# Hydrographic Survey of Apollo Marine Park



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Parks Australia



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#### Hydrographic Survey of Apollo Marine Park

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# 1 Executive Summary

Deakin University's Marine Mapping Group, in partnership with iXblue Pty Limited and Parks Australia, conducted a hydrographic survey in the Apollo Marine Park (MP) to complete the requirements outlined in the Approach to Market, DNP-MPA-1920-008. Prior to this program, high-resolution bathymetric mapping information for Apollo MP was limited to multibeam sonar mapping in a search and imaging of the City of Rayville conducted by Deakin University and partners in 2009. The only other available data for the Park was low resolution (250 m) magnetically-derived bathymetry information provided by Geoscience Australia (GA; Whiteway, 2009). The research outlined in this report is a first step in establishing a baseline understanding of the Apollo MP at a resolution useful to managers. This mapping work is critical for identifying the location of deep-shelf reefs to inform future deployment of Baited Remote Underwater Videos (BRUVs), Towed video (TV) and Autonomous Underwater Vehicle (AUVs) to characterise sessile benthic fauna and demersal fish communities. The bathymetry information can also be used to derive characteristics of the seafloor for developing a better understanding of the distribution of habitats in the Park, including the distribution of hard and soft substrates, to help manage the Park.

Apollo MP is located with its northern boundary 3 nautical miles south of Cape Otway and is recognised for its exposure to predominant south-westerly swells and strong tidal flows as the southern tip of the Cape interacts with high geoform complexity. Biological observations in state waters to the north show mesophotic reefs dominated by sessile invertebrates including: high diversity sponge assemblages, non-reef forming benthic assemblages dominated by sponge mounds, moderate to high complexity rock with prominent sea plumes- sea tulips-hydroid fans and erect octocorals on sediment (VEAC, 2019) that are likely to extend in their distribution into Apollo MP. To maximise multibeam echo sounder bathymetric mapping (including the acquisition of backscatter and water column data) of these important habitats within the Apollo MP, Deakin University targeted areas of likely reef, including the likely extension of reef off the Cape Otway headland as well as bathymetric highs identified in the GA magnetic product.

During this project, 872 linear kilometres of multibeam data were collected over ~75 hours resulting in a total mapped area of 119 km<sup>2</sup> (10 % of the Apollo Marine Park area). This high resolution mapping of the Apollo MP resulted in the discovery of multiple features of interest throughout the Park. Mapping in the northwest revealed reef and likely hard bottom with variable complexity, which is a continuation of features previously mapped within state waters off the Cape Otway headland. There was also evidence of cemented sediment with sections of hard bottom covered in a sediment veneer. The western section of the mapped area consisted of hard and consolidated sedimentary bedforms. Additionally, high density data collected in the vicinity of the City of Rayville wreck allowed for the development of a 3D point cloud for analysing the remains of the wreck site. A summary of results, data collection, data processing, calibration and geodetic parameters are provided throughout this report.

This initial mapping within the Apollo Marine Park not only provides vital information for management of the park but will help to guide future studies. First, these maps can be used to target areas for future mapping campaigns to extend coverage based on features of interest. These features may include the extension of mapping in the northwest to fill in the southern ridge feature extending from the north to the southwest. These maps can also be used to help inform ground truthing of habitat types and the biological communities they support. The topography and some information on the texture of the seafloor is provided through the

multibeam bathymetry and backscatter information, but extensive ground truthing is required to provide confidence in substrates inferred and needs to be considered in future programs. Ground truthing (e.g. Baited remote underwater video systems, towed video and autonomous underwater vehicles) can provide information on the biological communities supported by the variability in seabed structure that will allow us to increase understanding of the biodiversity within the marine park and the coverage achieved will allow in targeting efforts.

# 2 Study Site Location

#### 2.1 Site Location Overview

Extending over an area of 1184 km<sup>2</sup> of the continental shelf, the Apollo MP sits within the cool waters of Bass Strait, south of Cape Otway in Victoria, Australia (Figure 1). The MP starts in depths less than 50 m near Cape Otway, deepening offshore and within the Otway Depression, an ancient river valley from the Last Glacial Maximum (~21 ka) (Wass et al., 1970; Amini et al., 2004). Many different animals utilise the marine park for foraging including seabirds, dolphins, seals, and white sharks. It also serves as an important migration area for blue, fin, sei, and humpback whales (Gill, 2002). Less is known about those species that cannot be seen from the water surface, including the fishes and benthic fauna inhabiting the reefs and sediments. The maps from this work are providing insight into the habitats that are likely to support biodiversity rich communities. This type of information will help Parks Australia to more effectively manage the marine park and prioritise biological sampling such as baited camera systems, towed video and autonomous underwater video.

Along the southern shelf of Australia the circulation is predominantly the result of wind forcing. Observations strongly suggest that there is a wintertime eastward current over the continental shelf flowing from Cape Leeuwin to the southern tip of Tasmania. In the summer, the coastal wind reverses and changes to an upwelling favourable system producing westward flow at the coastal boundary (Butler et al., 2002).

The two dominant features of the ocean along the southern Australian margin are a warm mixed-surface layer that is underlain by cooler Antarctic Intermediate Water (AAIW). The mixed surface layer flows in a generally east south-east direction and is known as the Leeuwin Current off west Australia, and the Coastal Current off South Australia and Victoria (Levings and Gill, 2010). An underlying counter-current of AAIW flows in a generally north-westward direction at a depth of about 400-600 m extending to approximately 1200 m and is known as the Leeuwin Undercurrent off west Australia and the Flinders Current off western Tasmania, western Victoria, and South Australia (Middleton and Cirano, 2002). This current feeds into shallower shelf circulations during summer when wind from the south-east forces the mixed surface layer offshore and triggers a compensatory upwelling of AAIW from greater depths that can extend west to Cape Otway (Levings and Gill, 2010; Middleton and Bye, 2007).



Figure 1 Location map of Apollo Marine Park off Victoria, Australia (a, b). The coloured, shaded relief imagery shows the area mapped by Deakin University (c). The blue lines in b and c represent 25 m contours derived from the Geoscience Australia 250 m bathymetry product.

## 3 Methods

The objective of this project was to maximise multibeam echo sounder bathymetric mapping (including backscatter and water column) within the Apollo MP targeting probable areas of deep-shelf reefs within budget constraints. State mapping initiatives in Victoria have documented the extent of the Cape Otway headland to the state waters limit, thus providing a high likelihood of reef extension into the Apollo MP northern region. In collaboration with Parks Australia, Deakin University conducted a survey design with daily reports in an attempt to maximise the potential coverage of mesophotic reefs. This included the investigation of potential bathymetric highs identified from Geoscience Australia magnetically-derived coarse bathymetry data (Whiteway, 2009).

To meet the objectives of this project, multibeam surveys were conducted between the 7th and 29th January on board Deakin's vessel, MV Yolla. A total of 75 hours of multibeam sonar data were acquired by targeting available weather windows for data capture within the Apollo MP. More than 872 linear km (470 nautical miles excluding transits) of acquisition was achieved providing full coverage seabed mapping data for 119 km<sup>2</sup>, just over 10% of the Park. In addition, the team collected 29 linear km of acquisition on the northern boundary (collected in-kind by Deakin University), outside the MP, to enable continuous coverage of the subaquatic

component of the Otway ridge when combined with state data collection initiatives. The MV Yolla was equipped with a Kongsberg Maritime EM2040C multibeam echo sounder (MBES), Applanix POS MV Wavemaster and dual frequency Trimble Global Navigation Satellite System (GNSS) receivers. Sound velocity profiles (SVP) were measured three times daily using a Valeport MIDAS SVX2 Sound Velocity Profiler to correct the sonar data for local variations in sound speed. Please see Section 5 for details on Multibeam data collection and processing settings.

### 4 Results

This section outlines the bathymetry and backscatter data at the study site. Multibeam bathymetry (Figure 2), backscatter (Figure 4) and water column data were collected simultaneously during the MBES data acquisition. Horizontal positions are presented in the Geocentric Datum of Australia 2020 (GDA2020). The vertical datum is referenced to the Australian Height Datum (AHD) for all deliverables. A CUBE surface within CARIS HIPS & SIPS 10.3 was generated at a resolution of 2 m and the backscatter mosaic was processed at 1 m resolution in Fledermaus Geocoder Toolbox (FMGT). The bathymetry and backscatter data were used to provide an interpretation of the seafloor geomorphology.



Figure 2 Bathymetry of Apollo Marine Park gridded at 2 m resolution. Coloured by depth, and overlaid on shaded relief imagery (Azimuth 0°, Altitude 60°, Z factor 3). Four areas of interest are highlighted in the figure. The black lines in the extent indicators indicate the region where a profile of the seabed was derived (Figure 3 for the profiles, lettered according to the box they are from).



Figure 3 Cross section profiles of four areas of interest shown in Figure 2.



Figure 4 Backscatter mosaic of Apollo Marine Park. Gridded at 1 m resolution and overlaid on shaded relief imagery (Azimuth 0°, Altitude 60°, Z factor 3). Four areas of interest are highlighted in the figure (a-d).

#### 4.1 Overview of Seabed Characteristics

The depth range of the mapped area is 43.3 to 99.4 m (mean of  $77.5 \pm 8.7$  m) (Figure 2) with key features identified in Figure 5 and Table 1. Extensive reef and hard bottom with variable complexity with likely sand inundation was observed in the north-western sector (Figure 2a, Figure 4a, Figure 5a). This sector is most likely reef habitat including ridges and a paleoshoreline feature (Figure 5e). The reef topology profiles from each of the transects within the boxes (Figure 2) are shown in Figure 3. Profile 3a highlights the topographic complexity of the seabed in this region.

The western sector of the mapped area consists of hard and consolidated sedimentary bedforms, in the vicinity of the City of Rayville wreck (Figure 6). The multibeam sonar data provide a very clear picture of the orientation of the wreck and surrounding seabed (Figure 6). The wreck is laying upright on its keel, with a slight list to one side with the bow facing south-east.

A rising feature south of the wreck site extends from the south-west to north-east sector (Figure 2c, Figure 3c, Figure 4c, Figure 5f). This feature is possibly a consolidated sediment bedform or bedrock and includes linear ridge features with backscatter returns indicating hardness. The backscatter in this region (Figure 4c) shows evidence of sediment with variable reflectance and sections of likely hard bottom covered in a veneer sediment. Similar features north of the study area have supported invertebrate dominated communities (VEAC, 2019).

An irregular pattern of sand waves are present in the south-eastern sector of the mapped area (Figure 2d, Figure 3d, Figure 4d). Figure 5b shows what appear to be remobilised sand packages with W-E mobility with linear fingers trailing off the well-bedded outcrops of the marine extension of the Otway Ranges, with evidence of currents and potentially oscillating flow driving mobilisation. Transportation off the hard bedrock suggests transportation downslope from the first ridge feature and across a trough and a second ridge before heading to deeper water, potentially reducing sediment contributions in the littoral zone on the Victorian coast. Interestingly these bed forms have a strong reflectance indicating that they may be consolidated or have micro roughness properties influencing backscatter returns.

#### Table 1 Key Features

Key Features	Comments	
Extensive reef	<ul> <li>Ridge-like features that are parallel to the paleoshoreline.</li> <li>Subaquatic extension of the Otway Ranges is identified in the north-west sector and potential evidence of slope collapse.</li> </ul>	
Rising ridge feature	<ul> <li>Likely an expression of the underlying bedrock, with ridge features showing hard reflectance and minimal sediment accumulation.</li> <li>Two ridge-like features, which are parallel to a paleoshoreline around 70 m, and separated by a wide (3km) trough.</li> </ul>	
Hard substrate	<ul> <li>Mainly in the north-west sector. Likely to have a veneer of sediments in low profile areas. This is likely to be coarse material due to the high energy present off the Cape. Evidence of other areas of hard acoustic reflectance including linear rise features along the two ridges identified and isolated reef patches.</li> </ul>	
Soft substrate	<ul> <li>In some areas likely to be a veneer of sediment on harder bedforms based on acoustic properties.</li> </ul>	
Directional sand deposition features	• Caused by oscillating flow resulting in the eastward transport of sediments. These features are over the underlying bedrock. Interestingly these features have a hard backscatter return that may be an indication of their microroughness, coarse sediment properties or cemented bedforms.	



Figure 5 Features of interest within the Apollo Marine Park including the extensive reef areas in the northwest (a), the eastwest directional sand deposition features in the north (b), the areas of sand substrate in the east shown as the darker areas (lower intensity) in the backscatter (c), examples of sand-inundated reefs showing the darker backscatter (lower intensity) over the top of lighter reef (higher intensity) features (d), the paleo shoreline feature (e), and consolidated bedforms found in the southern mapped area (f). The locations of these features are shown as extent indicators in Figure 7 below.



Figure 6 Bathymetry data gridded at 50 cm resolution coloured by depth, and overlaid on shaded relief imagery (Azimuth 0°, Altitude 60°, Z factor 3) to highlight the City of Rayville shipwreck. A profile line is drawn across the wreck and the resulting profile is shown below the image.



Figure 7 The mapped extents of Apollo Marine Park gridded at 2 m resolution and coloured by depth and overlaid on shaded relief imagery (Azimuth 0°, Altitude 60°, Z factor 3). Each of the boxes (a-f) corresponds to the highlighted features of interest shown in Figure 5. The City of Rayville shipwreck is shown in Figure 6.

#### 4.2 Substrate Classification

The substrate of the mapped area within the Apollo MP was classified into hard substrate, soft substrate, and potential hard substrate using the ISO Cluster Unsupervised Classification in ArcGIS Pro 2.4 (ESRI, 2019) using layers derived within the Benthic Terrain Modeller tool (Walbridge et al., 2018). The derivatives used in the ISO Cluster analysis included depth, vector ruggedness measure (VRM), eastness, northness, slope, bathymetric position index (BPI), and backscatter. This classification resulted in 16.4 km<sup>2</sup> of hard substrate (12.6% of the mapped area), 15.6 km<sup>2</sup> potential hard bottom (12.0% of the mapped area) and 98.0 km<sup>2</sup> of soft substrate (75.4% of the mapped area) (Figure 8). The area defined as soft substrate or potential hard bottom are likely to have cemented bedforms or bedrock with veneer of coarse sediment and, based on previous surveys to the north of the park boundary, potentially providing attachment for invertebrate communities, thus these communities may be found throughout the mapped area. The majority of the hard substrate is found in the north-west section of the MP with the remaining hard bottom found throughout the site as linear features that are likely to support the greatest density of invertebrate communities due to the availability of hard substratum for attachment. Many of the areas of hard substrate (or potential hard substrate) indicate they have a veneer of sediment. The nature of the seafloor due to the lack of complexity over the majority of the site and low-lying features would require ground truthing for training and validation for deriving substrate and biological maps.



Figure 8 Substrate classification of the mapped areas of the Apollo Marine Park. The area was classified into three substrate classes using the ISO Cluster Unsupervised Classification in the Benthic Terrain Modeller: potential hard substrate, hard substrate, and soft substrate. The derivatives used included backscatter, bathymetry, bathymetry VRM, eastness, northness, slope, and Benthic Position Index. The classification resulted in 12.6% hard, 12.0% potential hard, and 75.4% soft substrate. Majority of areas identified as soft substrate are likely to have bedrock or cemented features covered in a veneer of coarse sediment. Note this is preliminary to inform biological surveys and would require ground truth for model training and validation.

#### 4.3 Recommendations

Seabed mapping data are increasingly being recognised for their importance in underpinning marine spatial planning. The ability to collect high resolution multibeam echosounder (MBES) data is often seen as the first step in mapping the distribution of benthic habitats and the biological communities they support. By generating bathymetry and backscatter models of the seabed we can get a better understanding of seabed complexity that can be used to identify candidate locations likely to support key ecological features and target biodiversity assessments. Seabed mapping also provides important insights into our geological past such as ancient shorelines from lower sea level stands, sediment transport and the ability to image sites of cultural significance.

This initial mapping within the Apollo Marine Park provides vital information for management of the park and also guide future studies. Below we list a series of recommendations.

- Approximately 10% of the Apollo Marine Park has been mapped in this study for the first time. Whilst we have likely mapped the most topographically complex section of the park extending off Cape Otway there are probable areas of hard bottom beyond the coverage achieved. This is most evident in a second ridge feature that would be covered by extending mapping from the northern coverage of the park.
- Whilst we investigated a potential bathymetric high identified from Geoscience Australia magnetically-derived coarse bathymetry data (See Figure 8 (d)) with no detectable features, there are at least another 4 targets further south and south east in the Apollo Marine Park that may be worthy of investigation.
- Multibeam bathymetry, backscatter data and initial estimates of substrate distribution can be used to help inform ground truth locations to map habitat types and the biological communities they support.
- The topography and some information on the texture of the seafloor is provided through the multibeam bathymetry and backscatter information that has been used to infer broad substrate classes in this study. However, extensive ground truthing is required to improve models of substrates inferred and validate these products. This may include sediment sampling using benthic grabs and remote observations from towed video. If sediment veneers over bedrock are verified in ground truthing, sub-bottom profiles may be of use to better understand sediment thickness and extent of sand inundated reefs.
- A combination of grab samples to investigate sediment characteristics/ infauna communities and benthic imaging using towed video and AUVS would be useful for biodiversity assessments. Stereo baited remote underwater video systems provide the likely best solution for evaluating fish assemblages.
- A spatially balanced design informed by seafloor mapping data would provide the best solution for ground truth prioritisation, sampling representative or targeted habitats such as reefs in the coverage achieved.

# 5 Appendix: Data Collection and Data Processing

### 5.1 Vessel and Equipment

#### 5.1.1 Vessel

The MBES survey was completed with Deakin University's MV Yolla (Figure 9). The vessel is 9.2 m long and has a draught of 0.6 m. MV Yolla is in 2C survey with dispensation to work to King Island through Marine Survey allowing coverage of the Apollo Marine Park. MV Yolla MBES acquisition speed in ~6knts with fuel usage of 10-20 litres per hour. MBES and ancillary systems are powered through a 2.5kva inverter with an uninterrupted power supply linked to 500 amps of batteries charged by the vessels twin 250hp outboard motors. Average transit speed is ~20 knts, capable of up to 40 knts in ideal conditions minimising transit time.



Figure 9 MBES data acquisition with the MV Yolla.

#### 5.1.2 Data

#### Capture

During January 2020 we targeted appropriate weather windows for MBES data capture. Over 8 days, 872 linear kilometres of multibeam data were collected over ~75 hours resulting in a total mapped area of 119 km2 (10 % of the Apollo Marine Park area). Table 2 shows the key dates, personnel and equipment deployed in the study. A summary of the key data files captured during acquisition is provided in Table 3. Key hardware and software deployed are documented in table 3 and 4 respectively.

Classification	Description
Survey Area	Apollo Marine Park
Survey Dates	7 January, 8 January, 13 January, 14 January, 21 January, 27 January, 28 January and 29 January 2020
Survey Vessel	MV Yolla
Survey Personnel	
Acquisition	Daniel Ierodiaconou (DI), Paul Tinkler and Samuel Wines
Processing	Mary Young (MY), Peter Porskamp and Stephan O'Brien (SO)
Preliminary Interpretation	DI, MY, SO, Rafael Carvalho, Yakup Niyazi
MBES System	Kongsberg EM2040C (Dual Swath)
Positioning System	Applanix POS Wavemaster V5
	Accuracy: 0.10 m (Horizontal), and 0.10 m (Vertical)
Motion System	Applanix POS Wavemaster V5
	Accuracy: 0.03° (Heading), 0.03° (Roll/Pitch), 0.05 m or 5 % (Heave)
Sound Velocity	Valeport Mini SVS (head) and Valeport MIDAS SVX2 (water column)
Horizontal Datum and Projection (Processed)	GDA2020 (GRS80, UTM Zone 54)
Vertical Datum (Processed)	Australian Height Datum (AHD)
Survey Standards (Processed)	International Hydrographic Office (IHO) Order 1a

Table 2 Apollo Marine Park survey details. Accuracies are quoted as 1 sigma (68% confidence interval).

#### Table 3 Summary of Data Files

Equipment	Data Type	Raw Data Size (GB)	Number of Files
EM2040C	Multibeam Echo Sounder Bathymetry and Backscatter (.all)	25	224
EM2040C	Multibeam Echo Sounder Water Column (.wcd)	220	224
POS MV	GNSS and IMU (.000)	15	827
Valeport MIDAS SVX2 SVP	Sound Velocity Profile (.asvp)	3.44×10 <sup>-4</sup>	24

#### Table 4 List of hardware used to complete the survey

Equipment	Manufacturer	Model	Serial Number
MBES and MRU acquisition laptop	Toshiba	Satellite	XC018373R
MBES Processing Unit	Kongsberg	EM2040C PU	
MBES Transducer	Kongsberg	EM2040C	0102
MRU	Applanix	Wavemaster V5	281262
Positioning	GPS Antennae	Trimble	13944 and 13936
Sound Velocity Sensor (MBES)	Valeport	Mini SVS	NZS1260
SVP	Valeport	MIDAS SVX2	40809

Table 5 List of software packages used to complete the survey

Item	Manufacturer	Model	Version
Data Acquisition	Kongsberg	SIS	4.3
Motion Reference Unit	Applanix	POSPac MMS	8.4
MBES Data Processing	CARIS	HIPS & SIPS	10.3.2
Backscatter data processing	QPS	Fledermaus Geocoder Toolbox	7.9.2

#### 5.2 Acquisition

#### 5.2.1 General Data Acquisition

Bathymetric data were collected with the EM2040C MBES at a frequency of 300 kHz and water column data were logged at 30% overlap of the main lines. Auxiliary data were collected by the Applanix POS MV Wavemaster (position and motion), Valeport Mini SVS (sound velocity at the head of the multibeam) and a Valeport MIDAS SVX2 (SVP). Three cross check lines were collected: one extended from the north-western to south-western boundaries, one in the small section in the south-east, and a final line in the north-eastern region of the survey area.

#### 5.2.2 Geodetic Positioning and Vertical Datum

Real time GPS positioning was collected with the Applanix POS Wavemaster and Trimble GPS antennae. Real time position was supplied to the EM2040C processing unit to georeference the multibeam soundings. Positioning data were post-processed in POSPac using global navigation satellite systems (GNSS) solutions, which were computed using corrections provided by VicMap Position-GPSnet base station network (secure.vicpos.com.au). The horizontal and vertical datums were referenced to GDA2020 and the vertical datum was referenced to the ellipsoid and then subsequently shifted to AHD using the AUSGeoid2020 geoid model provided by Geoscience Australia.

#### 5.2.3 Heading and Motion

The POS MV Wavemaster recorded real time vessel motion (roll, pitch, yaw and true heave). Attitude data were uploaded to the MRU acquisition laptop at a frequency of 100 Hz. The attitude data were post processed in POSPac and integrated with the multibeam and position data.

#### 5.2.4 Multibeam Bathymetry and Water Column

High resolution MBES and water column data were acquired with an EM2040C at a maximum survey speed of 6 knots. The main goal of the project was to maximise seabed acquisition and coverage within the allocated survey time. The MBES operated in dual swath mode with a long frequency modulated (LFM) pulse at a ping rate ranging from 2-4 Hz to increase the range performance. Although LFM improves the range performance, heave distortions may occur in low relief seafloors (Hughes Clarke, 2018). Long frequency modulated mode also corresponded to the MBES auto selection for this site. The minimum length of feature detected at the ping frequency was 3-7 m. The transmit power level was set to maximum and the water column offset was 20 dB. A Valeport Mini SVS sensor provided real time sound velocity corrections at the sonar head. Position and attitude data were transmitted to the multibeam processing unit at frequencies of 1 Hz and 100 Hz respectively.

#### 5.3 Processing

#### 5.3.1 Bathymetric Data

The MBES raw data was recorded in Kongsberg Seafloor Information System (SIS) as '.all' files containing depth, position and motion data. The files were converted to CARIS HDCS files in CARIS HIPS and SIPS version 10.3.2. Position and attitude data were post processed in POSPAC to obtain Smoothed Best Estimate of Trajectories (SBETs), and applied to the multibeam data.

MIDAS SVX2 SVP corrections were uploaded and applied to the data. Three sound velocity and CTD (conductivity, temperature and pressure) profiles were obtained on each day of the MBES data acquisition to capture the temporal and spatial changes in the survey area (Figure 10, Figure 11). The sound velocity ranged from 1507 to 1517 ms<sup>-1</sup>. A mixed layer depth was present at the marine park between 0 and 10 m and is evident by the constant sound velocity at this depth for each profile. South-east winds upwelled AAIW and was likely present at depths greater than 40 m (Figure 11) and resulted in a positive sound velocity gradient (Levings and Gill, 2010). Convergence of warmer surface and colder upwelled water masses generated a thermocline between the depths of 10 to 40 m and was characterised by a negative sound velocity gradient. Nearest distance algorithm (SVP measurement closest in distance to the sounding) was utilised to apply the sound velocity correction.



Figure 10 Sound velocity profiles measured during MBES data acquisition.



*Figure 11 Temperature profiles measured during MBES data acquisition.* 

Total Propagated Uncertainty (TPU) values were assigned to the navigation time and sensor position offsets. HIPS and SIPS default uncertainty values were assigned to all other variables. The MBES data were merged and the TPU for each sounding was computed from the propagation of the uncertainties from the other variables.

A 2 m Combined Uncertainty Bathymetry Estimator (CUBE) surface was generated utilising the 'Density and Locale' disambiguation method. Soundings located in the vicinity of artefacts within the CUBE surface were manually flagged as rejected. The updated CUBE surface and validated soundings were re-examined for additional artefacts and data gaps present in the surface. Only those soundings resulting in artefacts in the CUBE surface were flagged as rejected. Refraction coefficients were applied to survey lines to reduce refraction artefacts present in the multibeam data. A final CUBE surface referenced to GDA2020 horizontal and

AHD vertical was generated after the sounding outliers and refraction artefacts were removed from the data. All bathymetry data products were exported from the final CUBE surface.

#### 5.3.2 Navigation and Attitude Data

Position and attitude data were post processed in Applanix POSPac MMS. A GNSS Inertial Post Processed Kinematic (PPK) solution was computed with real time position and attitude data were replaced in HIPS and SIPS with the post processed SBETs (Figure 12).



Figure 12 SBET heave data in metres on 28 January 2020.

#### 5.3.3 Backscatter Data

Backscatter data processing was carried out in QPS software Fledermaus geocoder toolbox (FMGT) 7.9.2. The backscatter "beam time series" data type was used as a data source, and all beams were kept (setting starting and cutoff beam angles as 0 and 90 degrees, respectively, in the "Adjust" settings panel). The "Pipeline" settings were all kept as default. The "Navigation" settings were kept to the default "Use adjacent lines within time window of 5" without any other setting enabled. FMGT applies standard geometric and radiometric corrections including compensation for the built-in time varied gain (TVG). The "Adjust" settings were kept to default enabling of "Tx/Rx Power Gain Correction" (taken from runtime parameters datagrams) and default "Beam Pattern Correction". The "Absorption" setting in the "Oceanography" panel was kept at its default value of 0 dB/km with absorption in the watercolumn suitably compensated using absorption coefficients in the raw data files. The "Sonar Default" settings were set to "automatic", which means the software extracted the parameters necessary for radiometric correction (transmit power, frequency, pulse length, etc.) directly from the raw data files. After geometric and radiometric corrections, FMGT implements a standard "sliding window" method to correct for angular dependence, termed "AVG". The settings we used for this correction were the "trend" algorithm – which considers the two sides of the swath separately – and a "window size" of "300" (the number of pings surrounding the data to be corrected) using a reference angle for normalization as the average level between 20 and 60 degrees. Finally, the data for individual lines after corrections and AVG were all mosaicked together at a resolution of 1 m using a "Blend Mosaicking Style" algorithm with a parameter of 50%, a "dB Mean Filter Type", and requesting to "Fill gaps using adjacency". Backscatter mosaic was then exported as a float point geotiff.

### 5.4 Calibration and Checks

#### 5.4.1 Vessel Configuration

A vessel configuration survey of the MV Yolla was conducted on 14 November 2019 to establish a vessel reference frame with respect to the Inertial Motion Unit (IMU). Field work was completed utilising a local reference network and Leica total station. The local coordinate reference frame was transformed to the vessel coordinate reference system via a three dimensional least squares adjustment. The sensor offsets on the vessel are shown in table 6.

Table 6 Sensor offsets in the vessel reference frame with respect to the POS MV. X is positive towards the bow, Y is positive towards starboard and Z is positive down.

Sensor	X Offset (m)	Y Offset (m)	Z Offset (m)
Reference to IMU Target	1.0329	1.6938	-0.8592
Reference to Primary GNSS Lever Arm	0.6939	0.6621	-3.9400
Reference to Vessel Arm	0.0000	0.0000	0.0000
Reference to Centre of Rotation	0.3488	1.6973	-0.6534

#### 5.4.2 GNSS Azimuth Measurement Subsystem Calibration

A GNSS Azimuth Measurement Subsystem (GAMS) calibration was conducted on 26 November 2019 to improve the heading measurement of the POS MV, independent of latitude or vessel movement. A series of S-turns were completed for approximately 1 minute, followed by a steady course. The updated GAMS calibration settings were generated and saved in the POS MV (Table 7).

Table 7 GAMS	calibration	parameters
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Calibration	X Component (m)	Y Component (m)	Z Component (m)
Reference to Primary GNSS Lever Arm	0.7059	0.6490	-3.9380
Baseline Vector	0.0267	2.0928	-0.0021

#### 5.4.3 Patch Test Calibration

A patch test was completed on 21 January 2020 to calibrate the roll, pitch and yaw angles between the sensors and the IMU on the Yolla. The City of Rayville wreck site was selected as the patch test area because the sunken ship was an ideal target within the survey area. The patch test values were computed in HIPS and SIPS (Table 8).

Parameter	Value
Pitch (°)	-0.260
Yaw (°)	-0.110
Roll (°)	-0.200

Table 8 EM2040C (MV Yolla) Patch Test Results

#### 5.5 Post Survey Check

#### 5.5.1 Cross Check Analysis

The cross check analysis results are presented for beam angles 0 to  $65^{\circ}$  in table 9. Beam angles of 0 to  $65^{\circ}$  met the IHO Order 1a depth uncertainty criteria (> 95 %) (IHB, 2008). Ultimately, 99.19% of all the beams between 0 to  $65^{\circ}$  met IHO Order 1a criteria.

Beam	Count	Maximum (m)	Minimum (m)	Mean (m)	<b>Standard</b> <b>Deviation</b>	Order 1a
Augic()		(11)	(111)	(111)	(m)	(70)
0-5	387318	1.665	2.278	-0.042	0.202	99.976
5-10	403278	1.561	1.547	-0.064	0.221	99.982
10-15	409864	2.521	1.642	-0.065	0.215	99.976
15 - 20	433727	2.256	2.390	-0.070	0.198	99.990
20 - 25	460958	1.613	1.361	-0.063	0.193	99.995
25 - 30	500497	1.803	1.730	-0.076	0.194	99.992
30-35	554968	1.280	2.420	-0.083	0.195	99.991
35-40	628267	1.729	1.630	-0.087	0.200	99.992
40-45	728915	3.187	2.768	-0.095	0.213	99.981
45 - 50	869395	2.030	2.068	-0.097	0.228	99.963
50-55	1070859	2.585	2.378	-0.091	0.250	99.931
55-60	1240440	3.001	2.698	-0.097	0.282	99.864
60 - 65	3650	3.288	1.285	-0.062	0.320	99.233

Table 9 Cross check analysis results for beam angles between 0 and 65°

#### 5.5.2 Artefacts

To increase the range capability of the multibeam system and, therefore increase total area of mapped coverage in the Apollo MP, linear frequency modulated (LFM) pulses were used. Due to the sea state during the survey, including swell heights of 2.5m, heave was often > 1.5 m. These conditions resulted in a Doppler heave distortion of the pulse (Hughes Clarke, 2018), which caused minor heave artefacts to be present in the MBES data during acquisition and in the final, post-processed products. These artefacts occur when boat motion results in a minor time shift between the outgoing and incoming LFM pulse, which is due to a pulse distortion between the transmitter and receiver on the sonar. Heave distortions occur if the time shift correction is incorrectly applied (Vincent et al., 2011). The magnitude of the heave artefacts present in the post processed data was approximately 0.03 to 0.30% of the depth. Although these artefacts are visible in the final products, they are of small magnitude and do not interfere with the ability to detect features of interest on the seafloor.

#### 5.6 Geodetic Parameters

Horizontal positions were referenced to GDA2020. GDA2020 is based on the realisation of the International Terrestrial Reference Frame (ITRF) 2014 at epoch 2020.0 (1 January 2020). The parameters of the reference frame are listed in table 10.

Parameter	Value			
Datum	ITR F2014			
Filipsoid	Goodatia Pafaranaa System 1080 (CPS80)			
Sami maion Ania (m)	(278127.000			
Semi-major Axis (m)	63/813/.000			
Semi-minor Axis (m)	6356752.314			
Eccentricity Squared (e <sup>2</sup> )	0.006694380			
Flattening (1/f)	298.257222101			
Projection Type	Universal Transverse Mercator			
UTM Zone	54 S			
Central Meridian	141° E			
Scale Factor at Central Meridian	0.9996			
False Easting (m)	500000			
False Northing (m)	1000000			
Latitude of Origin (°)	0			

Table 10 GDA2020 datum parameters

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