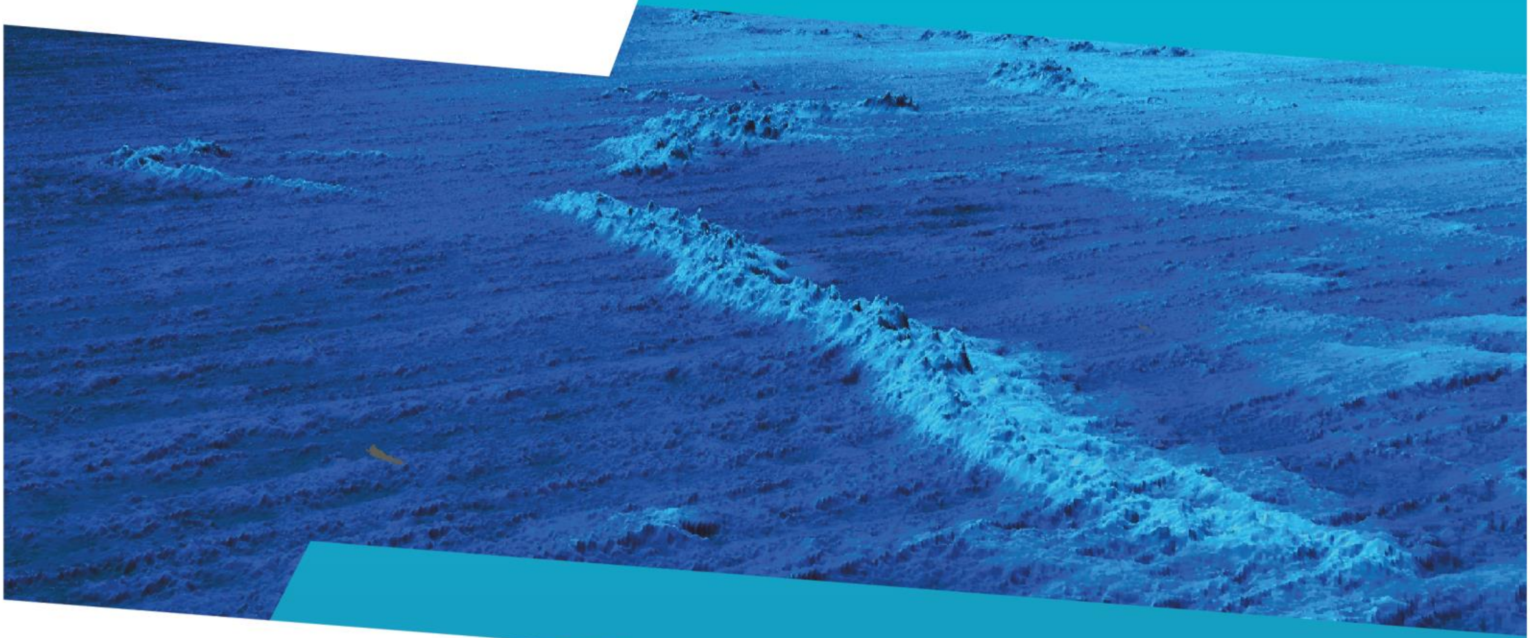

GEOSCIENCE AUSTRALIA
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Multibeam Echo Sounder Data Acquisition in Australia and Beyond

User Needs Summary

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Glossary of Acronyms

ACA	Australian Charting Area
AHD	Australian Height Datum
AHO	Australian Hydrographic Office
AIMS	The Australian Institute of Marine Science
BOM	Bureau of Meteorology
CD	Chart Datum
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CTD	Conductivity Temperature Depth
CUBE	Combined Bathymetry and Estimator
EEZ	Exclusive Economic Zone
ESRI	Environmental System Research Institute
FTP	File Transfer Protocol
GA	Geoscience Australia
GBRMPA	Great Barrier Reef Marine Park Authority
GEBCO	General Bathymetric Chart of the Oceans
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
ICSM	Intergovernmental Committee on Surveying and Mapping
IMCA	International Marine Contractors Association
IP	Intellectual Property
LAT	Lowest Astronomical Tide
LiDAR	Light Detection And Ranging
LINZ	Land Information New Zealand
MBES	Multibeam Echo Sounder
MESH	Marine European Seabed Habitats
MSL	Mean Sea Level
NESP	National Environmental Science Program
NIWA	National Institute of Water and Atmospheric Research
NOAA	National Oceanic and Atmospheric Administration
OGA	Oil and Gas Authority
QA	Quality Assurance
QC	Quality Check
RTK	Real-time Kinematic
SVP	Sound Velocity Profile
THU	Total Horizontal Uncertainty
TPU	Total Propagated Uncertainty
TVU	Total Vertical Uncertainty
XBT	Expendable Bathy Thermograph

Executive Summary

The value and recognition of seabed mapping has been rising, both internationally and in Australia, since the arrival of multibeam echosounder (MBES) technologies in the 1970s. This has been demonstrated recently by the large investments in programs such as Australia's SEA 2400, led by the Department of Defence, and the international GEBCO-Nippon Foundation Seabed 2030 project. The AusSeabed initiative was established in 2017 to support the seabed mapping community across all sectors and fulfil the increasing demand for seabed information. AusSeabed is composed of members from government, academia and the private sector who are seeking to improve the awareness, coverage, quality, discoverability and accessibility of seabed mapping data through coordination and collaboration.

As MBES remains the most popular technology for mapping the seabed, data derived from MBES is a primary focus for AusSeabed. FrontierSI, Geoscience Australia, and Deakin University undertook a study to understand MBES user requirements, in order to ensure AusSeabed meets the needs of MBES users. Specifically, the aim of this study was to identify end-user needs and challenges, and to subsequently capture survey requirements to inform the development of tools to support future MBES survey planning and quality assurance. The study took the form of an online questionnaire, supported by two workshops.

This report summarises the responses gathered from 103 people across 69 Australian and international government, private sector and academic entities. From the pool of participants, 56 per cent were directly involved in MBES acquisition (acquired themselves or outsourced) and the remainder sourced their data in other ways (e.g. using existing public data). Fifty-seven per cent of participants use existing specifications and guidelines during their survey planning, while the remainder sought guidance from other sources, including subject matter experts. In addition, 39% of participants checked for existing data within their area of interest, whilst the remainder identified it was too difficult and time-consuming to find previously-acquired data. Seventy-three per cent of participants reported a willingness to share their data with others, suggesting that the number of users accessing existing data could be increased via provision of an easy-to-use and free data sharing service. Current major obstacles for organisations openly sharing their data include cost recovery, data confidentiality and commercial sensitivities, including IP restrictions associated with the data.

This report identifies 30 specific MBES survey purposes across 10 general application areas, including 1) Coastal Zone Management and Marine Conservation, 2) Commercial Fishing and Aquaculture, 3) Habitat Mapping and Ecosystem Modelling, 4) Hydrodynamic and Storm Surge Modelling, 5) Hydrographic Charting and Navigation, 6) Marine Construction and Infrastructure, 7) Natural Disaster Recovery and Hazard Mitigation, 8) Resource and Mineral Exploration, 9) Geological Mapping and Seafloor Physical Characterisation, and 10) Reference Surface and Ground-Truthing. The technical specifications identified by participants for these applications are provided within the appendix of this report.

This report highlights the most common user challenges for MBES data are processing speeds, management, quality assurance and discovery. Responses also indicate a need for a standardised MBES survey planning workflow and quality assurance tool. AusSeabed, through a collaboration between FrontierSI, Geoscience Australia, CSIRO and the Australian Hydrographic Office, will use the results of this research to inform the development of tools and materials for MBES survey planning, acquisition and delivery. These will directly assist end users in their day-to-day workflow, and will contribute to improving the quality, discoverability and accessibility of the national pool of seabed data.

1 Introduction

Australia has sovereign rights over the seabed of the world's third largest Economic Exclusive Zone (EEZ) spanning around 10.2 million km^2 of the Indian, Pacific and Southern oceans (Figure 1). Australia also has specific obligations under several international conventions[1] to ensure the safety of navigation over another estimated 40 million km^2 of these oceans (Australian Charting Area [ACA] in Figure 1). A better understanding of Australia's seafloor topography (bathymetry) and its composition is required to fulfil this obligation, and to the broader needs of the maritime community.

Despite a significant increase in the global bathymetry coverage in the past decade [1], less than 25 per cent of Australia's marine jurisdiction has been mapped at high resolution resulting in much of the existing coverage of the seafloor providing only a general indication of depth [2]. Additionally, there are substantial gaps in knowledge of the seafloor characteristics, such as the sediment type, geology, and benthic habitats [3].

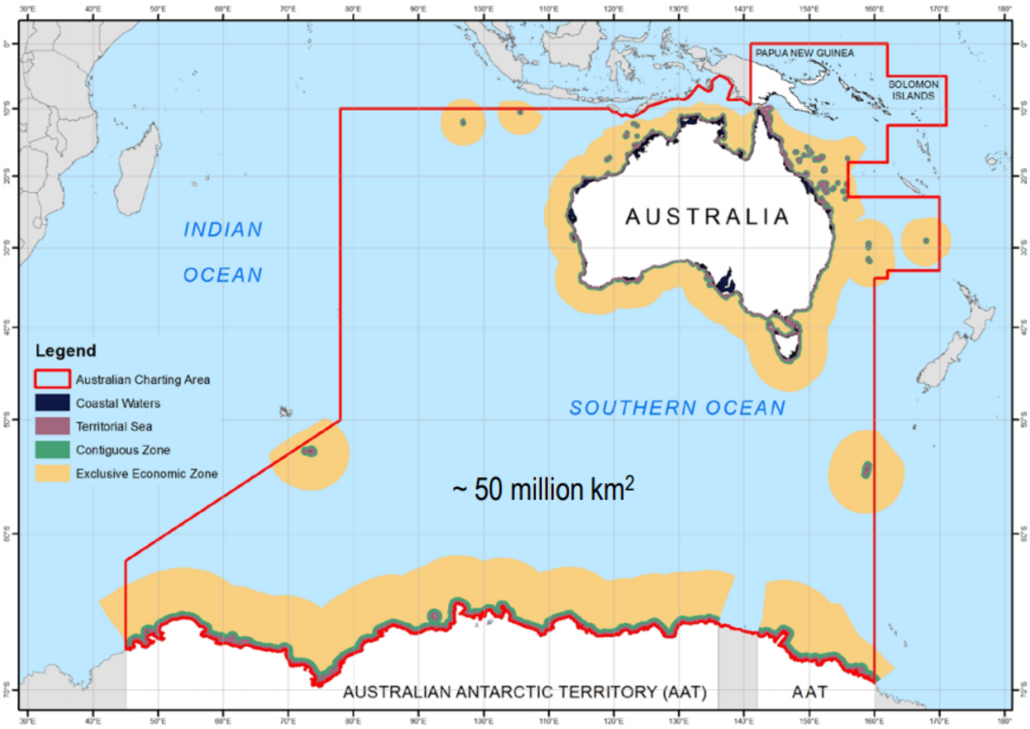


Figure 1: Australia Exclusive Economic Zone and Charting Area (source: Australian Forum for Operational Oceanography [4])

To address this knowledge gap, the Australian Government is investing in programs such as SEA 2400 program funded by the Department of Defence, and the National Environmental Science Program (NESP) funded by the Department of the Environment and Energy. This investment seeks to grow the knowledge, collaboration and sharing of seabed data between commercial providers, government and universities. Due to the lack of national

[1] i.e. Convention for the Safety Of Life At Sea (SOLAS) convention, United Nations Convention on the Law Of the Sea (UNCLOS) and the Navigation Act 2012

coordination of seabed mapping activities, AusSeabed has been established in parallel with these application-specific programs. AusSeabed aims to improve the awareness, coverage, quality, discoverability and accessibility of Australian seabed data. In addition, these initiatives align to a broader international push for increased seabed mapping, with the most significant international program being Seabed 2030 [5], which seeks to consolidate global seafloor data to produce a definitive map of the ocean floor by 2030.

In recognition of the need for high-resolution seabed data, and the substantial future growth in seabed mapping in Australia, AusSeabed has identified and established several national priorities for the better coordination and sharing of seabed data. One of these priorities is to develop a standardised workflow to ensure that seabed data products are fit-for-purpose and meet a minimum quality standard. Multibeam echosounders (MBES) are the most commonly used technology to map Australia's seafloor [6] at a high resolution. Supporting MBES as a priority will therefore provide the most immediate benefit to the seabed mapping community. A clear understanding of MBES users and their needs will place AusSeabed in an excellent position to guide and support the acquisition and maintenance of high-quality seabed data.

This report presents the results of collaborative research which aims to address this need for a better understanding of the MBES user community. The central component of this research was a user survey conducted across Australia (through the AusSeabed community) and internationally to gather specific recommendations to be incorporated into the first stage of an online survey planning tool. This survey planning tool will provide recommendations to users for their MBES acquisition, based on their specific industry and intended applications. The user survey findings presented in this report will also contribute to subsequent phases of the project and other activities within AusSeabed.

The next section of this report provides an overview of the research approach, which was based around a user-need analysis. The third and fourth sections present the user needs findings, including an overview of the participants, data acquisition technologies, data discovery challenges and quality assurance methods. They also include the identified applications of MBES and summarise their user requirements. The fifth and sixth sections summarise the research findings and provide the research conclusions and future directions (Figure 2).

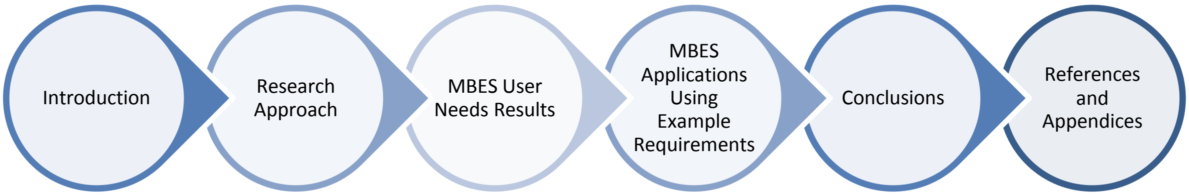


Figure 2: Structure of the report

2 Approach

This section provides a brief overview of the approach followed for the user needs research (Figure 3).

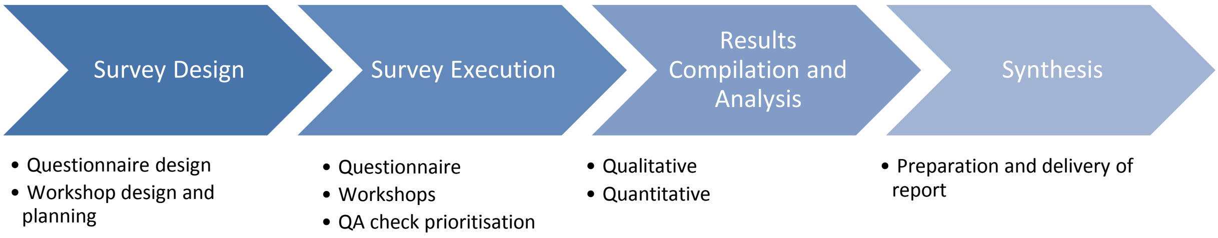


Figure 3: Research stages

The main instrument used to capture insights into MBES user needs was an online questionnaire, which included both closed- and open-ended questions organised in the following eight sections:

- General information about the participant
- Bathymetry data acquisition and interactions with MBES data
- Data discovery
- Data delivery
- Challenges and barriers for acquiring and using MBES data
- Software and data integration
- Quality assurance
- MBES application examples

The questionnaire was designed in consultation with Geoscience Australia, Deakin University, and a number of key AusSeabed members. To understand how the community's needs have changed with time, some questions from past user surveys were included here, to facilitate direct comparison [1,7].

The online questionnaire was distributed to a list of AusSeabed members, along with international experts. Special considerations were made to ensure all user groups were represented. The online questionnaire was available for three months between June and September 2018. In addition to the online questionnaire, two workshops were held in July 2018 (Adelaide) and February 2019 (Canberra) to obtain further details about the use of MBES in Australia.

The scope of this report is limited to reporting a summary of user needs according to the information collected from the questionnaire and workshops, supplemented with other relevant publicly available information.

3 MBES User Needs Results

This section summarises the findings of the questionnaire and workshops, including an overview of participants and the challenges they experience using MBES data.

3.1 Research Participants

The survey involved 103 participants from 69 organisations (Appendix 1). The response rate for the online survey was 50.2 per cent with responses well-distributed between government, private and academic sectors (Figure 4). In addition, 46 participants attended the workshop in July 2018, some of whom also expressed their views via the online questionnaire. The responses from these participants were carefully assessed and filtered to prevent duplicate inputs into user needs analysis. Seventy-two per cent of responses came from Australian experts; the remainder were submitted from New Zealand and other international experts (5 and 22 per cent respectively; Figure 5). In Australia, private companies were the highest-represented user group in the online survey followed by federal and state government agencies (Table 1).

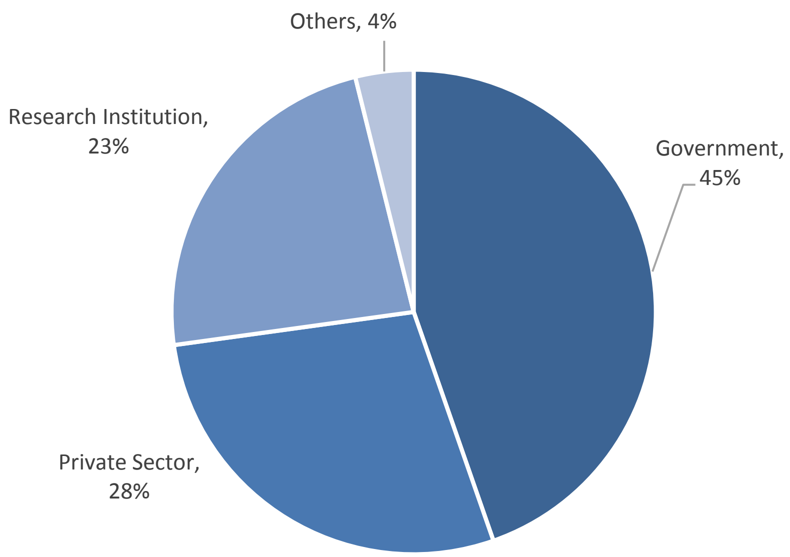


Figure 4: Participants by sector. "Others" includes Regional NGOs, Retirees, Private sector research and practical application. See Appendix 1 for a list of the participating entities

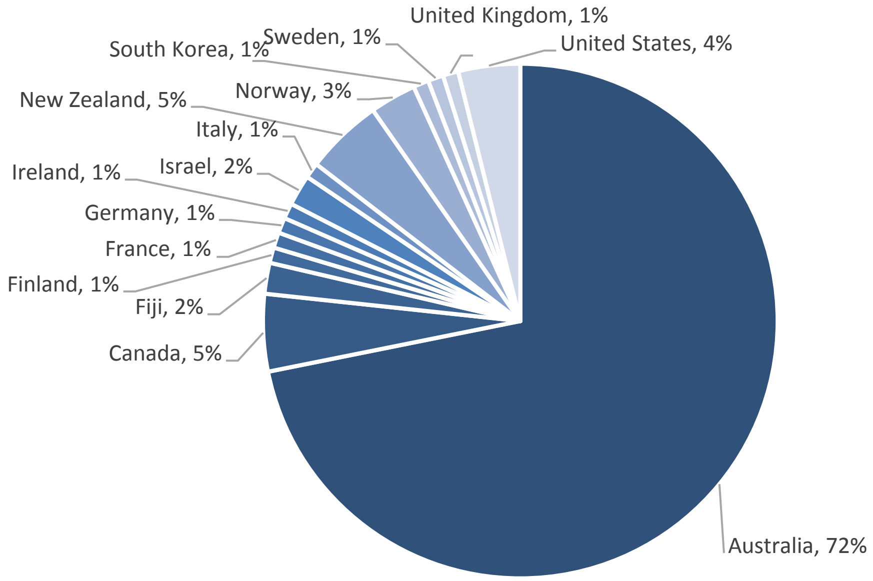


Figure 5: Participants by country

Table 1: Type of Organisations according to the country of origin

Country	Sector	User group / Organisation type	Responses
Australia	**Government**	Federal Government	17%
		State Government	16%
	Private sector	Private Companies	22%
		Port Authorities	6%
	Research institutions	Universities and research institutions	10%
	Others	Coastal Boards and Committees	1%
		Individuals, independent consultants and retirees	1%
		Hydrographic societies	1%
International	**New Zealand**		4%
	Oher international individuals/organisations		22%

The professions best represented by these survey responses were hydrographic surveying and marine science. Most of the organisations/teams participating in the research[2] had 10+ years of experience working with MBES data (Figure 6). For individuals using MBES data, the major drivers for MBES data use and acquisition are scientific research, and MBES as 'core business' (Figure 7). For some organisations, such as port authorities, it is a business requirement to acquire MBES data, but not *core* business. Surveying and mapping were the most common roles for participants' organisations (Figure 8).

[2] Represented by the survey participants.

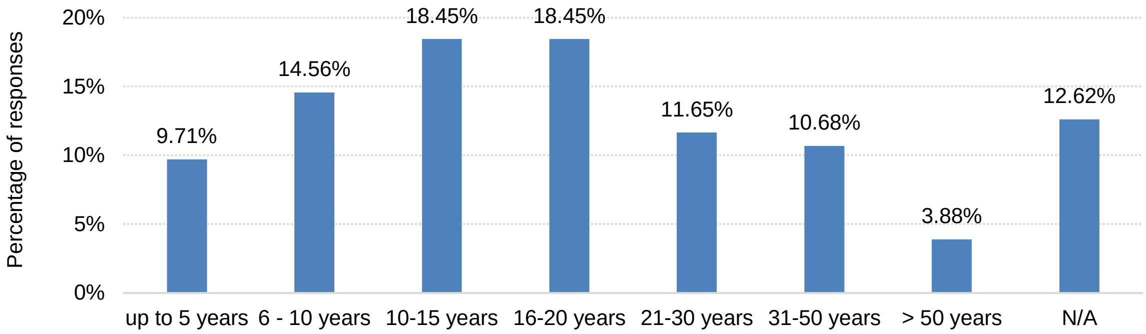


Figure 6: Total years of experience with MBES by organisation or team. Invalid responses were classified as "N/A".

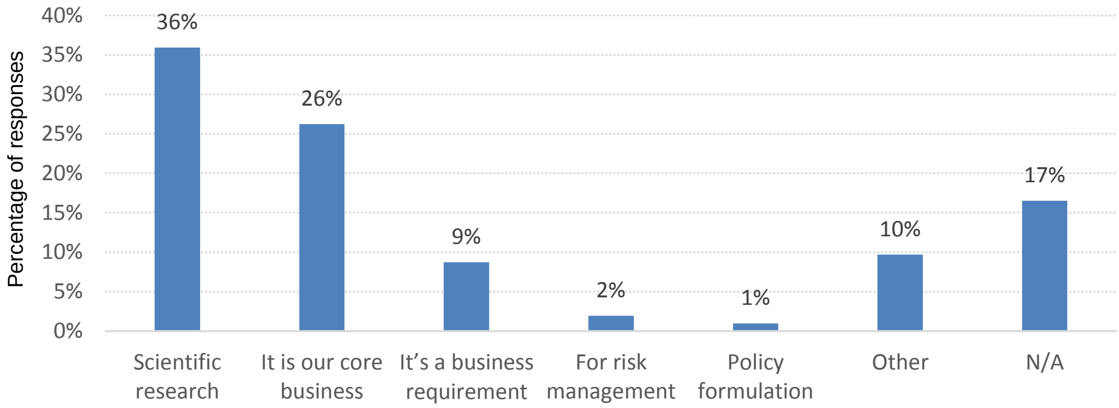


Figure 7: Major drivers for using MBES and MBES-derived data. "Other" includes nautical charting, capacity building, policy formulation and supporting the economy. Invalid responses were classified as "N/A".

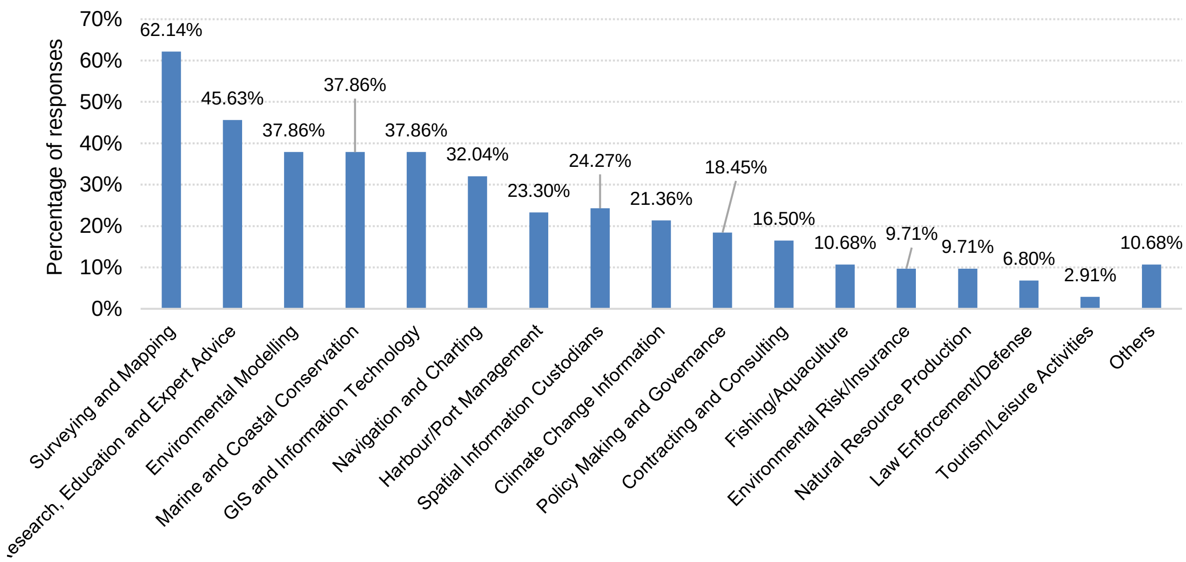


Figure 8: Primary roles of participants' organisations or teams. "Others" includes roles into geodetic infrastructure, geological mapping and industry promotion.

3.2 MBES Application Areas

One of the main aims of this study was to understand user applications of MBES and provide recommendations on the technical specifications for the acquisition of MBES data for these applications. This research identified over 22 distinct applications requiring MBES data. We compared results from this study with those from a similar study carried out in 2011 [7], illustrating changes in the use of MBES data for various applications from 2011 to 2018 (Figure 9). The relative popularity of MBES applications has not changed considerably, although there has been an increase in the percentage of organisations involved in only acquiring MBES data. This apparent increase may be due to differences in the survey demographic; this report targeted more MBES users than the 2011 study. However, it is also possible that there has been increased emphasis on seabed data acquisition in recent years, thereby increasing the demand for MBES contract services.

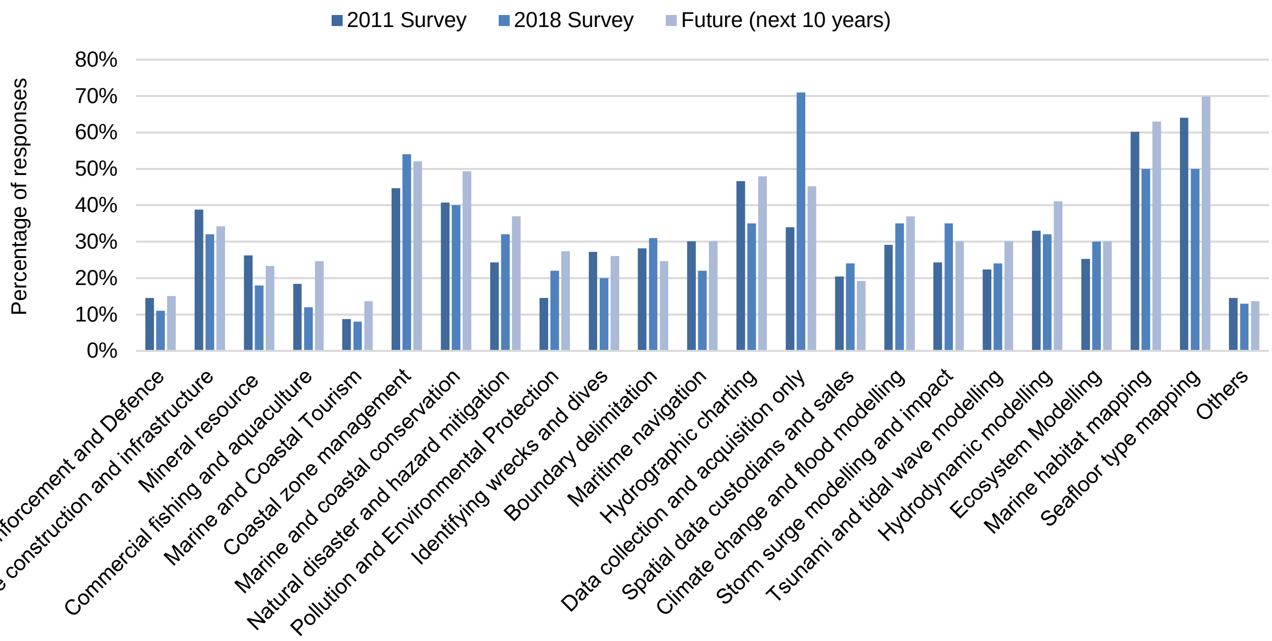


Figure 9: Application areas for the use of MBES data (Comparison between past, current, and future use). Categorisation is according to the 2011 CRCSI study [7] for allowing comparability.

Figure 9 also shows which application areas the survey respondents predicted they would use MBES data for in the future, and these do not differ significantly from current use. However, among the new applications mentioned, the largest increase would be in marine and coastal conservation, hydrographic charting, habitat and geological mapping.

3.3 MBES Related Software

Twenty software packages are used within the MBES workflow (Table 2). ESRI ArcGIS, Fledermaus and CARIS are the packages most commonly used by respondents.

Table 2: Software packages used for MBES data workflow categorised according to the type of task required. The packages listed have been identified by more than one participant and assigned to a task based on popularity, but in many cases were not limited to one task.

Task	Software	
Acquisition	• PDS 2000 (Teledyne) • TMC (Trimble) • Survey Information System (Kongsberg)	• Hysweep (Hypack) • QINSY (QPS) • Hydro Pro (Trimble)
Processing and cleaning	• Caris HIPS & SIPS (Teledyne) • Cleansweep (OIC) • Fledermaus (QPS) • Hysweep (HyPack) • POSPAC (Applanix) • Globalmapper (Blue Marble Geographics)	• GeoCap • Terramodel (Trimble) • Matlab • QINSY (QPS) • Surfer (Golden Software) • Qimera (QPS)
Visualisation	• ArcGIS (ESRI) • FMGT (QPS)	• Fledermaus (QPS) • MapInfo • Surfer (Golden Software)
Positioning	• POSPAC (Applanix) • GNSS Surfer	

3.4 Data Acquisition and Delivery

3.4.1 Depths and Areas of Acquisition

Nearly 90 per cent of the participants operate in the near-shore, i.e. in water depths less than 50m (Figure 10**Error! Reference source not found.**). Approximately 15 per cent of survey participants based their survey areas on features of interest, such as wrecks and reefs, which match with popular applications i.e. habitat mapping and navigation (Figure 9).

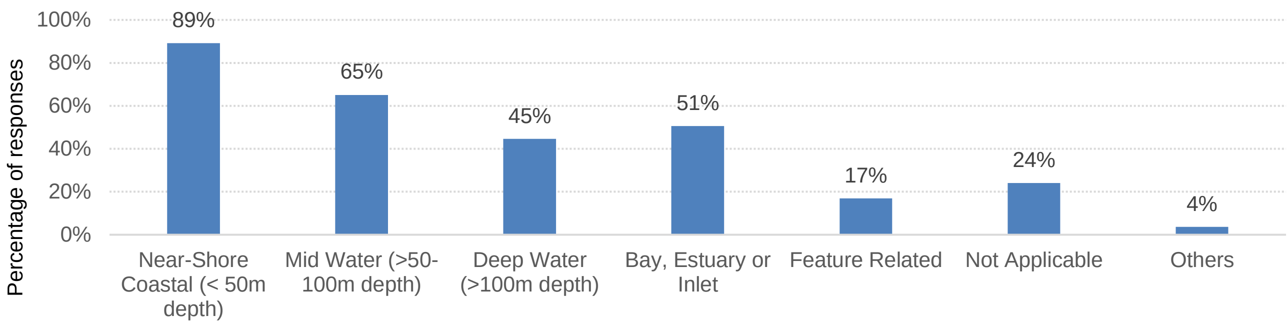


Figure 10: Areas of interest based on water depths or feature-related. N/A represents invalid responses. 'Others' include river trials.

3.4.2 Data Acquisition Strategies and Technologies

For those organisations that acquire bathymetry data, 40 per cent acquire bathymetry data directly, whilst 9 per cent fund bathymetry acquisition through sub-contracts. Of these organisations funding bathymetry acquisition through sub-contracts, 58 per cent required certified hydrographic surveyors. Thirty-six per cent of participants use both strategies to acquire seabed data, and 15 per cent acquire data in other ways e.g. access existing bathymetry data through online portals or other sources.

MBES is the most common technology used for seabed mapping around Australia and the percentage of survey respondents reporting its use has increased considerably since 2011 (Figure 11). Bathymetric LiDAR is used by 41 per cent of participants, a 12 per cent increase from 2011, a popularity increase similar to satellite-derived bathymetry. Other technologies all showed modest increases in popularity among participants.

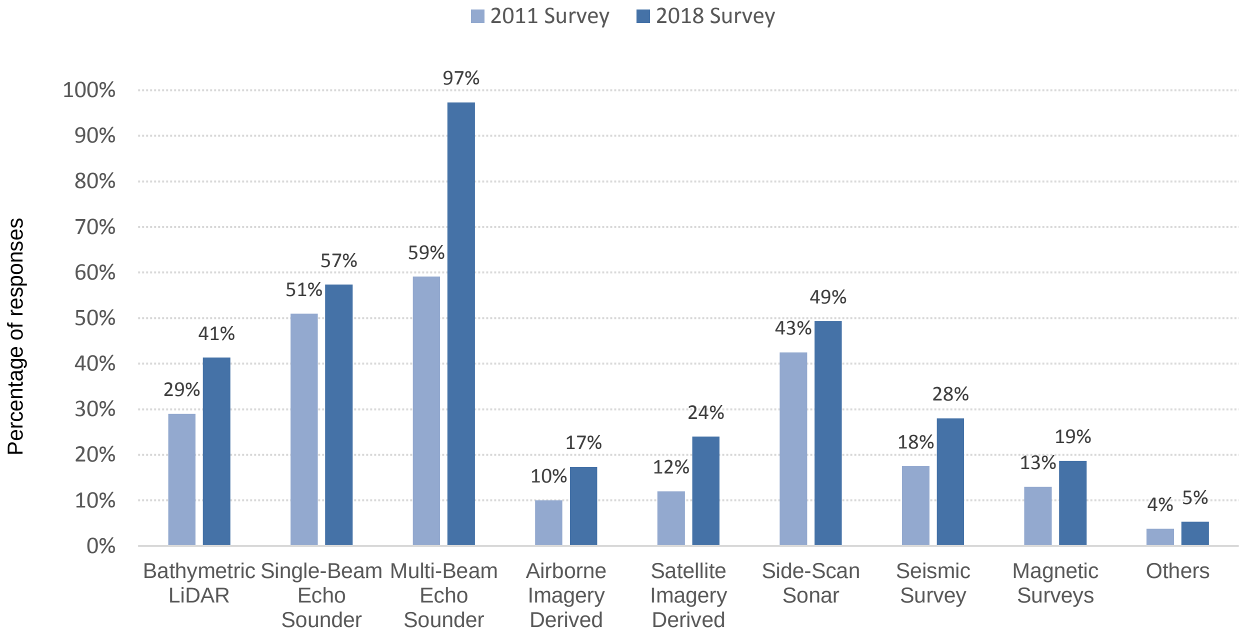


Figure 11: Technology (sensor type) used for bathymetric surveys among those who fund (direct and third-party acquisition) activities.

3.4.3 Approaches for Determining Technical Specifications

Participants were asked to identify the methods they use to identify their MBES acquisition project requirements and technical specifications. Fifty-seven per cent of respondents use existing specifications, guidelines or standards. Forty-nine per cent of participants rely on subject matter experts, and 35 per cent rely on advice from providers (Figure 12). Five per cent of participants guessed their requirements. A few, mostly hydrographic surveying companies, indicated that they set the technical specifications of their projects themselves as they had internal expertise. Some participants also highlighted that they used a combined approach.

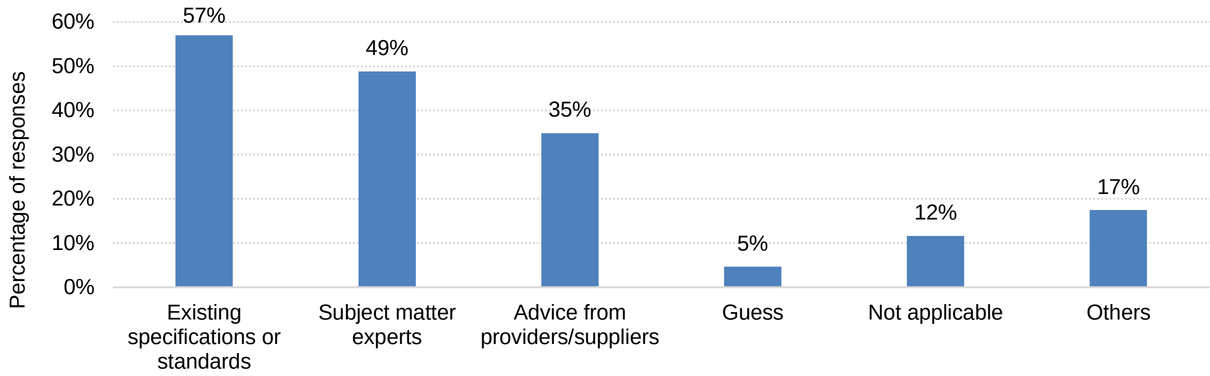


Figure 12: Approaches commonly used to determine survey requirements and technical specifications. Note that respondents were able to choose multiple answers.

3.4.4 Data Products

Ninety-four per cent of participants identified bathymetry data as the most common data product delivered from MBES surveys (Figure 13). This was followed by MBES seabed backscatter data and sound velocity profiles (SVP), both of which are intimately related to MBES data acquisition.

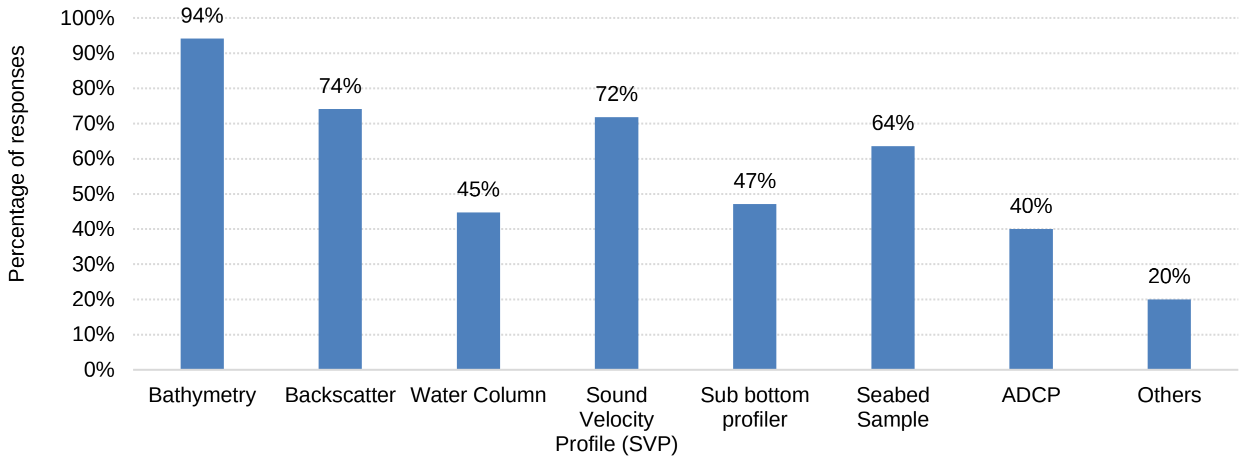


Figure 13: Data collected during seabed survey. 'Others' included water temperature, salinity, pressure and conductivity, single- or multi-channel seismic reflection data, gravity or magnetics, and tide data.

3.4.5 Data Transfer

To transfer their MBES data back to the office or for the final project delivery, 64 per cent of participants use hard disks (Figure 14). Of this 64 per cent, 48 per cent are from government agencies, 28% per cent from the private sector, and nearly 25 per cent from research institutions. Only one-third of participants use cloud storage solutions (e.g. Amazon S3) with the private sector being the highest user of cloud storage (40%) followed by government (< 30%). Concerns reported by participants regarding online cloud storage and usage included privacy and security of their data, and internet speeds resulting in slow data transfer.

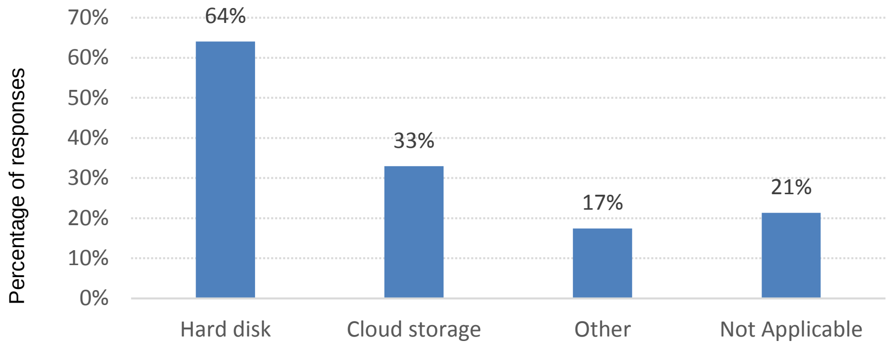


Figure 14: Data delivery medium. 'Other' include FTP downloads, transfer of smaller datasets via email, USB memory stick or thumb drive, Internal transfer using intranet, Enterprise GIS solution.

3.5 Data Discovery and Sharing

3.5.1 Data Discovery

Participants were asked about whether they check the availability of data for their area of interest prior to acquisition. Only 39 per cent do so, and among these, many indicated that it is very difficult to find such information. Search tools used include:

- Their own organisation's survey database
- Consultation with knowledgeable and experienced peers in industry
- Hydrographic or local charts
- Literature review and searches
- Online portals, databases and resources (e.g. AusSeabed Marine Data Discovery Portal)
- Internet search engines
- Consultation with clients or sub-contractors.

3.5.2 Data Sharing

Thirty-eight per cent of participants currently share their data freely, and 35 per cent share their data at a cost (Figure 15). All surveyed research institutions indicated that they currently share their data, and approximately 82 per cent of government organisations share their data. Participants already sharing data highlighted that this data is often only releasable on a case-by-case basis as there can be restrictions for various reasons (Table 3). Although *willingness* to share data is extremely high among research institutions, only 40 per cent make their data freely available. Less than 18 per cent of the private companies indicated their data is open and those that do not freely share their data cited various reasons (Table 3). Some participants who do not share their data suggested that their data acquisition is for their internal use (e.g. port management) and is likely of no interest to other users. These participants therefore have little incentive to invest in data sharing unless requested.

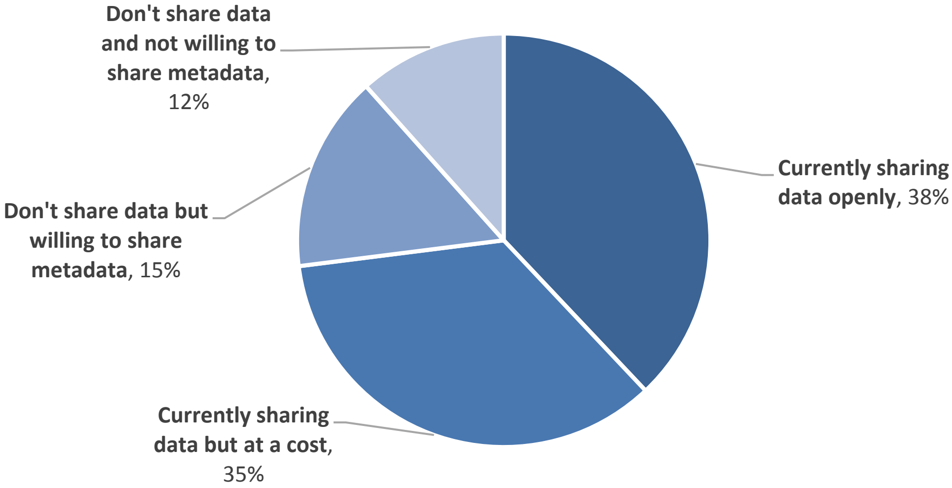


Figure 15: Data sharing characteristics and patterns

As an alternative to open data sharing, project metadata and coverage can facilitate data discovery and reduce duplication of effort. Of those participants who do not share their data, 57 per cent indicated that they are willing to share their project metadata (15 per cent of the total responses). This still leaves over 40 per cent of respondents *not* currently sharing their data (12 per cent of all responses) also unwilling to share in the future. Most of these participants work for private companies, although 18 per cent of these were from the government sector. Of participants who are willing to but currently do not share their data, 86 per cent indicated that they would do so only where it has minimum impact on the time and cost of the survey and also minor changes in their processes. Business cost recovery, data confidentiality and legal barriers are common reasons for private companies to not share, resourcing and staff limitations were more specific to government agencies (Table 3).

Table 3: Reasons behind unwillingness to share data or metadata

Category	Data	Metadata including coverage extent of data
Cost and resource related	• Recovering high cost of capture	• Business cost recovery • Resourcing and staff limitations for provision of this data
Business related	• Commercial sensitivity • Security and confidentiality	• Data confidentiality
Legal barriers	• Restricted Intellectual Property • Data licensing • Data ownership (i.e. client is the data owner not contractor)	• Approval requirement by clients
Others	Lack of a system to easily capture this information	

3.6 Delays in MBES Acquisition and Use

Participants identified the major factors leading to delays and setbacks in the acquisition and/or the use of MBES data (Table 4).

Table 4: Delays and setbacks for acquiring and using MBES data.

Category	Sub-categories
Environmental Conditions	• Weather-related factors during acquisition (e.g. sea state) • Complexity of the environment (e.g. < 20m depth is complex to work in)
Resourcing	• Underestimating the time required for data acquisition • Lack of funding • Staff availability • Competing priorities
Equipment related	• Equipment and vessel availability • Reliability of equipment • Mobilisation of vessels • Portability of equipment
Technology related	• Integration of sensors installed on vessels that are not owned by surveyors • Software related problems (e.g. Incapability of software) • Integrating new systems (e.g. Sonardyne Solstice, Kraken aquapix) • Connectivity issues (e.g. internet availability on the vessel)
Data related	• Processing speeds • Data delivery from custodians of existing data • Data discovery • Data quality (including noisy data, e.g. backscatter data) • Delivery of interoperable data format • Increasing data volumes • Permissions to release the data • Missing or incomplete metadata
Others	• Acquiring permissions for access (e.g. national parks) to particular areas • Decision making by clients • Timely contract awards

3.7 Data Integration

Eighty-one per cent of participants integrate their bathymetric data with complementary datasets for visualisation and analysis (Table 5). However, challenges occurred when integrating datasets and these were largely dependent on dataset type. All participants highlighted differences in data formats as major issue. Other reported difficulties included differing data resolutions and vertical datums, data mismatches due to different times of capture, and challenges associated with generating combined metadata for disparate datasets.

Table 5: Datasets that bathymetry data is most commonly integrated with.

Categories	Dataset
Other marine datasets	• Soundings from ENCs • Seabed characteristics • Sub-bottom profiles • Sea surface temperature • Wave models • Tide models
Land-based data	• Photogrammetric data (e.g. point cloud) • Aerial and Satellite imagery • Topography • UAV derived data • LiDAR (point cloud, reflectivity and depth) • Coastal features
Administrative Boundaries	• Shoreline/Coastline • Planning zones • Marine boundaries • Cadastral data
Others	• Fishing data • Navigation aids database • Marine infrastructure and remote assets • In-situ data (e.g. sensors) • Seismic profiles

3.8 Problems Affecting Data Quality

Participants listed problems commonly experienced during the acquisition and use of MBES data. These problems have been grouped into five main categories (Table 6).

Table 6: Common issues experienced when acquiring or working with MBES data, in addition to delays listed in Table 4.

Category	Issues
Data acquisition	• Instrument issues (e.g. malfunction or errors) • Incorrect system set up • System calibration issues • Small vessel issues related to fitting equipment • Lengthy acquisition time in shallow water (e.g. <5m) • Problems impacting data quality: • Motion and sound velocity artefacts (heave, roll, pitch, heading) • Outerbeam performance • RTK drifts • Accurate sound speed profiles
Data use related	• Currency of data (e.g. Long time between the time data was acquired and received) • Incomplete or poor coverage of the area of interest • Insufficient resolution of the data • Inappropriate or incorrect data format • Corrupted files delivered • Lack of metadata

Data processing	• Expensive processing software • High computational power needed to manipulate large datasets • Lengthy processing times • Merging different sensor data • Reliability of tide models • Inappropriate sound velocity data • Post-processing of motion and navigation • Artefacts bias in semi-automated classification • Subjective data interpretation
Data management	• Data cleaning (e.g. obtaining shoalest depth). • Incomplete or inaccurate metadata (e.g. datums and reduction methodology) • Difficulty in levelling data • Integrating large datasets from different vessels and operators • Integrating bathymetry with topography • Lack of familiarity with sources of data uncertainty • Data discoverability • Data access and dissemination
Data quality assurance	• Quality of installation (e.g. possible movement and vibrations in pole mounted systems) • Different data acquisition standards or no standards • Various quality and acquisition parameters • Lack of independent tools for data quality assessment • Insufficient repeat datasets to assess variability • Uncertainty about the quality of ancillary data (e.g. tides, SBP) • Backscatter quality (e.g. noisy backscatter data) • Error in calibration process

3.9 Quality Assurance Checks

To better understand the quality assurance (QA) processes within organisations, participants were asked to provide information about the quality checks they performed on data, both on the vessel and in the office. Accordingly, the identified QA checks have been categorised into *field* (Table 7) and *office* (Table 8) checks. Eighty-four per cent of participants indicated they perform QA checks on their data whilst on the vessel. Twenty-eight distinct field checks were reported by respondents; these have been classified in Table 7 according to four categories. Sixty-four per cent of participants indicated they check the quality of their data once it is supplied to the office. Thirty-four distinct office checks were reported by respondents; these have been classified in Table 8 into three categories.

Table 7: List of field QA checks and tools. Some participants indicated that the delivery completeness is sometime not performed on the vessel.

Check Category	Description	QA Checks
Mobilisation and calibration checks	To ensure proper set up and calibration of equipment and sensors prior to data acquisition	• Installation set up check (e.g. lever arm) • Absolute depth checks (bar check and positions check) • Run system diagnostics (e.g. BIST, BITE) • Patch test • Azimuth error check • Time synchronisation across different systems • Backscatter calibration checks
Monitoring checks	To review the progress of data acquisition and consistency of sensors	• Quality of multibeam return signal • Saturation of signal • Sound velocity deviation • Positioning and Inertial Motion Unit (IMU) deviation and quality • Tide monitoring • Line overlap • Visual inspection of data points • Review all data in real-time • Backup completeness
Data quality and accuracy checks	To ensure the collected data is free of artefacts and problems	• QA data using cross lines (if collected). If not collected, use transit lines. • Positioning and Inertial Motion Unit (IMU) deviation and quality • Surface artefacts (e.g. resulting from calibration error) • Coverage and identification of data gap areas (internal holes) • Sound, Velocity Profiles (SVP), Conductivity Temperature Depth (CTD) and Expendable Bathy Thermograph (XBT) data prior to and following the survey • Backscatter artefacts and consistency
Delivery checks	To check if all the required data is captured	• Delivery completeness – to check that all data and documentations is collected and ready to be sent to the office

Table 8: List of office QA checks or tools.

Check Group	Description	QA Check
Data quality	To assess the accuracy, resolution, or other data quality aspects	• Coverage for the entire project area • Check resolution of gridded bathymetry • Sounding density and statistics • Along and across-track • Cross-lines across survey area and crossline statistics • Cross-checking data from different runs (overlap check) • Visual inspection for artefacts (e.g. motion, SVP, Tide, etc) • Verification of SVP • Depth check against reference surface • Check against benchmarks or comparison with other baseline data • Total Horizontal Uncertainty (THU), Total Vertical Uncertainty (TVU) and Total Propagated Uncertainties (TPU) meet project requirements • CUBE modelling • Check for Backscatter data quality and consistency • Horizontal and vertical datum

Reports	To quickly assess the delivery of reports as part of the project deliverables	• Lever arm check report provided • Vessel configuration file delivered • Bar check (Depth check) report provided • Tide check report provided • Patch test report provided • System calibration checks report provided • Feature detection check report provided • Navigation quality check report • Time synchronisation across different systems report provided • Azimuth error check report provided • Ground truthing report provided
Data completeness	To ensure the complete delivery of various products and in the correct format	• All products delivered • File format conformance • File corruption • File naming follows requirements • Raw data presence • Metadata completeness

3.10 Commonly Used QA Software

The most common packages reported by participants to QA/QC data were QPS tools (42 per cent[3]) CARIS (36 per cent), Hypack (13 per cent), QA4LiDAR (13 per cent), MBQA from MBsystem (4 per cent), Applanix PosPAC (4 per cent), QC Tools from the HydrOffice framework (4 per cent) and Cube (2 per cent) (Appendix 4). While several software packages are well-established for the processing and assessment of MBES data, participants identified a need and requirements for independent QA/QC software (Table 9). Participants suggested that further in-depth research is necessary to investigate how such a tool can easily and cost-effectively be integrated into different workflows.

Table 9: Participants' requirements for an independent QA/QC tool.

Category	Requirements
Business	• Automate QA/QC process • Provide a data receipt checking tool • Automate report production • Use in field data collection and office delivery • Remind users about issues to consider before, during and after surveys • Reduce the number of software packages needed for QA • Ensure best practices of data acquisition and processing are used by multiple user groups • Apply standard national minimum QA documentation
Functional	• Consistent and exhaustive QA/QC of data against pre-defined requirements • Verify and validate data accuracy level • Identify areas which lack coverage or holidays • Provide transparency in the process used for QA/QC (not being a black box)

[3] Only 43 per cent of participants responded to this question. Percentages here are adjusted accordingly.

4 MBES Applications Using Example Requirements

One of the aims of this project was to establish an initial list of MBES survey purposes and their requisite technical specifications, in order to then provide the MBES user community with guidance and recommendations. A total of 55 sample MBES survey specifications were provided by participants. The results presented here exclude responses from those who rely on providers/suppliers to determine their projects' technical specifications or those who guess these requirements. Similar responses have been consolidated to produce a summary list of 30 distinct survey purposes (Appendix 2). For each for the 30 survey purposes in these application areas, the following 10 requirements and specifications were analysed:

- Geographical extent of data acquisition
- Features of interest
- Depth of acquisition
- Sonar frequencies for data collection
- Time sensitivity of data acquisition (if applicable)
- Positioning methods
- Resolution requirements
- Horizontal and depth accuracies
- Project deliverables
- Relevant standards for the survey purpose

The highest number (20 per cent) of responses which mentioned specifications were related to geological mapping and seafloor physical characterisation (Figure 16). Hydrographic charting and navigation, and coastal zone management and marine conservation, along marine construction and infrastructure also received a high number of responses (10 per cent each).

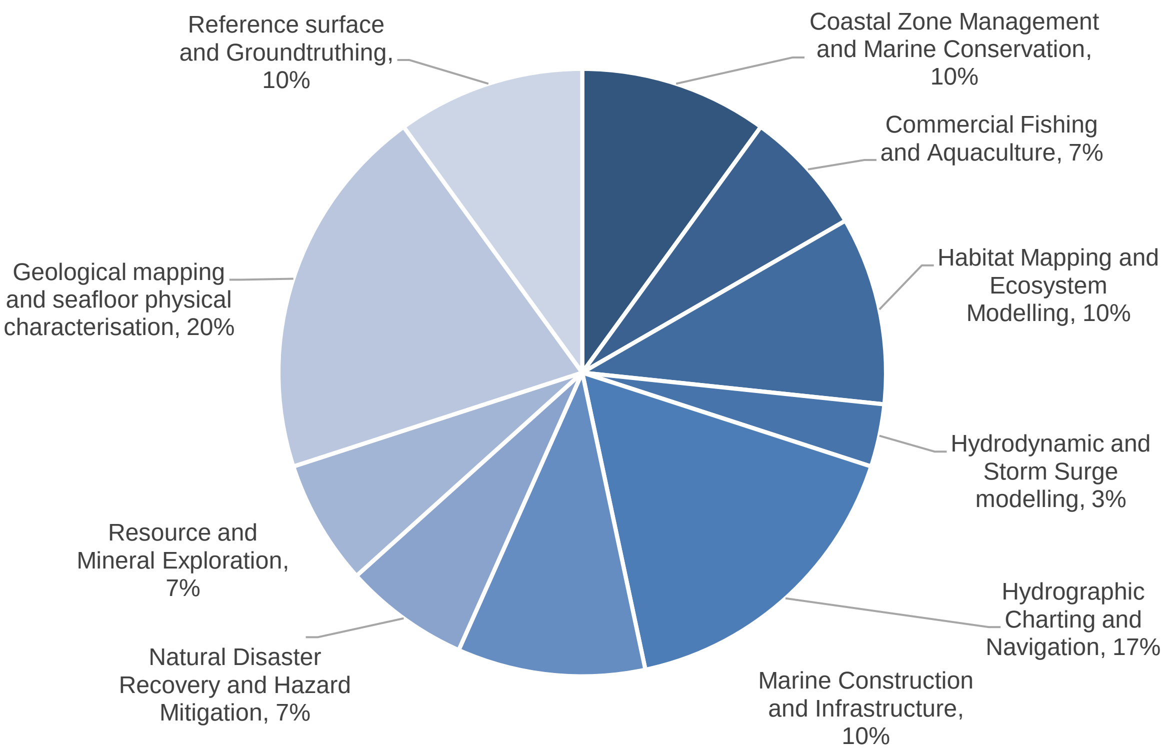


Figure 16: Survey purposes by application area

4.1 Survey Extent

There was considerable variation in the geographical extent of the sample survey areas. As Figure 17 shows, nearly half of these areas are 100–200km^2, 10–50km^2 or are smaller than 5km^2. Small project sizes (less than 5km^2) are generally associated with near-shore or port management (e.g. dredging support). Large size surveys are associated with hydrographic charting and navigation, exploratory mapping, and geological mapping (e.g. fault systems).

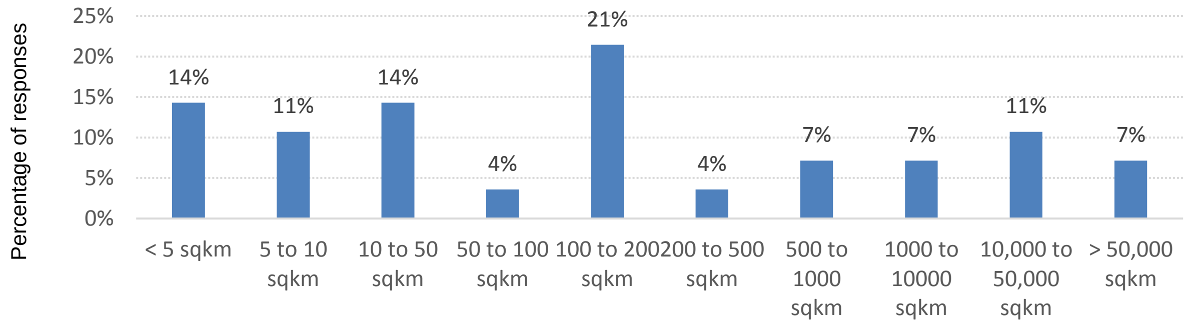


Figure 17: Geographic extent of surveys

4.2 Features of Interest

Specific features of interest vary according to the survey purpose. However, there are commonalities between survey purposes in the same application area. These features of interest have been classified into three categories i.e. bathymetry, geomorphology, and seafloor feature/type (Table 10). The most common features of interest across all survey purposes are bathymetry, sediments, reef, rocks, and hazardous objects for navigation.

Table 10: Features of interest listed by participants are classified per application area.

Application area	Features of Interest
Coastal Zone Management and Marine Conservation	Bathymetry, coast, channels and banks, reefs, sand, rocks, geomorphology and the extent, movement and distribution of sediment types and size.
Hydrographic Charting and Navigation	Bathymetry, shoals, obstructions or other features that may pose a danger to surface navigation and cause vessels to run aground.
Commercial Fishing and Aquaculture	Bathymetry, sediment distributions and geomorphology, seabed type, seagrass, macroalgae, sponges, reefs.
Habitat Mapping and Ecosystem Modelling	Bathymetry, variation in seabed characteristics (slope, rugosity, hardness etc.) and structure, Rocky reefs extent and the amount of cover on reefs.
Hydrodynamic and Storm Surge modelling	Bathymetry, channels, sand bars and reefs.
Marine Construction and Infrastructure	Bathymetry, bipes, spans scour damage, shoals, debris, and any feature that is above the declared depth of the channel, berth, or harbour and those features that pose a danger to navigation.
Natural Disaster Recovery and Hazard Mitigation	Bathymetry, extent of sand/reef, sediment compartments, faults, canyons, sedimentary bedforms and underwater volcanos.
Resource and Mineral Exploration	Bathymetry, large features that would make placing subsea assets difficult. Faults, mounds, pockmarks, tectonic features, authigenic carbonate outcrops, chemosynthetic clam beds, nodule beds, rock outcrops, brine pools, salt domes, mineral deposits
Geological mapping and seafloor physical characterisation	Bathymetry, canyons, landslides, drowned reefs, bedforms and bed rock, pock marks, faults exposed at seafloor, or hard grounds, sediments, sand, geomorphology, foot of slope and isobaths.
Reference surface and Ground-truthing	Bathymetry, stable sea floor, reef and marine sediment extent and location.

4.3 Depth range of Acquisition

The depth range of data acquisition for each application area varies (Table 11).

Table 11: Maximum depths of acquisition for MBES application areas.

Application areas	Maximum depth (metres)
Coastal Zone Management and Marine Conservation	200
Commercial Fishing and Aquaculture	100
Habitat Mapping and Ecosystem Modelling	3,000
Hydrodynamic and Storm Surge modelling	200
Hydrographic Charting and Navigation	450
Marine Construction and Infrastructure	1,400
Natural Disaster Recovery and Hazard Mitigation	2,500
Resource and Mineral Exploration	6,000
Geological mapping and seafloor physical characterisation	10,000
Reference surface and Ground-truthing	120

4.4 Commonly Used Sonar Frequencies

Participants were asked to provide the range of sonar frequencies they use for each survey purpose. The majority of examples identified frequencies spanning 200–400kHz (Table 10). Frequencies lower than 200kHz are employed for marine research, marine construction and infrastructure, seafloor type mapping, and natural disaster and hazard mitigation.

Table 10: Common MBES frequencies used by application area.

Application Category	*Frequency (in kHz)*
	50 100 150 200 250 300 350 400 450 500 550 600
Coastal Zone Management and Marine Conservation	**30-450 kHz**
Commercial Fishing and Aquaculture	**240 kHz**
Habitat Mapping and Ecosystem Modelling	**200 - 400 kHz**
Hydrodynamic and Storm Surge modelling	**200 - 400 kHz**
Hydrographic Charting and Navigation	**200 – 400 kHz**
Marine Construction and Infrastructure	**100 – 400 kHz**
Natural Disaster Recovery and Hazard Mitigation	**70 – 400 kHz**
Resource and Mineral Exploration	**12 – 200 kHz**
Geological mapping and seafloor physical characterisation	**12 - 400 kHz**
Reference surface and Ground-truthing	**200 – 400 kHz**

4.5 Time Sensitivity

Participants were asked to identify the time sensitivity of each survey purpose, and the ideal timeframes to undertake surveys. Seventy-three per cent of the example surveys provided were described as time sensitive (Figure 18). Time sensitivity of surveys was due to one or more of the following:

- **Sea and weather conditions** – e.g. when there is no storm or rough sea
- **Requirements of change detection** – e.g. change in coastal geomorphology before and after a storm
- **Regular monitoring requirements** – e.g. the subsequent survey should be within a specified time interval of previous one
- **Other specific requirements** – e.g. depth monitoring or hydrographic surveys for depth declaration must be conducted in daylight; dredging safety requires data collection during high tide.

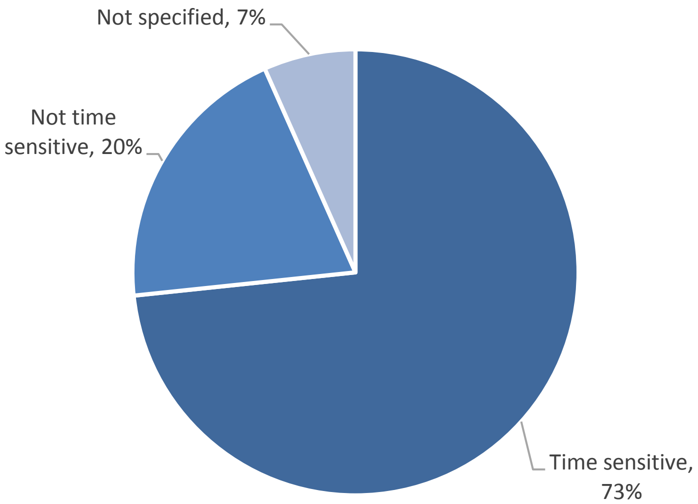


Figure 18: Time sensitivity of survey purposes

4.6 Vertical Datums

Twenty-eight per cent of participants use the Australian Height Datum (AHD, Figure 19), noting that AHD is typically a topographic datum. This finding correlates with the large number of MBES applications, such as coastal zone management, hydrodynamic modelling and marine infrastructure applications that require elevations across the littoral zone (Section 3.4.1 and Appendix 2). Lowest astronomical tide (LAT) and ellipsoid were other commonly used (22 per cent and 20 per cent of the responses respectively). For the ellipsoid group, some participants specified that although they acquired data at the ellipsoid, their products were subsequently transformed to AHD.

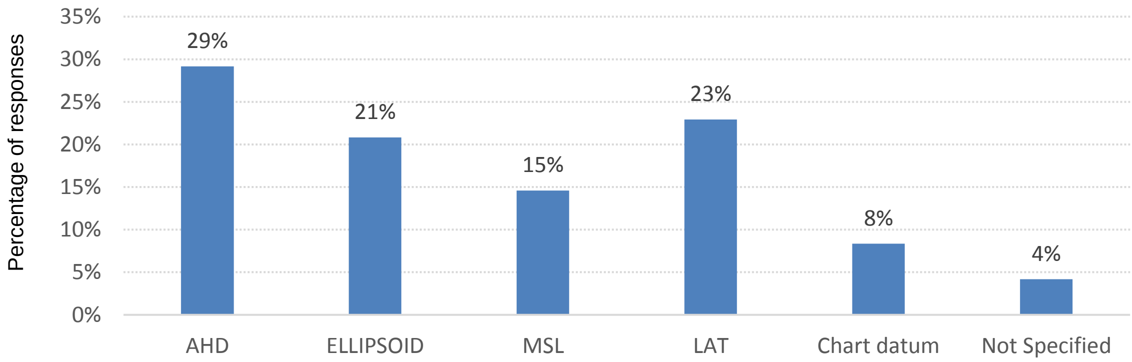


Figure 19: Vertical datums used by participants.

4.7 Positioning Methods

Participants were requested to report the positioning method they usually use for MBES data acquisition. Ninety-eight per cent use some form of satellite positioning. The most common methods identified are DGPS and RTK-GPS. Others used the POS MV system, along with the use of multi-constellations (GNSS).

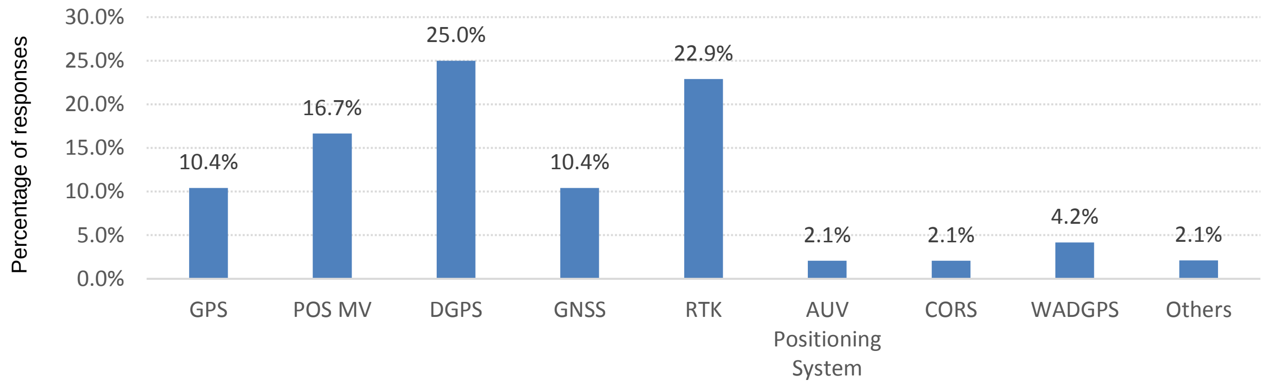


Figure 20: Positioning methods used for MBES data acquisition. 'Others' include satellite compass.

4.8 Resolution Requirements

The most common horizontal resolutions (61%) were between one and five metres (Figure 21). This resolution range is particularly common in coastal zone management and marine conservation, habitat mapping and ecosystem modelling and geological mapping and seafloor physical characterisation (

Table 12). Lower resolutions (up to 50 metres) were specific to survey purposes associated with large areas, such as mapping extended continental shelves. These surveys are also generally undertaken in deep waters (up to 10000 metres) where achieving high resolution is difficult. Very high-resolution data (< 0.5 metres) is primarily required for fisheries mapping, pipeline surveys, and those surveys related to port management (e.g. port safety analysis and risk assessment, port depth declaration) and dredging support (

Table 12).

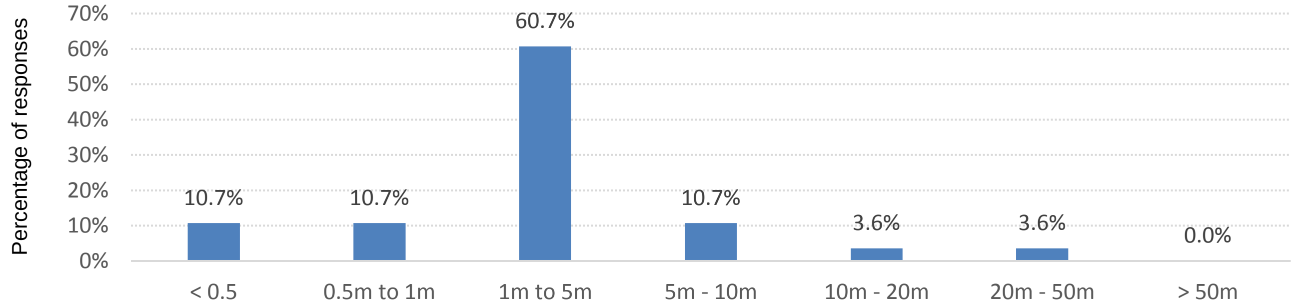
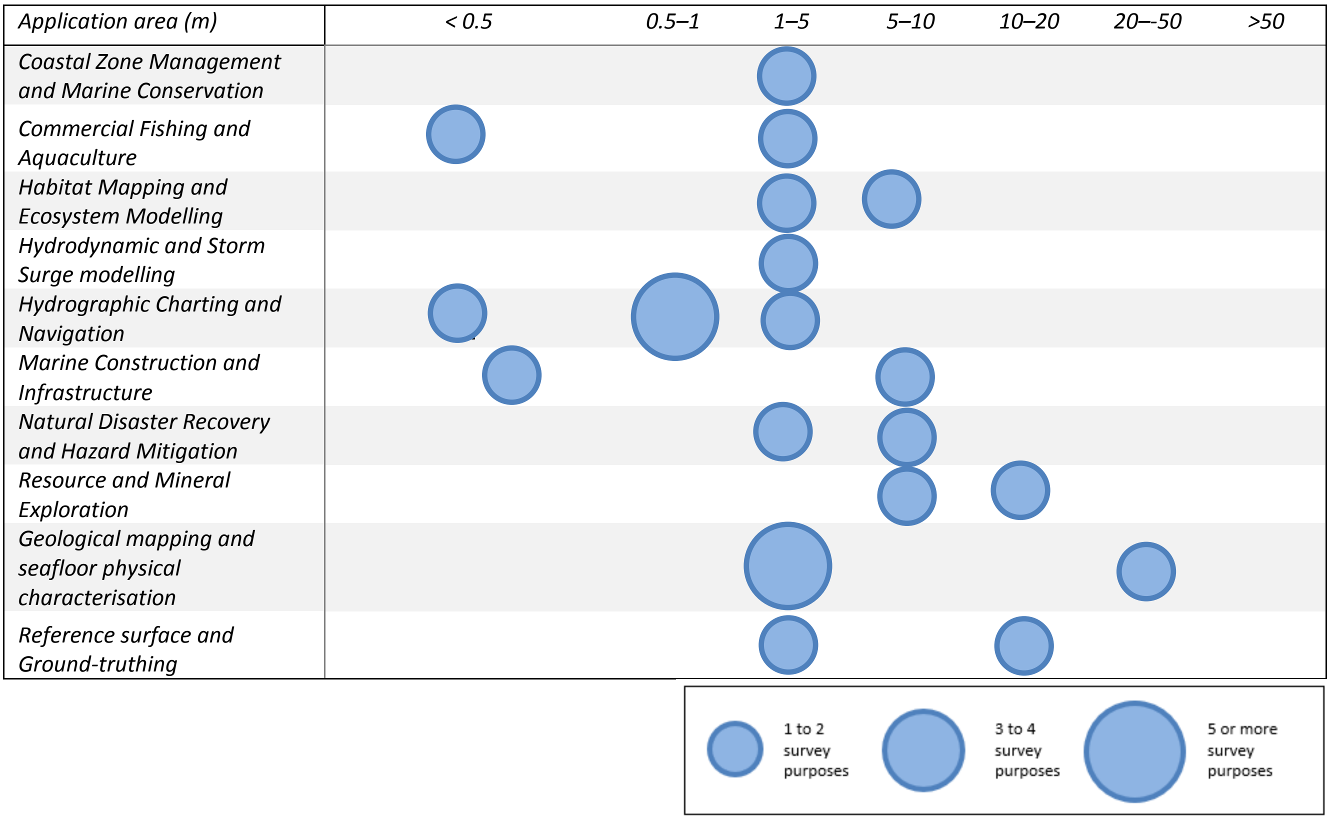


Figure 21: Grid resolution requirements.

Table 12: Grid resolution (m) requirements for different MBES application areas.



4.9 Horizontal and Depth Accuracies

Seventy-five per cent of participants required horizontal accuracy up to ten metres (Figure 22). Several responses within the hydrographic charting and navigation, marine construction and infrastructure, coastal zone management and marine conservation, and geological mapping and seafloor physical characterisation application areas required horizontal accuracies better than 0.5 metres (

Table 13).

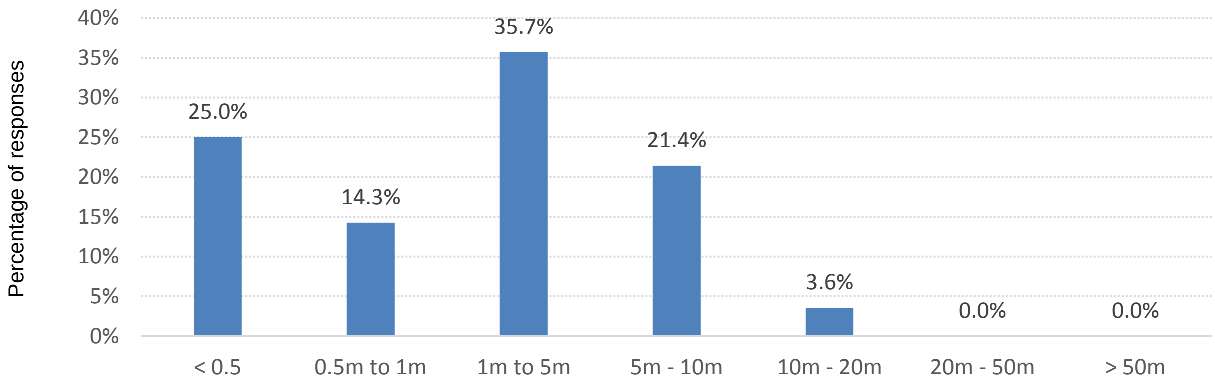


Figure 22: Horizontal accuracy requirements for their survey purposes.

Table 13: Horizontal accuracy requirements for different MBES application areas.

Application area (m)	*< 0.5*	*0.5–1*	*1–5*	*5–10*	*10–20*	*20–-50*	*> 50*
Coastal Zone Management and Marine Conservation	1 to 2			1 to 2			
Commercial Fishing and Aquaculture			1 to 2				
Habitat Mapping and Ecosystem Modelling			5 or more				
Hydrodynamic and Storm Surge modelling	1 to 2						
Hydrographic Charting and Navigation	5 or more	1 to 2		1 to 2			
Marine Construction and Infrastructure	1 to 2	1 to 2					
Natural Disaster Recovery and Hazard Mitigation			1 to 2	1 to 2			
Resource and Mineral Exploration			1 to 2				
Geological mapping and seafloor physical characterisation	1 to 2		5 or more	1 to 2	1 to 2		
Reference surface and Ground-truthing	1 to 2	1 to 2		1 to 2			

1 to 2 survey purposes; 3 to 4 survey purposes; 5 or more survey purposes

Participants were also asked to provide their depth accuracy requirements (Figure 23), with 54 per cent of respondents requiring depth accuracies of 0.5 metres or better. High vertical accuracy is particularly important for hydrographic charting and navigation, — where it is critical to ensure sufficient under keel clearance — and for coastal zone management and marine conservation for monitoring variations in the coastal zone (Table 14). Marine construction and infrastructure, and dredging support and port management also report a requirement for high vertical accuracy. Some participants reported their accuracy requirements in terms of the IHO survey classification, such as Order1A and as such also used depth accuracy as a function of water depth (e.g. 0.01 per cent of water depth).

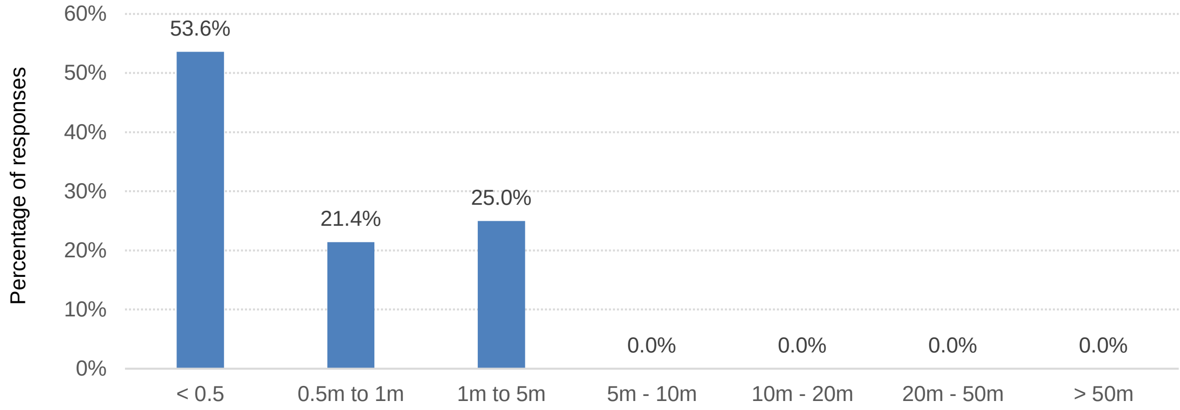
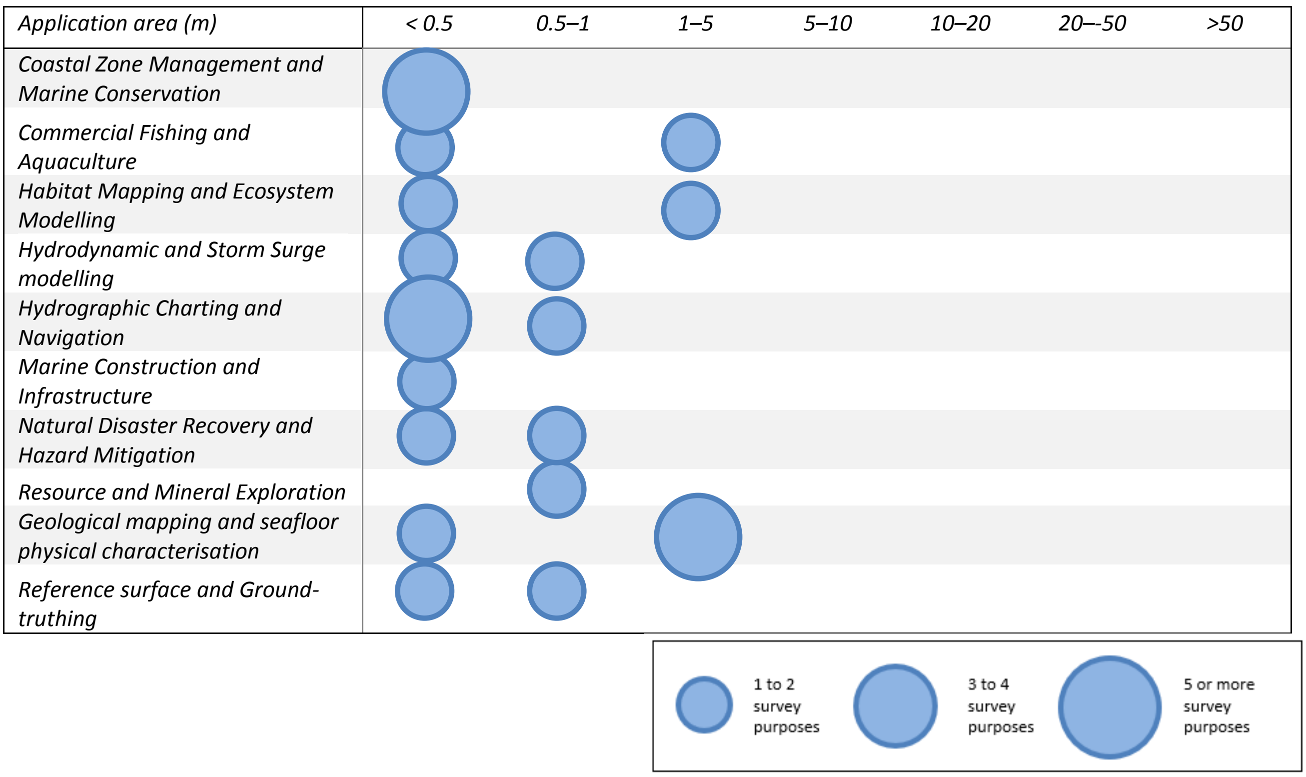


Figure 23: Depth accuracy requirements for the various survey purposes. This graph does not include participants who identified accuracy as percentage of depth.

Table 14: Depth accuracy requirements for different MBES application areas
This graph does not include participant who identified accuracy as percentage of depth



4.10 Relevant Standards

Fifty per cent of participants provided a list of relevant standards for each of their survey purposes, which included:

- International Hydrographic Organisation (IHO) S-44 and IHO Standards and guidelines
- Land Information New Zealand (LINZ) Specifications
- Australian Multibeam Guidelines
- Ports Australia Class A standards
- National Environmental Science Program (NESP) Multibeam guideline and Standard Operating Procedure
- Marine European Seabed Habitats (MESH) guidelines
- Maritime Safety Queensland - Standards for Hydrographic Surveys within Queensland Waters
- International Marine Contractors Association (IMCA)/ Oil and Gas Authority (OGA)
- Intergovernmental Committee on Surveying & Mapping (ICSM)
- GeoHab Backscatter working group recommendations
- National Oceanic and Atmospheric Administration (NOAA) – Geodesy, Global Positioning guidelines

In parallel to this user needs survey, a total of 73 guidelines and standards were identified which are listed in Appendix 3.

5 Summary and Conclusion

This research was conducted in order to support AusSeabed in improving the acquisition, quality, discoverability and accessibility of seabed data in Australia. Understanding the views, needs and challenges of the MBES user community were the key drivers for this research. The research was also conducted to gather technical specification recommendations for different survey purposes from the seabed community in support of a MBES online survey planning tool.

Nearly 70 per cent of the 103 participants came from organisations involved in MBES survey planning, acquisition and processing. Over half of these organisations acquire MBES data directly, and the remainder fund or outsource their data needs. The main applications of MBES include navigation and charting, geological mapping and seafloor physical characterisation, marine and coastal management and marine conservation, and marine construction and infrastructure management.

This report highlights that users primarily rely on existing guidelines and specifications along with subject matter experts to determine their survey requirements. A small number of users (5 per cent) estimate their project specifications based on experience. While there are a number of existing standards and guidelines (Appendix 3), many participants reported a need for more application-specific guidelines. This is reflected in the 30 distinct survey purposes and associated specifications that were identified from this research. It was found that over 70 per cent of these survey purposes were time sensitive, with many users requiring change detection and regular monitoring surveys. Although, the spatial resolutions and temporal frequencies required varied significantly across survey purposes, this research indicated that a grid resolution of between 1 and 5 metres was the most common requirement.

Cloud-based storages such as Amazon S3 are increasingly being used for the delivery for MBES products, however hard disks are still the preferred choice for data transfer. This preference is mainly due to concerns about the privacy and security of data within cloud-based storages and slow internet connections.

AHD and LAT are the most common reference datums for MBES data products. Many users indicated that although their delivery of bathymetry is in AHD, the data acquisition is usually performed referencing the ellipsoid, and then converted using datum transformation tools. The most commonly used positioning techniques for MBES acquisition are DGPS and RTK-GPS.

Regarding data discovery, sharing and accessibility, over 60 per cent of users do not search for existing datasets in their area of interest mainly due to the difficulty in finding such data. Over half of the participants raised concerns about allowing open access to their data, citing the cost of capture, commercial sensitivity of data, and security and confidentiality as the main barriers. For these reasons, some organisations were also not able to share their dataset coverage and metadata.

Twenty-five different factors commonly lead to delays and setbacks in executing MBES surveys. Of these factors, 32 per cent were linked to data issues, 14 per cent were associated with resourcing and 7 per cent related to environmental conditions. The research uncovered 40 different issues that participants experienced during the acquisition and use of MBES data, with data quality being the most common problem.

This report includes a list of 23 broad quality assurance checks that are performed on the vessel, and 31 checks performed once in the office. The commonly used tools for QA are the QPS suite of tools, CARIS, QA4LiDAR, MBQA and QC Tools. Users suggested the need for an independent QA tool that would streamline the QA/QC workflow and better communicate data quality.

In conclusion, this report has identified the main needs and challenges of seabed data users. It showed that technical specifications for MBES surveys are still a challenge for many individuals and organisations. While some users understand the requirements of their surveys, many still seek guidance from the seabed mapping community. This report is the first step in addressing this need. The next phase of this user needs study—including more detailed analysis of the data outlined in this report—is planned as part of the AusSeabed program and will continue to engage closely with the community.

6 References

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[7] Quadros, N. (2011) Investigating the data needs and challenges experienced by users of near-shore bathymetry. Report was prepared for the Commonwealth Government of Australia, Department of Climate Change and Energy Efficiency. September 2011. Melbourne, Australia.

Appendix 1 – List of Participating Organisations

Federal Government

- Australian Hydrographic Office (AHO)
- Australian Maritime Safety Authority
- Bureau of Meteorology (BOM)
- Commonwealth Scientific and Industrial Research Organisation (CSIRO)
- Defence Science and Technology Organisation
- Department of Environment and Energy
- Geoscience Australia (GA)
- Parks Australia
- Royal Australian Navy
- The Australian Institute of Marine Science (AIMS)

Academia and Research Institutions

- Curtin University
- Deakin University
- James Cook University
- Macquarie University
- University of New South Wales
- University of Sunshine Coast
- Integrated Marine Observation System (IMOS)

State Government

- Department of Environment and Natural Resources (South Australia)
- Department of Environment and Science (QLD)
- Department of Environment and Water (SA)
- Department of Transport (WA)
- Department of Water and Environmental Regulation (WA)
- Maritime Safety Queensland
- Northern Territory Government
- New South Wales (NSW) Department Primary Industry
- Office of Environment and Heritage (NSW)
- South Australian Research and Development Institute

Private Companies

- Fugro
- iXblue Pty Ltd
- Water Technology
- BHP Petroleum
- Hydrographic & Cadastral Survey Pty Ltd
- Guardian Geomatics Pty Ltd
- Acoustic Imaging Pty Ltd
- Precision Hydrographic Services
- Swathe Services Australia
- Teledyne
- EGS Survey Pty Ltd
- Veris Australia
- Total Hydrographic
- Cardno Lawson Treloar
- Trimble
- JVM Consulting

Port Authorities

- Gippsland Ports
- Port Authority of NSW
- Port of Brisbane Pty Ltd
- Port of Melbourne

New Zealand

- Land Information New Zealand (LINZ)
- National Institute Water & Atmosphere (NIWA)
- Royal New Zealand Navy

International

- Centre for Coastal and Ocean Mapping, University of New Hampshire
- Canadian Hydrographic Service
- Department of Fisheries and Oceans Canada
- National geological service, France
- Geological Survey of Canada
- Geological Survey of Finland
- Geological Survey of Ireland
- Geological Survey of Italy (ISPRA)
- Geological Survey of Norway (NGU)
- Israel Oceanographic and Limnological Research
- Ministry of Lands and Mineral Resources, Fiji
- National Oceanography Centre, UK
- Pacific Community (SPC)
- Stockholm University, Sweden
- Kiel University, Germany
- University of Florida, USA

Other

- Great Barrier Reef Marine Park Authority (GBRMPA)
- Australasian Hydrographic Society

Appendix 2 – MBES survey purposes and technical specifications

Application areas	Survey purpose	Objective	Features of Interest	Depth range	Frequency range	Time sensitivity	Resolution	Horizontal accuracy	Depth accuracy	Vertical datum	Deliverables
Coastal Zone Management and Marine Conservation	**Temporal variability in coastal geomorphology**	Understand the variability of coastal morphology through time	Coast, sand movement, rocks, channels, banks	1-30m	Not specified	Before and after large storms. Alternatively, routine monitoring (e.g. monthly).	1-5m	0.1m	0.1m	AHD	• Bathymetry model/DEM surface (.ascii, NetCDF)
	Mapping sediment compartments	Mapping bathymetry and backscatter for mapping entire sedimentary compartment and seafloor types, or species preference for the habitat	Geomorphology and the extent and distribution of sediment types and size. For reef (reef morphology, feature size and relief) and for soft-sediment (the sediment facies).	0-200m	100-450 kHz (30kHz for deep water)	N/A	1m (25-50m for deep waters)	0.1m (10m or lower for deep waters)	0.1m (10m or lower for deep waters)	ELLIPSOID, AHD, MSL	• Raw sonar data (.all) • Seabed classification map (geotiff, ESRI Grid) • Bathymetry model/DEM surface (geotiff, xyz) • Backscatter mosaic (xyz) • Subtrate map (ShapeFile) • Sound Velocity Profile (.txt) • Raw backscatter (not specified)
	Modelling change in the surf zone and nearshore	Test and improve numerical modelling of storms impacts at the coastline	Not specified	0-20m	Not specified	Immediately pre and post large storm events	1m	5m	0.2m	AHD	• Bathymetry model/DEM surface (xyz)
Commercial Fishing and Aquaculture	**Scallop mapping**	Identify and model preferred seabed habitats of Saucer Scallop	Sediment distributions and geomorphology, seabed type	10-40m	240kHz	N/A	1-3m	1m	0.2m	LAT	• Bathymetry model/DEM surface (geotiff) • Backscatter mosaic (geotiff), Angular Response curves (.ascii, txt) • Raw sonar data (.xtf)
	Fisheries mapping	Map the distribution of habitat types across fisheries	Seagrass, macroalgae, sponges, reefs	2-100m	Not specified	N/A	<1m	<1m	<1m	WGS84	• Roughness and Hardness (.evi) • seabed classification map (.geotiff)

Application areas	Survey purpose	Objective	Features of Interest	Depth range	Frequency range	Time sensitivity	Resolution	Horizontal accuracy	Depth accuracy	Vertical datum	Deliverables
Habitat Mapping and Ecosystem Modelling	**Geologically-based habitat mapping to establish baseline data**	Establish baseline data to identify seafloor characteristics. This also involves integration with other discipline data (sedimentology, hydrodynamic, geochem, ecology, SBP)	Variation in seabed characteristics (Slope, Rugosity, Hardness, etc) and structure	5-3000m	200-400kHz	Collect data when the sea conditions are good and there are no storms.	1m	2-10m	< 1m	Ellipsoid	• Processed bathymetry grid (xyz, ESRI Grid) • Bathymetry model/DEM surface (las, geotiff) • Raw sonar data (.all) • Sound Velocity Profile (txt) • Backscatter mosaic (ESRI Grid, ascii) • Water column Backscatter (.wcd)
	Geologically-based habitat mapping to monitor changes	Monitor changes in the seafloor characteristics, which involves integration with other discipline data (sedimentology, hydrodynamic, geochem, ecology, SBP)	Variation in seabed characteristics (Slope, Rugosity, Hardness, etc) and structure	10-250m	Not specified	Prior to and after disturbance or routinely	< 5m	2m	0.25m	MSL	• Bathymetry model/DEM surface (.ascii, xyz) • Seabed classification map (geotiff) • Roughness and Hardness (.evi)
	Reef systems mapping	Habitat mapping targeting reef systems (reef identification using bathymetry and backscatter)	Rocky reefs extent and the amount of cover on reefs	10-120m	200-400 kHz	N/A	2m	< 1m	< 1m	GDA94, AHD, Ellipsoid	• Seabed classification map (geotiff) • Backscatter processed (gsf) Backscatter mosaic (xyz, ESRI Grid) • Bathymetry model/DEM surface (geotiff. Xyz, ESRI Grid) • Reef extent and coverage (Shapefiles)
Hydrodynamic and Storm Surge modelling	**Hydrodynamic modelling**	Creating a bathymetric model (inland and offshore waterbodies) for input into hydrodynamic modelling software	Channels, sand bars, reefs	5-200m	200-400kHz	N/A	1-20m	0.5m	0.5-2m	ITRF, Ellipsoid, AHD	• Bathymetry model/DEM surface (ESRI Grid, geotiff) • Backscatter mosaic (geotiff, .ascii)

Application areas	Survey purpose	Objective	Features of Interest	Depth range	Frequency range	Time sensitivity	Resolution	Horizontal accuracy	Depth accuracy	Vertical datum	Deliverables
Hydrographic Charting and Navigation	**Hydrographic charting**	Upgrade existing or make new charts	Features that may pose a danger to surface navigation and cause vessels to run aground. Navigationally significant features - as defined in IHO s44	0-450m	200-400kHz	Sea State 0-3	1m	Varies (0.2-5m)	Varies (0.2-1m)	Chart Datum, LAT	• Report of Survey (pdf) • Bathymetric chart (contours) (Shapefile, dwg) • Bathymetry model/DEM surface (xyz) • Tide data (format not specified) • Raw sonar data (.all) • Backscatter mosaic (geotiff)
	Local hydrographic charting	Survey approach channels to corner Inlet (utilise by offshore oil and gas industry vessels)	Those features that pose a hazard to navigation	4-10m	380khz	Sometime between April and June.	1m	5m	0.5m	LAT	• Survey plan (pdf) • Bathymetry model/DEM surface (.ascii, xyz),
	Port safety analysis and risk assessment	Generate risk assessment profile in support of port safety work, including dredge works, erosion mapping or engineering design	Obstructions	0-120m	400KHz	Depends on the task - work must be performed around shipping and harbour traffic	0.5m-1m	0.1m	0.1m	Chart Datum, AHD	• Bathymetry model/DEM surface (geotiff, .ascii)
	Port depth declaration	Hydrographic Survey specific to port depth declaration	Any features which may affect under keel clearance	5-25m	400kHz	During daylight hours	0.5m	0.5m	0.15m	LAT	• Bathymetric chart (contours) (dwg) • Bathymetry model/DEM surface (.las) • Survey plan (pdf) • iView scene (for rockwalls / seabed features only) (.scene) • Volumes (pdf)
	Mapping local marinas	Hydrographic survey of local marina	Not specified	1-5m	Not specified	Sea State 0-3	0.5m - 1m	0.1m	0.1m	Chart Datum	• Survey Plan (pdf) • Bathymetry model/DEM surface (geotiff)
Marine Construction and Infrastructure	**Dredging support and maintenance**	Support dredging activities, including monitor channel depth (e.g. shoals) and port under keel clearances from dredging works .	Shoals, debris, and any feature that pose a danger to navigation.	0-110m	For MBES: 100 and 400 kHz For SBP: 4-15 kHz	Formal scheduling is needed.	0.2m	0.1m	0.1m	AHD, LAT, Chart Datum	• CARIS surface file (csar) • Bathymetry model/DEM surface (xyz, .ascii) • Backscatter processed (xyz) • Geophysical data (seg-y)

Application areas	Survey purpose	Objective	Features of Interest	Depth range	Frequency range	Time sensitivity	Resolution	Horizontal accuracy	Depth accuracy	Vertical datum	Deliverables
	Port maintenance	Survey bathymetry pre-dredging, dredging, and post-dredging of ports	Any feature that is above the declared depth of the channel, berth, or harbour	2-40m	400kHz	Every 2-3 weeks	1m	0.5m	0.1m	LAT, using a GDA-LAT hydroid model	• Bathymetry model/DEM surface (.pts, xyz) • Report of Survey (pdf) • Bathymetric chart (contours) (dwg)
	Pipeline surveys	Map pipeline and surrounding seafloor together with side scan to monitor pipeline condition and seafloor stability.	Pipes, spans scour damage	7-1400m	Not specified	Before specific dates, usually annual surveys	0.1m	Varies with depth.	Varies with depth	LAT	• Bathymetry model/DEM surface (geotiff, xyz) • Backscatter mosaic (xyz)
Natural Disaster Recovery and Hazard Mitigation	**Mapping coastal hazards**	Model coastal hazard, e.g. coastal erosion, inundation, etc.	Extent of sand/reef, bathymetry, sediment compartments	20-50m	200-400kHz	Best done in calm conditions	Not specified	5 metres + 5% of depth	0.5m	AHD	• Bathymetry model/DEM surface (xyz) • Backscatter processed (.gsf)
	Mapping submarine fault systems	Map major transform fault boundary where magnitude 7 to 8 earthquakes are common and tsunamis can be expected.	Faults, canyons, sedimentary bedforms, underwater volcanos	30-2500m	70 - 100kHz	Immediately after an earthquake event	5m	5m	0.1m	Not specified	• Fault map (geotiff, shapefile)
Resource and Mineral Exploration	**Site survey for oil and gas infrastructure development**	Site survey for a oil and gas field	Large features that would make placing subsea assets difficult	3-300m	200kHz	N/A	2m	2m	0.5m	MSL, LAT	• Bathymetry model/DEM surface (xyz, .ascii, geotiff)
	Mapping hydrocarbon seeps	Identify the location of seeps and choosing core sites .	Faults, mounds, pockmarks, tectonic features, authigenic carbonate outcrops, chemosynthetic clam beds, nodule beds, rock outcrops, brine pools, salt domes, mineral deposits	100-6000m	12-30kHz	Depends on the region. Good weather time preferably	Bathymetry: 15m, backscatter: 5m	<3 HDOP	1% of water depth	WGS84 usually unless client specifies differently	• Raw sonar data (.all) • Raw water column data (.wcd) • Bathymetry model/DEM surface (ascii, xyz) • Fledermaus 3D files (.scene), Sub-bottom profiles (.sgy)

Application areas	Survey purpose	Objective	Features of Interest	Depth range	Frequency range	Time sensitivity	Resolution	Horizontal accuracy	Depth accuracy	Vertical datum	Deliverables
Geological mapping and seafloor physical characterisation	**Geoscience research**	Generate bathymetry and backscatter to identify seafloor features	Canyons, landslides, drowned reefs, bedforms	20-5000m	12 - 240 kHz	Outside of cyclone season (Dec-Apr)	varies - highest possible	< 5m	< 1m	Both raw seabed depth, sometimes with MSL tides (applied using GPS tides or predicted tides from AusTides form nearest tide stations), and also to ellipsoid.	• Bathymetry model/DEM surface (csar) • Backscatter mosaic (geotiff)
	Mapping canyons and subsurface features	Map canyons and sub surface features to understand tectonics, exposure of seafloor rock samples, or natural sub surface seepage indicators.	Pock marks, faults exposed at sea floor, or hard grounds	100-7000m	12 kHz or 100 kHz	Not specified	1-30m	1-30m	2m	MSL	• Processed bathymetry grid (ESRI Grid) • Backscatter mosaic (.ascii)
	Mapping offshore geological surfaces	Map the bedrock geology (and seabed substrate)	Bedrock	0-250m	Not specified	Not specified	1-20m	1-5m	1-2m	LAT	• Processed bathymetry grid (ESRI Grid) • Backscatter mosaic (.ascii)
	Mapping sediment grain-size	Generate sediment maps derived from backscatter data	Sediments, sand	30-3000m	Not specified	April - September	3m	2m	1m	Not specified	• Raw sonar data (.all) • Map of distribution of sediments (geotiff, ShapeFile)
	Mapping seafloor types i.e. substrates	Map the spatial distribution of seafloor types or species preference for the habitat	Geomorphology	0-200m (up to 7000m)	100-400 kHz (30kHz for deep water)	N/A	1m (25-50m for deep waters)	0.1m (10m or lower for deep waters)	0.1m (10m or lower for deep waters)	AHD, MSL, Ellipsoid	• Raw sonar data (.all) • Raw water column data (.wcd) • Bathymetry model/DEM surface (geotiff, csar, ESRI Grid) • Backscatter mosaic (geotiff) • Sound Velocity Profile (.txt) • Sub-bottom profile (chirp) (seg-y) • Metadata (pdf)
	Mapping extended continental shelf	Delineate the outer continental shelf of countries and identify Foot of Slope (FOS) points for their	Foot of slope, 2500m isobath	200-10000m	Not specified	Depends on location - Arctic in late summer - Atlantic	depends on water depth from ~25m	< 10m	0.01% of water depth	WGS84, MSL	• Bathymetry model/DEM surface (geotiff, ascii, SD) • Backscatter mosaic (geotiff, .ascii) • Sound Velocity Profile (.ascii, edf) • Sub-bottom profile (chirp) (seg-y) • Metadata (pdf)

Application areas	Survey purpose	Objective	Features of Interest	Depth range	Frequency range	Time sensitivity	Resolution	Horizontal accuracy	Depth accuracy	Vertical datum	Deliverables
		Extended Continental Shelf (ECS).				need to avoid hurricane season.	- 100m horizontal				
Reference surface and Ground-truthing	**Reference surfaces for airborne LiDAR bathymetry**	Use of MBES for serving as "ground truth" for a subsequent Airborne LiDAR Bathymetry survey.	N/A	5-50m	Not specified	Ideally before ALB data acquisition starts, usually a couple of weeks turnaround.	10m	5m	0.5m	WGS84, ITRF2014	• Bathymetry model/DEM surface (.ascii, xyz) • Metadata (pdf)
	Reference surfaces for bathymetry sensor	Use of MBES for serving as "ground truth" for a subsequent bathymetric survey using any sonar sensor.	Stable sea floor	0-20m	>200 kHz	Data remains current for a maximum of 1-3 months, hence every 1-3 months.	<2m	<1m	0.5-2 m	LAT (port datum) horizontal datum GDA 94	• Bathymetry model/DEM surface (.ascii, xyz)
	Ground truthing of backscatter data	Collect seabed samples to ground truth backscatter data and predict seafloor type. This application may involve identification of sediment compartments and video ground truthing.	Reef and marine sediment extent and location.	5-120m	350-400 kHz	N/A	1m to 5m gridded	0.5m DGPS & 0.05m RTK	0.3m Deepwater & 0.1m nearshore & estuary	AHD	• Seabed classification map (geotiff) • Report of Survey (PDF) • Bathymetry model/DEM surface (xyz) • Video (.avi)

Appendix 3 – List of Guidelines and Standards

no.	Specifications/guidelines	Year	Country	Link to standard
1	*A reassessment of vessel coordinate systems: what is it that we are really aligning?*	*2003*	*International*	http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.491.4731&rep=rep1&type=pdf
2	*Accuracy estimation of Canadian swath and sweep sounding systems*	*1995*	*Canada*	*AusSeabed Google Drive*
3	*Australian multibeam guidelines (2018)*	*2018*	*Australia*	https://ecat.ga.gov.au/geonetwork/srv/eng/catalog.search?node=srv#/metadata/854f5bbd-91fd-4f64-82ab-59662ce3aa89
4	*Australian tides manual: special publication no. 9*	*2018*	*Australia*	-
5	*Automated tools to improve the ping-to-chart workflow*	*2017*	*International*	https://ccom.unh.edu/sites/default/files/publications/IHR_May2017_QCTools.pdf
6	*Backscatter measurements by seafloor-mapping sonars guidelines and recommendations (GEOHAB Backscatter Working Group)*	*2015*	*International*	https://www.niwa.co.nz/static/backscatter_measurement_guidelines.pdf
7	*Bathymetric surface product specification*	*2012*	*International*	https://www.iho.int/iho_pubs/standard/S-102/S-102_Ed1.0.0_Apr12.pdf
8	*Calibration of acoustic instrument*	*2015*	*International*	http://www.ices.dk/sites/pub/Publication%20Reports/Cooperative%20Research%20Report%20%28CRR%29/crr326/CRR326.pdf
9	*Calibration of acoustic instruments for fish density estimation: a practical guide*	*1986*	*UK*	http://courses.washington.edu/fish538/resources/CRR%20144%20acoustic%20calibration.pdf
10	*Contract specifications for*	*2016*	*New Zealand*	*https://www.linz.govt.nz/file/13317/download?token=aN6Ss7-i*
11	*Contract specifications for hydrographic surveys*	*2016*	*New Zealand*	https://www.linz.govt.nz/system/files_force/media/doc/hydro_linz-contract-specifications-for-hydrographic-surveys_20160607_0.pdf?download=1
12	*Definitions for hydrographic chart production*	*2003*	*New Zealand*	https://www.linz.govt.nz/system/files_force/media/pages-attachments/CTHTechnicalreport15vers2.pdf?download=1
13	*Dutch standards for hydrographic surveys*	*2009*	*Netherlands*	*AusSeabed Google Drive*
14	*Ellipsoidally referenced surveying for hydrography*	*2014*	*International*	http://www.fig.net/resources/publications/figpub/pub62/figpub62.asp
15	*Error budget analysis for surface and underwater survey system*	*2016*	*International*	https://journals.lib.unb.ca/index.php/ihr/article/download/25812/29960
16	*GDA2020 and gda94 technical manuals*	*2018*	*Australia*	https://www.icsm.gov.au/datum/gda2020-and-gda94-technical-manuals
17	*General instructions for hydrographic surveyors*	*1996*	*UK*	https://catalogue.nla.gov.au/Record/1823924
18	*Geophysical survey & mapping (GSM): shallow-water multibeam surveying standard operating procedure*	*2015*	*Australia*	*AusSeabed Google Drive*
19	*Guidance notes for the production of discovery metadata for the marine environmental data and information network (MEDIN)*	*2009*	International	http://www.oceannet.org/marine_data_standards/documents/medin_schema_doc_2_3_8.pdf
20	*Guideline for control surveys*	*2014*	*Australia/NZ*	https://www.icsm.gov.au/sites/default/files/2018-02/Guideline-for-Control-Surveys-by-Differential-Levelling_v2.1.pdf
21	*Guideline for control surveys by GNSS (special publication 1)*	*2014*	*Australia*	https://www.icsm.gov.au/sites/default/files/2018-02/Guideline-for-Control-Surveys-by-GNSS_v2.1.pdf
22	*Guideline for seafloor mapping in German marine waters*	*2016*	*Germany*	*AusSeabed Google Drive*
23	*Guidelines for control surveys by differential levelling (special publication 1)*	*2014*	*Australia*	https://www.icsm.gov.au/sites/default/files/2018-02/Guideline-for-Control-Surveys-by-Differential-Levelling_v2.1.pdf

24	*Guidelines for the planning, execution and management of hydrographic surveys in ports and harbours*	*2010*	*International*	https://www.fig.net/resources/publications/figpub/pub56/figpub56.pdf
25	*Guidelines for the use of multibeam echosounders for offshore surveys*	*2006*	*UK*	https://books.google.com.au/books/about/Guidelines_for_the_Use_of_Multibeam_Echo.html?id=EhZiNAAACAAJ&redir_esc=y
26	*Hydrographic quality assurance instructions for admiralty surveys (HQAIS)*	*2003*	*UK*	http://indiannavy.gov.in/nih/sites/default/files/nihpdf/HQAI.pdf
27	*Hydrographic survey management guidelines*	*2013*	*Canada*	http://www.charts.gc.ca/documents/data-gestion/guidelines-directrices/sg-ld-2013-eng.pdf
28	*Hydrographic survey management guidelines*	*2013*	*Canada*	http://www.charts.gc.ca/documents/data-gestion/guidelines-directrices/sg-ld-2013-eng.pdf
29	*hydrographic surveys (v 1.3)*			
30	*ICES guidelines for discrete water sample data*	*2006*	*International*	http://ices.dk/sites/pub/Publication%20Reports/Data%20Guidelines/Data_Guidelines_water%20samples_v7_revised_2006.pdf
31	*ICES guidelines for multibeam echosounder data*	*2006*	*UK*	https://www.oceanbestpractices.net/handle/11329/239
32	*ICSM Australian tides manual (SP9) version 4.4*	*2017*	*Australia*	http://www.icsm.gov.au/sites/default/files/2017-07/SP9_v4.4_May2017.pdf
33	*ICSM lidar acquisition specifications and tender template*	*2011*	*Australia/NZ*	https://www.icsm.gov.au/sites/default/files/2017-03/NZ-LiDAR_Specifications_and_Tender_Template.pdf
34	*IHO manual on hydrography (c-13)*		*International*	https://www.iho.int/iho_pubs/CB/C13_Index.htm
35	*IHO S-44 (5th Edition)*	*2008*	*International*	https://www.iho.int/iho_pubs/standard/S-44_5E.pdf
36	*IHO transfer standard for digital hydrographic data (edition 3.1)*	*2000*	*International*	https://www.iho.int/iho_pubs/standard/S-57Ed3.1/31Main.pdf
37	*Int1 symbols, abbreviations and terms used on charts (s-4)*	*2015*	*-*	https://www.iho.int/iho_pubs/IHO_Download.htm
38	*JNCC guidelines for minimising the risk of injury to marine mammals from geophysical surveys*	*2017*	*UK*	http://jncc.defra.gov.uk/pdf/jncc_guidelines_seismicsurvey_aug2017.pdf
39	*LINZ source data specification (v 4.0)*	*2013*	*New Zealand*	https://www.linz.govt.nz/system/files_force/media/pages-attachments/linz__source_data_specification_v_4.0.pdf?download=1
40	*Manual on maritime safety information (MSI)*	*2016*	*International*	https://www.iho.int/iho_pubs/standard/S-53/S_53_JAN16_E.pdf
41	*Marine sampling field manual for grabs and box corers*	*2018*	*Australia*	*https://www.nespmarine.edu.au/sites/default/files/_PUBLIC_/FieldManuals_NESPMarineHub_Chapter9_Grab_v1.pdf*
42	*MESH guide: how do I collect my data?*	*2007*	*Europe*	https://www.researchgate.net/profile/Jonathan_White12/publication/281293856_MESH_Guide_How_Do_I_Collect_My_Data/links/55e084cd08aede0b572e6875/MESH-Guide-How-Do-I-Collect-My-Data.pdf?origin=publication_detail
43	*Methodologies for seabed substrate characterisation using multibeam bathymetry, backscatter and video data*	*2013*	*Australia*	https://d28rz98at9flks.cloudfront.net/74092/Rec2013_011.pdf
44	*NIWA multibeam operator notes*	*2013*	*New Zealand*	*AusSeabed Google Drive*
45	*NZ hydrographic surveys guidelines*	*2004*	*New Zealand*	https://www.maritimenz.govt.nz/commercial/ports-and-harbours/documents/Hydrographic-surveys-guidelines.pdf
46	*Pillbara ports authority - hydrographic survey standards and deliverables*	*2017*	*Australia*	https://www.pilbaraports.com.au/PilbaraPortsAuthority/media/Documents/PORT%20OPERATIONS/ENVIRONMENT%20AND%20HERITAGE/Hydrographic-Survey-Standards-and-Deliverables-(A306835).pdf
47	*Principles for gathering and processing hydrographic information in Australian ports*	*2012*	*Australia*	http://www.portsaustralia.com.au/assets/Publications/Principles-for-Gathering-and-Processing-Hydrographic-Infomration-in-Australian-Ports-inc.-PA-Port-Survey-Principles-Appendix-V-1.5-JAN13-a.pdf
48	*Product specification for Raster Navigational Charts (RNC)*	*1999*	*International*	https://www.iho.int/iho_pubs/standard/S61E.pdf

49	*Recommended operating guidelines (rog) for swath bathymetry*	*2007*	*Europe*	*AusSeabed Google Drive*
50	*Recommended operating guidelines (ROGs) for habitat mapping*	*2007*	*UK*	http://webarchive.nationalarchives.gov.uk/20101014090644/http://www.searchmesh.net/pdf/GMHM3-3%20ROGs%20for%20habitat%20mapping.pdf
51	*Regulations for international (int) charts and chart specifications of the IHO*	*2017*	*International*	https://www.iho.int/iho_pubs/standard/S-4/S-4%20Ed%204.7.0%20July%202017%20EN.pdf
52	*Reporting discrepancies on nautical charts and publications*	*2017*	*Australia*	http://www.hydro.gov.au/feedback/feedback-hydronote.htm
53	*Sea floor mapping field manual for multibeam sonar*	*2018*	*Australia*	https://www.oceanbestpractices.net/handle/11329/455
54	*Seabed backscatter, data collection, and quality overview*	*2007*	*Australia*	https://publications.csiro.au/rpr/pub?list=BRO&pid=procite:d260c1f3-0119-4fa8-9820-d158bb63b4d6
55	*Seabed survey data model (SSDM)*	*2017*	-	http://www.iogp.org/geomatics/#ssdm
56	*Seafarers handbook for Australian waters (ahp20)*	*2016*	*Australia*	http://www.hydro.gov.au/prodserv/publications/ash.htm
57	*Seafloor mapping field manual for multibeam sonar*	*2018*	*Australia*	*https://www.nespmarine.edu.au/sites/default/files/_PUBLIC_/FieldManuals_NESPMarineHub_Chapter3_MBES_v1.pdf*
58	*Specifications for chart content and display aspects of ECDIS*	*2014*	*International*	https://www.iho.int/iho_pubs/standard/S-52/S-52%20Edition%206.1.1%20-%20June%202015.pdf
59	*Standard for official New Zealand sea level information*	*2003*	*New Zealand*	https://www.linz.govt.nz/system/files_force/media/pages-attachments/THStandard54.pdf?download=1
60	*Standard for the Australian survey control network (sp1)*	*2018*	*Australia*	https://www.icsm.gov.au/sites/default/files/2018-02/Standard-for-Australian-Survey-Control-Network_v2.1.pdf
61	*Standard operation procedure for a multibeam survey: acquisition & processing*	*2013*	*Australia*	https://d28rz98at9flks.cloudfront.net/76713/Rec2013_033.pdf
62	*Standards for hydrographic surveys*	*2013*	*Canada*	http://www.ppa.gc.ca/text/publications/CHS%20Standards%20for%20Hydrographic%20Surveys.pdf
63	*Standards for hydrographic surveys within Queensland waters*	*2009*	*Australia*	https://www.msq.qld.gov.au/-/media/MSQInternet/MSQFiles/Home/boatingmaps/Hydrographic-survey-standards/Pdf_standards_hydro_surveys.pdf?la=en
64	*Statistical considerations for monitoring and sampling*	*2018*	*Australia*	https://www.nespmarine.edu.au/sites/default/files/_PUBLIC_/FieldManuals_NESPMarineHub_Chapter2_Design_v1.pdf
65	*Technical specification for ultra-short baseline acoustic navigation systems*	*2012*	*International*	*AusSeabed Google Drive*
66	*The calibration of shallow water multibeam echo-sounding systems (technical report no. 217)*	*1998*	*Canada*	http://www2.unb.ca/gge/Pubs/TR190.pdf
67	*Universal hydrographic data model*	*2017*	*International*	https://www.iho.int/iho_pubs/standard/S-100/S-100_Ed_3/S-100_Edition_3.0.0.pdf
68	*User's handbook on datum transformations involving WGS84*	*2003*	*International*	https://www.iho.int/iho_pubs/standard/S60_Ed3Eng.pdf

Appendix 4 – List of Commonly Used QA/QC Tools

no.	Tool name	Entity	Web link/reference
1	*QC Tools*	*HydrOffice*	*https://www.hydroffice.org/qctools*
2	*Cube*	*Center for Coastal and Ocean Mapping/Joint Hydrographic Center (CCOM/JHC)*	*http://ccom.unh.edu/theme/data-processing/cube*
3	*Caris HIPS and SIPS*	*Teledyne*	*http://www.caris.com/products/hips-sips/*
4	*MBQA*	*MBsystem*	*https://www.mbari.org/products/research-software/mb-system/*
5	*QPS suite: QINSy, Qimera and Fledermaus*	*QPS*	*http://www.qps.nl*
6	*LandMark Marine*	*Applanix (a Trimble company)*	*https://www.applanix.com/products/landmark-marine.htm*
7	*HydroBib (Scansurvey)*	*HydroCharting*	*https://www.mbari.org/products/*
8	*Hypack (Hypack Survey and Hysweep)*	*Xylem*	*http://www.hypack.com/products*
9	*PosPac MMS*	*Applanix*	*https://www.applanix.com/products/pospac-mms.htm*
10	*SonarScope*	*Ifremer*	*http://flotte.ifremer.fr/fleet/Presentation-of-the-fleet/Logiciels-embarques/SonarScope*
11	*Seafloor Information System Quality Assurance (SIS QA)*	*Kongsberg*	*https://www.km.kongsberg.com/ks/web/nokbg0397.nsf/AllWeb/17A82CA49F3A8E6EC1257FE2002C6F48/$file/403644-sis-qa-product-sheet.pdf?OpenElement*
12	*LasTool*	*Rapidlasso*	*https://rapidlasso.com/lastools/*
13	*QA4LiDAR*	*FrontierSI (formerly CRCSI)*	*https://qa4lab.com/qa4lidar/*
14	*Beamworx products*	*Beamworx*	*https://www.beamworx.com/autopatch/*
15	*TMC*	*Trimble*	*https://construction.trimble.com/products-and-solutions/trimble-marine-construction-tmc-software*

Note. The data provided in the survey did not allow for more cross-analysis of the use of this data (e.g. most common tool used per sector)