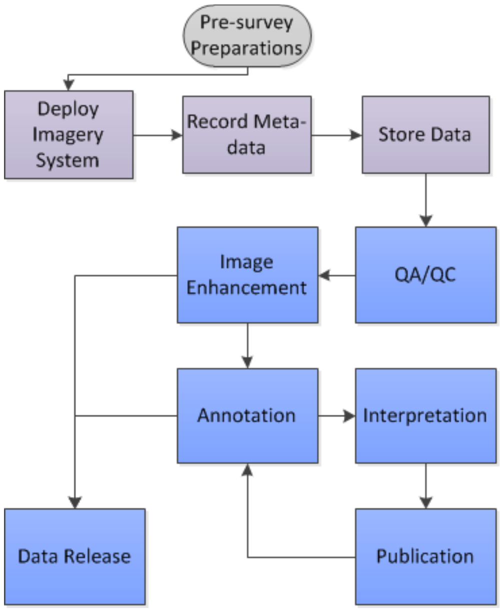

Figure 7.2: Workflow for towed camera image acquisition and processing. Purple represents onboard methods, while blue represents post-survey methods.

Towed Underwater Cameras in Marine Monitoring

Standardised methods of survey design, data collection, analysis and reporting are essential to monitoring both the status and change in Australia's vast benthic marine environment. Efficient management of a given area requires first establishing a baseline of the key biota, and then regularly monitoring their status to detect changes over time. Changes to the diversity and abundance of benthic organisms and communities are commonly used ecological metrics in marine imagery because epibenthos is considered to be functionally important and sensitive to human activities (Williams et al. 2015). Although repeated presence-absence surveys for occupancy estimation or changes in benthic community composition can be achieved using towed camera systems, returning to a precise geographical location for a particular monitoring purpose (e.g. Bridge et al. 2014, Ferrari et al. 2016, Pizarro et al. 2017) requires an alternate sampling platform entirely (e.g. AUV in Chapter 4). However, despite known biases and limitations (e.g. Jones et al. 2009, Katsanevakis et al. 2012, Durden et al. 2016a, Durden et al. 2016b), towed camera systems are anticipated to play an important role in future monitoring strategies, and have been identified as one of the sampling methods capable of monitoring the indicators associated with shelf reef systems (Hayes et al. 2015).

The application of towed underwater camera systems to environmental monitoring involves several key steps. These include survey design (Chapter 2), pre-survey preparations, field implementation (e.g. image acquisition and onboard data storage and description), and post-survey procedures (e.g. processing of imagery for data extraction, image annotation, statistical analyses of extracted data and data release). A brief overview of these fundamental steps is provided below.

Pre-Survey Preparations

Ensure all permits, safety plans and approvals (e.g. Animal Ethics) have been obtained. Any research undertaken within AMPs requires a research permit issued from Parks Australia. See Appendix A for a list of potential permits that may be required.

Confirm sampling design meets survey objectives, is achievable with planned equipment and time, and has been communicated to all key scientists and managers. Generally, the sampling design in an ecological study should be statistically sound with adequate spatial coverage and replication, and it should use an explicit randomization procedure to ensure that independent replicates are obtained (Durden et al. 2016a). Increasing sample size where possible will also help to better inform models, and increase the study's robustness (Mitchell et al. 2017). See Chapter 2 for further details on sampling design.

Define the sampling area to be surveyed in terms of space and time and identify any categorical constraints that may need to be imposed (e.g. acceptance of only those images captured within an altitude range of 2–4 m above the seabed) (Durden et al. 2016a).

Determine sampling unit (what to quantify within an image) and sample size (number of images, number of transects) to sample the habitat of interest. A complication in the determination of sample size in image-based studies using towed camera systems is variability in the physical size represented by respective images as the camera-to-subject distance often varies (Durden et al. 2016a).

Determine appropriate imagery system based on metric to be quantified. For seafloor imagery, some of the most important operational factors for the design of a platform and its deployment are depth, bottom topography, duration and spatial extent of survey, current speed, altitude control, turbidity and surface sea conditions (Barker et al. 1999). The specific configuration of equipment will depend on the scientific objectives of the survey and the type of data required. For example, high-definition video is commonly used to assess the spatial distribution, abundance and behaviour of benthic epifauna, and is also well-suited to identifying the spatial extent of substratum types and biological habitats (Bowden and Jones 2016). High-resolution images from stereo-cameras on the other hand are necessary for detailed species identification and precise sizing of individual organisms and quantifying specific seabed features (see Dunlop et al. 2015, Durden et al. 2016a, Sheehan et al. 2016).

Determine appropriate camera orientation. Camera orientation for towed systems is a critical parameter for quantitative interpretation of imagery (Bowden and Jones 2016). Images captured perpendicular (i.e. downward-facing) to the seabed are commonly used for spatial benthic ecological studies of sessile organisms, and substratum or seabed composition (Durden et al. 2016a). Whereas, images captured at oblique angles tend to be used for studies of motile fauna, such as demersal fish, as the image frame captures a greater area of seabed (or a larger volume of the water column) (see Bowden and Jones 2016, Durden et al. 2016a). Oblique camera orientation typically introduces inherent gradients of both lens-to-subject distance and illumination intensity, while a vertical orientation generally provides more even illumination and uniform subject-to-camera distance (Bowden and Jones 2016). These properties make vertical (i.e. downward-facing) orientated images more optimal for quantitative analyses of benthic substrata and sessile or sedentary biota. We recommend combining high-definition oblique video with high-resolution downward-facing camera/s, as this makes full use of both the descriptive potential of oblique-facing video (N.B, stereo -video required for examining fish metrics) and the potential for accurate quantitative analyses from vertical images, as well as reducing the risk of collision with seabed obstacles (Bowden and Jones 2016). Downward-facing camera/s, coupled with accurate geographic positioning (e.g. USBL, motion sensor) can facilitate mosaicking of images similar to that achievable with AUV platforms.

Particular care should be taken when selecting platform and optics, especially when developing a long-term ecological monitoring program. For example, it is not recommended to change the gear specifications over the monitoring period if the purpose of the study is to detect change over space and time (Sheehan et al. 2016).

Ensure accurate geo-referencing (position, position, position!). The geographic position and orientation of the camera(s) at the time of image capture is *critical* for ensuring accurate geo-referencing of an image (and the objects within it). This geographic position must be integrated with other sensor data to develop habitat maps or interpolations (see below). It is also critical for relating the sampled area to environmental covariates extracted from hydro-acoustic (Mitchell et al. 2017) and other platform sensors (Shortis et al. 2007).

Ensure synchronisation of time stamps. The time standard (typically UTC) for a given survey needs to be pre-determined and strictly adhered to. Synchronisation of timestamps across all systems (e.g. USBL and other platform sensors, PC time(s), ship navigation, video and still camera systems) is *critical* for ensuring accurate geo-referencing of images. Time accuracy to three decimal places is optimal.

Determine real-time annotation protocols, if desired. Although real-time annotation is not required for this field manual, it is recognised that this is an established practice for many individuals and agencies. If a real-time imagery feed is available, follow agency-specific protocols for onboard annotation. At the least, a qualitative description can be written for each station, thus ensuring some information is immediately available for post-survey reporting and to guide subsequent analysis (see Appendix B) *[Recommended]*.

Stereo-cameras should be pre- or post-calibrated in shallow water using the techniques outlined in Shortis and Harvey (2009). Typical requirements of a multi-station, self-calibration network include multiple convergent photographs, camera roll at each location and a 3D target array (see Shortis et al. 2009). If housings or mounts are changed or damaged during deployment, re-calibration is required.

Paired calibrated lasers should be used if not using stereo-cameras, with a known separation distance used as a reference for scaling objects. This can enhance the performance of 2-D and 3-D imaging systems/reconstructions (Caimi et al. 2008) and align video and stills by time.

Consider potential spatial and temporal errors that may result from the choice of towed camera system and how these errors may potentially affect habitat mapping and modelling of data (e.g. Monk et al. 2012, Rattray et al. 2014). It is important to take into account errors from vessel motion (i.e. heave, pitch, roll and yaw), USBL beacon positioning, GPS, and measurement inaccuracies resulting from the application of stereo-camera calibrations carried out in shallow water to imagery gathered at greater depths (see Shortis et al. 2009). It is also important to ensure that the recording frequency of sensor data is matched to the intended use of the sensor data – e.g. pitch recorded at 1s intervals may not be sufficient to correct for changes in the field of view in a video as the camera is towed.

Consider locational uncertainty in occurrence data. To generate realistic predictions, species distribution models require accurate geo-referencing of occurrence data with environmental variables (Mitchell et al. 2017). Although some high-performing, fine-scale models can be generated from data containing locational uncertainty, interpreting their predictions can be misleading if the predictions are interpreted at scales similar to the spatial errors (Mitchell et al. 2017). See Foster et al. (2012) and Stoklasa et al. (2015) for a more statistical view of this issue in an ecological context.

Consider onboard data formats and establish workflow for data transfer and battery charging prior to survey commencement. This field manual does not mandate particular data formats as these may differ depending on the choice of annotation software and process for specific extensions. For example, video data may require transcoding into web-viewable format (e.g. H264). Common formats include .mp4 and .avi for video data and .jpeg, and .tiff for still imagery. Several video containers (e.g. Quicktime) allow embedding of timecode and/or closed caption tracks into the video file and are frame-accurate during playback. Where possible such formats are preferable. The H264 codec is suboptimal for high speed transects so original video file copies should be kept for reference during analysis. In some instances, saving information in raw format may be necessary for the purpose of post-processing. Files may also need to be compressed for public accessibility. Regardless of data formats, it is essential to establish a *documented* workflow for data transfer and battery charging prior to survey commencement.

Consider the metadata required for subsequent data post processing, storage and release, such as the video or image location, camera attributes, date, time (in UTC), altitude (in m), angle of acceptance, motion of towed platform (i.e. heave, pitch, roll and yaw in degrees) and the precision required of each (Durden et al. 2016a). Consider size, location and access of final imagery and video datasets and where these will be archived. Metadata must be adequate enough to satisfy conformance checks for data release via open access data portals such as the Australian Ocean Data Network (AODN http://imos.org.au/facilities/aodn/aodn-submit-data/).

Consider metadata at various levels:

- Archived survey (project) level: to specify the decisions regarding sampling design, image selection, platform used etc.
- Imagery platform level: camera types, camera orientation, sensors, instrumentation settings (should be kept stable throughout a survey, but metadata needs to reflect any adjustments/ changes made with a timestamp when they are made in the survey.
- At image/ video level (as per below).

Consider how metadata will link to media type. The most effective way to link visual imagery with metadata is by incorporation into a spatially enabled relational database (Bowden and Jones 2016), using the synchronised time stamps and GIS position for linking imagery and sensor data. Important considerations include:

- Archived file names should include Platform, Survey, Deployment, Date and Start-Time (e.g. Platform name_ survey name_deployment or site number_YYYY-MM-DDTHH:MM:SSZ_descriptor.json).
- If possible we recommend writing image metadata into EXIF fields embedded in the digital image file to ensure metadata are not separated from images.

- Geotagging video imagery is less established but various options exist including: i) Embedding position, date and time on the imagery itself suggest using an inconspicuous location within the field of view; ii) Utilizing the video audio track or closed-caption track to record position date and time using a geostamping device, iii) Proprietary video recording and playback equipment and /or software that associates position metadata with recorded video files (e.g. Streampix https://www.norpix.com/products/streampix/modules/gps.php; GeoDVR https://www.remotegeo.com/geospatial-video-recorders/geodvr-gen3/); and iv) Embedding UTC timecode into the video media file (e.g. Quicktime .imov files recorded by AJA KiPro devices can have timecode generated and embedded by a GPS-timecode generator).

Field Procedures

The steps below are comprehensive for the entire workflow of towed camera systems. In many cases, there will be a designated specialist or team to perform some of these steps. Indeed, for heavy deep-tow and complex systems (e.g. JAMSTEC's deep-tow systems), most, if not all of these steps may be managed by external technicians and engineers. In this case, it is the researcher's responsibility to ensure that the externally managed workflow is comprehensive and addresses the steps as described in this field manual. This is best done in Pre-Survey Preparations.

Pre-deployment

Risk Assessment

Complete an on-site Workplace Health and Safety risk assessment following agency-specific protocols. A risk assessment should always be completed prior to deploying equipment to ensure the operation can be completed safely. Always adopt a precautionary approach.

Set up and testing

Allow sufficient time during survey mobilisation to undertake system checks, calibrations and testing of equipment and account for unforeseen problems. In most cases it will be possible to complete all system tests and checks within a few hours to half a day. The conduct of pre-start checks should be noted in the trip log and any test failures specifically recorded for later-reference. Detailed settings for each component should be made using relevant operations manuals (e.g. USBL operations manual etc.).

<u>On-deck dry tests</u> should include, but are not limited to, the following checks:

- On-board storage;
- On-board power;
- Cameras, including a review of image quality (colour chart test);
- Lights and strobes;
- Seals/o-rings;
- Recording devices (e.g. computer/s with appropriate software, USB drives, SD cards etc);
- File copy times for offline recording devices (e.g. GoPro);

- Winch operation;
- Sea fastening;
- Surface communications; and
- X-Y-Z coordinates from the tether termination to the imaging chip of each camera, altimeter, depth sensor/CTD and transponder.

Wet testing should include checks of the following:

- Power;
- Cameras, including a review of image quality;
- Acoustic tracking system (USBL) and any internal navigation; and
- Lighting and strobes.

Acoustic tracking setup:

- Set position of GPS receiver. Differential GPS is recommended as a minimum and is mandatory for repeat site monitoring;
- Deploy acoustic tracking transceiver (e.g. pole, flange or vessel mounted);
- Measure offsets of USBL transceiver head to GPS receiver and put offsets into navigation system; and
- Ensure accurate vessel dimensions are obtained and entered into the vessel plan repository of the navigation software.

Stills camera time calibration

- Calibrate the stills camera and video feed from GPS in the video overlay relative to UTC time;
- Ensure all sensor logging systems, cameras, computers have been synchronised to UTC time;
- Time coding calibration should be applied at the commencement of a survey and checked for consistency at least once a day while the survey is in progress; and
- Ensure recording media/storage devices are working correctly and review imagery/video.

Pre-deployment checks

1. Ensure all personnel understand their roles by conducting an appropriate toolbox talk, incorporating risk assessment and appropriate PPE to be worn. See Chapter 1 for further information about risk assessments.
2. Confirm with the vessel Master that GPS tracks for the proposed deployments are accurate and the order of transect sampling is clearly communicated.
3. Discuss the desired target location and the feasibility of deploying at that location. Main items to take into account are:

- Terrain. To minimise the risk of a deployment almost all tows will be conducted on either a flat or downward sloping seafloor. This will reduce the chance of the camera hooking up and allow for the platform to fly out into deeper water if there is a winch failure. Consider if there are any large ridges, boulders, drop-offs, etc. along the proposed tow route as with minimal forward vision, 10 m or less, there is not a large margin for avoidance.

- Weather/sea state. When the camera is flying along the ocean floor, the ship will need to travel at ~ 0.5-1ms^{-1}. This can limit the manoeuvrability of the ship and depending on the direction of the prevailing wind and swell, is not always possible on a particular heading. As the sea-state and swell can affect the ships manoeuvrability when travelling at low speeds it is essential to regularly check the weather forecast to ensure the sea state is acceptable and the platform can be safely deployed and retrieved.

- Depth. Be aware of the depth limitations of the towed body and the wire that the platform is deployed on.

4. The vessel Master must approve each deployment and communicate with crew prior to launch.

5. Prepare tow body on deck and ensure only essential personnel participate in its preparation and deployment.

6. Check for correct operation of cameras and lights (check explicitly for miss-timing between image capture and strobe firing) and winch including watertight seals, power requirements, hydraulic power and hoses, time synchronisation (PC, USBL, camera systems) and recording media. (e.g. check all recording systems are synchronised to UTC time).

7. If necessary, attach the USBL beacon to the frame and check that it is operational.

8. Perform laser alignments as per manufacturer's procedure.

9. Inspect the platform for any deterioration in cables and cable ties, ensure frame nuts and bolts are tight and all equipment mounts are secure.

10. Ensure all connection to pressure housings and equipment are tight and secure.

11. Ensure the winch clutch or load relief mechanism is adjusted to the correct tension prior to initial deployment.

12. Once all instruments are confirmed working, handclap within an overlapping field of view of all cameras.

13. Inform the bridge and deck you are ready to deploy and wait for confirmation from the bridge that the ship is at deployment speed and is approaching the start of the survey line.

14. Ensure the nominated winch driver is in the operations room with a functional and fully charged winch remote control, set to the specified channel.

15. Ensure that all staff are familiar with the seabed 'hook-up' procedure (see section below) and how to respond should it occur before commencing deployment.

Deployment

1. Run the towed body termination through the large block on the centre of the A-Frame and make sure there are no twists in the wire.

2. Following the signal to deploy from the vessel Master, use the winch and A-Frame to lift and guide the tow body from the deck into the water as the vessel begins tracking towards the start of the transect line.

3. Minimise the time taken from when the tow body is let out of reach, to when it is lowered in the water, so as to reduce potential swing and impact against the vessel.

4. Deploy the platform into the water.

5. Check for cable loops or problems at the surface while the tow body is being lowered into the water before losing sight of the platform below the waterline.

6. Once in the water, lower the camera to an appropriate depth where the system can be checked, turn everything on, including the lasers, and check that all is functional. If recording ascents/descents through the water column, perform system checks just below water surface

7. Check the USBL is receiving and the ship and platform are indicated on the bathymetry overlay.

8. Confirm that the USBL data are being logged.

9. There are several factors that affect how much wire out is required for the towed camera system to reach a target depth. These include: vessel speed through the water, payout/haul in speed, and cable diameter, package drag and weight. Determine the appropriate wireout ratio specific to the vessel and its speed, noting that ocean currents can affect this ratio.

10. Continually monitor the descent rate at separate intervals, checking the ratio of wire out to depth. This can impact on when the platform will actually reach the required depth and the location this will be. If the ratio is too high, there is the possibility of not reaching the required depth before passing over the target area. If the ratio is too low, the platform will reach the required depth well before the target area. The platform descent rate and estimated touchdown location needs to be continually monitored for a successful tow.

11. Maintain active communication with the Vessel Master and other crew/staff/technicians by providing clear, suitably loud and concise instructions/updates on the status of the equipment in water. Crew/staff/technicians to acknowledge they have received and understood instructions with clear, concise, suitably loud response(s).

12. To mitigate any positional errors, it is important to carefully monitor the ship speed and deployment rate to an appropriate ratio. If you have reached the seafloor too early, try to resist speeding up the ship. This will cause the platform to rise when speeding up and fall uncontrollably when slowing down again.

13. Continue descent to a pre-determined height above the seafloor (e.g. 2–3m) and try to maintain this height throughout the tow using the winch remote control. Record/document the time the target depth (i.e. altitude) is reached (typically this is at the start of the transect where data collection begins, unless the objective of the work includes water column imagery acquisition during descent). Note: hauling in cable onto the winch or paying out cable has an immediate effect on the camera platform height above the seafloor; however, the degree of change on height above bottom is in relation to the cable angle, which is determined by the vessel's speed and current.

14. Confirm still photos are being taken and video feeds are being recorded where possible (e.g. recording indicators, hard drive operating).

15. Confirm timecode being embedded is GPS-time accurate.

16. If employing real-time annotation, record the time and position of the camera on the seafloor (See Pre-Survey Preparations).

17. While maintaining a consistent flying altitude above the seabed, the co-pilot needs to continually check the camera feeds to ensure all footage is being recorded and anticipate the need to come up on the winch so as to avoid approaching obstacles and minimise the chance of a seabed hook-up, and review.

18. Monitor sea conditions during deployment to maintain a safe working environment.

19. Consider aborting operations if sea conditions are marginal, visibility is poor or any fault develops that may interfere with the towed camera system operation.

Retrieval

1. Continue deployment until advised by the watch leader/chief scientist that enough footage has been recorded.

2. When the survey line is complete or if the transect is being aborted, advise vessel Master of intention to retrieve the tow body. Record/document the time the target depth (i.e. altitude) is left (usually this is at the end of the transect where data collection ceases, unless the objective of the work includes water column imagery acquisition during ascent).

3. When close to the surface ask the officer on watch to confirm the ship is on the best heading for retrieval and hand over operational control to the deck crew.

4. Watch for the approach of the tow body near the surface ensuring only required personnel near the open transom.

5. If possible, turn off lasers and lights before reaching the ocean surface. If lasers are self-contained then ensure staff are wearing protective eyewear.

6. Use winch and A-Frame to guide tow body back onto deck with smooth winch and A-Frame control inputs.

7. If safe to do so, ensure the crew grab hold of the tow body as soon as the tow body leaves the water, so it can be guided safely away forward of the transom and lowered to the deck. Alternatively from small vessels, boat hooks with loaded snap-buckles on tether-lines can be attached just below the surface before the tow body leaves the water. Ends of tether-lines can be pre-fed through A-Frame cleats to control the 'swing' of the tow-fish as it rises out of the water and is brought up on deck.

8. Once clear of the water, stop all recordings, and turn all cameras, sensors and power off.

9. Rinse the towed platform frame and all camera(s)/sensors with fresh water.

10. If attached, remove USBL beacon and recharge.

11. Check and rename video footage, still camera photos and log files and complete Metadata Information sheet. Archive all data files (imagery, sensor data, metadata) on a drive that is backed-up regularly (see Section 'On-board data processing and storage').

Seabed hook-up procedures

1. Hook-up of the tow body is always a possibility with the ideal altitude for capturing quality still images close to the seabed. The following procedures should minimise the potential of a hook-up occurring and lower the potential of damage to the tow body or total loss:
2. Communication link between tow camera winch station and bridge should be maintained at all times (e.g. VHF or intercom).

3. Bridge should monitor video feed from tow body while undertaking tows

4. At the first sign of a hook-up (e.g. video image stationary over seabed), ensure the forward speed of the vessel is backed off to reduce tensile load on cable.

5. With the crew monitoring the position of the cable and directing the vessel Master with regard to the position of the cable, the vessel is to maneuver back to a point directly over the hook-up point to see if the tow body can be freed.

6. Cable tension should be taken up by the winch to ensure no loose cable enters the vessel propellers.

7. If the initial retrieval attempt from overhead fails, various points of the compass should be tested by the vessel to pull the tow body off the seafloor, using only the winch to ensure enough cable remains.

8. If all options for retrieval have been exhausted the cable must be cut at the shortest possible point and the position recorded with GPS. Note: With a live video feed there

is power to the cable so due consideration must be given to ensure that all power to systems and deck boxes etc. are off prior to cutting the cable.

9. A substitute tow body and cable would need to be prepared for continuance of survey operations.

Operation completion

Prior to any vessel movement or engine start-up, operators should check the following:

- All equipment is clear of the water, including acoustic tracking equipment;
- All gear is safely stowed and powered down where appropriate;
- Any servicing that requires the vessel to be stationary is completed;
- When the towed camera team is satisfied it is OK for the vessel to move on, an "All Clear to Move" command should be given to Vessel Master; and
- Data collected from previous tows should be checked for integrity prior to deploying the towed system on further tows.

Onboard data processing and storage

<u>Consider navigation, data logging, real-time quality control, and display.</u> A range of specialized marine image annotation tools have been developed worldwide to facilitate real-time underwater image analysis (reviewed in Gomes-Pereira et al. 2016). These tools generally consist of a graphical user interface, with a video player or image browser that recognizes a specific time code or image code, allowing events to be logged in a time-stamped (and/or geo-referenced) manner . Examples include: Adelie, Customizable Observation Video imagE Record (COVER), Frame-Grabber, Ocean Floor Observation Protocol (OFOP), SeaScribe/Seatube, Video Annotation & Reference System (VARS), VideoNavigator, Jason Virtual Control Van (web browser logger on a ships network allowing for digitally logging comments and observations during capture), CampodLogger. These software packages integrate data associated with video collection, the simplest being the position coordinates of the video recording platform, with more advanced packages allowing the input and display of data from multiple sensors or multiple annotators via intranet or internet.

<u>Name data files according to established conventions.</u> File naming conventions are important for ensuring both efficient and effective management of field data and its integration into appropriate data management repositories. It is important to note that these conventions will differ among agencies and academic institutions.
For example, CSIRO uses 'Platform_Camera_Survey_deployment_YYYYMMDDThhmmssZ_other', while NSW Department of Planning, Industry and Environment uses 'Organisation_Platform_Survey_Locale_Site_ Transect_date_starttime_imagenumber'. Note: 'camera' is specified as many towed platforms have multiple cameras (e.g. video and stills, stereo cameras, port and starboard cameras).

<u>Ensure accurate recording of metadata.</u> Metadata are descriptive data sources composed of information that may be used to process the images or information therein (Durden et al. 2016a). While it is important to follow agency specific protocols for capturing metadata, it is also essential that metadata are of sufficient detail to satisfy conformance checks for subsequent data release via AODN (See Table 7.2 for sample metadata sheet). Metadata

should also contain survey-specific information such as camera specifications and imagery file naming protocol, as well as product lineage. Minimum data for each image/frame capture should include georeferenced information, as well as any other related sensor information and (where appropriate) real-time characterisation details:

- Campaign (i.e. Survey identifier)
- Station/event number
- Platform
- Latitude and longitude (WGS 1984 in decimal degrees [Recommended])
- Altitude
- Depth
- Time and date stamp
- Platform and/or vessel motion (roll, pitch, heave)
- Metadata from other sensor data (see example below, CSIRO data file headers)
- Precision details (e.g. type of navigation system used and its associated errors)
- Data provenance

Example Video (MNF):

- Retrieval of Floreat Shallow Towed Video on survey LN2018_V02, deployment 012, at 15:25:01 UTC, on the 6th of June, 2018.
- FSTV_LN2018_V02_012_20180606T152501Z_RETRIEVAL.json
- The json file is processed into flat, 1 second csv, with an identical name:
- FSTV_LN2018_V02_012_20180606T152501Z_RETRIEVAL.csv

Example Stills (MNF):

Digital Still files are renamed and placed in a folder identifying its site/operation number. The date/time stamp is taken from each still .exif and a script or program is written to take this data, plus data from the log file to do this batch renaming.

FSTV_LN2018_V02_012_20180606T152501Z_00001.jpg

Quality control. Once the towed camera transect is complete, it is good practise to download associated raw imagery and positional data. Imagery and associated position data should be checked to ensure no failures have occurred, including but not limited to the following:

- Mis-timing between image capture and strobes (i.e. dark/black imagery)
- Failure of camera/s
- Failure of positional logging

Backup data. This is necessary to ensure all data collected in the field are safely returned and securely backed-up at host facilities, prior to final quality control and public release. Onboard copies of data should be made as soon as practically possible following acquisition. It is recommended that all data be backed up on a RAID or a NAS that contains built-in storage redundancy in case of hard-drive failure. A duplicate copy of all data onto external hard drives or LTO tapes for transportation back to host facilities is [*Recommended*].

Table 7.2: Sample field datasheet to record metadata (i.e. deployment or event data) from each towed camera deployment.

	Gear in water			Gear on bottom				Tow speed	Wire out (length)[1]	Wire out (angle)[1]	Gear off bottom				Gear out of water			Notes
Tow ID	Long	Lat	Time	Long	Lat	Depth	Time				Long	Lat	Depth	Time	Long	Lat	Time	

Post-survey procedures

Data processing

Image/video post-processing, selection and annotation method and detail will depend on the objectives of the survey/project. For example, if the objective is to describe benthic habitats/biota/communities, then consider limiting the imagery to the ‘on bottom’ part of the towed camera transect, prior to running any selection processes. If documented properly using adequate metadata, imagery can be analysed, processed and annotated in a number of different ways to achieve different purposes. It is also important to document the reasons for, and effect of, removing selected imagery/footage from annotations/analyses.

- A general workflow for data processing methodology can be found in Williams et al. (2012a). If constructing photomosaics from imagery, key requirements for raw image processing and positional data are as follows:
- It is recommended that at least one of the stereo images is in colour and enhanced following similar procedures as outlined by Shortis and Harvey (2009) and Bryson et al. (2016).
- All stereo images should be georectified following Williams et al. (2012b).
- Positional data should be post-processed using Simultaneous Localisation and Mapping (SLAM) as demonstrated in (Barkby et al. 2009) and (Palomer et al. 2013).

Annotation framework

Scoring of individual images can be done using a number of annotation software tools. Examples include, Transect measure, Coral Point Count, CoralNet and Squidle+. For national consistency Squidle+ is recommended as it allows for different approaches to subsample images, which appears to influence inferences from data, as well as stratified and random point count distribution on images. It also automatically imports the collected towed camera data once it is uploaded to the AODN making it ready for analysis, and has tools for exploring survey data as well as analyses. In addition, it supports multiple annotation schemes, and will provide consistency through translation between schemes, which is an important point that differentiates Squidle+.

There are two main approaches recommended for annotating georeferenced imagery from towed camera systems:

- Annotation of individual images/frame grabs (real-time or post-acquisition)
- Annotation of photomosaics

Annotation of individual images or photomosaics can be undertaken using two methods:

1. <u>Full assemblage scoring of imagery</u> across space and time. It is important to note that this is a time consuming process, requiring a lot of replicate images to be scored to enable sufficient power to detect biologically meaningful change as most morphospecies are < 10 % cover within images. This approach appears to be good for delineating bioregional and cross-shelf patterns at a morphospecies and CATAMI (Althaus et al. 2015) level (Monk et al. 2016, James et al. 2017). This approach would

be effective in choosing an initial suite of indicators for national level monitoring and reporting.

As a general guideline for full assemblage scoring, we recommend that 25 random points per image from at least 50 images per transect leg are a good starting point for recording most morphospecies present within images (based on Perkins et al. 2016). It is important to note that the properties of the organism themselves will also influence the number of points/images to score. Obviously morphospecies that are less abundant require more effort, but also the 'clumpiness' of species will affect the scoring effort needed (Perkins et al. 2016). Van Rein et al. (2011) and Perkins et al. (2016) suggest that, while a higher number of points per image can increase the detection rate of more organisms within an image, increasing the number of scored images using fewer points is likely to have a similar (or greater) effect. Ideally, increasing both the number of images scored and the number of points scored within an image would result in greater power (Roelfsema et al. 2006), but preference is usually for increasing the number of images (Perkins et al. 2016). Unfortunately, the adoption of this approach is likely to result in substantial increases in processing time and thus cost.

2. Targeted scoring of indicators or proxies (such as grouping fine level morphospecies into broader level CATAMI classes). This approach has been shown to work very well at an indicator morphospecies level for detecting change at a regional level (Perkins et al. 2017) as well as for detecting invasive species trends (Perkins et al. 2015, Ling et al. 2016). More recently this approach has been extended to mobile species, such as fish (Seiler et al. 2012) and lobster (Bessell et al., unpublished data). Care needs to be taken if length data (using photogrammetry or structure from motion) is extracted from stereo pairs as Seiler et al.(2012) found precision can be poor for mobile species if camera separation is inadequate (see Boutros et al. 2015).

Since this approach requires substantially less effort to score each image, more images (i.e. often all images) can be scored, thus increasing statistical power. The drawback is that a narrower understanding of the environment may result.

Data curation and quality control

Data quality control at both the collection and annotation stage is critical. Most importantly, the annotation schema needs to be consistent between studies. Where possible morphospecies and associated CATAMI parent classes should be used *[Recommended]*. Clearly, other annotation schemas are available and can be applied. Where an alternative schema is used to annotate towed camera imagery, it is most important that it can be mapped to CATAMI so that comparisons can be made with previous studies or between regions. Translations between schema can be readily applied within Squidle +. The quality control of all annotations undertaken by novice scorers should be assessed against an experienced analyst (e.g. using confusion matrices; see Figure 4.4 in Chapter 4). Logically, it is important to correct any discrepancies between annotators. This can be done by re-examining the images to ensure an agreement can be reached between annotators. Alternatively, if an agreement cannot be reached, then the miss-classified morphospecies could be potentially grouped into a higher level CATAMI class.

Data release

Squidle+ is a centralised online platform for standardised analysis and annotation of georeferenced imagery and video. Many national marine observing programs (for example

IMOS through the Australian Ocean Data Network (AODN), or the Marine Geoscience Data System (MGDS) in the USA) routinely store imagery data online in an openly accessible location. Squidle + operates based on flexible distributed data storage facilities (i.e. imagery can be stored anywhere in an openly accessible online location) to reduce data duplication and inconsistencies, and provides a flexible annotation system with the capability to translate between different annotation schemes.

Following the steps listed below will ensure the timely release of imagery and associated annotation data in a standardised, highly discoverable format.

1. Create a metadata record describing the data collection. Provide as much detail as possible on the deployment (either directly in the metadata record itself, or in the form of attached field sheets as .csv, .txt or similar). Details of minimum metadata requirements are provided in the On-board Data Storage section above. Publish metadata record(s) to the Australian Ocean Data Network (AODN) catalogue as soon as possible after metadata has been QC-d. This can be done in one of two ways:

- If metadata from your agency is regularly harvested by the AODN, follow agency-specific protocols for metadata and data release.
- Otherwise, metadata records can be created and submitted via the AODN Data Submission Tool. Note that user registration is required, but this is free and immediate.

Lodging metadata with AODN in advance of annotation data being available is an important step in documenting the methods and location of acquired imagery and enhancing future discoverability of the data.

2. Upload raw imagery from the survey to a secure, publicly accessible online repository (contact AODN if you require assistance in locating a suitable repository).
3. Create a Squidle+ campaign as soon as possible after imagery is uploaded, choose the most appropriate annotation schema, and commence annotation of imagery.
4. Add links to the location of the Squidle+ campaign to the previously published metadata record. You may also wish to attach or link a copy of the annotation data directly to the record.
5. Produce a technical or post-survey report documenting the purpose of the survey, sampling design, sampling locations, sampling equipment specifications, annotation schema (e.g. morphospecies, CATAMI, etc.), and any challenges or limitations encountered. Provide links to this report in all associated metadata *[Recommended]*

The workflow for the discoverability and accessibility of marine imagery from towed systems is still under development, with several issues related to long-term support and functionality pending (Przeslawski et al. 2019).

Data analysis

The breadth of research questions precludes any detailed advice on the analysis of data from underwater towed camera transects. However, one common attribute of the image-based data that will have to be contended with for all analyses is spatial proximity. The closeness of images, within and sometimes between transects, means that image data are unlikely to be independent (due to spatial autocorrelation). Yet, this is an assumption that most statistical methods rely upon. The failure to meet this assumption means that the inferences from the statistical analysis may be: (i) over-confident, e.g. having a p-value that is too small; (ii) biased, i.e. the estimates do not reflect the truth; (iii) both, or; (iv) no effect. Obviously, the fourth category is what a researcher hopes for, but it is improbable and must be validated. However, if it is known that the study organism exhibits particularly low autocorrelation at the scales of interest then the analysis need not consider it explicitly.

Methods to analyse data, accounting for autocorrelation are available. These include geostatistical models (see Foster et al. 2012 for an AUV-based example) and other models that incorporate dependence (e.g. Foster et al. 2009). However, in certain situations subsampling images will help (e.g. Mitchell et al. 2017 for a marine based example), but not necessarily alleviate it completely. Further, if the study is for a broad area, where transects are small and are well-separated, then amalgamating data to transect level may also be appropriate. The potential for observer bias, vignetting, and intra and inter station variability should also be carefully considered.

Field Manual Maintenance

In accordance with the universal field manual maintenance protocol described in Chapter 1 of the Field Manual package, this manual was updated in 2020 as Version 2. Updates reflect user feedback and new developments. There is currently no long-term plan or support for future updates. See Chapter 1 (Introduction to field manual package) for further details.

The version control for Chapter 7 (field manual for towed camera) is below:

Version Number	Description	Date
0	Submitted for review (NESP Marine Hub, GA, external reviewers as listed in Chapter 1.	22 Dec 2017
1	Publicly released on www.nespmarine.edu	28 Feb 2018
2	Minor corrections, updates and clarifications. Revised Data Release section	July 2020

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Marine Biodiversity Hub

National Environmental Science Programme

8. MARINE SAMPLING FIELD MANUAL FOR BENTHIC SLEDS AND BOTTOM TRAWLS

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Platform Description

Benthic sleds (also called sledges) and bottom trawls both use nets to collect organisms while they are towed across the seafloor. While trawls use free nets with doors or beams to spread the net, sleds use frames and runners to protect and secure the net (Eleftheriou and Mcintyre 2005). Benthic sleds target sessile or sedentary macrofauna and megafauna with some designs able to be deployed over rugged terrain, while bottom trawls are typically more successful in collecting demersal or mobile fauna and are deployed over smooth but compact terrain or soft sediments.

There is no one type of sled or trawl suitable for all habitats and depths, and selection of the most suitable gear type depends on scientific objectives, previous knowledge, targeted fauna, environment, depth, and vessel capabilities (Clark et al. 2016, Kaiser and Brenke 2016). Acquired data are often described as semi-quantitative (Table 2.1 in Schiaparelli et al. 2016a) due to inconsistencies in gear path, swept area, and movement (e.g. sled skipping along seafloor), as well as taxa targeted by the gear (e.g. avoidance by highly mobile megafauna, herding effect in some fish). Imagery of the seafloor helps enormously with sled choice and deployment techniques. Imagery and geospatial positioning can be obtained with available technology and can aid in the success of each deployment. In the absence of imagery, bathymetry can also provide a good indication of gear suitability. The use of multiple types of sleds and trawls may be most appropriate for surveys trying to quantify overall biodiversity in a given location (Williams and Bax 2001, Clark and Roberts 2008), while a single sled or trawl type may be more efficient for quantifying species in a particular location or habitat for monitoring purposes (Przeslawski et al. 2015). For these reasons, this manual does not mandate specific gear types, although sled and trawl types historically used in Australian waters are listed in Table 8.1 to help facilitate decisions regarding equipment for a given marine survey. Nevertheless, for monitoring purposes, it is preferable to maintain consistent gear in time and space, and we therefore recommend this where possible.

For further information on the advantages and disadvantages of sleds and trawls compared to other benthic sampling platforms, refer to *Comparative assessment of seafloor sampling platforms* Przeslawski et al 2018).

Table 8.1: Types of benthic sleds and trawls deployed in Australian waters and their associated characteristics. See reviews on benthic sleds and trawls for information about gear deployed elsewhere in the world (Clark et al. 2016, Kaiser and Brenke 2016). Unavailable indicates information that was unable to be obtained for this manual.

Type	Dimensions (mouth, h x w)	Weight	Target taxa	Cod end	Other features	Suitable terrain	Ref
Sherman (CSIRO-SEBS) sled	600 x 1200 mm	860 kg (excluding modifications from Lewis 2009)	Benthic invertebrates and fish	Polyethylene twine, 3.2 m long, 25 mm mesh	Reinforced frame, weak link chains, chaffing mat, net sonde, optional infaunal or 1 mm net	Seamount, rugged terrain, hard substrates	(Lewis 1999, 2009)
Rainer sled	2900 mm width	590 kg	Benthic invertebrates	25 mm stretch mesh	Sled divided into epibenthic and infaunal halves	Various shelf substrates	(Bax et al. 1999)
AIMS sled	1500 x 1000 mm		Large benthic invertebrates	45 mm stretch diamond mesh		Various shelf substrates	(Colquhoun et al. 2007)
SARDI sled	600 x 1800 mm		Sessile and sedentary epibenthos	50 mm mesh		Soft sediment shelf ecosystems	(Ward et al. 2006)
NIWA seamount sled	1130 x 380 mm	400 kg	Sessile and sedentary epibenthos	28 mm mesh	Reinforced frame, weak link chains, location beacon, anti-chafing net, smaller model available (250 kg)	Seamount, rugged terrain, hard substrates	(Clark and Stewart 2016)
Brenke Sledge (MNF)	1300 x 1240 mm	unavailable	Benthic macrofauna	0.5 mm mesh	Dual nets, nodule exclusion mesh, insulated cod end	Smooth terrain	(Brenke 2005)
MAPS sled	300 x 500 mm	unavailable	Planktobenthos	100, 500, and 1000 µm	Concurrent planktobenthic and benthic sampling, tri-layered net	Smooth terrain	(Przeslawski and McArthur 2009)
Scaled down Woods Hole	300 mm	unavailable	unavailable	unavailable	unavailable	Estuaries	(Hirst 2004)

CSIRO beam trawl	500 x 4000 mm	unavailable	unavailable	25 mm mesh	Tickler chains, triple tow bridle, chaffing mat, pivot points	Flat to low relief terrain, soft substrates	(Lewis 2010)
Orange roughy trawl (ORH)	26 000 x 6500 m	3 t in water	Large mobile fauna	Various depending on cod-end fitted (40 mm common)	Small attached cone nets to sample small animals, otter boards, heavy duty high ground gear	Rough bottom, including seamounts	(Clark et al. 2016)
Full-wing bottom trawl	28 000 x 3500 m	3 t in water	Mobile fauna, demersal and benthic species	Various depending on cod-end fitted (40 mm common)	Otter boards	Smooth terrain	(Clark and Roberts 2008)
NORFANZ beam trawl	300 x 4000 mm	unavailable	Slower-moving demersal fish, benthic invertebrate mega-fauna	10 mm	Chaffing mat	Smooth terrain	(Clark and Roberts 2008)
Florida flyer shrimp trawl	unavailable	unavailable	Mobile fauna, demersal and benthic species	unavailable	unavailable	Smooth terrain	(Wassenberg et al. 1997)
McKenna market trawl (CSIRO)	19 000 x 5000 mm	unavailable	Mobile fauna, demersal and benthic species	15 mm	Weighted bottom line, floats hold up the upper line, doors keep the net	Smooth terrain	SEF voyages, NWS voyages, *RV Investigator* deep-sea

Scope

This Sled and Trawl Field Manual includes gear designed to sample organisms on the seafloor, excluding microbes and meiofauna (see chapters in Eleftheriou and Mcintyre 2005, Danovaro 2010 for such methods).

Pipe dredges, rock dredges and other such gear are not included because biological collections by these are incidental. Similarly, commercial dredges are not considered because they have a narrow taxonomic focus (e.g. scallop dredge) and are not suitable for general monitoring purposes. Fish traps and similar gear are not included because they often apply to shallow waters or reef-associated species and often use bait. This Field Manual does not target endobionts or burrowing species (e.g. animals living within sponges, rocks, corals) due to the excessive amount of time needed to process such animals (Coggan et al. 2005) and their limited use in a national monitoring program. Although some sleds are designed to sample small macrofauna and infauna (e.g. Brenke 2005), for the purposes of this field manual, we include only larger macrofauna and megafauna. Smaller taxa are targeted in the Grab and Boxcore Field Manual. If researchers opt to use a sled to sample smaller fauna, we recommend combining *Pre-survey Planning* and *Onboard Sample Acquisition* sections from this field manual with *Onboard Sample Processing* from the Grab and Box Corer Field Manual (Chapter 9).

Sleds and Trawls in Marine Monitoring

Sleds and trawls can be used to successfully monitor changes in benthic communities over time (Billett et al. 2001). However, they are becoming less popular for this purpose due to their destructive sampling, difficulty in revisiting locations, and sampling variability due to species and size selectivity. In addition, more quantitative underwater imagery technologies continue to develop and become more accessible.

Instead, sleds and trawls are now most likely to be used in the early stages of a monitoring program to obtain baseline data which can then inform imagery annotations by providing species inventories or biodiversity assessments (Przeslawski et al. 2015), particularly as related to new, endemic, or cryptic taxa. This is essential for environments and regions in which extractive sampling is the only means to examine and identify many species in complex ecosystems. The specimens themselves are used to inform taxonomic studies, ascertain species distributions, and as a source of genetic (DNA) data and isotope data. Thus their application is similar to grabs and boxcores, but sleds and trawls sample a large transect rather than a point. Therefore, they may be more suitable to assess macrofaunal biodiversity in the deep sea where abundances may be low and deployment times are high (e.g. O'Hara et al 2020a,b).

Equipment

Equipment must be appropriately set-up to ensure as much consistency as possible among surveys and also to facilitate gear replacement if necessary. Equipment configurations can vary among substrate types. For example, in abyssal plains, wider skids on a beam trawl reduce sinking into mud. Table 8.1 lists the specifications, where available, of benthic sleds and trawls deployed in Australian waters.

The key components for a bottom trawl include the following, all of which should be documented and photographed:

- Sampling gear
  - Net (full net plans, including mesh types and sizes)
  - Floatation system (headline floatation plan, size, number, and position of floats)
  - Groundrope (groundrope composition, length, details of all components)
- Rigging plans
  - Sweep and bridle size and lengths
  - Layback of the headline (if any)
- Deployment procedures
  - Warp-to-depth ratios for amount of trawl wire
  - Standard electronics to be used (e.g. USBL, CTD), and acceptable values of certain measurements
  - Required towing speed

The key components for a benthic sled include:

- Sampling gear
  - Net (full net plans, including mesh types and sizes)
  - Frame (full frame plan, including dimensions and weight, chafing mat)
  - Buoys (size, number, position)
  - Mouth dimensions
- Rigging plans
  - Bridle size and lengths
  - Weak links
- Deployment procedures
  - Estimated amount of trawl wire
  - Standard electronics to be used, and acceptable values of certain measurements
  - Required towing speed

Pre-Survey Preparations

Identify a chief biologist or ecologist who will be responsible for making decisions related to samples onboard, particularly regarding prioritisation of samples during onboard processing. This will be particularly helpful during busy periods with large hauls or multiple back-to-back tows. If 24-hour operations are planned, a second-in-charge will be needed as well.

Confirm sampling design meets survey objectives, is achievable with planned equipment and time, and has been communicated to all key scientists and managers. See Chapter 2 for further details on sampling design. If the study area is small with respect to the size of the combined length of all transects, then the sampling design may be better suited to transects, not points (see Foster et al. 2019 and Chapter 2).

Consideration must be given to the location of the trawl or sled during deployment. Ultra-short baseline acoustic technology (USBL) is recommended to identify the true location of the sled/trawl during bottom contact (Schlacher et al. 2007), particularly in deep waters where the sled/trawl may be kilometres away from the vessel during a tow (Clark and Stewart 2016). If a USBL is unavailable in deep waters, the angle and length of wire payed out should be recorded so that sled/trawl location can be trigonometrically estimated (Milroy 2016). Station record forms should record gear location wherever possible, with vessel location recorded as a back-up.

Consideration must be given to the stability of the trawl or sled during deployment. Ideally, a Netsonde or bottom contact sensor will be used to indicate when the gear is lifting off the seafloor so that speed can be reduced or more wire payed out or retracted. With trawls, door-spread or wing-end sensors are also useful to ensure consistency of gear set-up and performance. If these are unavailable, strict attention must be paid to the winch wire and constant adjustments performed or a self-tensioning winch used to ensure continuous bottom contact (Clark et al. 2016).

During the planning phases, taxonomists and museum curators must be engaged to ensure that samples will be appropriately identified and preserved and voucher specimens are lodged at national repositories (i.e. museums). They can also advise on the likely species selectivity of the proposed gear for certain taxa. Preferably, taxonomists will participate in marine surveys in which case they can identify much of their respective groups onboard (Zintzen et al. 2011). The appropriate taxonomic resolution at which specimens will be identified should also be determined. Species-level identification may be appropriate for voyages of discovery (Poore et al. 2015), while family level may be suited for measuring relationships with environmental covariates (Hirst 2006). For many surveys, identifications will only target selected groups (e.g. sponges in Przeslawski et al. 2015). This should be decided in the pre-survey planning stage, not after sampling has been undertaken. Importantly, non-target specimens should still be retained for museum lodgement if possible, in order to facilitate identification in the future if resources or priorities allow, particularly in locations that are infrequently visited (e.g. deep sea).

The purposes of biological samples must be determined. For monitoring purposes, samples of each target species or operational taxonomic unit (OTU) must be collected for taxonomic identifications. Further objectives specific to a given survey or project may also include samples for genetic or biochemical analyses for particular groups. Protocols for these samples (including preservation as per point below) must be developed prior to the start of the survey.

The level of onboard searching and sorting should be decided during the planning phase where there is sufficient information to inform discussion of likely catch rates. Onboard searching refers to the time spent looking through non-biogenic material to find biota, while onboard sorting refers to the taxonomic level to which biota are identified. Both will be determined by the key survey objectives, onboard taxonomic expertise, and available time and space. It is important that search effort is not adjusted between deployments as this is a source of variation in the resulting data. Onboard sorting may vary among groups (i.e. many fish may get sorted to species while invertebrates stay in coarse groups). At a minimum, samples should be sorted onboard by phylum to ensure correct preservation and assist dissemination post-voyage, but samples should also be able to readily be subdivided for many phyla (e.g. Cnidaria, Arthropoda, Echinodermata). Taxonomists are far more likely to be willing to engage in post-survey identifications where the sample has been sorted to an appropriate level onboard.

Decide on preservation methods. This should be done in consultation with curators, taxonomists, molecular biologists, and biochemists that will be involved in using the samples. See Coggan et al. (2005) and Schiaparelli et al. (2016b) for information about appropriate preservatives for a range of taxa and purposes (e.g., species identification and description, genetic analysis, biochemical analysis), noting the variation between taxa.

Ensure adequate risk assessments are undertaken regarding safety and use of chemicals onboard (i.e. ethanol, formalin), abiding by relevant state and federal legislation. This should include where appropriate onboard storage for chemicals, as well as personal protective gear, ventilation, and safety data sheets for hazardous chemicals.

Determine if specialists are needed for gear use. Many nets and sleds require experience to prepare, deploy and retrieve. The details below are not targeted for any one particular equipment or system or item, and we recommend engaging an experienced crew who have previously deployed similar devices.

Obtain appropriate permits that may apply for collection (Appendix A). Ideally, all surveys using sled, trawls or dredges will have a permit for biological collection, even if target samples are rocks and sediments. This will ensure incidental biological specimens do not get discarded overboard. Current regulations require permits for biological material being deposited in registered institutions. For Commonwealth waters, these include

1. Australian Fisheries Management Authority (AFMA) “Application for Scientific Permit”
2. Parks Australia: “Application for a permit to access biological resources in Commonwealth areas”
3. Parks Australia: “Application to Conduct Research Activities Within Commonwealth Marine Reserves”

State-based permits may also be required. For example AFMA have delegated authority in offshore areas of New South Wales and Queensland waters to the states.

Collection ethics approval may also be required from the research institution. In addition, more focussed permits including animal ethics may be needed for particular taxa (e.g. fish and cephalopods). Permits must be considered not just for collecting activities, but also for shipping and storage (e.g., biosecurity containment facilities). For example scleractinians, antipatharians, and some fishes are regulated under the Convention on International Trade in Endangered Species (CITES), and there may be restrictions on shipping these taxa to museums or other repositories (especially overseas institutions) without a permit.

Document the specifications of all sampling gear to be used, including photographs (see Equipment). Specifications that should be documented include gear size and configuration (mesh, floats, ground ropes, frame, spread between trawl doors), rigging plans (bridle, headline layback), and deployment needs (wire length estimated, required towing speed, netsonde or USBL methods). This can assist with estimating location and area of the seafloor sampled, as well as providing crucial information for comparisons with other surveys. Where possible, the gear set-up and specifications should be standardised across all surveys using the same equipment.

Decide on procedures for very large hauls. Sub-sampling or a focus on key taxonomic groups may save time needed for other survey operations (e.g. multibeam mapping) or objectives (e.g. biodiversity characterisation in a different location) (Shimadzu and Darnell 2015). Alternatively, coarse level estimation of abundances could occur based on visual estimates or case counts. Such procedures must be decided before gear deployment and remain consistent for a given survey, and in all cases, representatives of all taxa should be collected and appropriately preserved. If time permits, pilot deployments can help determine the efficiency of the gear, deployment times, suitability of terrain, catch sizes over distances, and processing times.

Organise shipment of samples from vessel to repository (e.g. museum). If samples are frozen and are not too bulky, it may be most cost-effective to have individuals transport them on aircraft in which case airline requirements should be considered. If samples are in ethanol or formalin, transport of dangerous goods must be organised. Planning for shipment of samples well in advance of the survey will expedite demobilisation and ensures sample integrity. The destination museum can likely provide advice on shipping methods and regulations. See Schiaparelli et al. (2016b) for shipping advice.

Pre-survey checklist

	Task	Description/comments
☐	Identify onboard chief ecologist/biologist	
☐	Confirm sampling design meets necessary criteria (e.g. randomised, sufficient number of samples)	
☐	Engage taxonomists and curators	
☐	Determine onboard sorting level	
☐	Determine preservation methods	
☐	Complete necessary risk assessments	
☐	Identify specialists needed for gear configuration and deployment	
☐	Data storage needs identified and hardware purchased accordingly	
☐	Decide on methods for locating gear during deployment	
☐	Decide on methods to assess gear stability during deployment	
☐	Obtain appropriate permits	
☐	Document gear specifications	
☐	Determine procedures for large hauls	
☐	Organise shipment of samples	

Field Procedures

A visual summary of the key steps to follow when deploying benthic sleds or bottom trawls is shown in Figure 8.1.

Figure 8.1: Images from key steps involved in the use of benthic sleds and bottom trawls for marine monitoring: a) a modified WHOI sled with attached pipe dredges, b) seafloor imagery from towed video and bathymetric grids, c) lowering the AIMS benthic sled, d) sorting animals on the back deck, e) photographing specimens in ship laboratory, f) securely sealed containers to ship animals to museums

Onboard sample acquisition

1. Use acoustic data or underwater imagery to confirm areas to sample with the appropriate benthic gear (Schlacher et al. 2007, Williams et al. 2010). Do not deploy blind, as this increases the risk of equipment loss and damage, as well as unnecessary impact on potentially vulnerable ecosystems.

2. Brief crew and sorting staff on potential venomous or otherwise dangerous catch (i.e. cone shell, blue-ringed octopus, some fishes, corals, sponges, urchins).

3. Ensure the gear is set-up and deployment parameters and procedures are as documented in the gear-specific protocols.

4. Use netsonde or bottom contact sensor to ensure sled or trawl is suitably deployed along the seafloor *[Recommended]*

5. Use USBL System to ensure accurate positioning (Schlacher et al. 2007, Williams et al. 2015) *[Recommended]*

6. Mark sled runners or trawl groundline with waterproof pencil or paint to gauge success of seafloor deployment. Also check for polishing on the bobbins or runners. *[Recommended]*

7. Record all metadata related to a given tow, specified in Table 8.2.

8. For rugged slopes (e.g. seamounts), ensure appropriate gear is used and tow downslope to reduce snags.

9. Maintain speed that is appropriate for the gear and seafloor terrain. Epibenthic sleds and most beam and Agassiz trawls should be towed at 1–2 knots to maintain bottom contact, while faster speeds of 3–3.5 knots are appropriate for otter trawls and other gear dependent on speed to maintain net spreading. See Clark et al. 2016 and Kaiser and Brenke 2016 for details.

10. Tow into the swell, tide, current and/or wind so that vessel speed and steerage can be better controlled.

11. A standard fixed tow distance (i.e. bottom time) for monitoring purposes is not practical because because tow distance is highly dependent on gear type and seafloor environment. However, within a given survey, tow distance for each sled or trawl should be standardised to assess relative abundances. It should also be recorded in the metadata (Table 8.2). If the same sled is used on multiple surveys in similar environments, the tow distance should remain the same so that spatio-temporal comparisons can be made. For benthic sleds deployed along the continental shelf over mixed terrain, a tow distance of ~100 m is recommended. Longer tows (commonly 300 m) will be needed in deep waters due to lower density of macro- and megafauna. Information from multibeam data (see point 1) can help inform tow duration decisions.

12. Assess success of deployment. If there is significant damage to gear, signs of minimal bottom contact, or ripped nets, this should be recorded in the metadata (Table 8.2). The catch from such deployments can be considered for presence-only analyses, species inventories or biological analyses. Inclusion in quantitative comparisons with other tows should only be done after careful consideration of appropriate statistical methods (e.g. transformation, standardisation). In such situations, gear configuration should also be checked after recovery to ensure its correct specification for the next deployment (see point 3).

13. When the sled or trawl is lifted from the water, follow gear- and vessel-specific protocols for safe release of the catch onto the deck or sorting table.

14. Record biomass of entire catch using electronics from winch system or onboard scale *[Recommended]*

15. Photograph entire catch with station identification placard and make notes of catch composition (e.g. lots of mud or rocks) in metadata sheet (Table 8.2).

16. Remove all animals from the entire net, including the fore-parts of nets and sleds and not just the codend where most of the catch should have been collected. As soon as practical, begin onboard processing of the samples (next section).

17. Clean sled of all material and prepare for next deployment.

Onboard sample processing

1. For very large catches, implement the agreed sub-sampling protocol if applicable (see Pre-Survey Preparations).

2. Consider retaining material on ice or in an ice slurry while awaiting sorting to ensure material remains in best condition to assist accurate and consistent identification.

3. Separate large easily visible taxa into sorting trays by coarse groups: fish, sponges, soft corals, echinoderms, molluscs, ascidians, bryozoans, annelids, other. Weigh each group. Discard severely damaged organisms and non-biogenic material, unless otherwise needed. It can be useful to record the weights, descriptions, and images of rock, coral rubble and other non-biogenic material as this gives useful information on substrate type. Add a label to each sorting tray with Tow ID so as to avoid confusion when multiple tows are being processed.

4. Follow Animal Ethics procedures to euthanize animals where applicable

5. Place fragile organisms in seawater in the sorting trays. Use chilled seawater for deep-sea and polar samples to minimise sample degradation during sorting time.

6. Transfer groups to the sorting station, if not already there. See Coggan et al. (2005) for practical advice on setting up a sorting station.

7. Based on previous decisions about onboard level of sorting (see 'Pre-survey Preparations' section above), progressively sort organisms into finer taxonomic groups, as much as time or expertise allows, with OTU (operational taxonomic unit) or species representing the finest taxonomic level.

8. Weigh, count, and photograph each of the final groups, including a scale bar and unique identifying sample number. Ensure this is done in a way that doesn't destroy the DNA in the specimens (e.g. pericards need to be kept chilled and moist). Refer to Schiaparelli et al. 2016 for suggestions on specimen photography.

9. Record data against a unique station identifier for the data base and keep a label with the same unique identifier with the specimen(s) (Table 8.3). At this stage identify specimens (or subset of specimens) for analyses purposes (whole specimens for taxonomy/isotopes/genetics etc.) or where appropriate (and pre-determined in plan) take tissue samples for analyses (genetics, isotopes etc.) If there are large numbers of the same species or OTU, only a sub-set may need to be preserved for museum collections; this should be established during Pre-Survey Planning in consultation with taxonomists or curators. In this case, record the total number collected (i.e. number caught) as well as the number in the collection container (i.e. number preserved).

10. If applicable relax and fix specimens according to survey objectives and taxonomists' preferences (e.g. samples for genetic analysis should not be fixed in formalin).

11. Preserve specimen according to methods decided in Pre-Survey Preparations, and place into container. See Rees (2009) and Schiaparelli et al. (2016b) for comprehensive description of fixatives and preservatives used for marine invertebrates.

12. Place solvent-hardy label with unique identifier in each sample container. It is not sufficient to label only the outside of the container, as this can easily rub off. See Box 15.6 in Schiaparelli et al. 2016 for suitable label characteristics.

13. Place container in large sealable container (i.e. lidded drum) with other samples preserved using the same chemicals (e.g. ethanol) or method (e.g. freezing). It saves time in post-survey sample distribution if taxa are grouped together in containers rather than by station.

Onboard sample storage

1. Store large labelled drum onboard in the freezer or in an approved storage area for hazardous chemicals.

2. Transcribe metadata from Tables 8.2 and 8.3 into digital format as soon as possible to minimise the build-up of data entry. This must be done onboard preferably during the same shift because it provides a back-up and an immediate check of the record, as well as facilitating timely metadata release.

3. Check the data entry is correct by cross-checking field sheets with database. This is best done by a person who didn't enter the data *[Recommended]*.

4. During demobilisation, ensure samples and drums are properly labelled and closed, and implement shipping according to decisions made during pre-survey planning.

Table 8.2: Sample field datasheet to record metadata (i.e. deployment or event data) from each sled or trawl haul. Waterproof paper and pen/pencil is required.

	Gear in water			Gear on bottom				Tow speed	Wire out (length)[8]	Wire out (angle)[8]	Gear off bottom				Gear out of water			Total catch biomass[9]	Notes[10]
Tow ID	**Lon**	**Lat**	**Time**	**Lon**	**Lat**	**Depth**	**Time[11]**				**Lon**	**Lat**	**Depth**	**Time[11]**	**Lon**	**Lat**	**Time[11]**		
GENERAL GEAR NOTES (e.g. equipment configuration changes during survey, torn net, etc):																			

[8] Record the length and angle of wire payed out during seafloor contact. This is required if deep water survey with no USBL; otherwise recommended.
[9] Include units (e.g. kilograms)
[10] Record person entering data, spread of trawl doors if applicable
[11] UTC timezone

Table 8.3: Sample field datasheet to record metadata from each sorted biological sample. Waterproof paper and pen/pencil is required.

Tow ID	Sample ID	Phylum	Class	Order	Family	Genus, Species / Common Name	Weight	Abundance	Preservative / Quantity	Photos	Notes

Post-survey procedures

Sample curation

1. Lodge all specimens in an internationally recognised and routinely maintained specimen collection (e.g. museum) for curation and public accessibility *[Recommended]*.

35. If all specimens are unable to be lodged at a museum due to lack of resources or need for destructive analyses (e.g. biochemical analyses), voucher specimens must be lodged (i.e. at least one animal per OTU).

Data release

All data should be publicly released, unless circumstances require otherwise (e.g. confidentiality clause or embargo for commercial work). Even in situations when data cannot be shared, the metadata and deployment information should be made available (Steps 1-2 below). Poor scientific data management and lack of data sharing has been shown to hamper scientific progress (Stocks et al. 2016).

Traditionally, data related to biological specimens have been delivered as presence-only taxonomic identifications. These are often managed by individual museum scientists or curators and subsequently harvested by the Atlas of Living Australia (ALA). ALA does not yet include absences or information related to sampling effort, thus reducing the applicability of such databases to monitoring purposes.

OBIS is using the data structure described in the project called OBIS-ENV-DATA that allows the linking of species data to other related information (e.g. environmental data, images, sampling effort) (De Pooter et al. 2017). It now has the capacity to store absence records and sampling effort, and is working to include this information in data downloads.

In the meantime, the steps listed below will ensure appropriate and timely release of both metadata and data:

1. Create a metadata record describing the data collection. Provide as much detail as possible on the collection/deployment (either directly in the metadata record itself, or in the form of attached field sheets as .csv, .txt or similar). This should include sampling locations and dates, equipment used, level of sorting applied, etc. All collection/deployment information must be QC-d before inclusion.

2. Publish metadata record(s) to the Australian Ocean Data Network (AODN) catalogue as soon as possible after metadata has been QC-d. This can be done in one of two ways:

   - If metadata from your agency is regularly harvested by the AODN, follow agency-specific protocols for metadata and data release.
   - Otherwise, metadata records can be created and submitted via the AODN Data Submission Tool. Note that this tool requires user registration, but this is free and immediate.

   This step provides immediate documentation of the methods and location of the collection of biological material. This stage may also include links to field reports or data sheets.

3. Produce a technical or post-survey report documenting the purpose of the survey, survey design, sampling locations, sampling equipment specifications, and any challenges or limitations encountered (Appendix B). Provide links to this report in all associated metadata records *[Recommended]*

4. Complete the species identifications and associated abundance or biomass for targeted groups identified. This can take quite some time, depending on sample size and available resources. It is not unusual for taxonomic identifications to lag years behind survey completion, but this should not delay publication of initial metadata and deployment information. Care must be taken to ensure consistent nomenclature is used and documented for undescribed or unnamed species (e.g. defined Operational Taxonomic Units, OTUs). Ideally photographic catalogues of OTUs are established such that subsequent surveys may use consistent OTU classification, thereby ensuring comparability of data between surveys.

5. QC the data. This includes checking for spelling errors, missing data, consistent nomenclature and use of OTUs, and confirmation that outliers are not data entry errors (e.g. 100 individuals really were collected, not just 10).

6. Attach or link the full data spreadsheet (including absences and abundances/biomass) to the metadata record previously created and published to the AODN. This will ensure public discoverability and accessibility of the complete data, including absences.

To then publish data to OBIS, inform OBIS Australia (OBISAU) using the contact details and information on http://www.obis.org.au.

OBISAU will download the data from AODN or any other site and apply the following procedures.

- OBISAU provides a taxa matching service using WoRMS web services and will validate the dataset as best as possible.
- The data is tested for any temporal or spatial outliers.
- Any observed parameters (biotic and abiotic) are matched where possible to vocabularies maintained by AODN and BODC.
- Metadata is authored from any existing metadata or publications.
- Finally the datasets are published via the OBIS Australia data node http://ogc-act.csiro.au/ipt/

OBISAU has the option to publish the data at the same time directly to GBIF, and it has developed a service to inform ALA that a new dataset is available to be harvested for .inclusion into ALA

Field Manual Maintenance

In accordance with the universal field manual maintenance protocol described in Chapter 1 of the Field Manual package, this manual was updated in 2020 as Version 2. Updates reflect user feedback and new developments. There is currently no long-term plan or support for future updates. See Chapter 1 (Introduction to field manual package) for further details.

The version control for Chapter 8 (field manual for sleds and trawls) is below:

Version Number	Description	Date
0	Submitted for review (NESP Marine Hub, GA, external reviewers as listed in Chapter 1.	22 Dec 2017
1	Publicly released on www.nespmarine.edu	28 Feb 2018
2	Minor corrections, updates and clarifications. Revised Data Release section	July 2020

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9. MARINE SAMPLING FIELD MANUAL FOR GRABS AND BOX CORERS

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Platform Description

Grabs and box corers both use receptacles to collect sediment after they are dropped to the seafloor. While the scooping motion of grabs disrupts unconsolidated sediment to various degrees, box corers return largely undisturbed samples of the sediment strata (Eleftheriou 2013). Grabs and box corers target surface sediment and associated porewater and fauna. They are typically deployed over sandy or muddy substrates, although some grabs can also collect gravel or cobbles.

There is no single type of grab or box corer suitable for all environments, and selection of the most suitable type depends on the biological or physical target, substrate, depth, and vessel capabilities (Narayanaswamy et al. 2016). Acquired data can be quantitative (e.g. surface area, volumetric or mass specific) or semi-quantitative due to inconsistencies in sample volume and sediment disruption due to bow waves or other gear effects (Blomqvist 1991). For these reasons, this manual does not mandate specific gear types. There are numerous references to help facilitate decisions regarding grab and box corer equipment for a given marine survey (Riddle 1989, Eleftheriou and Moore 2013, Danovaro 2010, Narayanaswamy et al. 2016). Nevertheless, for monitoring purposes, it is preferable to maintain consistent gear through time and space, and we therefore recommend this where possible.

Scope

This field manual encompasses gear designed to sample unconsolidated sediment and organisms on the seafloor, including grabs, box corers, and push corers.

The samples collected by grabs and box corers can be used to derive a range of physical, chemical, and biological parameters (Eleftheriou 2013), and each of these parameters requires a particular method to process and analyse the sample (Danovaro 2010). In the interest of developing a standard protocol for marine monitoring that is readily accessible to multiple users among various disciplines, this field manual includes only a sub-set of these variables (Table 9.1). These variables were chosen because they can be used by multiple disciplines, are relatively easy to undertake, require minimal specialised equipment or chemicals, and are applicable to ecological indicators in marine monitoring (Hayes et al. 2015). Importantly, the protocol detailed here does not preclude other parameters from being investigated; rather it provides an achievable standard for acquiring fundamental data for monitoring that can be expanded as required to meet additional objectives on a given survey.

This field manual does not include methods for sediment contaminant monitoring, as this is comprehensively covered elsewhere (Simpson et al. 2005). As activities develop (e.g. deep-sea mining) the scope may be expanded in future field manual versions to encompass sediment contaminant monitoring.

Other equipment able to sample sediment is not included in this field manual due to difficulties deploying in deeper waters (e.g. suction samplers) or limited applicability to biological sampling (e.g. gravity, piston, vibro-cores) (Eleftheriou and Moore 2013). In addition, multicorers are not explicitly included because small sample volume may preclude the collection of representative biological communities without aggregation (Williams et al. 2018), although we note that multicorer samples can be aggregated and processed as described in this manual. Although they are able to quantify infaunal activity, sedimentology, and biogeochemistry, sediment profile imaging (SPI) is also excluded from this field manual due to the vast differences in equipment requirements and data processing (i.e. imagery instead of sediment samples) (Aller et al. 2001, Germano et al. 2011).

Although larger grabs and box corers can sample larger macrofauna and megafauna, including epifauna, for the purposes of this field manual, we focus on smaller macrofauna, including infauna (e.g. Przeslawski et al. 2018). Epifauna are targeted in the Sled and Trawl Field Manual. If researchers opt to use a grab or box corer to sample epifauna, we recommend combining Pre-Survey Preparations and Onboard Sample Acquisition from this Field Manual with Onboard Sample Processing from the Sled and Trawl Field Manual (Chapter 8). Meiofauna and microbes are not included in this field manual, and we refer researchers instead to Somerfield and Warwick (2013).

For the purposes of this manual, macrofauna refer to organisms larger than 500 µm. There are varying definitions of faunal size classifications, and these differences seem to reflect the environment under consideration. For example, deep-sea researchers often consider macrofauna to be anything larger than 300 µm (e.g. De Smet et al. 2017) due to the prevalence of small body sizes in the deep-sea, while researchers in coastal or shelf waters are more likely to consider macrofauna as > 500 -1000 µm (e.g. Gray and Elliot 2009).

Table 9.1: List of potential measurements from grabs and corers, including whether they are included in this field manual.

	Parameter	Description	Included in field manual
Sedimentology	Sediment texture	A measure of the proportions of mud, sand and gravel size fractions within a sample	Y
	Mean grain size	A summary statistical measure of the size of sediment grains by using effective spherical diameter (ESD)	Y
	Kurtosis	A summary statistical measure of the range of grain size within a sample, ranging from platykurtic (wide range) to leptokurtic (narrow range)	N
	Skewness	A summary statistical measure of the size and direction of the tail in a sediment size frequency distribution, ranging from negative skewness (coarse-tailed) to positive skewness (fine-tailed)	N
	Carbonate	A measure of the proportion of a sample comprising calcium carbonate material	Y
	Mass physical properties	A measure of bulk or dry density, water content, porosity, or permeability	N
Biogeochemistry	Organic matter content	A measure of the total organic matter content , organic carbon, or organic phosphorus	Y
	Contaminants	Concentrations of various pollutants including heavy metals, PAHs, PCBs, etc	N
	Pigment	Quantification of chlorophyll-a, phaeophytin and other by-products of photosynthesis	Y
	Bioavailable organic matter	Quantification of carbohydrates, proteins and lipids	N
	Redox balance	Quantification of the Eh of sediments, providing an indication of anaerobic conditions and diagenesis	Y
	Sediment respiration	Quantification of the release of CO_2 from sediments over time	N
	Porewater chemistry	Chemical characterisation of water between sediment grains	N
Biology	Microbes	Abundance, biomass, or composition of viruses, bacteria and other prokaryotes, protists	N

	Meiofauna	Abundance, biomass, or composition of metazoan meiofauna	N
	Macrofauna	Abundance, biomass, or composition of macrofauna	Y
	Megafauna	Abundance, biomass, or composition of megafauna	N

Grabs and Box Corers in Marine Monitoring

Grabs and box corers have been used successfully to monitor changes in benthic environments over time (Maurer et al. 1993, Ruso et al. 2007, Frid 2011, Clare et al. 2015), although the challenge of revisiting sites mean that multiple samples across a representative area of a given habitat type may be necessary to detect trends (Morrisey et al. 1992a,b, Rogers et al. 2008, Spencer et al. 2011). In addition, repeated sampling using grabs and corers in the same area may result in habitat disturbance and associated statistical artefacts (Skilleter 1996). Grabs and corers can also provide species inventories or biodiversity assessments which can then be applied to a monitoring program as baseline data or to inform the interpretation of imagery (Przeslawski et al. 2013). In this way, they are similar to sleds and trawls, but grabs and corers sample a much smaller spatial area (< 1 m^2, often considered a point location) rather than the hundreds of square metres often traversed by a sled. This characteristic needs to be considered in environments of low faunal abundance (e.g. some deep sea areas) or high heterogeneity.

In addition to their collection of fauna, grabs and corers are also useful to marine monitoring for their ability to characterise substrate and provide environmental baseline data. For example, EMODNet has harmonised data from disparate sediment samples to produce classification schemes at regional and national scales (Kaskela et al. 2019).

However, because they are a point location, grab and box corer sampling is a very effective method for quantifying heterogeneity at a range of spatial scales (i.e. within- and between-site heterogeneity), as long as the GPS position for each 'drop' is recorded and the sampling area is constrained for comparability of analysis (replicate samples are all collected within a standardised distance from the target position at every site).

Equipment

Equipment must be appropriately set-up to ensure as much consistency as possible among surveys and to facilitate gear replacement if necessary. The overarching goal of appropriately choosing and setting up equipment is to sample as much of the sediment as possible with minimal disruption, within the limitations of the given equipment. It is recommended that a survey include at least two gear types to sample sediments, one targeted for finer sediment (muds) and the other targeted for sands and coarser sediments (gravel). Researchers should ensure appropriate statistical tests are performed to test for potential confounding factors of gear type on biological variables (e.g. Pennington et al. 1998, Souza and Barros 2015), particularly regarding penetration depth and substrate type.

The key components for a grab include the following, all of which should be documented:

- Type of grab, including firing mechanism (e.g. Van Veen, Smith-McIntyre, Shipek);
- Weight of grab;
- Bucket dimensions (surface area sampled, shape, maximum volume);

- Maximum penetration into the substrate;
- Trap door to allow examination of sample volume upon recovery and to allow sediment sampling from the relative undisturbed centre. Most grab designs can have this feature, but not all manufacturers include it;
- Additional weights (by providing an option for extra attached weights to a grab or corer, equipment functionality can be optimised among more habitat types); and
- Standard electronics to be used (e.g. GPS, camera, USBL, vessel sounder).

The key components for a corer include the following, all of which should be documented:

- Type of corer (e.g. box, multicorer);
- Weight of corer;
- Surface area of sample;
- Maximum volume of sample;
- Additional weights (by providing an option for extra attached weights to a grab or corer, equipment functionality can be optimised among more habitat types); and
- Standard electronics to be used (e.g. GPS, camera, USBL, vessel sounder).

Grabs and box corers can also be fitted with other sampling platforms and sensors. A mounted video camera can add valuable information about the *in situ* appearance of the seabed that is sampled including opportunistic imagery of biota, as well as an indication of the performance of the gear (Blomqvist 1991). Similarly, conductivity-temperature-depth (CTD) meters and other sensors provide information about the surrounding environment, while a pinger (i.e. near-bottom echosounder) provides information to the operator about distance to the seafloor which can be very important for controlling the final operation near the seafloor (Narayanaswamy et al. 2016).

Pre-Survey Preparations

Identify a chief scientist who will be responsible for making onboard decisions related to samples, particularly regarding prioritisation of samples during onboard processing. This will be particularly helpful during busy periods with multiple back-to-back deployments. For 24-hour operations, a second-in-charge must also be identified to cover alternating shifts.

Confirm sampling design meets survey objectives, is achievable with planned equipment and time, and has been communicated to all key scientists and managers. See Chapter 2 for further details on sampling design.

Address fine-scale variation and the need for replication in survey sampling design. Although replication should be considered in sampling design among all platforms (Chapter 2), it is particularly important for grabs and box corers due to the large potential variation in biological and environmental variables across metres to centimetres that may preclude the detection of changes over time (Rogers et al. 2008). Each box core or grab deployment should be treated as a discrete sample (i.e. sub-dividing sample is not replication, nor is the aggregation of samples representative). In addition, the type and size of bedforms present should be considered in the assessment of replicates. For example, a grab may land on the crest of a sand wave, thereby returning a sample that is not representative of the variability of the seafloor at the sampling site. We recommend at least three replicate deployments be undertaken at each station (e.g. Long and Poiner 1994) to enable the quantification of fine-scale variation. When this is not be feasible (e.g. in deeper waters with long deployment times, priority to maximise spatial extent of sampling area), replicates should be collected from a sub-set of stations (e.g. Przeslawski et al. 2013) or appropriate geostatistical methods must be used to estimate grab-to-grab variance (Diggle and Ribeiro 2007).

The most appropriate grab or box corer must be identified to suit the vessel, environment, and scientific objectives (Rumohr 1999). Although this Field Manual does not require equipment that preserves the integrity of sediment samples (e.g. multicorer), the use of such equipment may be necessary if a marine survey has scientific aims complementary to the monitoring program (e.g. characterising infauna or geochemical variables through the vertical sediment profile (Eleftheriou 2013)). The results of some sedimentological and geochemical analyses are sensitive to the manner in which the original samples are collected, handled and stored. Ideally, marine sediment collection for the assessment of sedimentology and biogeochemistry should be carried out avoiding any unnecessary manipulation of the sample that could preclude identification of the surface layers. In order to concurrently acquire the fundamental data identified in this Field Manual (biology, sedimentology, biogeochemistry), the chosen grab or box corer should sample an area of the seafloor at least 0.1 m^2 and be able to penetrate 5-10 cm into the sediment (Rumohr 1999, Bale and Kenny 2005). To maintain consistency between sites and repeat surveys, only the top 2 cm should be sampled for sedimentology and biogeochemistry; if the sample is disturbed such that the top 2 cm cannot be identified, we recommend redeploying the gear.

Consideration must be given to the location of the grab or corer during deployment. For deep waters where the gear may be hundreds of metres away from the vessel during sample collection, an ultra-short baseline (USBL) is recommended to identify the true location (Narayanaswamy et al. 2016). If a USBL is unavailable, the angle and length of wire payed out should be recorded so that gear location can be trigonometrically estimated (Milroy 2016).

During the planning phases, taxonomists and museum curators must be engaged to ensure that all biological specimens are appropriately preserved, identified and lodged at national repositories (i.e. museums) if feasible. The appropriate taxonomic resolution at which specimens will be identified should also be determined. Species-level identification may be appropriate for voyages of discovery (Przeslawski et al. 2013) and impact assessments, while family level identifications may be acceptable measures of response to environmental gradients (Olsgard et al. 1998, Thompson et al. 2003, Wlodarska-Kowalczuk and Kedra 2007).

Similarly, contractors or collaborators for sedimentological and geochemical analyses must be engaged if in-house capability is not available, including cost and funding sources for such analyses.

Decide on sediment storage and biological specimen preservation or fixation methods. Sediment samples will need to be refrigerated (for sedimentology) or frozen (for biogeochemistry) while biological specimens will need to be preserved. Depending on the collaborating taxonomists and project objectives, larger or fragile biological specimens may be preserved separately (e.g. ophiuroids) or in a different preservative (e.g. buffered formalin to retain morphological integrity of soft-bodied animals). In addition, staining may be used to aide sorting, although this may hinder species-level identifications. Choice of fixatives, preservatives and stains must be done in consultation with taxonomists, molecular biologists, and biochemists who will be involved in using the samples. See Coggan et al. (2005) and Schiaparelli et al. (2016) for information about appropriate preservatives for a range of purposes (species identification and description, genetic analysis, biochemical analysis).

Ensure adequate work health and safety (WH&S) risk assessments are undertaken regarding correct use of sampling equipment and chemicals onboard (i.e. ethanol, formalin). This should include identifying appropriate storage locations for chemicals, as well as personal protective equipment, ventilation, and first aid kits.

Obtain appropriate permits that may apply to collect specimens. Ideally, all surveys using grabs or corers will have a permit for biological collection. If target samples are sediments for physical analyses (e.g. geology survey), biota will still be collected as part of the sample. Without appropriate permits, biological material simply gets discarded overboard. Permits must be considered not just for collecting activities, but also for sample transport to receiving institutions. For example, scleractinian corals are regulated under the Convention on International Trade in Endangered Species, and there may be restrictions on shipping these taxa to museums or other repositories (especially those overseas) without a permit. See Appendix A for a list of possible permits needed for sampling in Commonwealth waters.

Determine if specialists are needed for gear use. Many grabs and box corers require experience to safely prepare, deploy and retrieve. The details below are not targeted for any one particular equipment or system, and we recommend engaging an experienced crew who have previously deployed similar devices. Refer to point above regarding WH&S, and ensure all gear operators are thoroughly briefed.

Establish a standardized winching process suitable for the chosen gear, as this is critical to maintenance of sample quality. For example, most gear should involve a complete stop and slow lowering for the last few metres. This will reduce the bow wave and associated loss of surface material and reduce the likelihood of raising of the sampler before closure is completed (Rumohr 1999).

Design workspaces and workflows for sedimentology, biogeochemistry, and biological sub-sampling. Each collected sediment sample must be sub-sampled or whole samples assigned to a single discipline because each discipline requires particular methods and preservatives that may interfere with the other. For example, the decomposition of infaunal animals affects organic content and other biogeochemical parameters, but biological preservatives will interfere with many geochemical analyses (Bale and Kenny 2005).

Organise shipment of samples from vessel to repository. If only of a small size, refrigerated and frozen sediment samples may be more cost-effective to be transported as baggage with aircraft passengers in which case airline requirements should be considered. Samples in ethanol or formalin are considered dangerous goods, and associated transport must be arranged. Planning for shipment of samples well in advance of the survey will expedite demobilisation and will ensure sample integrity.

Pre-survey checklist

	Task	Description/comments
☐	Identify onboard chief scientist .	
☐	Confirm sampling design meets necessary criteria (e.g. replicates).	
☐	Identify most appropriate grab(s) or corer(s) to be used.	
☐	Engage taxonomists, curators and contractors. Cost activities.	
☐	Determine storage and preservation methods.	
☐	Complete WH&S risk assessment.	
☐	Decide method(s) for locating gear during deployment.	
☐	Obtain appropriate permits.	
☐	Document gear specification and establish winch protocols.	
☐	Determine if specialists needed for deployment.	
☐	Design workspaces and workflows.	
☐	Organise shipment of samples.	

Field Procedures

A visual summary of some the key steps to follow when deploying benthic sleds or bottom trawls is shown in Figure 9.1.

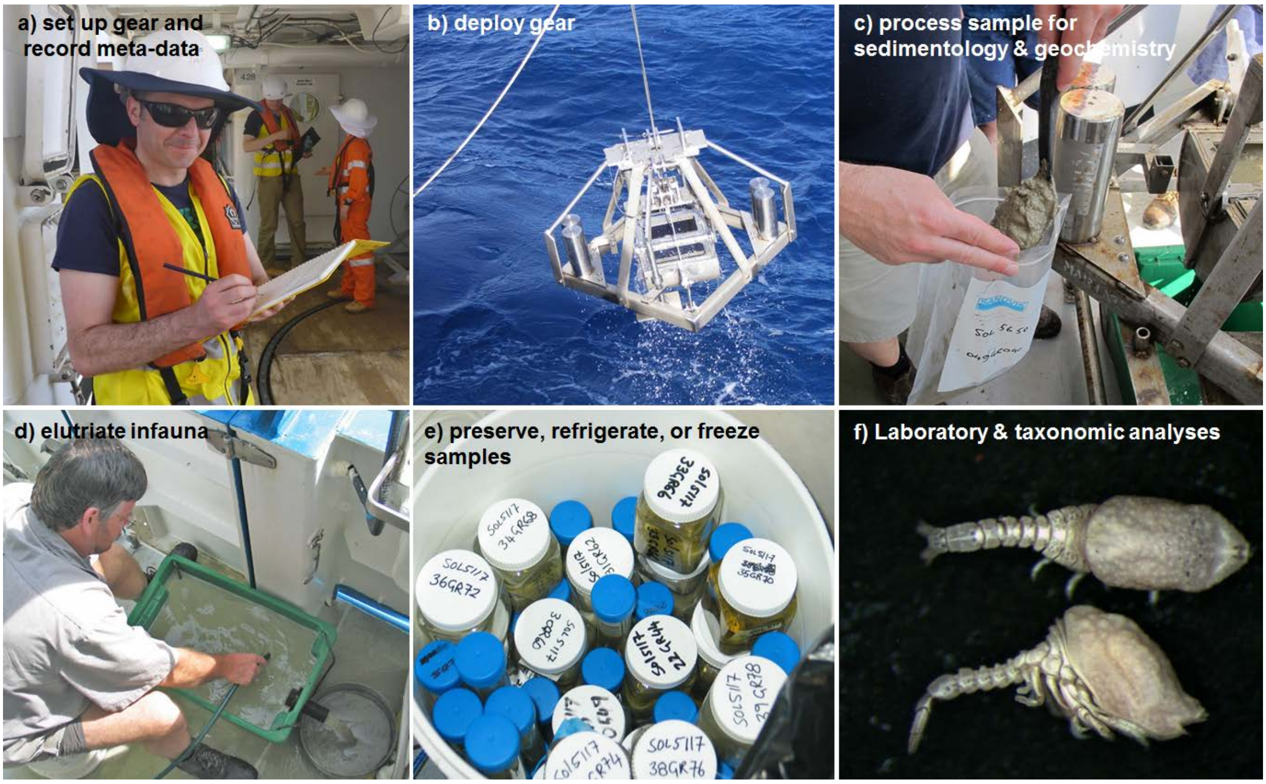


Figure 9.1: Images from key steps involved in the use of grabs or box cores for marine monitoring: a) Recording metadata during gear deployment, b) Retrieving a Smith-McIntyre grab, c) Transferring sample for sedimentological analysis from grab to storage bag, d) Elutriating sediment over a sieve, e) Preserving a bucket of infaunal samples in ethanol, f) Sorting cumaceans under the microscope from elutriated infaunal samples.

Onboard sample acquisition

1. Use multibeam data or underwater imagery to confirm appropriate areas to sample (soft vs hard substrate) and to identify the most appropriate equipment based on fine or coarse sediments.

2. Use USBL System to ensure accurate positioning (Schlacher et al. 2007, Williams et al. 2015) *[recommended, especially in deep waters]*

3. Document the specifications of all sampling gear to be used. This includes gear size and configuration (dimensions, weight) and deployment needs (wire length estimated, USBL methods), as well as sampling surface area, maximum volume, and maximum digging depth. This information must be included in survey metadata.

4. Record all metadata related to each sample station, specified in Table 9.2.

5. Deploy the grab or corer according to gear-specific protocols. Record GPS position, date, time and water depth when the sampler reaches the sea bed.

6. When the equipment is lifted from the water, follow gear-specific protocols for its safe return to deck and access to the sample. Special care may be needed in rough conditions to ensure the sample is not spilled or in situations when the grab or corer has not been triggered.

7. Assess the success of deployment and record the proportion of grab or corer filled (Table 9.2).

8. If there is significant damage to gear, gear closure failure, sample spillage or scant sample return, the sample should not be used in quantitative comparisons with other deployments. If possible, repeat a deployment at that location. Scant sample is defined as being at least 50% empty.

9. Record general observations, particularly conspicuous biota, general sediment description, and evidence of anoxic or reduced sediments (i.e. black/green colour, sulphur smell).

10. Photograph the entire sample with the station identification placard. If taking photos of individual biota from the sample (must be done after step 10), photograph them on the station identification placard. It may be worth considering including a basic scale bar on station identification placards for this purpose.

11. As soon as practical, begin onboard processing of the sample for sedimentology, biology, and biogeochemistry (next sections, Figure 9.2).

12. After all samples have been removed (next sections, Figure 9.2), thoroughly wash gear to prevent cross-contamination. Set up gear for next deployment or safely secure for long transits or if operations have ceased for the day.

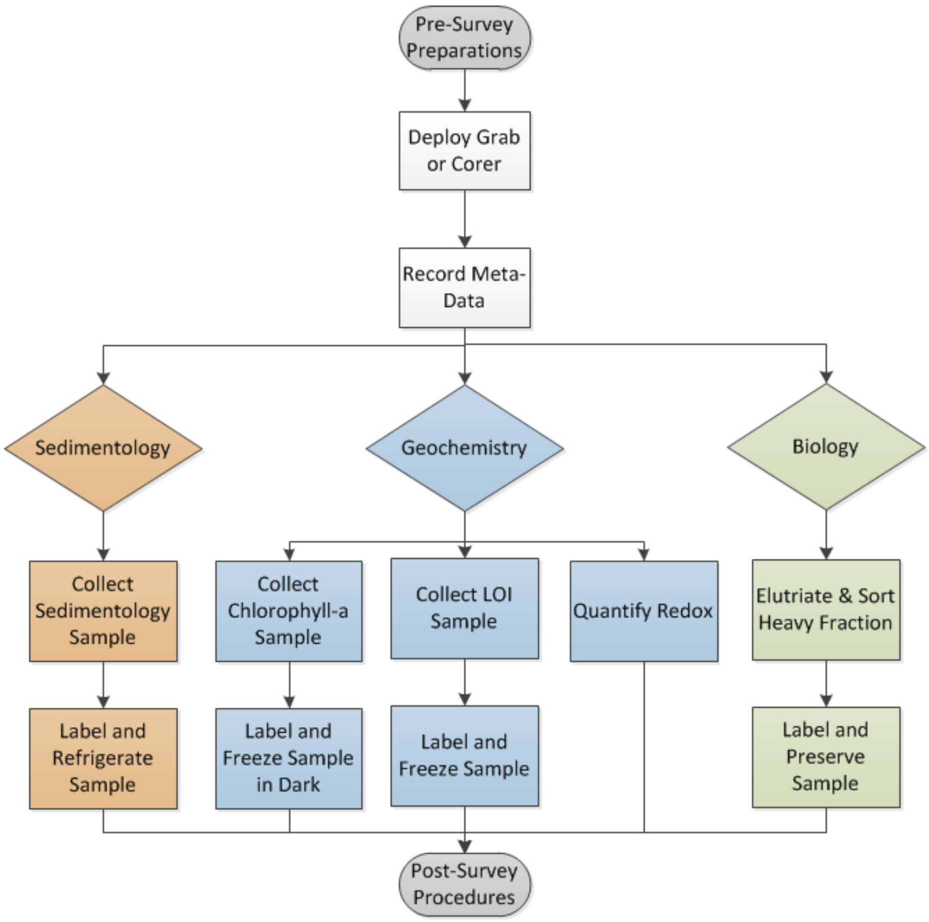


Figure 9.2: Workflow for onboard sample acquisition and processing from grabs and box cores.

Table 9.2: Sample field datasheet to record metadata from each grab or corer deployment. Waterproof paper and pen/pencil is required.

		Gear on bottom				Wire out (length, angle)[1]	% recovery	Sample weight	Photo (Y/N)	Sample taken (Y/N), Sample ID number			Qualitative data and other comments		
Gear ID	Date	Long	Lat	Depth	Time					Bio	Sed	Geo chem	Biology	Sed (Folk, Munsell, carbonate/lithic, other materials)	Geoch (anoxic sediments)
GR01	1/1/17	152.444	-24.675	20 m	19:28	25 m, 0°	75	7 kg	Y	Y 1001	Y 1002	Y 1003	Large worm preserved separately	sG (Sandy Gravel) 7.5 YR 7/6 (red yellow) Carbonate dominant Trace of volcanic rocks	Patches of sediment are black with sulfur smell

[1] Recording the length and angle of wire payed out during seafloor contact is required if the survey is in deep water with no USBL; otherwise this is just recommended

Onboard sample processing & storage

1. For most equipment, the sedimentology and geochemical sub-samples can be accessed while the sample remains in the grab or corer, thus minimising disturbance. The biological sub-sample can be processed after these sub-samples have been removed.
2. When processing biological samples, pass any excess water from the sampling gear over the sieve; for a box core this will likely need to be done with a siphon. Process the material retained on the sieve, refer to biological steps below.
3. Undertake geochemical, sedimentological, and biological processing steps below for each sediment sample collected.
4. After samples are processed, transcribe the metadata from Table 9.2 into digital format. This can be done in the evening or during other shipboard operations, but it should be done onboard because it provides an immediate back-up, allows for correction of obvious errors, and facilitates timely metadata release.
5. During demobilisation, ensure samples and drums are properly closed and implement shipping according to decisions made during pre-survey planning.

Sedimentology (texture, colour and composition)

The following procedures are to be used to obtain sediment samples for quantification of commonly analysed metrics related to grain size and carbonate content (Nichol et al. 2013).

a) Using a spatula or spoon, scrape surface sediment, collect a maximum 300 g wet weight (~2-4 tablespoons) in a plastic zip-lock bag. If you're collecting a particle size sample for comparison with contaminants data or for integration in the national seabed sediments collection, this must be taken from the top 2 cm of the sample. If you're collecting a particle size sample for comparison with infaunal data, then the particle size sample should be representative of the whole sample profile. If you are sub-sampling a grab sample for sedimentology, biogeochemistry, and biology, leave any visible living organisms for biological steps below, but retain shell material.

b) Describe the entire sediment sample using a visual assessment. First identify whether the dominant constituent is Mud, Sand or Gravel. Gravel is > 2 mm diameter, including any shell fragments, coral, rhodoliths or rocks. Sand is < 2 mm and > 0.063 mm diameter. Mud is < 0.063 mm diameter.

The following description will assist a visual and tactile assessment:

- *Sand* – Individual grains can be readily seen and felt. When wet, sand will form a cast that crumbles when touched.
- *Muddy sand* – Sand grains are visible but the sample contains enough mud (silt and clay) to make it somewhat cohesive. Will form a cast when moist that can bear careful handling without breaking.
- *Mixed sediments* – Mixture of sand and mud. Has a gritty feel, but smooth overall and slightly plastic. Will form a cast when moist that can bear firm handling without breaking.
- *Sandy mud* – Overall fine texture, slightly gritty to feel that can form a thin ribbon when rolled between fingers. Will form a cast when moist that can bear robust handling without breaking.
- *Mud* – Uniformly fine texture, sticky and with very slight gritty feel if silt is present. Will form a long flexible ribbon when rolled.

c) Assign a Simplified Folk Textural Class to the sample, based on the estimated mud, sand, and gravel proportions (e.g. Figure 9.3, Table 9.3).

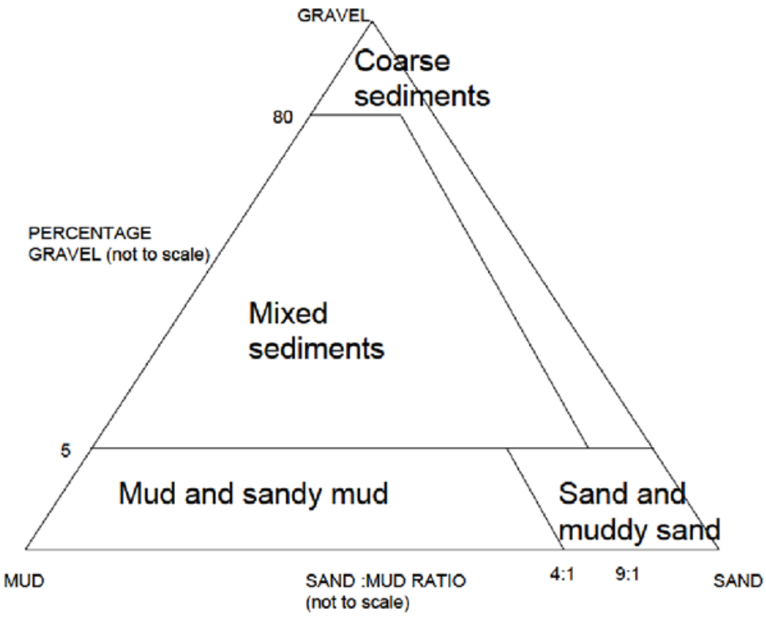


Figure 9.3: Simplified Folk Textural classes

Table 9.3: Simplified Modified Folk Textural classes for visual classification of seabed sediments.

% Gravel	Sand : Mud Ratio	Simplified Folk Class
>80	>9:1	Coarse sediment
>5, <80	<9:1	Mixed sediments
<5	>4:1	Sand and muddy sand
<5	<4:1	Mud and sandy mud

d) Assign a colour to the whole sample using a Munsell colour chart, noting the Munsell code (colour, value, chroma) and colour name *[Recommended]*.

e) Estimate whether the sample is comprised of dominantly (>50%) carbonate material, non-carbonate (i.e. lithics), or mixed.

f) Note the presence of other materials, such as whole shells, articulated bivalves, shell fragments, corals, wood or lithics and record the relative abundance as: Trace (just noticeable); Few (noticeable); Common (very noticeable); Abundant (little else noticeable).

Record the above properties with all available metadata (Table 9.2), as in the example below:

- Sand and muddy sand
- 7.5 YR 7/6 (reddish yellow)
- Carbonate dominant
- Trace of volcanic rock fragments

g) Photograph the sediment sample with a label, scale and Munsell colour chart *[Recommended].*

h) Double bag the sample. Label clearly on the surface of the bags, as well as on aluminium tags or waterproof paper placed between the bags. Refrigerate.

Biogeochemistry (chlorophyll-a, organic matter content, redox)

These geochemical analyses are based on the assumption that the sediment surface is relatively intact and the surface sediments can be identified. If this is not the case, it is recommended only organic matter content is assessed, with information on sediment mixing recorded in the comments section of the metadata sheets (Table 9.2). The following procedures are to be used to obtain geochemical samples for quantification of commonly analysed metrics related to chlorophyll-*a* (Danovaro 2010), organic matter content (Heiri et al. 2001, Wang et al. 2011), and redox (Danovaro 2010, Edgar et al. 2010). For all biogeochemical samples, record the geochemical samples taken on a station form with all available metadata (Table 9.2).

Chlorophyll-a & phaeophytin

a. Using a spatula or spoon, scrape the surface sediment to a maximum depth of 2 cm. Collect ~ 100 g wet sediment (1-2 tablespoons).

b. Remove any visible living or soft-bodied organisms for biological steps below, but retain shell gravel.

c. Place a sub-sample of wet sediment into a 50 mL plastic vial for chl-*a* analysis. Chl-*a* degrades in sunlight so this step should be performed quickly and out of direct sunlight if possible.

d. Wrap in foil and store frozen at -20°C in the dark until post-survey analysis of chl-*a*. Ensure sufficient head-space in the vial or bag to allow for the expansion of sample when frozen. Note that analysis should be performed within 4 weeks of collection, although use of ultra-cold freezers extends storage times.

Organic matter content

e. Place another sub-sample of wet sediment into a 50 mL plastic vial or small zip-lock bag for post-survey analysis of total organic carbon.

f. Homogenise this sample, and store frozen at -20°C until analysis of organic matter content, generally within 3 months of collection. If liquid nitrogen is available, samples should be snap frozen and stored in a dewar following appropriate protocols.

Redox

g. Use a suitable redox probe consisting of a portable pH/Eh meter, redox electrode (with shaft >15 cm long, preferably as thin as possible, with Platinum indicator electrode) and a reference electrode (double junction silver/silver chloride).

h. Use Zobell's solution as a reference to calibrate the redox electrode before each redox profile, recording the redox measurement of the solution. The solution (0.003M potassium ferricyanide, 0.003M potassium ferrocyanide, and 0.1M potassium chloride) has an Eh value of +430 mV at 25°C.

i. Carefully insert the redox electrode into the intact sediment surface as soon as possible after collection at depth intervals of 1 cm from the surface to 10-20 cm (depending on depth of sediment).

j. Record the Eh readings (in mV) when the meter readings stabilise (for a minimum of 5 seconds) at each depth.

This method provides a rough indication of the levels of oxygen in the substrate. This information is crucial to assess the interstitial conditions of the sediment as affected by burrowing organisms or anthropogenic factors. Measured in millivolt, often reported as Eh (hydrogen standard electrode) the redox potential has a low-definition significance because of the multi-factors interacting in producing it, and as such is semi-quantitative. Generally positive values are associated with well-oxygenated sediments, whereas highly negative values (<-200 mV) are typical of suboxic or anoxic conditions (Danovaro 2010).

To convert to redox potential and ensure quantitative outputs for comparability between studies, measurements must be calibrated on the Zobell's measurement, i.e. add the difference to each reading in the profile (difference = std reading at 25°C – field Zobell's measurement) to standardise measurements for local conditions (e.g. temperature). This must then be standardised based on the standard hydrogen electrode which gives the potential.

Biology (infauna and macrofauna)

a. After supernatant water has been passed through a sieve and sedimentology and geochemistry steps have been performed (< 5 tablespoons of sediment removed, see above), transfer the remaining sample from grab or corer to an elutriating bin. If additional survey objectives require data on sediment depth (see Pre-Survey Preparations), each sediment layer should be in a separate nally bin.

b. Weigh the whole sample using an onboard scale. Record in metadata sheet (Table 9.3).

c. Rinse the grab or corer thoroughly to avoid contaminating the next sample collected.

d. Elutriate the sample by running moderately flowing seawater into the elutriating bin and gently agitating the sediment to release light-bodied animals into the water. The water should flow from the bin through an outlet under which the sieve is placed (next step). To avoid damage to animals during elutriation, avoid directing water from the deck hose at the sieve, separate fragile visible animals, and remove rocks and shells (these can be saved as part of the heavy fraction if desired, Step 12). Elutriation should be performed until water runs clear, ideally the same amount of time among all sample sites. For coarse-grained sediments, this may only be ~5 minutes, but for deep-sea ooze this may be far longer due to stickiness of the sediment which makes elutriating a challenge.

   Fine sediments may require two steps here: semi-elutriation which often retains clods of fine sediment on the sieve, followed by puddling in which a full sieve is immersed in seawater and vertically agitated to further remove fine sediment (CEFAS 2002). This 2-stage option also accounts for shelled molluscs and other heavy-bodied organisms often missed by elutriation. Regardless, the main goal in this step is to ensure that all animals are separated intact from as much of the sediment as possible.

e. Stacked sieving is an alternative to elutriation and can provide immediate data related to invertebrate size distribution and biomass (Edgar 1990), although sieving is not ideal in coarse-grained sediments where a large fraction is retained on the sieve and subsequently require much time to sort from organisms from the sediment. If a researcher elects this option, stack larger sieves (e.g. 1000 µm) on top of smaller ones (e.g. 500 µm), add small amounts of sample to the top sieve and gently flush through with seawater. Skip to Step 12.

f. Retain macrofauna by allowing water to flow onto a 500 µm sieve. This size was chosen, as it has already been used in AMPs (Nichol et al. 2013, Przeslawski et al. 2013, Przeslawski et al. 2018) as well as successful international monitoring of soft sediment communities (Frid 2011). It is a compromise between the 1 mm recommended by other protocols (Rumohr 1999) and the time and effort needed to process specimens using 300 µm or smaller. If individual survey objectives require a finer mesh size (e.g. 100 µm or 300 µm) or comparison with datasets from larger mesh size (e.g. 1000 µm), layer the sieves and process samples separately so that the recommended standard of 500 µm is still followed and data are comparable.

g. Sort the heavy fraction by hand and remove any live animals that do not float during elutriation (e.g. molluscs, hermit crabs, animals attached to rocks) (i.e. heavy fraction specimens) and place them in the sample container.

h. Material retained on the sieve should be flushed off using seawater in a squirt bottle directed from the underside of the sieve into a funnel and sample container. It is important to minimize the amount of water used in this step to ensure adequate preservative concentration. If a large amount of seawater is used for flushing, the sample can be sieved and flushed again. Alternatively, a puddling bin can be used to concentrate the sample into one small area of the sieve for flushing into the sample container (CEFAS 2002).

i. Preserve elutriated and heavy fraction specimens according to methods decided in 'Pre-survey Planning' in sample container. If there is a large volume of material, use multiple sample containers to ensure enough preservative in each container. Consider museum requirements for sample preservation, and also see Rees (2009) and Schiaparelli et al. (2016) for comprehensive description of fixatives and preservatives used for marine invertebrates. Larger organisms may be preserved separately (e.g. polychaetes may be relaxed in $MgCl_2$ and fixed in formalin).

j. Place a solvent-hardy label in each sample container with sample and station number, date, location and vessel/collector. This information is essential for quality control in processing and archiving of specimens. It is not sufficient to label only the outside of the container, as this can easily rub off. See Box 15.6 in Schiaparelli et al. (2016) for suitable label characteristics.

k. Place the sample container in a large sealable container (i.e. lidded drum) double-lined with a durable plastic bag with other samples preserved using the same chemicals (e.g. ethanol). Label the drum with survey details and the type of chemical fixative/preservative inside. Since samples from the same grab may end up in different drums due to different preservatives, it is imperative to have a good record-keeping system.

l. After placing samples within the inner bag of the drum, back fill between the bags with an appropriate amount of spill kit (e.g. vermiculite or absorbent kitty litter). In this way the contained specimens are compliant with handling (triple bagged) for road transport of Dangerous Goods. *[Recommended]*

m. Store large drum onboard in an approved storage area for hazardous chemicals.

Post-Survey Procedures

Sample curation and submission for analysis

Sedimentology

Sedimentology samples can be transported as refrigerated freight in a fully sealed, rigid container (e.g. esky) to Geoscience Australia for laboratory measurement. Alternatively, researchers may transport samples to their own labs if performing analyses in-house or through laboratories accredited by the National Association of Testing Authorities (NATA). Regardless of whether the sample is analysed by GA or elsewhere, data should still be submitted to the national seabed sediments collection data repository on the AusSeabed Marine Data Discovery portal (http://marine.ga.gov.au) (see 'Data Release' section). Analytical methods include wet sieve separation into mud, sand and gravel fractions, laser granulometry of mud and sand fractions, and acid digestion of carbonate content for the bulk or mud and coarse fractions. Other methods are also available for those with their own expertise and equipment (e.g. calcimeter method in Kennedy and Woods (2013)).

If lodging samples at GA for analysis, the following metadata are required prior to receipt of sediment samples:

- Survey metadata including: survey name, survey number, survey vessel, start and end date of survey, latitude and longitude of survey bounding area, name of chief investigator;

- Sample location for every sample listed in decimal degrees to at least five decimal places;
- Sample water depth for every sample listed;
- Sample ID follows a standard naming convention (see example attached);
- Sample bags are labelled clearly with the sample ID (as above); and
- Sample condition as when collected (i.e. wet, disaggregated, excess water drained).

Biogeochemistry

Geochemical analysis of sediment samples should be conducted by the organisation undertaking the survey. Alternatively, sample analysis should be outsourced to Geoscience Australia (Loss on Ignition analysis, as described below) or NATO-accredited commercial laboratories or collaborators (chl-*a* analysis).

Total organic matter content

Total organic matter content of marine sediments is determined by Loss on Ignition (LOI). Note that LOI is not the same as total organic carbon (TOC) (Schumacher 2002). Parameters such as temperature and combustion time vary among individual researchers, and there is no universally adopted standard. Here we choose parameters based on a compromise appropriate to a diverse range of environments (Heiri et al. 2001, Wang et al. 2011). We strongly recommend that researchers use these guidelines to ensure data from different surveys can be compared. The general recommended steps for LOI to contribute to a national standardised dataset are:

1. Record wet weight of the sample.
2. Homogenise the wet sample (1-2 g dry weight).
3. Place sample into a pre-weighed crucible.
4. Oven dry for at least 24 h at 105°; longer times may be needed in fine sediments.
5. Reweigh crucible and dry sediment.
6. Place crucible in muffle furnace and combust at 550°C for 4 h.
7. Weigh crucible and combusted sediment.

The water content is the difference between the wet and dry sediment weights and is expressed as a percentage of the initial sediment weight. The total organic matter content is obtained as the difference between the dry and combusted sediment weights and is expressed as a percentage of the sediment dry weight.

Chlorophyll-a & phaeophytin

Chlorophyll-*a* is the principal pigment in plants and is a biomass indicator of aquatic micro-algae which support food webs in the sea, and phaeopigments (e.g. phaeophytin) are the degraded non-photosynthetic products of chlorophyll (e.g. Bax et al. 2001). The ratio between them indicates the “freshness” of the organic matter. Note that samples can be freeze-dried first and this may increase extraction efficiency but also increases the risk of chlorophyll degradation over time. For the purposes of this field manual, we recommend using wet material; this will ensure comparability among datasets. The general steps for chl-*a* analysis are:

1. Place approx. 5 g wet sediment into centrifuge tube.
2. Add 10 mL acetone (90% saturated with $MgCO_3$).
3. Mix rigorously (with glass rod or vortex mixer).
4. Place in an ultrasonic bath for 30 minutes under dark conditions (Note: other methods can be used, e.g. shaker).
5. Centrifuge sample (>1500 g for 5 minutes) and decant extract.
6. Use a spectrophotometer to measure absorbance at 665 and 750 nm.
7. Acidify extract with 2 drops of 0.1 N HCl, mix and rest for 60 s.
8. Measure absorbance again at 665 and 750 nm.
9. Calculate the concentrations of corrected chl-*a* and phaeophytin using the equations of Lorenzen (1967).

Redox
Redox measurements are provided onboard with a probe and there are thus no post-survey procedures are required, other than to calculate redox potential and QC data.

Biology

1. All animals from a given grab or box core should be sorted into separate small containers based on phylum or class to facilitate taxonomic identifications (arthropod, annelid, mollusc, echinoderm, other). This can be done onboard if time permits, but consideration must be given to working under a microscope on a moving vessel. Sorting can usually be done by a non-expert, with only a few groups posing potential challenges (Figure 9.4). Containers should be filled with ethanol or formalin (as per Pre-Survey Preparations) and labelled appropriately with solvent-proof paper.

2. In order to test for potential bias due to differences in sorting efficiency among people, randomly selected samples should be re-sorted by a different person. Removal of 95% or more of the organisms during the sorting process is acceptable; otherwise, re-sorting may be necessary (Simpson et al. 2005) *[recommended when multiple people are involved in Step 1]*

3. Within each sorted phylum, identify organisms to a taxonomic resolution that enables data production in a timely manner, and then count individuals. Identifications can be done by the organisation that collected the samples, museum taxonomists, geneticists, or external private consultants. Care must be taken to ensure consistent nomenclature is used for undescribed or unnamed species (e.g. defined operational taxonomic units, OTUs).

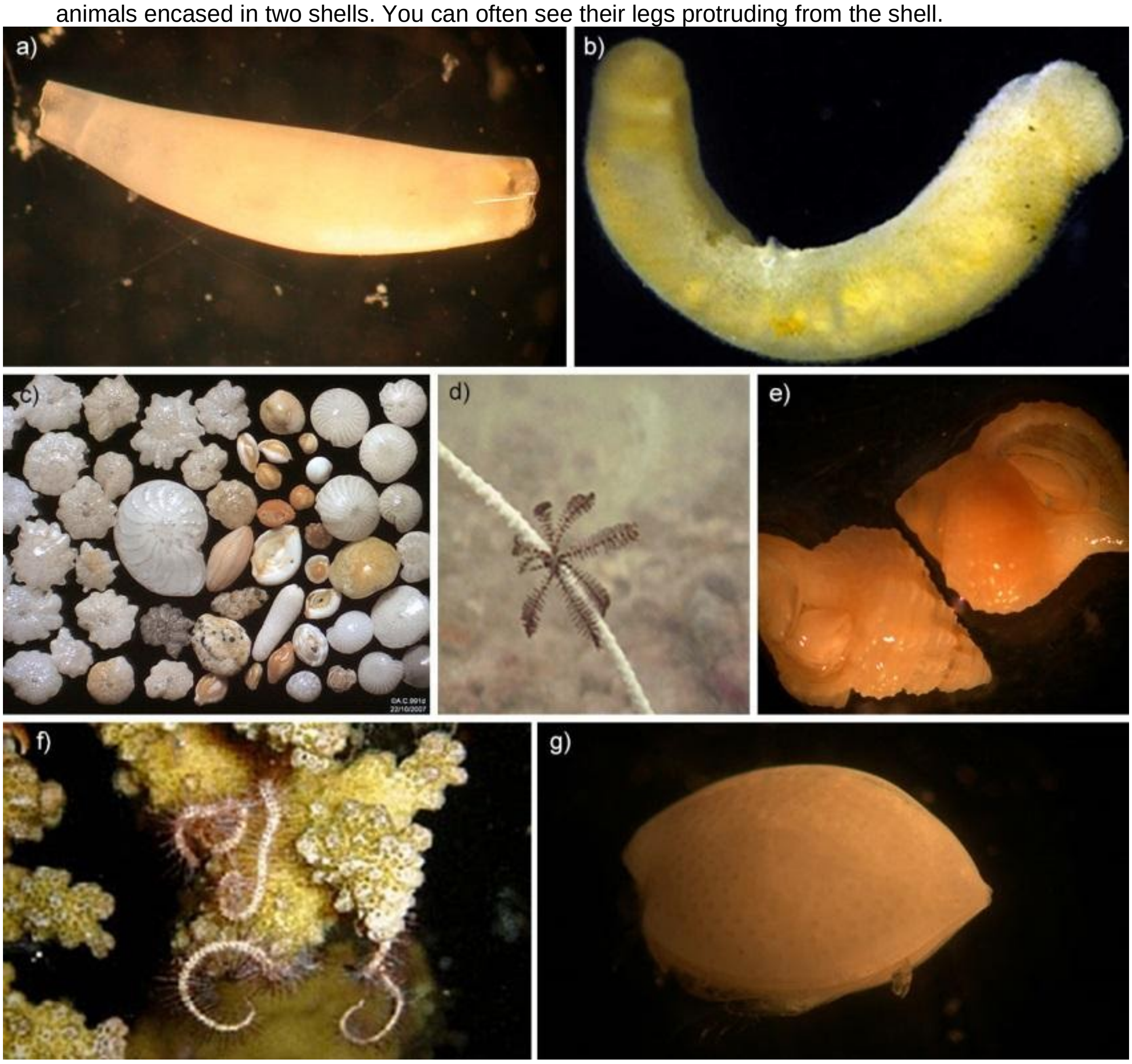
4. Lodge all specimens in an internationally recognised specimen collection (e.g. museum) for curation and public accessibility *[Recommended]*.

5. If all specimens are unable to be lodged at a museum due to lack of resources or the need for destructive analyses (e.g. biochemical extractions), then a voucher collection should be produced (i.e. at least one animal per OTU). This voucher collection can be held temporarily by the agency undertaking the survey if there are other surveys planned in the region to aid in subsequent identification. Ultimately, this voucher

collection should be lodged in an internationally recognised specimen collection (e.g. museum).

Figure 9.4: A brief description of taxa that can be challenging to identify but are often encountered when sorting organisms from elutriated sediment samples.

a) ***Scaphopods (molluscs).*** These are curved shells with a larger and smaller hole on each end.
b) ***Aplacophorans (molluscs).*** These are often confused with worms but are actually molluscs covered with spicules that can make them look furry.
c) ***Foraminiferans (protists).*** Forams with tests (i.e. shells) can be mistaken for gastropod shells and can be particularly common in deep-sea sediments and beach sand. This field manual does not target forams so their inclusion in sample processing is not required (image from Wikimedia).
d) ***Crinoids (echinoderms).*** The small animals or their dropped arms can superficially resemble polychaete worms.
e) ***Hermit crabs (crustaceans)***. These can be mistakenly sorted as gastropods because the crab has retreated into its shell and is barely visible.
f) ***Ophiuroid arms (echinoderms)***. These can often be confused with polychaetes, but you'll never see a head. There is no need to save ophiuroid arms unless the central disk is present.
g) ***Ostracods (crustaceans).*** Ostracods can be mistaken for bivalves, but they are small shrimp-like animals encased in two shells. You can often see their legs protruding from the shell.



Data Release

Produce a technical or post-survey report documenting the purpose of the survey, survey design, sampling locations, sampling equipment specifications, and any challenges or limitations encountered. See Appendix B for a sample template. Provide links to this report in all associated metadata *[Recommended].*

Sedimentology

For samples submitted to GA for sedimentological analysis, sedimentology data will be publicly available in the national Marine Sediments collection (MARS, https://portal.ga.gov.au/persona/marine) following lab analysis and QC checks as part of GA's internal workflow processes. This database includes sediments from estuaries, coasts, shelf, and the deep-sea.

For samples from which sedimentological analysis were done elsewhere, please submit the data to marine@ga.gov.au, along with required metadata.

Biogeochemistry

Submit all geochemical sample metadata and analysis results to GA including:

- Reduced sediments (Y/N);
- Total organic matter content (%); and
- Chl *a* (ug g^{-1} dry sediment).

The easiest way to do this is to add two columns to Table 9.3 for LOI and chl-*a* data and submit this to marine@ga.gov.au.

Biology

All biological data should be publicly released, unless circumstances require otherwise (e.g. confidentiality clause or embargo for commercial work). Even in situations when data cannot be shared, the metadata and deployment information should be made available (Steps 1-2 below). Poor scientific data management and lack of data sharing has been shown to hamper scientific progress (Stocks et al. 2016).

Traditionally, data related to biological specimens have been delivered as presence-only taxonomic identifications. These are often managed by individual museum scientists or curators and subsequently harvested by the Atlas of Living Australia (ALA). Ala does not yet include absences or information related to sampling effort, thus reducing the applicability of such databases to monitoring purposes.

OBIS is using the data structure described in the project called OBIS-ENV-DATA that allows the linking of species data to other related information (e.g. environmental data, images, sampling effort) (De Pooter et al. 2017). It now has the capacity to store absence records and sampling effort, and is working to include this information in data downloads.

In the meantime, the steps listed below will ensure appropriate and timely release of both metadata and data:

1. Create a metadata record describing the data collection. Provide as much detail as possible on the collection/deployment (either directly in the metadata record itself, or in the form of attached field sheets as .csv, .txt or similar). This should include sampling locations and dates, equipment used, level of sorting applied, etc. All collection/deployment information must be QC-d before inclusion.

2. Publish metadata record(s) to the Australian Ocean Data Network (AODN) catalogue as soon as possible after metadata has gone through the QC process. This can be done in one of two ways:

    - If metadata from your agency is regularly harvested by the AODN, follow agency-specific protocols for metadata and data release.

    - Otherwise, metadata records can be created and submitted via the AODN Data Submission Tool. Note that this tool requires user registration, but this is free and immediate.

    This step provides immediate documentation of the methods and location of the collection of biological material. This stage may also include links to field reports or data sheets.

3. Complete the species identifications and associated abundance for targeted groups identified. This can take quite some time, depending on sample size and available resources. It is not unusual for taxonomic identifications to lag years behind survey completion, but this should not delay publication of initial metadata and deployment information. Care must be taken to ensure consistent nomenclature is used and documented for undescribed or unnamed species (e.g. defined Operational Taxonomic Units, OTUs). Ideally catalogues of OTUs are established such that subsequent surveys may use consistent OTU classification, thereby ensuring comparability of data between surveys.

4. QC the data. This includes checking for spelling errors, missing data, consistent nomenclature and use of OTUs, and confirmation that outliers are not data entry errors (e.g. 100 individuals really were collected, not just 10). Current taxonomic nomenclature can be checked using the World Register of Marine Species (WoRMS) ‘match taxa’ tool (https://www.marinespecies.org/aphia.php?p=match). This process provides accepted scientific name, the scientific authority and full taxonomic breakdown for each taxon.

5. Technical specialists should also consider whether the data has to be rationalised. This process is often required to remove potential ‘ecological noise’ which may adversely affect the statistical analysis of the data. Examples include non-target taxa (e.g. purely pelagic biota such as chaetognaths or ctenophores; or terrestrial biota such as dipterans in grab samples) or juveniles. Newly-settled juveniles are often ephemeral, with high abundance and post-settlement mortality rates, and are therefore not generally representative of prevailing benthic faunal communities (OSPAR Commission 2004).

6. Additional analysis of data may be required, including classifying trophic levels of taxa, and classifying or characterising habitat types for each sample (e.g. National Intertidal and Subtidal Benthic classification in Mount et al. 2007; Combined Biotope Classification Scheme in Edmunds and Flynn 2018).

7. Attach or link the full data spreadsheet (including absences and abundances/biomass) to the metadata record previously created and published to the AODN. This will ensure public discoverability and accessibility of the complete data, including absences.

   To then publish data to OBIS, inform OBIS Australia (OBISAU) using the contact details and information on http://www.obis.org.au.

   OBISAU will download the data from AODN or any other site and apply the following procedures.

- OBISAU provides a taxa matching service using WoRMS web services and will validate the dataset as best as possible.
- The data is tested for any temporal or spatial outliers.
- Any observed parameters (biotic and abiotic) are matched where possible to vocabularies maintained by AODN and BODC.
- Metadata is authored from any existing metadata or publications.
- Finally the datasets is published via the OBIS Australia data node http://ogc-act.csiro.au/ipt/

   OBISAU has the option to publish the data at the same time directly to GBIF, and it has developed a service to inform ALA that a new dataset is available to be harvested for inclusion into ALA.

Field Manual Maintenance

In accordance with the universal field manual maintenance protocol described in Chapter 1 of the Field Manual package, this manual was updated in 2020 as Version 2. Updates reflect user feedback and new developments. There is currently no long-term plan or support for future updates. See Chapter 1 (Introduction to field manual package) for further details.

The version control for Chapter 9 (field manual for grabs and box corers) is below:

Version Number	Description	Date
0	Submitted for review (NESP Marine Hub, GA, external reviewers as listed in Chapter 1.	22 Dec 2017
1	Publicly released on www.nespmarine.edu	28 Feb 2018
2	Relevant updates addressing stakeholder feedback and new co-author contributions	July 2020

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10. FIELD MANUAL FOR IMAGERY BASED SURVEYS USING REMOTELY OPERATED VEHICLES (ROVS)

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Platform Description

Remotely Operated Vehicles (ROVs) are piloted, tethered unmanned submersibles typically controlled from a vessel (sometimes from other fixed structures such as oil and gas platform jackets) via a reinforced umbilical cable as the main tethering device. The tether historically provided electrical power and also allowed the real-time transfer of data between the vessel and ROV to be transmitted. With advancements in battery technology, smaller ROVs can now be powered by onboard battery systems, which reduces the diameter of the tether, decreasing drag and improving ROV maneuverability. The motion of ROVs are controlled by multiple thrusters that allow movement and manipulation in all directions and speeds up to 3 knots. Onboard cameras and sensors provide data and visual information that is relayed back to the surface personnel to observe the seabed or other structures and control the ROV. Onboard sensors typically provide feedback on water depth, temperature, currents, orientation and location of the ROV. The attachment of manipulator arms can also allow for specimens and samples to be collected (including on in the water column).

ROVs were originally designed in the mid-1980s to complement manned scientific submersibles. With the increase in technology since, ROVs have gained acceptance because of their distinct advantages over manned submersibles in many areas, notably reduced risk to pilots and researchers. For instance, they can remain on the seafloor for extended periods efficiently performing large surveys, running extended time series observations, and conducting multidisciplinary operations (Shepherd 2001, Macreadie et al. 2018, Sward et al. 2019). A large volume of data is transmitted to the surface, via multiple channels including real time video, sonar, CTD (conductivity–temperature–depth) data, real time location and other information.

ROVs are available in a range of sizes and configurations from smaller observation-class vehicles (~3-20 kg for mini and ~30-120 kg for regular-sized models) to larger work-class systems (100-1,500 kg for light- and up to 5,000 kg for heavy-duty models), which vary in power, depth rating, accessibility, and additional payload capabilities (Baker et al. 2012, Capocci et al. 2017, Huvenne et al. 2018). As a result of the versatility, ROVs are increasingly being used for deep-water surveys, with published examples of using ROVs for physical sampling via manipulator and grabber arms, scanning sonars and high-definition cameras to provide researchers with still or video images of the physical environment (Shepherd 2001, Leckie et al. 2015, Robert et al. 2017, Macreadie et al. 2018) and associated sessile mega-benthic taxa (Salvati et al. 2010; Thresher et al. 2014; Lacharité et al. 2015; Cánovas-Molina et al. 2016; Price et al. 2019; López-Garrido et al. 2020) as well as mobile organisms (such as fish; Karpov et al. 2006, Pradella et al. 2014, McLean et al. 2017, Thomson et al. 2018). With advances in technology, a wider range of ROV models are becoming available, including many low-cost systems, resulting in a greater uptake by researchers.

For further information on the advantages and disadvantages of ROVs compared to other benthic imagery and sampling platforms, refer to *Comparative assessment of seafloor sampling platforms* Przeslawski et al. 2018 and review by Sward et al. 2019).

Scope

The primary aim of this field manual is to establish a consistent sampling protocol for marine benthic assemblages using ROVs and to facilitate statistically sound research to allow comparisons between studies. This manual will focus on the use of ROVs for the collection of still and video imagery of fish and associated seabed habitats but consider researchers may use them for other purposes as detailed in Table 10.1. We also consider all ROV classes here and provide some guidance around the limitations associated with each class. The document leverages the expertise of the working group focusing on still and video imagery (Chapters 4 and 7 for example, but see Table 10.1 for a brief summary of additional uses for ROVs). The scope of the manual covers equipment, pre-survey preparation, field procedures, and post-survey procedure for using ROVs to photographically and videographically survey seabed assemblages (including fishes) found within Australia's vast marine estate.

Table 10.1: Additional uses of ROVs in monitoring the marine environment that are not covered in this manual (modified from McLean et al. 2020).

Payload	Description
CTD	Seawater temperature and salinity depth profiles
Bio-optical sensors	Fluorescence and backscatter (turbidity) sensor
Light meter	Upwelling and downwelling light, photosynthetically active radiation (PAR)
Dissolved oxygen sensor	Dissolved oxygen concentrations
pH sensor	Water column pH
Water sampler	Water column samples for microbes, nutrients, pollutants, chlorophyll using bottle samplers
Acoustic telemetry, Hydrophones/passive acoustics	Detection of tagged and untagged animals, migration patterns, connectivity
Scanning/Imaging sonar	Bathymetry, structural complexity
Sediment Corers/grabs	Sedimentology or biogeochemistry e.g. particle size, sediment chemistry
Faunal traps	Deployment and retrieval of baited traps for sampling of mobile fauna, including fish and invertebrates
Faunal sampling	*In situ* sampling of sessile and mobile fauna, including pelagic and demersal fish and benthic invertebrates

ROVs in Marine Monitoring

Using ROVs to visually monitor marine ecosystems has experienced a rapid increase over the past two decades as a result of cheaper, smaller ROVs becoming available as well as improved access to oil and gas sector ROVs (e.g. through the SERPENT initiative; Macreadie et al. 2018) and philanthropic ROVs (e.g. Schmidt Ocean Institute). Researchers have used ROVs in monitoring the impacts of invasive species (Whitfield et al. 2007), assessing marine protected areas (Dauble 2006, Torriente et al. 2019) assessing population trends in demersal fishes (reviewed in Sward et al. 2019), mapping of benthic habitats (García-Alegre et al. 2014, Torriente et al. 2019), examining diversity in reef communities (including on vertical walls; (Robert et al. 2017, Price et al. 2019), detecting marine litter (GESAMP 2019), and assessing spatial and temporal changes in fish and sessile benthos associated with artificial structures (such as oil and gas infrastructure; McLean et al. 2017, Bond et al. 2018).

While ROVs can be used for deploying a variety of sensors, as well as taking samples of substrata and organisms (Table 10.1) they are also used to generate spatially accurate photomosaics and finescale digital elevation models. Multibeam data which is often available with accurate georeferencing can provide important information regarding habitat types and structural complexity but is often limited to cell resolutions of 50 cm to 5 m. Finescale digital elevation models from ROV photomosaics can be done at 1-10 cm cell resolution, and on vertical structures (something AUVs currently struggle to achieve), thus enabling extremely detailed structural information to be extracted (Robert et al. 2017). Additionally, and perhaps more importantly, the benefits of using ROV to provide digital elevation models is that they also provide colour information (via the photomosaics), which is crucial for identification of species and evaluation of condition (e.g. live vs. dead coral).

ROVs are not without their limitations when visually monitoring organisms. Different classes of ROVs are better suited to certain situations and components of a species assemblage (Table 10.2). There is generally a trade-off with high-quality macro-imagery and ROV functionality associated with high costs and technical requirements (Figure 10.1). When using ROVs for visually monitoring marine organisms, researchers should consider the potential effects of differing light intensity and wavelength, impacts of sound intensity and frequencies (for example, large hydraulic ROVs are noisy), and consequences of vehicle speed, size, altitude on survey bias particularly on mobile organisms. Research suggests that a combination of these factors can have substantial effects on the data collected (Stoner et al. 2008, Ryer et al. 2009, Rountree & Juanes 2010). While all sampling platforms have associated biases, the limited access to work-class ROVs and a steady uptake of cheaper smaller vehicles may make ROVs particularly prone to this bias. This is particularly important if different vehicles are used between regions (e.g. inside vs outside no-take reserves) or across time series sampling.

A key advantage that ROVs have in a monitoring context is their ability to be dynamically controlled in ‘real time’ across a range of depths and habitats. This is because data are streamed real time which means that the vehicle can survey vast areas with constant supervision and can be easily focused on areas of interest. ROVs are the only marine imagery systems available in Australia that are able to readily collect quality imagery from highly rugose environments, including vertical rock walls, steep slopes, and overhangs. These environments are prevalent in many marine parks, along the continental slope and offshore reefs. Similar to AUVs, when equipped with acoustic positioning (e.g., ultra-short baseline, USBL), ROVs can be piloted along precisely defined transects, at a constant altitude, with the geolocation of individual still images along this path as well as forward facing stereo-video (along with other sensors if required/fitted). The geolocation of imagery and flight paths allows relatively precise repeat transects to be conducted for monitoring purposes, and also for the imagery to be used to ground-truth multibeam sonar (Ierodiaconou et al. 2011), assessing the effectiveness of marine protected areas (Torriente et al. 2019), as well as for modelling the environmental factors driving species’ distributions (Salvati et al. 2010, García-Alegre et al. 2014, Lastras et al. 2016). Although ROVs have been shown to collect comparable reef fish assemblage data as diver-operated video and slow towed video (Shchramm et al 2019), they are uniquely suited to collect data in environments that are otherwise challenging to other sampling platforms.

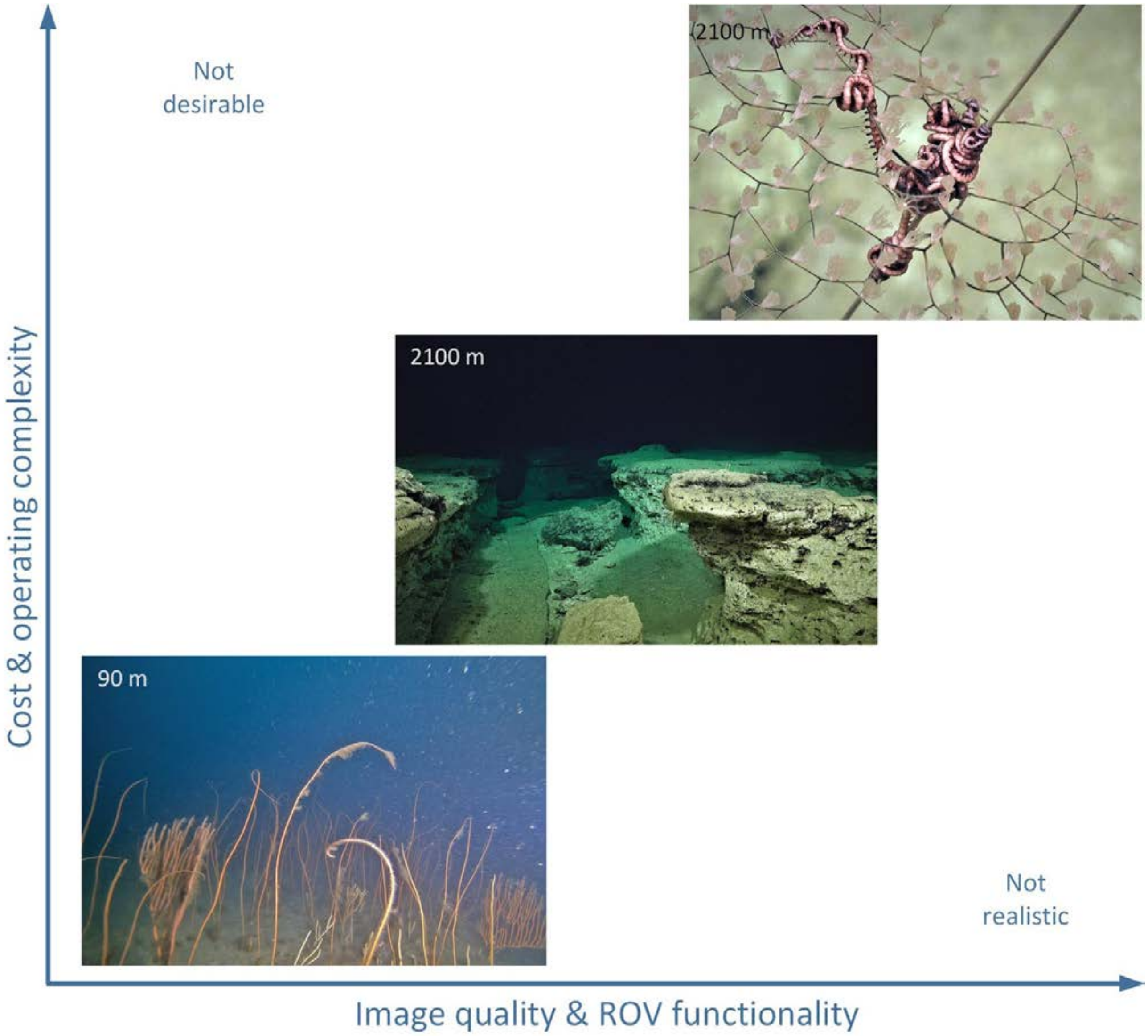

Figure 10.1: Sample images showing the tradeoffs for different ROVs: [left]: sessile invertebrates from Hunter Marine Park from a BlueRobotics BlueROV (with a heavy kit upgrade) fitted with stereo GoPro HERO7 Black cameras, [middle] limestone outcrops along a canyon slope in the Gascoyne Marine Park from the ROV SuBastien's situational camera, and [right] brittlestars entwined around a black coral from the ROV SuBastien's 4K camera.

Table 10.2: Summary of ROV classes and considerations associated with each when used for monitoring Australia's marine estate (table modified from JNCC, 2018).

ROV class	**Class I:** **Observation**	**Class II:** **Observation (with payload option)**	**Class III:** **Work**
			
Definition and capability	Typically < 40kg in weight these vehicles are primarily intended for observation only. Fitted with inbuilt camera and lights, may be able to handle one additional sensor (such as USBL), simple grabber claws, as well as an additional stereo-video camera.	Larger vehicles than Class I, weighing ~100-150kg, are capable of basic physical sampling and observations. Capable of carrying multiple cameras and sensors as well as simple gabber claws.	Weighing <~5000kg, these vehicles have a broad carrying capability and operational conditions (e.g. depth and currents). Usually used in deeper waters (i.e. off continental shelf) these are the most complex and versatile of ROVs used. They are often used in the Oil and Gas sector.
Examples	BlueROV, Boxfish, DeepTrekker, Fusion, Ocean Modules V4 S300, OpenROV, Seabotix LBV300, Trident, VideoRay Pro4	Ocean Modules V8 M500, Pollox, Phantom, Saab Seaeye Falcon (DR)/Cougar XT	Argus Mariner XL/Worker, Hercules; Holland, Isis; Jason 2; Kiel6000; Ocean Modules V8 L3000, SuBastian
Scale of operation^	Fine (<20m) - Meso (200m - 1km)	Meso - Macro (>1km)	Meso - Macro
Max. operational conditions	Depth: <100m Sea state: <2m Current: <1.5kt	Depth: 0 - 300m#, Sea state: <3m Current: <3kt	Depth: >300m, Sea state: <4m Current: <4kt
Deployment type	Manual	Manual (<300m depth) or vessel A Frame/crane and winch or Launch And Recovery System (LARS) package.	LARS package or vessel A-frame/crane (for shallow deployment). A moonpool is a further option.

Tether management	Free swimming - tether connected to ROV. Clump weight recommended in deep/high current deployments.	Single body on main umbilical (live boating) or Tether Management System (TMS).	Single body on main umbilical (live boating) or TMS.
Approx. survey cost per day*	AUD 2,000 - 10,000	AUD 5,000 - 40,000	AUD 50,000 - 120,000
Approx. purchase cost^^	AUD 10,000-250,000	AUD 200,000-1,000,000	AUD 1,000,000-6,000,000+
Vessel requirements	Fixed platform (jetty/pontoon/oil/gas platform), small vessel (<10m) (with or without power supply) or other small vessel.	Shallow draught vessels suitable for inshore waters (10-30m), for extended offshore surveys larger (~>30m) vessels will be used.	Large vessel (~>50m) with Dynamic Positioning (DP), deck capacity for container storage and LARS.

^ Ability to navigate across distance

Deep Rated vehicles are available for >300m but have limited mobility at these depths.

* Planning and field work only. Purchase of ROV, consumables, processing of samples and reporting are not included.

^^ Estimates include basic positioning systems (such as USBL), grabber/manipulator and depth rated stereo cameras. Based on quotes from the companies as well as catalogue entries.

Pre-Survey Preparations

Ensure all permits, safety plans and approvals have been obtained. Any research undertaken within Australian Marine Parks (AMPs) requires a research permit issued from Parks Australia. See Appendix A for a list of potential permits needed. The observation of animals should be undertaken in an ethical manner and in many cases, surveys may require approval from an Animal Ethics Committee.

Define the aim of the project. This is a mandatory step in any marine monitoring project, but with their multiple capabilities (imagery, sampling, sensors), projects using ROVs may be particularly vulnerable to competing research interests or distractions during a dive. A clearly defined aim or hypothesis ensures the ROV pilot stays on task and is not distracted.

Confirm sampling design is statistically sound with adequate spatial coverage and replication, and addresses the aim or hypothesis. This is generally achieved through the use of an explicit randomization procedure to ensure that a sufficient number of independent replicates are obtained (Foster et al. 2017, 2019, Smith et al. 2017). See Chapter 2 for further details on sampling design.

Select appropriate transect design for ROV deployment (Foster et al. 2019). The decision to which transect design is most appropriate is driven by the question being addressed, the applied capabilities of the ROV (i.e. sampling may be applied concurrently with image acquisition), the environment, available time and logistics of ROV deployment and retrieval (e.g. size of system). For example, tether and vessel drag within environments exposed to strong currents makes piloting an ROV along a predetermined transect difficult if not impossible. In such situations ROVs (particularly small ROVs) may not be the best system for temporal monitoring purposes because of the challenges with maintaining physical position to enable sufficient overlap between repeat surveys (i.e., within 20 m) (e.g. Przeslawski et al. 2012 in northern Australia). In addition, some consideration must be given to the unique capability of ROVs to traverse steep slopes, including vertical deployments, when undertaking quantitative image transects of a set distance. For these situations, calculated distance cannot be 'as the crow flies' and will rely on high-resolution bathymetry as well as continuous monitoring by the ROV crew during deployment to determine actual distance traversed.

For marine monitoring demersal fishes on the continental shelf a transect of ~150-200 m is sufficient. Monk et al. (Unpublished) contrasted three transect lengths (50, 100, 150 m) finding that at least 150 m was a generally sufficient design for monitoring purposes of demersal fish diversity (< 200 m). For surveys aiming to collect imagery of the epibenthos, or in deeper environments, then longer transects are possibly required to gather sufficient imagery to characterise the focal regions.

For surveys that include fauna of mixed mobility, for example fish and invertebrates, a dual transect approach may be suitable. The transect area can first be surveyed rapidly to ensure individuals of highly mobile taxa are included, and then again at a slower speed to ensure observation of smaller and more cryptic species.

For survey of fauna associated with topographical features, for example seamounts, vertical reef structures or oil and gas facilities, transects conducted in an arc around the feature may be more suitable than linear transects. The ROV can be thrusted laterally, allowing cameras to be consistently oriented toward the feature throughout the transect.

Stereo-cameras specifications and calibration (must be pre- and post-calibrated) in shallow water using the techniques similar to those outlined in Boutros et al. (2015). We recommend cameras with full, high-definition resolution of at least 1920 x 1080 pixels and a capture rate of at least 30 frames per second. Higher camera resolution will improve identification of fish, and the pixel selection required for measurement, but some models of action cameras can overheat at high resolution. Higher frame rates reduce blur on fast-moving species. To maintain stereo-calibrations, cameras must have video stabilisation disabled, and a fixed focal length can facilitate measurements both close to and far from the camera systems when correctly calibrated (Boutros et al. 2015). The field of view should be standardised and chosen to limit distortion in the image (e.g. no more than a medium angle, ~95° H-FOV). When sampling demersal fish assemblages at typical maximum range (6 m) from the cameras, Boutros et al. (2015) suggested a separation < 450 mm will result in a decrease in the accuracy of measurements. Cameras are fixed to a rigid base bar to preserve the stereo-calibration required to calculate accurate length and range measurements (Boutros et al. 2015). As outlined in Chapter 5 for stereo-BRUVs, SeaGIS software and 3D calibration hardware is recommended for calibration of stereo video imagery. For stereo still imagery then a similar approach documented in Chapter 4 for AUVs, with consistent lighting and adequate base separation ~ 300 mm are important to obtain well-lit and calibrated stereo imagery (Boutros et al. 2015).

Decide on appropriate navigational systems (e.g. USBL) and required spatial precision of imagery. In many cases a USBL should be used for both navigation and georeferencing imagery. However, other methods can be employed such as doppler velocity logging or simple timed directional transects for navigation and calibrated stereo imagery or stereo lasers for image scaling. For many ROV studies the choice of navigational and georeferencing of imagery is often limited to what is fitted to the unit available. However, appropriate effort must be given to this during the survey planning phase as it may limit the questions sought to be answered by the imagery. For example, spatial precision is very important for fine scale analysis whereas navigational accuracy is important for temporal replication. Some alternative navigational methods, simple timed directional transects are sometimes used if a USBL is not used, are not well suited to temporal replication as the exact spatial location of the track cannot be determined. This results in resultant data needing to be pooled to transect level. This reduces a key advantage of ROVs that individual observations can be co-location with finescale covariates (such as from multibeam sonar). This makes that data collected in this fashion more akin to stereo BRUVs or underwater visual census which essentially aggregate individuals to a sample. We suggest that both accuracy and spatial precision need to be addressed for distance and swept area determination.

Ensure appropriate software is installed on onboard laptops (e.g. ROV navigation software platform, GIS, etc), and potential users are familiar with it so that the ROV can be tracked and its mission success monitored while underway. It is worth setting all equipment up in the laboratory or at dock to ensure everything is operational and no software updates are required.

Ensure a trained technical team. For the work-class ROVs, a professional technical and piloting team with training specific to the designated ROV will be required. For the smaller ROVs, training on piloting and technical issues is still highly recommended during the pre-survey planning stage.

Field Procedures

Many of the steps in this section are designed for smaller class ROVs and are to be managed by researchers or general marine technicians. Work-class ROVs will have their own deployment protocols based on the technical capabilities and logistic requirements for the particular ROV and associated professional team, and these may supersede the specific steps below.

Onboard sample acquisition

Complete an on-site briefing.

Prior to deployment, a deployment briefing should always be completed to ensure the operation can be completed safely. Always take a precautionary approach to risks associated with vehicle deployment. See Chapter 1 for further information about risk assessments.

Set up and test the ROV system.

Allow sufficient time during survey mobilisation to undertake system checks, calibrations and testing of equipment and account for unforeseen problems; in most cases it will be possible to complete all system setup and tests within half a day. The conduct of pre-start checks should be noted in the trip log and any test failures specifically recorded for later-reference. Detailed settings for each component should be made using relevant operations manuals (e.g. USBL operations manual etc.).

Acoustic tracking setup

- Set position of GPS receiver. *Differential GPS is mandatory for repeat site monitoring.*
- Measure offsets of USBL transceiver head to GPS receiver and put offsets into navigation systems.
- Deploy USBL transceiver (e.g. pole or vessel mounted).
- USBL calibration dockside is a good idea as well to verify that range and bearing (and depth if estimated by USBL) are within expected tolerances. Understanding the selection and recording of filtering/smoothing settings of the USBL system should also be noted.

On-deck tests should include, but not limited to, the following checks:

- on-board data storage
- on-board power (if fitted)
- cameras
- tether management system (including assessing for nicks in tether)
- strobe lighting
- thrusters (assessing for fouling and operation)
- Manipulator arm(s) and sample container(s) (if fitted)
- all blanking plugs are installed
- crane and associated shackles are working order
- check all seals/o-rings and blanking plugs are good working order
- check all surface communications

Wet testing should include checks of the following:

- Thrusters (including all directions)
- USBL and internal navigation (e.g. compass and avoidance sonar)
- cameras and strobes
- avoidance/scanning sonar (if fitted)
- through-water communications

<u>Conduct ROV transects</u>

Pre-deployment

- Transects should only be undertaken in areas where the substratum is known, preferably in the form of multibeam mapping, so as to avoid entrapment and potential loss of ROV. <u>Do not deploy blind</u>, as this increases the risk of equipment loss and damage, as well as unnecessary impact on potentially vulnerable ecosystems.

- Once final transect locations have been determined, provide the locations of the transects (usually in ESRI shapefile format or start and end waypoints) and associated multibeam maps (in geotif format) to the ROV crew responsible for piloting missions. Cross-check the uploaded transect corresponds to the correct area on the geotif (i.e. ensure the geographic coordinates are defined for all spatial data).
- Discuss the desired target location and the feasibility of deploying at that location. Main items to take into account are:
    - Terrain. To minimise the risk of a deployment in highly rugose seafloor (e.g. walls) it is recommended that transects should be conducted up or along walls. Also consider the water visibility. If there are any large ridges, boulders, drop-offs, etc. along the proposed transect with minimal forward vision (< 10 m) there may not be a large margin for avoidance.
    - Currents/weather/sea state. During the transect, the USBL display will show the boat and ROV position, allowing the skipper and ROV pilot to discuss tracks and adjust speed if required. This can limit the manoeuvrability of the ship and depending on the direction of the prevailing wind and sea, is not always possible on a particular heading. As the sea-state and swell can affect the ships manoeuvrability when travelling at low speeds it is essential to regularly check the weather forecast to ensure the sea state is acceptable and the platform can be safely deployed and retrieved.
    - Depth. Be aware of the depth limitations of the ROV and the length of the tether.
    - Entanglement procedure. Discuss potential entanglement procedure (detailed below) making sure each person is familiar with their role.
- Prepare for ROV launch and recovery on deck and ensure only essential personnel participate in its preparation and deployment.
- Place USBL transceiver in water and ensure functionality.
- Ensure tether is connected, turn on ROV and run all surface checks of the ROV as per manufacturer's requirements.
- Check camera settings (if external cameras are being used).
- Check data sheet is ready (note site, camera numbers and memory card numbers).
- Turn external cameras on, check there is battery and storage space available.
- Insert cameras into housings, check that the housing is dry and that there is no sand, hair or other objects obstructing the o-rings, and ensure there is a good seal and the o-ring is not pinched.
- Film data sheet or clapper board so that the site/location is identifiable at the beginning of the video (only needed if cameras are external to ROV).
- Film diode, or use clapper board, or alternative device to synchronise video footage.
- Correctly insert the deployment release pin (if using).

ROV deployment

1. Vessel master must ensure the vessel is positioned at the start of the transect location.
2. Following the signal to deploy from the vessel Master, use the crane and/or A-Frame to lift and guide the ROV from the deck into the water. Or, if using a small observation class ROV signal to the deckhand to gently place the ROV in the water ensuring the thrusters are disabled or unarmed.
3. Minimise the time taken from when the ROV is out of reach, to when it is lowered in the water, so as to reduce potential swing and impact against the vessel. As soon as the ROV enters the water, pilot it below or away from the vessel to avoid drifting into or over the ROV.
4. Using appropriate software (see Pre-Survey Preparations), rapidly pilot the ROV to the seabed and at the start of transect location to avoid drifting off the starting point.
5. Confirm imagery and positional data are being recorded where possible (e.g. recording indicators, hard drive operating).

ROV maneuvering

1. At the start of the transect flash lights or something similar should be used to indicate the start of the transect. This is important to be able to sync footage with a USBL track (if used) when the cameras are not integrated into the ROV.
2. The ROV should be positioned so that it is on course for the transect trajectory before the transect start-point, so that movements are stable when it reaches the start of the transect. Once the ROV is following the planned transect track the pilot can switch to ‘auto-heading’ to hold course (if available).
3. The flight elevation of the ROV should be set (either manually or automatically) and maintained at ~ 1 m from the seafloor to facilitate a consistent field of view (i.e. ~5 m width transect for mobile organisms with this width being measurable if calibrated stereo cameras are fitted). Try to maintain a constant forward momentum of ~ 0.5-1 ms^{-1} (1-2 kt). Avoid stopping or chasing fish/organisms off the transect. Also avoid disturbing the substratum as sediment clouds will obscure the image (Hitchin et al. 2015). However, if elevation is too high then fish observations are likely to be reduced. These factors need to be informed by the 'survey question', camera type and performance, illumination type and output power, etc.
4. Ask the vessel's Master to follow the ROV during transects. If current/wind is too strong then the vessel may need to anchor. A sea anchor or drop/clump weight can be used to reduce the effects of vessel and tether drag, respectively. If survey designs require live-boat procedures it is more likely that operations would cease if weather conditions deteriorate too much, unless there was an alternate survey objective that could be accomplished at anchor.
5. Make sure that the tether is kept away from vessel propellers at all times. A crew member must maintain tether management at all times. Clear and uninterrupted communication between ROV pilot, tether crew and vessel master must be maintained at all times.
6. Monitor weather forecast conditions prior to and during deployment to maintain a safe working environment. Consider aborting operations if local weather and forecast conditions are marginal.

7. Vessel/ROV maneuvering is a nuanced topic, with most work class ROV teams having their own protocols. Importantly, planning a transect in a fashion that avoids positioning the ROV between the vessel and known entanglement risks (ledges, pinnacles, fishing gear, etc) is the most important general protocol. The goal being to avoid a situation where the vessel drags the tether into the entanglement because the vessel is typically less maneuverable and has less situational awareness of the terrain. Current direction and speed become forces that influence how easy this is to accomplish but many other factors may dictate how a team chooses to mitigate this risk. Before each transect operators should discuss with vessel master if the entrapment risks associated with the seafloor are low enough for the transect to be completed successfully.

ROV retrieval

1. When the transect is complete or if the transect is being aborted, advise the vessel Master of the intention to retrieve the ROV.
2. Watch for the ROV to resurface, ensuring only required personnel are near open transom. Avoid approaching the ROV looking into the sun as this increases the risks of collision.
3. Use a grapple hook to connect the lift line to the ROV for retrieval. Depending on the size of the ROV, at least three personnel should be present with hooks to avoid the ROV colliding with the vessel *[Recommended]*.
4. Shut down the ROV. (Dis)connect relevant tether or data transfer cables.
5. For the last transect of the day, if available, wash down the ROV with freshwater and unplug the USBL.
6. Raise the USBL transducer (if pole mounted) before moving the vessel to the next location.

Procedures for seabed entanglement or loss of communications with ROV

Potential entanglement of the ROV is always a possibility. The following procedures should be followed upon entanglement/loss:

1. Log the last known position of the ROV.
2. If the ROV appears entangled (i.e. not moving) try to maneuver the vehicle so as to be able to follow back along the tether to see if and where the tether has become snared. If the ROV is trapped under a ledge/cave, or ensnared in a fishing line or kelp, a dive team or additional ROV may be required. It may be required that the tether is disconnected from the vessel before recovery equipment is launched. In such circumstances, the tether end should be temporally sealed and attached to surface floats which will reduce water damage to the tether.
3. Ensure the vessel is maintaining position and is not adding increased tension to entangled tether.
4. Ensure that you check ROV thoroughly for damage before redeployment.

Completion of operations

Prior to any vessel movement or engine start-up, operators should check the following:

- All equipment is clear of the water, including the USBL transducer pole.
- ROV is shut down.
- All gear is safely stowed.
- All power and data cables are (dis)connected.
- External cameras are turned off.
- An "All Clear to Move" command is given to the vessel Master when the ROV team is satisfied it is OK for the vessel to move on.

Onboard data processing and storage

1. Once the ROV transect is complete, it is good practice to download associated raw imagery and associated positional data. Imagery and associated positional data should be checked to ensure no failures have occurred, including but not limited to the following:

    - Miss-timing between image capture and strobes (i.e. dark/black imagery)
    - Failure of one of the stereo cameras
    - Failure of positional logging

2. Name data files according to established conventions. File naming conventions are vital for ensuring both efficient and effective management of field data and its integration into appropriate data management repositories. It is important to note that these conventions will differ among agencies and academic institutions. Examples of stereo imagery naming conventions are provided in Chapter 5 for benthic stereo-BRUVs.

3. Ensure accurate recording of metadata. Metadata are descriptive data sources composed of information that may be used to process the images or information therein and for archiving data on data portals (Durden et al. 2016). While it is important to follow agency specific protocols for capturing metadata, it is also essential that metadata are sufficient enough in detail to satisfy conformance checks for subsequent data release via AODN. Minimum data for each transect should contain as follows:

    - Campaign (i.e. Survey identifier)
    - Station/event number
    - Platform
    - Latitude and longitude (WGS 1984 in decimal degrees with a minimum of 6 decimal places *[Recommend]*)
    - Altitude in m
    - Depth in m
    - Time and date stamp in UTC
    - AUV orientation (roll, pitch, heading) in degrees

- Precision details (e.g. type of navigation system used and its associated errors)
- Data provenance

4. Backup data. This is necessary to ensure all data collected in the field is safely returned and securely backed-up at host facilities, prior to quality control and public release. Onboard copies of data should be made as soon as practical following acquisition. When operating external to a network, it is recommended that all data be backed up on a RAID or a NAS that contain built-in storage redundancy in case of hard-drive failure. A duplicate copy of all data can be copied onto external hard drives for transportation back to host facilities *[Recommended]*.

Post-Survey Procedures

Imagery collected by ROV can be either in the form of video footage or still imagery. What type of imagery is collected and annotated is dependent on the aims or hypothesis. Each has its advantages and disadvantages. Below outlines the workflow for both video and still imagery.

Processing and annotation of video footage

The annotation of ROV imagery will vary according to survey aims and hypotheses, as well as availability of staff and time for this activity. Below we provide standards for annotating ROV imagery for fish based on stereo imagery and habitat and communities based on downward-facing stills.

ROV based stereo-video should be treated similar to stereo-DOV footage (Goetze et al. 2019). Where possible and in line with survey aims and hypotheses, species composition, abundance and length data for all species should be recorded.

For studies focussing on fish or overall community composition, every fish along a transect should be measured (where possible). However, fish that occur in large schools, and are of similar size, can be attributed to binned length measurement using the Number field associated with each length in EventMeasure (or equivalent if analysed using other softwares). It is important to document the range from camera as this is likely to change between regions/ecosystems. This information is included in the standard outputs of EventMeasure and is imported by default into GlobalArchive (see below).

There are several software packages available, but it is important the output from the analysis of data is in the same or similar formats to facilitate comparison of data between campaigns, studies, and organisations. The most commonly used annotation software is EventMeasure from SeaGIS (https://www.seagis.com.au). If afforded, then the EventMeasure software is recommended, unless your organisation already has an alternative established stereo-video annotation workflow (e.g. AIMS). The essential information produced by such annotation software includes three main outputs:

- Point information
- Length measurements
- 3-D point information

Point information is typically used to calculate abundance values, while length and 3D point information is used to calculate length and biomass metrics. EventMeasure has established queries built-in to produce typical metrics over a user defined period within the footage. Periods can be used to define the start and end transects if multiple are conducted in the same deployment. In addition, EventMeasure annotation datasets held within GlobalArchive (http://globalarchive.org/) can be queried in a similar fashion to produce such metrics (see the manual for GlobalArchive).

Type of fish length (e.g., fork length or total length for fish and disc length for rays) should be clearly indicated as part of the adequate annotation information for each transect/campaign.

Processing and annotation of downward facing still imagery

A general workflow for processing and annotating epibenthos still imagery can be found in Williams et al. (2012). Key requirements for raw image processing and positional data are as follows:

- It is recommended that at least one of the stereo images is in colour and enhanced following similar procedures as outlined by Bryson et al. (2016).
- Ideally all stereo images should be georectified similar to Williams et al. (2012). If not stereo then processing routines can be found in Morris et al. (2014).
- Positional data should be post-processed. This could include using Simultaneous Localisation and Mapping (SLAM) as demonstrated in (Barkby et al. 2009) and (Palomer et al. 2013) for AUV imagery.

Annotation of individual images can be done using a number of annotation software tools. Examples include, Transect Measure, BenthoBox, Coral Point Count, CoralNet and Squidle+. For national consistency Squidle+ (http://squidle.org) is recommended as it is free and allows for different approaches in image subsampling (such as a spatially balanced selection), which is important to minimise spatial autocorrelation and influence inferences from data (Monk et al. unpublished data), as well as stratified and random point count distribution on images. Squidle+ will also automatically import the ROV data once it is linked to a data portal (such as IMAS data repository) making it ready for analysis. Squidle+ also has tools for exploring survey data as well as analysis. In addition, it supports multiple annotation schemes, and will provide consistency through translation between schemes, which is an important point that differentiates Squidle+.

There are three approaches recommended for annotating imagery from ROVs:

- Annotation of individual images
- Annotation of photomosaics
- Extracting structural complexity from orthomosaics

Annotation of individual images or photomosaics can be undertaken using three methods:

- Full assemblage scoring of imagery across space and time. It is important to note that this is a time-consuming process, requiring a lot of replicate images to be scored to enable sufficient power to detect biologically meaningful change as most morphospecies cover < 10 % of an image. This approach appears to be good for delineating bioregional and cross-shelf patterns at a morphospecies (Monk et al. unpublished data) and CATAMI (Althaus et al. 2015) level (Monk et al. 2016, James et al. 2017). This approach will no doubt be effective in choosing an initial suite of indicators for national level monitoring and reporting.

As a general guideline, and dependent on the survey question, we recommend that 25 random points per image from at least 50 images per transect are a good starting point for recording most morphospecies present within images (based on Perkins et al. 2016). It is important to note that the properties of the organism themselves will also influence the number of points/images to score. Obviously morphospecies that are less abundant require more effort, but also the 'clumpiness' of species will affect the scoring effort needed (Perkins et al. 2016). (Van Rein et al. 2011) and Perkins et al. (2016) suggest that, while a higher number of points per image can increase the detection rate of more organisms within an image, increasing the number of scored images using fewer points is likely to have a similar (or greater) effect. Ideally, increasing both the number of images scored and the number of points scored within an image would result in greater power (Roelfsema et al. 2006), but preference is usually for increasing the number of images (Perkins et al. 2016). Unfortunately, the adoption of this approach is likely to result in substantial increases in processing time and thus cost.

- <u>Targeted scoring of indicators or proxies</u> (such as grouping fine level morphospecies into broader level CATAMI classes; Monk et al. unpublished data). This approach has been shown to work very well at an indicator morphospecies level for detecting change at a regional level (e.g. AUV imagery used by Perkins et al. 2017) as well as for detecting invasive species trends (Whitfield et al. 2007). Since this approach requires substantially less effort to score each image, more images (i.e. often all images) can be scored and, thus, increasing statistical power. The drawback is that narrower understanding of the environment is produced.

- <u>Automated analysis of imagery</u> potentially provides a cost-effective alternative to annotating imagery from ROVs. It is important to note that automated imagery analysis is a relatively new, and largely developmental, way of annotating images. Despite this, some studies suggest that coral and macroalgae can be reliably identified using automated image analysis (Table 4.1 in Chapter 4 AUV).

- The last approach to annotating ROV imagery involves the extraction of 3D structural information from stereo images using structure from motion techniques (Marcon 2014). This approach works particularly well for sessile species to track changes in growth form through time at a fine scale (Price et al. 2019). It also has application for vertical structure such as reef walls or artificial structures (Robert et al. 2017).

Data curation and quality control

Data quality control at both the collection and annotation stage is critical. For fish datasets we suggest that the same protocols outlined in Chapter 5 (benthic stereo-BRUVs) be followed, whereby strict training of new annotators is undertaken and thorough checks of species IDs are done by trained taxonomists. It is crucial to include the salary or in-kind contribution of taxonomists into project budgets. For epibenthic sessile communities we recommend that the same protocols outlined in Chapter 4 (AUV) be followed, with, most importantly, the annotation schema needs to be consistent between studies. Where possible morphospecies and associated CATAMI parent classes should be used *[Recommended]*. An initial morphospecies catalogue for southeastern shelf waters is currently held and maintained at the Institute for Marine and Antarctic Studies (IMAS) (contact Assoc. Prof. Neville Barrett or Dr Jacquomo Monk). Clearly, other annotation schemas are available and can be applied. Where existing protocols prevent the adoption of this approach the alternative schema must be mapped to CATAMI so that comparisons can be made with previous studies or between regions. Translations between schema can be readily applied within Squidle+. The quality control of all annotations of epibenthic sessile organisms undertaken by novice scorers should be assessed against an experienced analyst or machine learning algorithm (e.g. using confusion matrices; see Figure 4.4 in Chapter 4). Similarly, all datasets annotated by multiple people, even skilled scorers, should be tested for observer bias. If there are significant differences among annotators it is important to correct discrepancies. This can be done by re-examining the images to ensure an agreement can be reached between annotators. Alternatively, if an agreement cannot be reached, then the miss-classified item could be potentially grouped into a higher level CATAMI class.

Data release

Many national marine observing programs (for example IMOS through the Australian Ocean Data Network (AODN), or the Marine Geoscience Data System (MGDS) in the USA) routinely store imagery online in an openly accessible location. Squidle+ is a centralised online platform for standardised analysis and annotation of georeferenced imagery and video. Squidle+ operates based on flexible distributed data storage facilities (i.e. imagery can be stored anywhere in an openly accessible online location) to reduce data duplication and inconsistencies, and provides a flexible annotation system with the capability to translate between different annotation schemes.

Following the steps listed below will ensure the timely release of imagery and associated annotation data in a standardised, highly discoverable format.

1. Create a metadata record describing the data collection. Provide as much detail as possible on the deployment (either directly in the metadata record itself, or in the form of attached field sheets as .csv, .txt or similar). Details of minimum metadata requirements are provided in the On-board Data Storage section above. Publish metadata record(s) to the Australian Ocean Data Network (AODN) catalogue as soon as possible after metadata has been QC-d. This can be done in one of two ways:

    - If metadata from your agency is regularly harvested by the AODN, follow agency-specific protocols for metadata and data release.

    - Otherwise, metadata records can be created and submitted via the AODN Data Submission Tool. Note that user registration is required, but this is free and immediate.

Lodging metadata with AODN in advance of annotation data being available is an important step in documenting the methods and location of acquired imagery and enhancing future discoverability of the data.

2. Upload raw imagery from the survey to a secure, publicly accessible online repository (contact AODN if you require assistance in locating a suitable repository).

3. Create a Squidle+ campaign as soon as possible after imagery is uploaded, choose the most appropriate annotation schema, and commence annotation of imagery.

4. Add links to the location of the Squidle+ campaign to the previously published metadata record. You may also wish to attach or link a copy of the annotation data directly to the record.

5. Produce a technical or post-survey report documenting the purpose of the survey, sampling design, sampling locations, sampling equipment specifications, annotation schema (e.g. morphospecies, CATAMI, etc.), and any challenges or limitations encountered. Provide links to this report in all associated metadata *[Recommended]*.

Data analysis

The breadth of research questions precludes any detailed advice on the analysis of data from ROV transects. However, one common attribute of the image-based data that will have to be considered for all analyses is spatial proximity. The closeness of images, within and sometimes between transects (for example if triangle or clover-leaf transect designs or subsets of longer transects are used), means that image data are unlikely to be independent (due to spatial autocorrelation). Yet, this is an assumption that many statistical methods rely upon. The failure to meet this assumption means that the inferences from the statistical analysis may be: (i) over-confident, e.g. having a p-value that is too small; (ii) biased, i.e. the estimates do not reflect the truth; (iii) both, or; (iv) no effect. Obviously, the fourth category is what a researcher hopes for, but it is improbable and must be validated. However, if it is known that the study organism exhibits particularly low autocorrelation then the analysis need not consider it explicitly.

Methods to analyse data, accounting for autocorrelation are available. These include geostatistical models (Foster et al. 2014). However, in certain situations subsampling images will help (Mitchell et al. 2017), but not necessarily alleviate completely. Further, if the study is for a broad area, where transects are small and are well-separated, then amalgamating data to transect level may also be appropriate. The issues of spatial auto-correlation should also be considered if longer transects are being broken up into smaller sections for analysis (as is commonly done in the oil and gas sector).

Some effort should be made to estimate sources of error inherent in navigational (USBL) systems (and/or other geo-referencing methods) and understand how these errors affect the overall target parameter estimation and variability (see Karpov 2006, Rattray et al., 2017, Mitchell et al. 2017).

Field Manual Maintenance

At the time of writing this manual, there is currently no support for future versions of this manual. However, in accordance with the universal field manual maintenance protocol described in Chapter 1 of the Field Manual package, if such support arises, this manual will be updated in the future as Version 3. Updates will reflect user feedback and new developments (e.g. data discoverability and accessibility). Version 3 will also detail subsequent version control and maintenance.

The version control for Chapter 10 (field manual for ROVs) is below:

Version Number	Description	Date
0	Submitted for review (NESP Marine Hub, external reviewer as listed Acknowledgements.	25 May 2020

1	There was no ROV manual included in Version 1 of the field manual package	n/a
2	Publicly released as Chapter 10 on www.nespmarine.edu.au through online portal	July 2020

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APPENDIX A – PERMISSIONS

List of permissioning documents relevant to marine sampling in the Commonwealth waters (defined as 3 nm to the EEZ 200 nm and extended continental shelf). This list is a guide only, and certainty should be sought from responsible agencies. Also see Chapter 3 for permissions related to multibeam operations. AWE = Department of Agriculture, Water and Environment. Compiled by Melissa Fellows, Dec 2017.

Activity	Sample type	Jurisdiction	Responsible agency	Legislation/Treaty/ Documents	Requirements for approval	Link
Research and monitoring	All activities	Australian Marine Parks	AWE	*Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) Australia Marine Park Management Plans	Authorisation is required for all zones	https://parksaustralia.gov.au/marine/
	Activities that could have a significant impact on a matter of national environmental significance	Within EEZ and on or in the continental shelf beyond 200nm	AWE	EPBC Act	EPBC Act referral	http://www.environment.gov.au/protection/environment-assessments\ http://www.environment.gov.au/epbc/what-is-protected
Sampling	Biological Samples	EEZ (3-200nm)	AWE	*Biosecurity Act 2015*	No importation required if preserved by storage in a sealed container with 70% alcohol or 10% formalin or Minimum 2% glutaraldehyde or plastinated curable polymers and labelled Otherwise refer to BICON for importation requirements	https://bicon.agriculture.gov.au/BiconWeb4.0/ImportConditions/Questions/EvaluateCase?elementID=0000086465&elementVersionID=201 https://bicon.agriculture.gov.au/BiconWeb4.0/ImportConditions/Search

		Waters and seabed of the EEZ and the continental shelf	AWE	*Environment Protection and Biodiversity Conservation Regulations 2000* Part 8A		http://www.environment.gov.au/topics/science-and-research/australias-biological-resources/permits
	Sediment			*Biosecurity Act 2015*	Import requirements for samples collected beyond 200 nm.	https://bicon.agriculture.gov.au/BiconWeb4.0/ImportConditions/Search
Interactions with Cetaceans	Seismic and other acoustic equipment	3nm to EEZ (200nm)	AWE	EPBC Act Policy Statement 2.1	EPBC Referral and comply with Policy Statement 2.1	http://www.environment.gov.au/resource/epbc-act-policy-statement-21-interaction-between-offshore-seismic-exploration-and-whales
	Whale and Dolphin watching	3nm to EEZ (200nm)	AWE	*Environment Protection and Biodiversity Conservation Regulations 2000* EPBC Regulations' *Australian National Guidelines for Whale and Dolphin Watching 2005* Whale and Dolphin Watching Guidelines	Comply with EPBC Regulations	http://www.environment.gov.au/marine/publications/australian-national-guidelines-whale-and-dolphin-watching-2017
	Aircraft, helicopters and drones	3nm to EEZ (200nm)	AWE	EPBC Regulations Whale and Dolphin Watching Guidelines	Comply with EPBC Regulations Permits required to operate a drone in close proximity to a whale or dolphin. Refer to Whale and Dolphin Watching Guidelines for allowable operating distances	http://www.environment.gov.au/system/files/resources/7f15bfc1-ed3d-40b6-a177-c81349028ef6/files/aust-national-guidelines-whale-dolphin-watching-2017.pdf
	Vessel interaction	3nm to EEZ (200nm)	AWE	EPBC Act EPBC Regulations (part 8)	Report death, injury, stranding or entanglement of whales and dolphins to AWE Specific requirements for vessels	

	Study of cetaceans: take, keep, move, interfere with (harass, chase, herd, tag, mark or brand) and to possess or treat (divide cut up, extract any product from)	Australian Whale Sanctuary 3nm to the EEZ (200nm) And in waters beyond for Australian residents	AWE	EPBC Act	Research permits for research actions that contribute significantly to the conservation of cetaceans	http://www.environment.gov.au/marine/marine-species/cetaceans/research-permits
Interaction with Heritage	Historic Ship wrecks	Waters above the Australian continental shelf	AWE	*Historic Shipwrecks Act 1976*	Ship wrecks and relics older than 75 years are protected. Some ship wrecks lie within protected zones. Permits required to enter a protected zone for some activities.	http://www.environment.gov.au/heritage/historic-shipwrecks
Offshore petroleum and greenhouse gas exploration	Geophysical, geotechnical, seismic, drilling.	3nm seawards to the outer limits of the continental shelf.	National Offshore Petroleum Title Administrator NOPTA	*Offshore Petroleum and Greenhouse Gas Storage Act 2006* (OPGGSA) *Offshore Petroleum and Greenhouse Gas Storage (Resource Management and Administration) Regulations 2011*	Title required to undertake activity.	http://www.nopta.gov.au/ http://www.nopta.gov.au/guidelines-and-factsheets/offshore-petroleum-guidelines.html
		3nm seawards to the outer limits of the continental shelf.	National Offshore Petroleum Safety Environment NOPSEMA	*Offshore Petroleum and Greenhouse Gas Storage Act 2006* *Offshore Petroleum and Greenhouse Gas Storage (Environment) Regulations 2009*	Accepted Environment Plan in place, includes EPBC Act requirements.	https://www.nopsema.gov.au/environmental-management/assessment-process/environment-plans
Installations	Installations, in contact directly or by cable or similar device with the seabed for 30	3nms seaward to EEZ or outer limits of the continental shelf		*Sea Installations Act 1987*	Permitting system no longer applies, however maritime safety, customs, immigration and quarantine matters continue.	http://www.environment.gov.au/topics/marine/marine-pollution/sea-dumping/sea-installations

	continuous days or one or more period during the 60 days that sum to 40 days.				Safety zone of 500m may apply.	
Restricted vessel movement and moored scientific equipment that create navigation hazards			Australian Hydrographic Service AHS Australian Marine Safety AMSA		Notice to mariners 2-3 weeks prior to survey commences. Vessel to RCC to update NAVAREA X alerts	http://www.hydro.gov.au/n2m/about-notices.htm datacentre@hydro.gov.au,rccaus@amsa.gov.au https://www.amsa.gov.au/safety-navigation/navigation-systems/maritime-safety-information-database natuticaladvice@amsa.gov.au rccaus@amsa.gov.au
Research in the Great Barrier Reef Marine Park GBRMP	Research, except for limited impact research.	GBRMP	Great Barrier Reef Marine Park Authority GBRMPA	*Great Barrier Reef Marine Park Act 1975* *EPBC Act*	Limited impact research may be conducted under a letter of authority issued by an accredited educational or research institutions All other research requires permission	http://www.gbrmpa.gov.au/zoning-permits-and-plans/permits http://www.gbrmpa.gov.au/zoning-permits-and-plans/permits/research-permissions
Research around infrastructure, cables and pipelines	Disturbance of the seafloor and strong acoustic disturbance (seismic)	Cables – Australian continental shelf Pipelines – 3 nm to 200 nm and extended continental shelf	Cables Australian Communications and Media Authority ACMA Pipelines National Offshore Petroleum Titles Administrator NOPTA	*Telecommuncations Act 1997* International Cable Protection Committee (ICPC) recommendations	500m safety zone Liability for damage to cables Spatial pipeline data	https://www.acma.gov.au/Industry/Telco/Infrastructure/Submarine-cabling-and-protection-zones/submarine-telecommunications-cables-submarine-cable-zones-i-acma https://www.submarinecablemap.com/ https://www.iscpc.org/ https://www.iscpc.org/publications/recommendations/ http://www.nopta.gov.au

Sea dumping	Deliberate dumping of wastes at sea	EEZ	AWE GBRMPA	*Environment Protection (Sea Dumping) Act 1981* London Convention, 1972/96	Permits for large scale dumping required	http://www.environment.gov.au/marine/marine-pollution/sea-dumping

APPENDIX B – POST-SURVEY REPORT TEMPLATE FOR SAMPLING IN AUSTRALIAN MARINE PARKS

Organisation Name

AUSTRALIAN MARINE PARK BASELINE AND MONITORING SURVEY

POST SURVEY REPORT

<insert Marine Park name>

<month year>

<insert image(s)>

Insert Author
[Pick the date]

Table of Contents

EXECUTIVE SUMMARY

Guidance note: Provide a short summary of the post survey report, including:

- survey name and ID, vessel, survey location and dates of survey;
- participating agencies and institutions;
- brief description of AMP and study area, including regional context;
- high-level survey objectives that link to Parks Australia research priorities and information needs (e.g. "…to build the baseline inventory of seabed habitats in xxxx marine park….");
- specific survey objectives, including science questions and/or hypotheses being addressed/tested;
- key results including summary statistics for data types acquired (e.g. km^2 seabed bathymetry and backscatter coverage; line km of towed video/AUV; number of hours of baited underwater video deployment; number of physical seabed samples etc)
- preliminary interpretations of survey results – at high level and in terms of habitats, biodiversity, trends, responses to pressures, etc
- highlights of new science discoveries (new species, seabed features previously unknown, etc)

INTRODUCTION

Background and Rationale for Survey

Guidance note: Narrative that provides the context and drivers for the survey in terms of scientific questions/issues being addressed and links to the research priorities and information needs of key stakeholders. Briefly introduce the marine park that the survey was conducted within.

Australian Marine Park Context

Guidance note: Overview of management plan that applies to the particular marine park that was covered by the survey, including identification of conservation values (physical, biological, oceanographic), pressures, key ecological features and biologically important areas that intersect the survey area. Include relevant maps, and reference monitoring plan and objectives if one exists.

Aims and Objectives

Guidance note: List of overarching aims of survey and specific objectives, including scientific questions and/or hypotheses being addressed

SURVEY AREA

Location & Description

Guidance note: Description of the survey area in terms of general physiographic, oceanographic and biogeographic setting. Identify the marine planning region and the marine park the survey was undertaken within. Provide a description of the seabed characteristics, oceanography and biological communities, as they are known and/or understood for the particular marine park, including previous studies (referenced). Identify knowledge gaps for the particular marine park.

Survey Grids

Guidance note: Identify the specific areas within the marine park where data acquisition was undertaken. This could be presented as grids, transects and points; or a combination of these. Include relevant maps.

SURVEY DESIGN AND SCHEDULE

General Information

Guidance note: Describe the approach to survey design as linked to survey objectives and research questions. For example, the survey may have applied a spatially balanced randomised method for pre-selection of sampling sites; or a survey that is weighted towards sampling at certain depth intervals (transects), or across particular habitats.

Survey Design

Guidance note: Present details of areas targeted for mapping, sampling stations/transects.

Survey Timetable

Guidance note: Tabulated schedule of events as they occurred during the survey. Optional (could go in Appendix).

METHODS AND DATA COLLECTED

Seabed mapping (multibeam sonar bathymetry and backscatter; sub-bottom profiles; side-scan sonar)

Guidance note: Brief description of instruments used to undertake seabed mapping (e.g. XYZ 300 kHz dual-head multibeam sonar) and statistics for the area mapped. Statistics should include km^2, line kilometres, bathymetric range and acoustic reflectance (backscatter) range for multibeam sonar and depths of penetration for sub-bottom profiles. Include summary tables and maps that show navigation tracks and spatial coverage in the context of the marine park boundary and zones. Also include summary of basic processing steps completed for multibeam, backscatter, sub-bottom and side-scan data)

Seabed sampling (grab samples, cores, other)

Guidance note: Brief description of sampling instrument(s) used and seabed samples collected, including number and bathymetric range. Include a summary table that lists samples collected per site (station), and maps showing sample locations. Include a summary of planned analytical methods (e.g. identification of infauna by expert taxonomist) and lodgement of samples (e.g. sediment samples lodged at GA, infauna lodged at Museum of Victoria).

Seabed observations (towed video, AUV, BRUV)

Guidance note: Brief description of imagery systems used for seabed observations and number, duration and bathymetric range. Supported by a summary table that lists data collected (line km), and maps showing navigation tracks. Include a summary of planned image processing (e.g. Simultaneous Location Algorithm Mapping to develop photomosaics) and annotation (e.g. point count using CATAMI classification in Squidle+) methods.

Pelagic observations (BRUV, visual sightings)

Guidance note: Description of pelagic observations, including number and duration. Include a summary table and maps showing sample locations. Include a summary of planned annotation methods (e.g. use EventMeasure to extract size and MaxN data from video).

Oceanographic measurements (underway, moorings, glider)

Guidance note: Description of oceanographic observations, including number and duration. Include a summary table that lists samples collected per site (station), and maps showing sample locations and navigation tracks. Include a summary of planned post-processing and analysis methods.

RESULTS AND PRELIMINARY INTERPRETATIONS

Seabed Features

Geomorphic features

Sub-seabed structure

Guidance note: Description of seabed geomorphic features as identified from processed multibeam sonar and backscatter data. Features should be classified using standardised terms (e.g. Geoscience Australia glossary of seabed features, in prep.). Include summary statistic on these features (e.g. depth range, area, slope gradients, acoustic reflectance range) as preliminary measurements/assessments. If sub-bottom profiles were collected, include a description of representative transects that illustrate sub-seabed structure of key habitats (e.g. sediment veneer over reef; evidence for sedimentary infilling of depressions/scours; evidence for active bedform migration). Include representative examples of bathymetry grids produced from multibeam data. Relate new findings to previous research if possible. Specify where metadata and data can be accessed.

Seabed Biological Communities

Epifaunal Communities

Infaunal Communities

Guidance note: Description of seabed biological communities as determined by direct sampling and/or imagery. Present in the context of seabed bathymetry and backscatter by overlay onto survey maps. Include summary statistics as recorded during the survey (e.g. depth range, percent cover, area, linear distance) as preliminary measurements/assessments. If specimens were collected, include summary statistics of number of specimens collected, general lifeforms and preliminary identifications. Include example imagery if acquired during the survey. Relate new findings to previous research if possible. Specify where metadata and data can be accessed including DOIs if available.

Pelagic Fauna

Guidance note: Description of pelagic biological communities as mapped by direct sampling and/or imagery. Present in the context of seabed bathymetry and backscatter by overlay onto survey maps. Include example imagery, summary statistics as recorded during the survey (e.g. depth range of observed individuals/schools, number of individuals observed), and preliminary identifications. Relate new findings to previous research if possible. Specify where metadata and data can be accessed, including DOIs if available.

Oceanographic Data

Guidance note: Description of oceanographic data collected. Include general spatial patterns in currents/temperature/salinity/turbidity and summary statistics as recorded during the survey (e.g. trends in CTD profiles, presence of stratified layers, ADCP current patterns). Relate new findings to previous research if possible. Specify where metadata and data can be accessed including DOIs if available.

New Discoveries

Guidance note: Identify and highlight any new discoveries from the survey that serve to add to the knowledge base of the marine park. For example, first-time mapping of particular seabed features; detection of change in habitat and/or biological communities; new marine fauna and flora discovered etc. Specify where metadata and data can be accessed including DOIs if available.

FUTURE WORK

Guidance note: Description of planned, proposed or potential analyses (including future surveys) that will maximise the value of the datasets collected, and contribute to the evidence base to support monitoring and performance assessments of the particular marine park.

Identify science products that can be used to promote the awareness and public interest in this particular marine park, and in marine science in general.

REFERENCES

As appropriate

ATTACHMENT 1 – DAILY LOG OF SURVEY ACTIVITIES

Guidance note: Narrative of daily activities, including key events, decisions and progressive description of survey progress against aims and objectives.

ATTACHMENT 2 – PERSONNEL ON BOARD

Guidance note: Personnel list, including roles performed during the survey (e.g. Survey Leader/Chief Scientist; Multibeam sonar acquisition/processing; Towed-video operator…etc)

Scientific Personnel

Ship Crew

ATTACHMENT 3 – SAMPLES LIST

Guidance note: Tabulated list(s) of all physical samples collected and any descriptions recorded during the survey (following Standard Operating Procedures for various data types). As a minimum, sample lists to include:

- Sample ID (following a standard naming convention);
- Sample type (e.g. sediment, biological
- Gear type (grab, core, sled, towvid etc)
- Sample location (latitude, longitude, decimal degrees to 6 d.p)
  - Recorded as one set of co-ordinates for point observations/samples
  - Recorded as start-of-line (sol) and end-of-line (eol) co-ordinates for transects
- Date of collection (yyyymmdd)
- Date of collection (Julian Day)
- Time of collection (UTC)
  - Recorded as an 'event time' for point observations/samples
  - Recorded as start-of-line (sol) and end-of-line (eol) time for transects
  - Recorded as start-of-deployment and end-of-deployment for instrument/mooring deployments (e.g. BUVs)
- Water depth (m, to 2 d.p)
  - Recorded as an single depth for point observations/samples
  - Recorded as water depth at start-of-line and at end-of-line for transects
- Repository where sample has been lodged
- Comments/Descriptions

ATTACHMENT 4 – LICENCES AND PERMITS

Guidance note: Copies of Permits obtained to undertake work in the particular marine park, including one or both of the following:

Permit to Undertake Research in a Commonwealth Marine Park

Permit to Access Biological Resources in a Commonwealth Marine Area www.nespmarine.edu.au

Contact:
Rachel Przeslawski
Geoscience Australia

Address | GPO Box 378 |Canberra ACT 2601
email | rachel.przeslawski@ga.gov.au
tel | +61 6249 9111