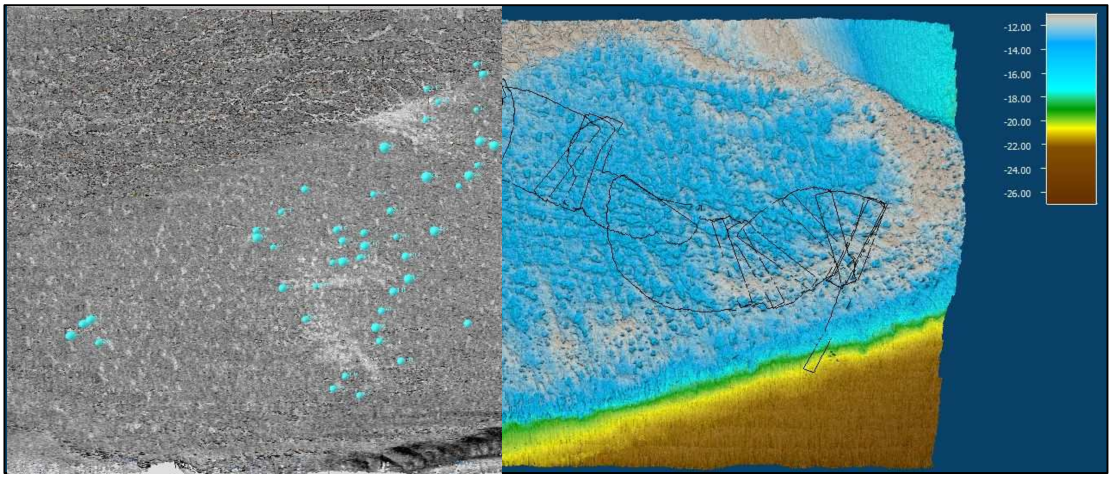
Appendix C to the Douglas Shoal remediation project: Site assessment report (2019)

acoustic imaging

Douglas Shoal Survey
May 2019

Advisian



Assembled by D. Bergersen
20 July 2019
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Australian Government

Great Barrier Reef
Marine Park Authority

Contents

Executive Summary

A two-day geophysical survey consisting of a multibeam echo sounder and subbottom profiler was conducted over Douglas Shoal in May 2019. Processing and analysis of the data showed that assessment and monitoring of the Shen Neng 2010 grounding sites across Douglas Shoal benefited substantially from these instruments, in particular the multibeam echo sounder. Both the bathymetry and backscatter data provide different insights into changes occurring through time.

The backscatter data in particular was useful for identifying the distribution of coarse (gravel) size sediment associated or created by the 2010 grounding event. Bright pixels in the backscatter mosaic highlighted the location of coarser sediments, and the Angle-Range Analysis technique showed good correspondence with sediment samples taken during diving missions. Future projects across Douglas Shoal should incorporate a geophysical survey in advance of any diving / sampling program to better focus those efforts on areas highlighted as acoustically different.

Results from the subbottom profiler survey were ambiguous. No clear acoustic penetration difference was discernible between sand and gravel areas across Douglas Shoal but more focused tuning of the subbottom profiler system might produce a better delineation if used in future monitoring projects.

1.0 Introduction

Acoustic Imaging Pty Ltd (AI) was contracted by Advisian to carry out a high-resolution bathymetry, backscatter, and subbottom profiler (SBP) survey over a 200ha area encompassing a vessel grounding site on Douglas Shoal in the southern Great Barrier Reef. The survey was designed to assess changes to the grounding site(s) relative to another bathymetry/backscatter survey conducted in 2010.

The specific survey services requested by Advisian included:

- Multibeam echo sounding (with backscatter) (MBES) across 100% of an area approximately 200ha which encompasses all Priority Remediation Areas (A, C, E and F) and surrounds (including reference sites) to examine substrate type and physical damage.
- Sub-bottom profiling (SBP) at regional and local scales (smaller target areas) to assess depth and types of sediments across Douglas Shoal and the grounding footprint. Regional mapping consisted of 11 main lines at a 100m spacing and 9 cross lines at a 250m spacing. Line spacing across the target areas (A, C, E, and F above) was to be reduced for better discrimination of sediment boundaries.
- All data were to be adjusted to the Lowest Astronomical Tide (LAT) datum as defined at Tyron Island tide station (1.63m below mean sea level). Horizontal projection was to be UTM Zone 56S, WGS84.

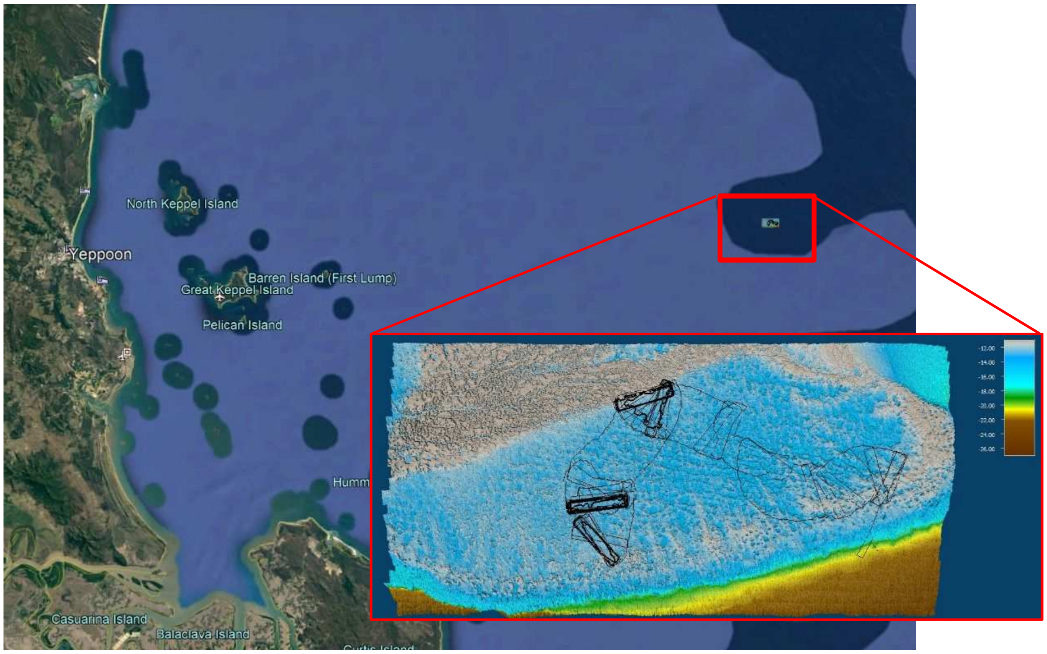


Figure 1: Regional overview of Douglas Shoal survey.

The MBES survey was conducted on May 22, 2019 with the SBP survey work carried out on May 23.

The hydrographic and geophysical systems consisted of:

- R2Sonic 2022 Multibeam Echo Sounder (bathymetry and backscatter);
- Innomar SES-2000 Subbottom Profiler;
- Applanix POS MV Wavemaster (positioning, motion, and heading data);
- Valeport mini-SVS (sound velocity at the sonar head);
- SonTek Castaway CTD (sound velocity through the water column);
- QPS QINSy software (MBES data acquisition and real-time quality control);
- QPS Qimera and Fledermaus (MBES data processing, editing, validation, and presentation);
- Innomar SESWIN software (SBP data acquisition);
- Chesapeake Technology SonarWiz (SBP data processing).

This report provides an overview of the equipment and data processing techniques employed for the Douglas Shoal survey and forms a part of the contracted data deliverables consisting of:

- Clean sounding set in either XYZ ASCII or GSF format;
- Gridded sounding set in either XYZ ASCII or ArcGIS binary format;
- GeoTiff and PDF of gridded/clean bathymetry;
- GeoTiff and PDF of gridded backscatter data;
- Tiff images and PDF of SBP data;
- XY_Thickness ASCII files for different substrate types;
- Polygons of different substrate types as derived from a combination of bathymetry/backscatter/SBP data in DXF/DWG/Shapefile format.
- Delineation of Areas of flattened substrate which may relate to the grounding down or compaction of the seafloor due to the grounding

2.0 System Components

2.1 R2Sonic 2022 Multibeam Echo Sounder

The swath mapping sonar used for the survey was a R2Sonic 2022 Multibeam Echo Sounder (MBES). The 2022 produces real-time, high resolution bathymetry of the seafloor whilst also logging seabed intensity in a variety of forms (beam intensity, beam time series intensity, and TruePix sidescan imagery).

For the bathymetry, the 2022 uses a Projector array to send an acoustic pulse to seabed that's narrow in the along-track direction and wide in the across-track direction. The returned signal from the seabed is received by a Receiver array oriented orthogonal to the Projector array. Signal processing within the transducer head results in 256 distinct beams formed across seabed with an effective footprint size of 0.9º x 0.9º at 450kHz. The system operating frequency can be changed on-the-fly from 170kHz to 450kHz.

Figure 2: R2Sonic 2022 transducer array

A Valeport mini-Sound Velocity Sensor (mini-SVS) at the head of the sonar was intended to provide sound velocity information required for beam steering on a per ping basis. The mini-SVS has capabilities for measuring sound velocity ranges from 1375 m/s to 1625 m/s at an accuracy of 0.025 m/s. However, mini-SVS failed during the course of surveying so a static sound velocity derived from a water column cast at the survey location was used. Given the open-ocean environment of Douglas Shoal and the well-mixed / stable nature of the water column in this region the static value was deemed acceptable for this particular survey.

2.2 Applanix POS MV Wavemaster

The Positioning and Orientation solution for this project was an Applanix POS MV Wavemaster consisting of a small form factor (SFF) POS Control System (PCS) with IP68 water submersible Titanium sealed IMU and a pair of Trimble antennas.

Figure 3: Applanix POS MV Wavemaster components.

The POS MV Wavemaster is a user-friendly, turnkey system designed and built to provide accurate attitude, heading, heave, position, and velocity data. POS MV is proven in all conditions and is the georeferencing and motion compensation solution of choice for hydrographic professionals.

A Fugro Marinestar navigation aiding subscription was activated as part of the Douglas Shoal survey, improving the real-time positioning of the system to less than 10cm horizontally and vertically. The raw positioning and orientation data were post-processed in the Applanix POSPac MMS software package to further improve horizontal and vertical accuracy to less than 5cm.

Roll and Pitch accuracy from the IMU were approximately 0.03°, with Heave accuracy around 5cm. Heading accuracy post-calibration was around 0.1°.

2.3 Sontek Castaway CTD

To correct for refraction through the water column a sound velocity probe must be employed during any hydrographic survey. The unit used for this survey was a SonTek CastAway CTD.

Designed for coastal profiling, the CastAway-CTD® incorporates a 6-electrode conductivity cell, coupled with a fast response thermistor to provide highly accurate, high resolution CTD measurements to depths of 100 m. The sound velocity accuracy derived from the CTD is 0.15 m/s. The unit has an in-built GNSS chip that captures the time and location of the CTD profile, and BlueTooth capability for transferring data.

Figure 4: Sontek Castaway CTD.

During acquisition a comparison between the currently loaded SVP and the sound velocity measured at the transducer head was monitored. If differences became too pronounced, then another CTD cast was implemented. In water depths where relevant, a cast was made at a minimum of the start, the middle, and the end of each survey day.

2.4 QPS, Innomar, and Chesapeake Acquisition, Processing, and Analysis Software

The QPS QINSy package was used for MBES data acquisition. The software has an excellent reputation for robustness and stability and provided a number of useful online quality control (QC) displays for data monitoring. QINSy logs all raw data in a proprietary DB format, and geospatially corrected data (XYZ solution) in a QPD format. Options exist for exporting a variety of non-proprietary formats.

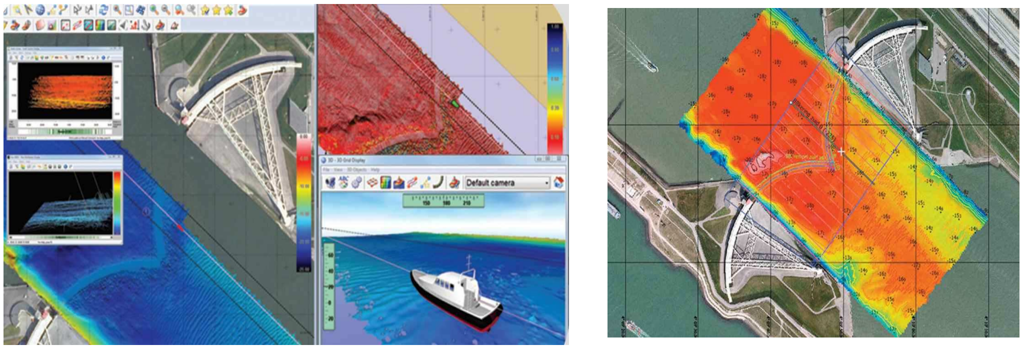
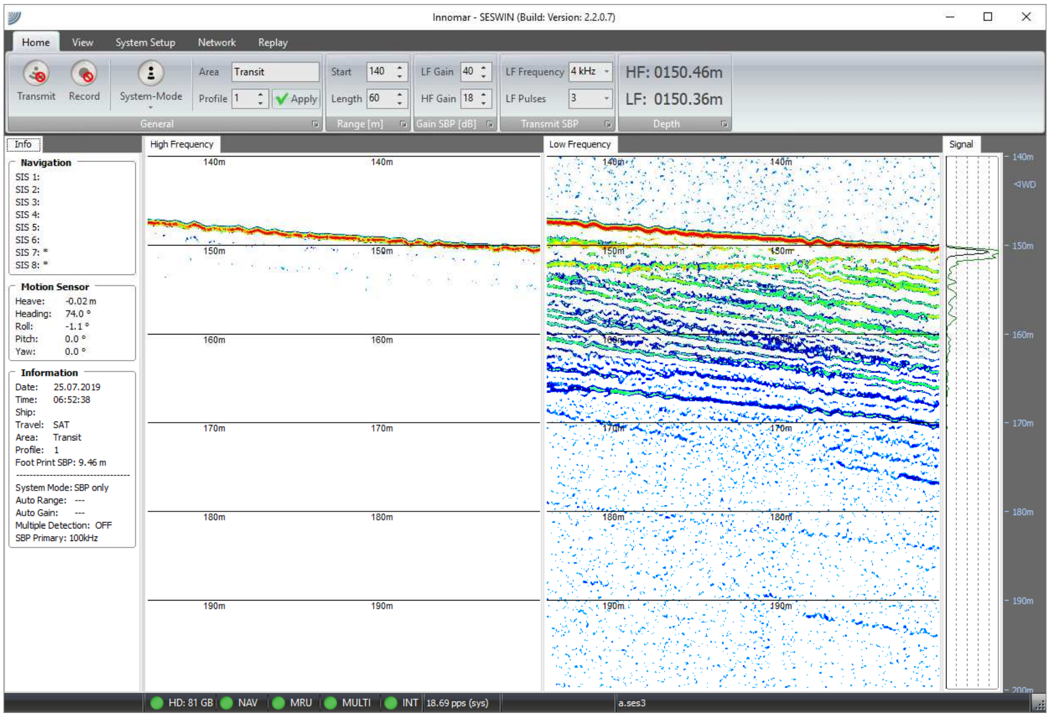


Figure 5: Typical QC displays offered by QINSy.

The Innomar SESWIN software was used for logging of SBP data. The system was interfaced to the navigation and motion data supplied by the POS MV to provide highly accurate, heave-compensated subsurface data across the survey area. SESWIN provides a user-friendly interface to configure and control the system during the survey. Online echo prints are used for quality assurance, with both high frequency and low frequency channels visible simultaneously.



Area: Transit
Profile: 1
Start: 140
Length: 60
LF Gain: 40
HF Gain: 18
LF Frequency: 4 kHz
LF Pulses: 3
HF: 0150.46m
LF: 0150.36m

Navigation
SIS 1:
SIS 2:
SIS 3:
SIS 4:
SIS 5:
SIS 6:
SIS 7: *
SIS 8: *

Motion Sensor
Heave: -0.02 m
Heading: 74.0 °
Roll: -1.1 °
Pitch: 0.0 °
Yaw: 0.0 °

Information
Date: 25.07.2019
Time: 06:52:38
Ship:
Travel: SAT
Area: Transit
Profile: 1
Foot Print SBP: 9.46 m

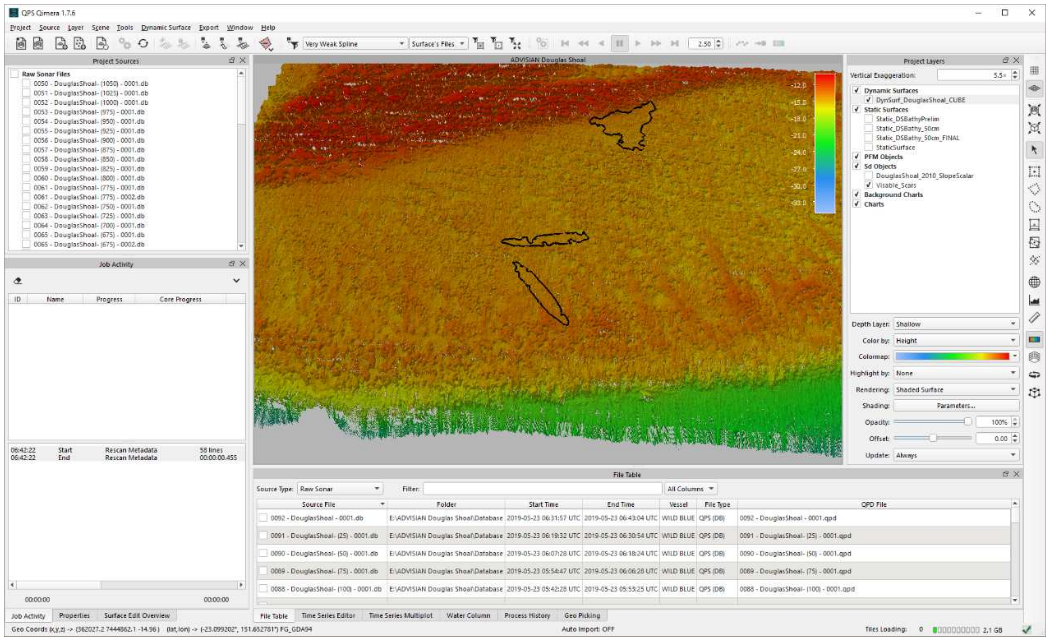
System Mode: SBP only
Auto Range: ---
Auto Gain: ---
Multiple Detection: OFF
SBP Primary: 100kHz

18.69 pps (sys)
a.ses3

Figure 6: SESWIN acquisition software.

Further processing of the MBES data was done in the QPS Qimera and FM Geocoder Toolbox software packages, and the SBP data in Chesapeake SonarWiz software.

Qimera was used to correct, clean, and reduce the bathymetry data to the AUSGEOID09 datum before final reduction to chart datum.



Raw Sonar Files
- 0050 - DouglasShoal- (1050) - 0001.db
- 0051 - DouglasShoal- (1025) - 0001.db
- 0052 - DouglasShoal- (1000) - 0001.db
- 0053 - DouglasShoal- (975) - 0001.db
- 0054 - DouglasShoal- (950) - 0001.db
- 0055 - DouglasShoal- (925) - 0001.db
- 0056 - DouglasShoal- (900) - 0001.db
- 0057 - DouglasShoal- (875) - 0001.db
- 0058 - DouglasShoal- (850) - 0001.db
- 0059 - DouglasShoal- (825) - 0001.db
- 0060 - DouglasShoal- (800) - 0001.db
- 0061 - DouglasShoal- (775) - 0001.db
- 0061 - DouglasShoal- (775) - 0002.db
- 0062 - DouglasShoal- (750) - 0001.db
- 0063 - DouglasShoal- (725) - 0001.db
- 0064 - DouglasShoal- (700) - 0001.db
- 0065 - DouglasShoal- (675) - 0001.db
- 0065 - DouglasShoal- (675) - 0002.db

```
06:42:22    Start    Rescan Metadata    58 lines
06:42:22    End      Rescan Metadata    00:00:00.455
```

00:00:00 00:00:00

Vertical Exaggeration: 5.5×

- ☑ Dynamic Surfaces
  - ☑ DynSurf_DouglasShoal_CUBE
- ☑ Static Surfaces
  - ☐ Static_DSBathyPrelim
  - ☐ Static_DSBathy_50cm
  - ☐ Static_DSBathy_50cm_FINAL
  - ☐ StaticSurface
- ☑ PFM Objects
- ☑ Sd Objects
  - ☐ DouglasShoal_2010_SlopeScalar
  - ☑ Visable_Scars
- ☑ Background Charts
- ☑ Charts

Depth Layer: Shallow
Color by: Height
Colormap:
Highlight by: None
Rendering: Shaded Surface
Shading: Parameters...
Opacity: 100%
Offset: 0.00
Update: Always

File Table

Source Type: Raw Sonar Filter: All Columns

Source File	Folder	Start Time	End Time	Vessel	File Type	QPD File
0092 - DouglasShoal - 0001.db	E:\ADVISIAN Douglas Shoal\Database	2019-05-23 06:31:57 UTC	2019-05-23 06:43:04 UTC	WILD BLUE	QPS (DB)	0092 - DouglasShoal - 0001.qpd
0091 - DouglasShoal- (25) - 0001.db	E:\ADVISIAN Douglas Shoal\Database	2019-05-23 06:19:32 UTC	2019-05-23 06:30:54 UTC	WILD BLUE	QPS (DB)	0091 - DouglasShoal- (25) - 0001.qpd
0090 - DouglasShoal- (50) - 0001.db	E:\ADVISIAN Douglas Shoal\Database	2019-05-23 06:07:28 UTC	2019-05-23 06:18:24 UTC	WILD BLUE	QPS (DB)	0090 - DouglasShoal- (50) - 0001.qpd
0089 - DouglasShoal- (75) - 0001.db	E:\ADVISIAN Douglas Shoal\Database	2019-05-23 05:54:47 UTC	2019-05-23 06:06:28 UTC	WILD BLUE	QPS (DB)	0089 - DouglasShoal- (75) - 0001.qpd
0088 - DouglasShoal- (100) - 0001.db	E:\ADVISIAN Douglas Shoal\Database	2019-05-23 05:42:28 UTC	2019-05-23 05:53:25 UTC	WILD BLUE	QPS (DB)	0088 - DouglasShoal- (100) - 0001.qpd

Geo Coords (x,y,z) -> (362027.2 7444862.1 -14.96) (lat,lon) -> (-23.099202°, 151.652781°) FG_GDA94 Auto Import: OFF Tiles Loading: 0 2.1 GB

Figure 7: Qimera post-processing software.

The FM Geocoder Toolbox (FMGT) software was used to process the MBES backscatter data into a seabed intensity mosaic as well as analyse the fully-corrected intensity returns for automated seabed characterisation (discussed in more detail in the Processing section of this report).

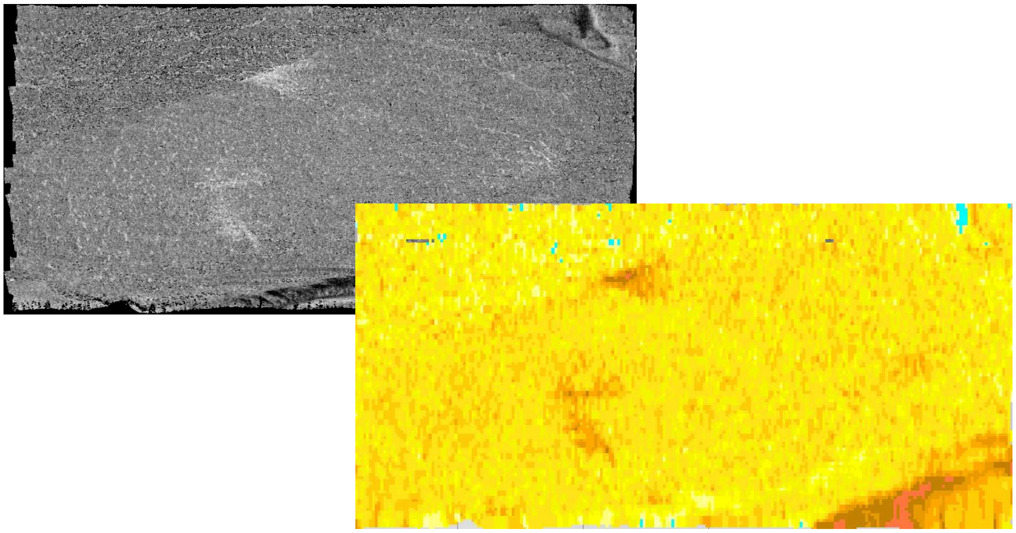


Figure 8: MBES backscatter mosaic (top left) and ARA image (bottom right) generated from FMGT across survey area.

SonarWiz was used to process and interpret the SBP data. Simple image enhancement techniques were applied to the raw data to improve image clarity for distinguishing sand and gravel regions, with the focus of interpretation efforts on the areas of vessel impact across the survey area.

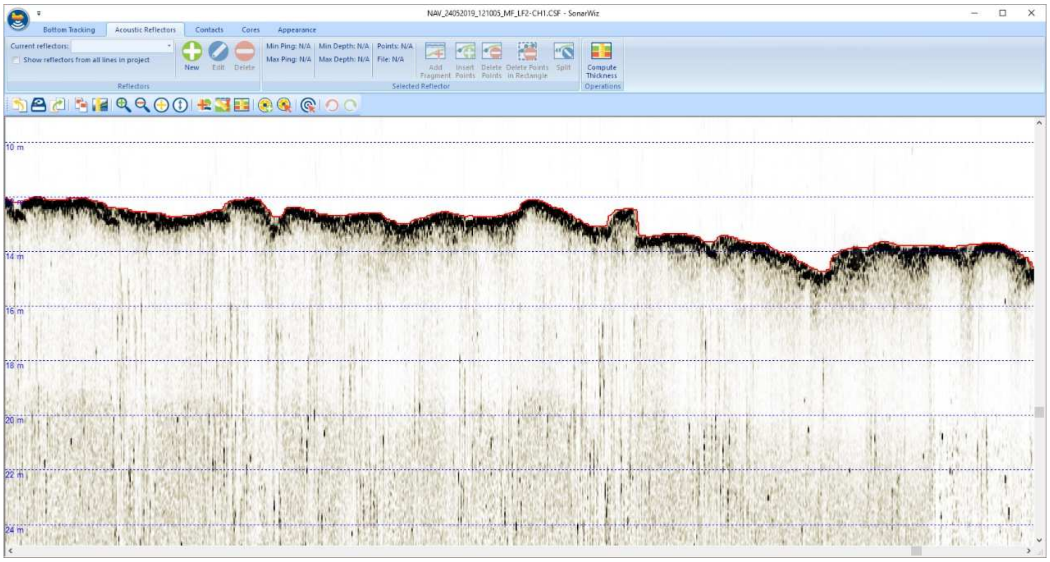
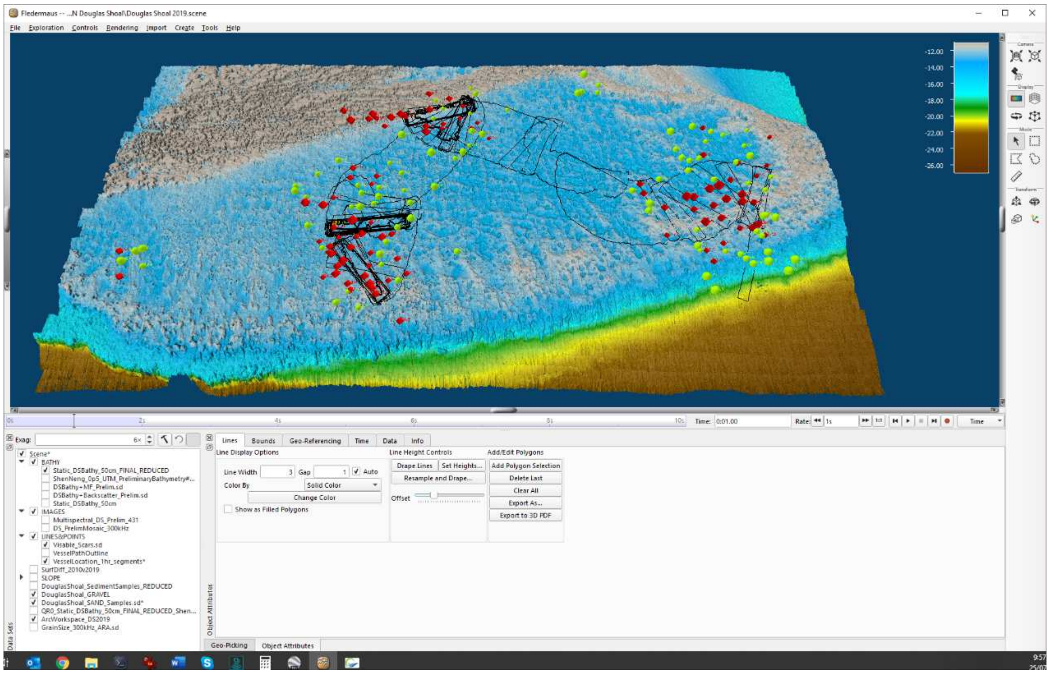


Figure 9: SonarWiz Profile window for SBP data.

All data were combined in Fledermaus to better assess the relationship between the bathymetry, backscatter, and SBP data, along with derived products from all 3 data types (e.g., slope, rugosity, seabed characterisation, etc.).



Line Width: 3
Gap: 1
☑ Auto
Color By: Solid Color
☐ Show as Filled Polygons

☑ Scene*
- ☑ BATHY
  - ☑ Static_DSBathy_50cm_FINAL_REDUCED
  - ☐ ShenNeng_0p5_UTM_PreliminaryBathymetry#...
  - ☐ DSBathy+MF_Prelim.sd
  - ☐ DSBathy+Backscatter_Prelim.sd
  - ☐ Static_DSBathy_50cm
- ☑ IMAGES
  - ☐ Multispectral_DS_Prelim_431
  - ☐ DS_PrelimMosaic_300kHz
- ☑ LINES&POINTS
  - ☑ Visable_Scars.sd
  - ☐ VesselPathOutline
  - ☑ VesselLocation_1hr_segments*
- ☐ SurfDiff_2010v2019
- ☐ SLOPE
- ☐ DouglasShoal_SedimentSamples_REDUCED
- ☑ DouglasShoal_GRAVEL
- ☑ DouglasShoal_SAND_Samples.sd*
- ☐ QR0_Static_DSBathy_50cm_FINAL_REDUCED_Shen...
- ☑ ArcWorkspace_DS2019
- ☐ GrainSize_300kHz_ARA.sd

Figure 10: Fledermaus Scene for Douglas Shoal.

3.0 Geodetics and Data Reduction

For the Advisian / Douglas Shoal survey real-time positioning was provided via a direct Fugro Marinestar G4+ tight coupling with the POS MV Primary GNSS antenna and GNSS inertial solution. This aiding solution was at the ITRF2014 Ellipsoid. Transformation parameters to reduce the data to GDA94 were registered within the POSView control software, and further reductions to AUSGEOID09 were implemented in the QINSy logging software. Background to the reduction process is shown in the bullet points below.

- Satellite positioning systems generate positions to the WGS84 datum. WGS84 is the World Geodetic System 1984 and is the main reference for all GPS-based measurement systems.
- Australia uses the GDA94 datum. Differences between WGS84 and GDA94 are small, but become significant for detailed survey operations, and change in time due to the movement of the Australian continent relative to the satellite constellation.
- MGA94 is a Universal Transverse Mercator (UTM) projection of GDA94 geographical coordinates.
- Real Time Kinematic PPP GNSS systems use a geostationary satellite to transmit corrections to the equipped GNSS antenna positioning unit, allowing much higher accuracy for positioning, generally to sub 15cm level.
- AUSGeoid09 is a geodetic model maintained online by the Australian Government Dept. of Resources, Energy and Tourism. This model describes the relationship between the ellipsoidal height (GDA94) and the orthometric height in AHD.

Following acquisition, the POS MV data were post-processed using the Trimble CentrePoint RTX service to improve the accuracy of the ellipsoid-referenced height in GDA94. Trimble RTX leverages real-time satellite and atmospheric data from a global network of tracking stations, along with highly accurate models and algorithms to generate Trimble RTX corrections. These corrections were used to provide 1-2 cm accuracy for the georeferencing of the dataset to AHD.

AHD is mean sea level (MSL) datum for coastal areas as defined by permanent tide gauges sparsely distributed around Australia. This MSL datum was further reduced to the Lowest Astronomical Tide (LAT) datum as specified at the Tyron Island tide station (1.63m below MSL), basically to align the 2019 bathymetry data as closely as possible to the 2010 bathymetry data whilst noting that the 2010 data set was arbitrarily shifted by 50cm to better align with RAN LADS data.

A surface difference analysis was conducted between the 2010 gridded bathymetry and the 2019 gridded bathymetry, with bin size specified to be the same for both data sets (50cm). A median difference of +16cm exists between the two data sets (with the 2010 data set declared as the Reference Surface). Some of the difference may be related to actual sediment accretion but given the arbitrary Z-shift applied to the 2010 data the true amount of sedimentation change is unknown. However, for future monitoring surveys the data reduction techniques as outlined above are 100% repeatable and hence true seabed changes can be assessed.

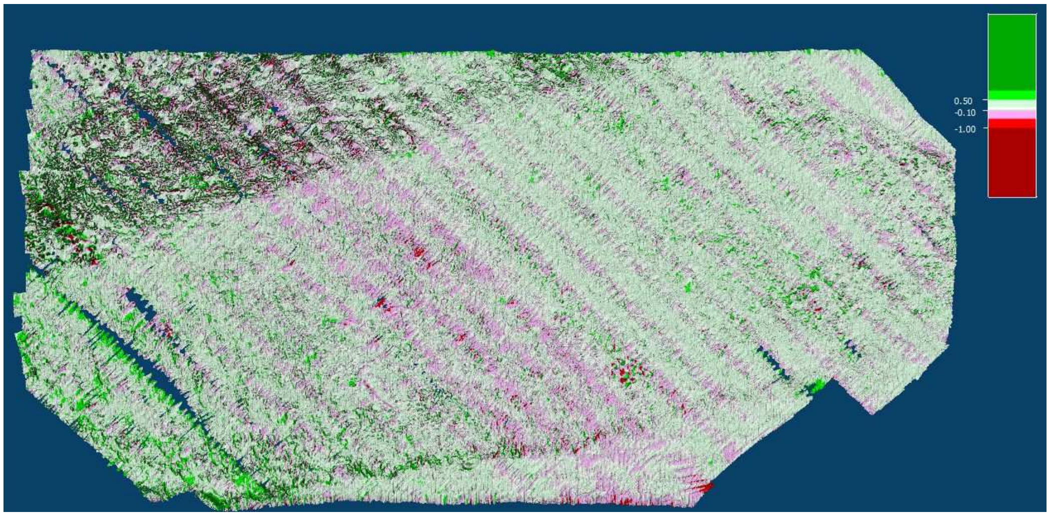


Figure 11: Surface difference results between 2010 bathymetry (Reference Surface) and 2019 bathymetry. White and grey pixels represent difference values <10cm whereas green pixels represent deposition and pink/red represent erosion.

4.0 System Installation and Calibration

4.1 System Installation

Installation of the MBES system on the WILD BLUE occurred on May 20/21, 2019. A purpose built pole was mounted over the port side of WILD BLUE, with some modifications to allow attachment of an AI supplied mounting plate for the POS MV IMU (circled in red in the figure below). The R2Sonic 2022 transducer bolted directly on to the flange associated with the pole, and an adaptor flange was attached to the R2Sonic flange to allow connection of the SES-2000 SBP transducer.

Figure 12: Mounting pole on WILD BLUE. POS MV IMU located inboard of pole on an AI supplied plate. SES-2000 SBP transducer attached to an adaptor flange connected to the R2Sonic flange associated with pole.

To deploy the sonar equipment, the pole was first rotated outboard and then rotated into a vertical position. A bracing arm was then secured between the pole and boat to provide greater stability/rigidity entire assembly.

The POS MV GNSS antennas (Trimble 540AP) were mounted on top of the awning covering the back deck of WILD BLUE. Holes were drilled into a support railing running fore-aft, and the base of each GNSS antenna was secured flush to the rail via a 5/8” bolt threaded through the hole. The location of the antennas provided clear views of all available GNSS satellites. Separation between the two antennas physically was measured but refined X, Y, Z offsets were derived from the GNSS Azimuthal Measurement System (GAMS) calibration (see Calibration section below)..

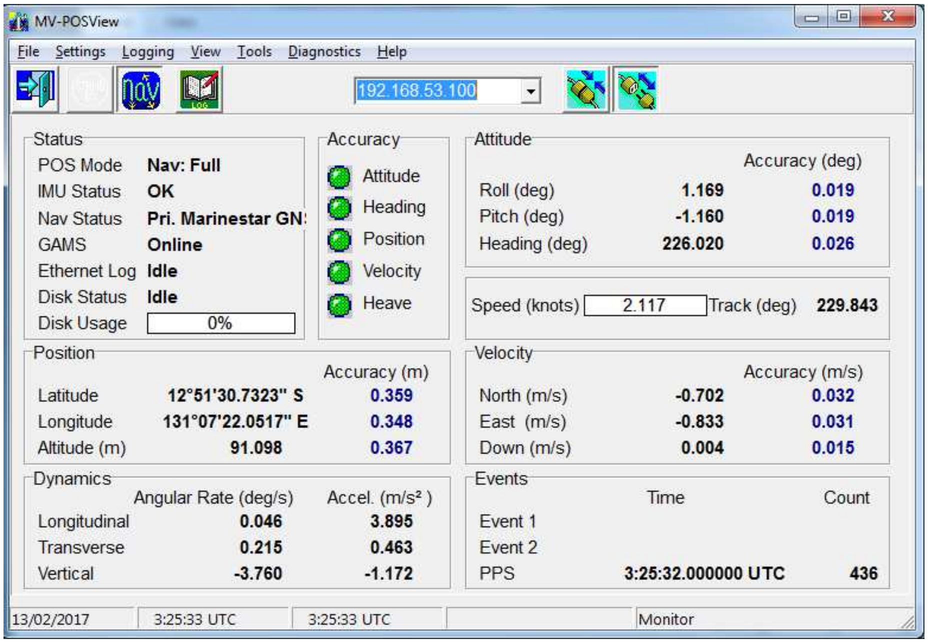
The POS MV PCS and R2Sonic Sonar Interface Module (SIM) were housed in the main cabin of WILD BLUE. GNSS antenna and IMU cables were fed into a hatchway on the roof of the vessel. Excess cable was neatly coiled to minimise the risk of trips/slips/falls and possible damage to the cables.

The acquisition PC was also located in the main cabin. A 2nd external monitor was connected to provide displays for the helmsman (assistance in vessel steerage).

4.2 System Communication and Calibration

After the POS MV system was installed and all cables connected, basic system communication tests were conducted to ensure that all sensors composing the POS MV were receiving or sending data. This included checking whether the Marinestar navigation aiding solution was being received.

The figure below shows an example of Marinestar reception in POSView, the online interface associated with the POS MV. Fields within the User Interface (UI) were monitored for changing values and reception of the Marinestar signal is shown in the Nav Status field.



Status

POS Mode	Nav: Full
IMU Status	OK
Nav Status	Pri. Marinestar GN:
GAMS	Online
Ethernet Log	Idle
Disk Status	Idle
Disk Usage	0%

Accuracy

- ● Attitude
- ● Heading
- ● Position
- ● Velocity
- ● Heave

Attitude

		Accuracy (deg)
Roll (deg)	1.169	0.019
Pitch (deg)	-1.160	0.019
Heading (deg)	226.020	0.026

Speed (knots) 2.117 Track (deg) 229.843

Position

		Accuracy (m)
Latitude	12°51'30.7323" S	0.359
Longitude	131°07'22.0517" E	0.348
Altitude (m)	91.098	0.367

Velocity

		Accuracy (m/s)
North (m/s)	-0.702	0.032
East (m/s)	-0.833	0.031
Down (m/s)	0.004	0.015

Dynamics

	Angular Rate (deg/s)	Accel. (m/s²)
Longitudinal	0.046	3.895
Transverse	0.215	0.463
Vertical	-3.760	-1.172

Events

	Time	Count
Event 1		
Event 2		
PPS	3:25:32.000000 UTC	436

13/02/2017 | 3:25:33 UTC | 3:25:33 UTC | Monitor

Figure 13: POS MV Communication and Integration Tests – Marinestar integration received successful, IMU, PGNSS and SGNSS received successfully.

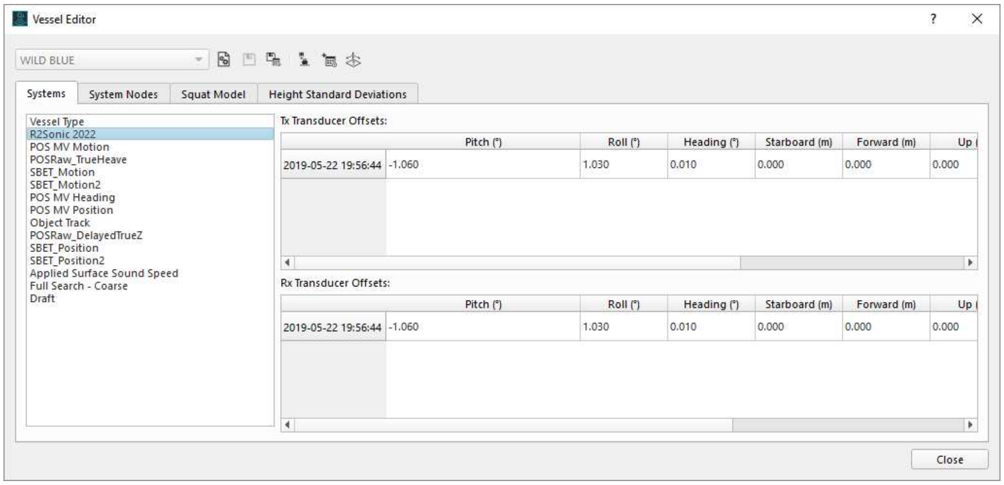
Communication between the POS MV and the R2Sonic SIM were also tested. Successful reception of NMEA ZDA string and TSS1 binary motion data for time synchronisation and roll stabilisation, respectively.

The GNSS Azimuth Measurement System (GAMS) calibration run on 20 May provided a heading solution for the system accurate to less than 0.1 degree. The GAMS data also provided a refined vector between the two GNSS antennas as follows: X = 2.004m, Y = 0.028m, and Z = -0.065m.

Another vector derived from the data is the Primary GNSS antenna to the survey Reference Point (selected as the target on top of the IMU). This vector was manually measured but further refinement was possible through analysing the POS MV data The final values derived are as follows: X = -3.280m, Y = 0.040m, and Z = -1.860m.

Finally, a combination of physical measurements and design drawings were used to derive a lever arm vector for the Reference Point to the Acoustic Centre of the 2022. This vector is required to provide proper motion compensation and positioning for the MBES data. The final values derived are as follows: X = 0.137m, Y = 0.750m, and Z = 2.850m.

Calibration of the R2Sonic 2022 transducer mounting relative the vessel reference frame was achieved through a Patch Test conducted in the Gladstone channel on May 21. The final bias values for the sonar are shown in the figure below.



Tx Transducer Offsets:

	Pitch (°)	Roll (°)	Heading (°)	Starboard (m)	Forward (m)	Up (
2019-05-22 19:56:44	-1.060	1.030	0.010	0.000	0.000	0.000

Rx Transducer Offsets:

	Pitch (°)	Roll (°)	Heading (°)	Starboard (m)	Forward (m)	Up (
2019-05-22 19:56:44	-1.060	1.030	0.010	0.000	0.000	0.000

Figure 14: Bias values and lever arms used during processing for the R2Sonic 2022 transducer.

5.0 Data Processing

As one of the objectives of this survey was seabed characterisation the R2Sonic 2022 was operated in a MultiMode (multi-frequency) manner. In this mode the sonar alternates frequencies on a ping-by-ping basis. The idea was to use the backscatter information from 3 different frequencies to assemble a RGB composite image that might provide more information on subtle changes to sediment types across the survey area.

The 3 frequencies adopted for this survey were 170kHz (lowest frequency available for the 2022), 300kHz, and 400kHz. The 300kHz frequency was intended to be used for another seabed characterisation technique called Angle Range Analysis (ARA; described in more detail later in this section).

For the final bathymetry product, the soundings from all 3 frequencies were used as part of the solution to keep the sounding density as high as possible. Technically the footprint size of each beam changes for each frequency (170kHz = ~2° x 2°; 300kHz = ~1.5° x x 1.5°; 400kHz = ~1° x 1°) but no discernible difference in the derived depths was noted during processing.

Bathymetry processing in the QPS Qimera package employed the following workflow:

- Load logged DB files;
- Convert raw Range/Theta data to a geospatially corrected (XYZ) solution resulting in the creation of QPD files;
- Generate a Dynamic Surface;
- Load and apply processed positioning and orientation data from the Applanix POSPAC MMS software;
- Load and apply any extra SVP files from the Sontek Castaway CTD;
- Apply a weak Spline Filter to flag anomalous soundings as REJECTED;
- Manually clean (REJECT) any soundings deemed inconsistent with the sea bed;
- Check Shallow and Deep Surfaces for any remaining anomalous soundings;
- Grid data at 0.5m bin size using a Weighted Moving Average algorithm with a Weight Diameter of 3.
- Export data products in a variety of formats.

Some minor modifications to this general workflow were implemented for selected lines and areas (e.g., differing levels of Spline filtering or Beam Number filtering).

For the backscatter processing, the QPS FMGT software package was used. GSF format files were exported from Qimera after cleaning/validation had been completed. The general workflow in FMGT consisted of:

- Load exported GSF files from Qimera;
- Create 3 separate Processing parameter files for each of the 3 frequencies contained within the GSF files;
- Load gridded bathymetry Reference Surface to allow the software to correct the seabed intensity for regional slope differences relative to sonar location;
- Set the Absorption values for each of the 3 frequencies within the Processing parameter files;
- Set the pixel size to be used for the backscatter mosaic and the Statistics / ARA layers (0.5m for backscatter mosaic and 5m for Statistics / ARA);
- Specify the Processing parameter file to use for the first run. This generated mosaics, statistical layers, and ARA layers for the nominated frequency;

- Repeat the above step for the 2 other frequencies;
- Export data products in a variety of formats.

For the SBP data the processing and interpretation was done in the Chesapeake SonarWiz software. In this case the processing workflow was:

- Load the SES format files into SonarWiz;
- Bottom track the seabed and create a seabed reflector;
- Apply simple image enhancement algorithms including Automatic Gain Control and colour palette stretching / compression;
- Digitize selected portions of the profiles that may represent gravel locations.
- Export data products in a variety of formats.

Data deliverables included:

- Clean sounding set in either XYZ ASCII or GSF format;
- Gridded sounding set in either XYZ ASCII or ArcGIS binary format;
- GeoTiff and PDF of gridded/clean bathymetry;
- GeoTiff and PDF of gridded backscatter data;
- GeoTiff of ARA results;
- Tiff images and PDF of SBP data;
- Delineation of Areas of flattened substrate which may relate to the grounding down or compaction of the seafloor due to the grounding

6.0 Results

As this project was essentially a data gathering exercise with data products feeding into a more extensive report being assembled by Advisian the Results section is limited to a discussion of the various derived data products.

Bathymetry

As noted above, the bathymetry data were gridded at a 0.5m bin size, with the results as shown in the figure below. For this survey the R2Sonic 2022 was operated in “normal” density mode, which means that 256 beams were generated per ping.

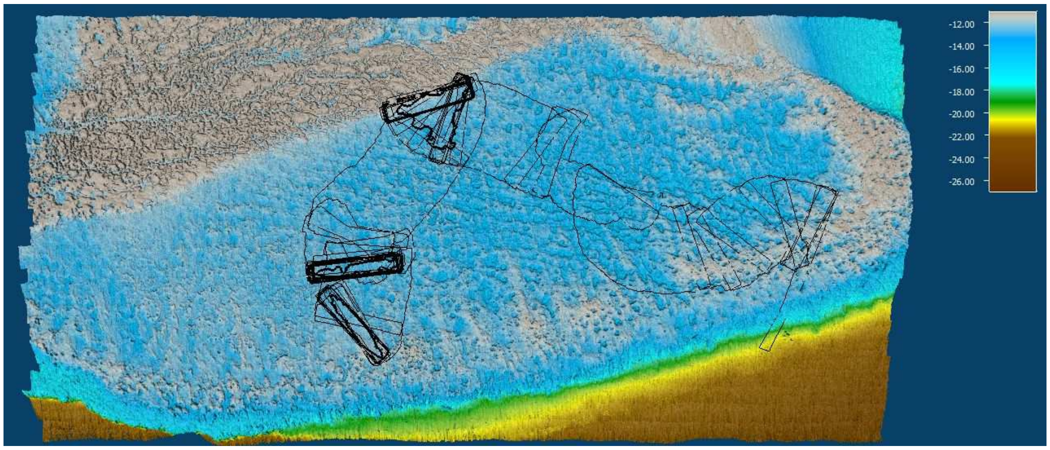
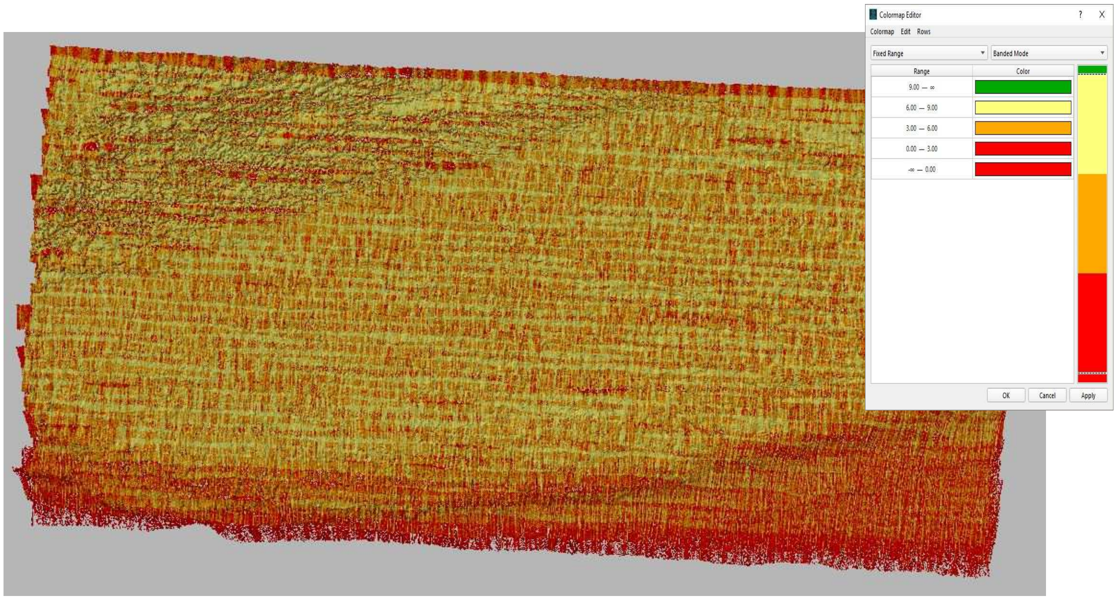


Figure 15: Final gridded bathymetry for 2019 survey across Douglas Shoal (0.5m bin size).

This bin size is probably the minimum supported by the data without holes emerging in the final gridded product. The figure below shows the sounding density associated with a 50cm bin size. One of the hydrographic standards for feature detection of a certain size is for a total of 9 soundings to exist across the feature (3 consecutive pings with 3 soundings per ping). The sounding density across the bulk of Douglas Shoal is between 3-9 soundings per cell.



Fixed Range
Banded Mode

Range	Color
9.00 — ∞	🟩
6.00 — 9.00	🟨
3.00 — 6.00	🟧
0.00 — 3.00	🟥
-∞ — 0.00	🟥

Figure 16: Sounding density from 2019 survey across Douglas Shoal.

Sounding density could be increased by operating the sonar in Ultra High Density mode, in which case 1024 independent soundings would generated per ping. However, this operating mode precludes the use of 3 different frequencies adopted for the 2019 survey to maximise the information content of the backscatter data.

Another data product derived from the bathymetry was slope magnitude. When comparing with the 2010 data set there's a clear "flattening" of the seabed around the areas where the vessel grounding occurred. This removal of a sediment berm around the grounding site was also highlighted in the surface difference analysis conducted between the 2010 and 2019 data sets.

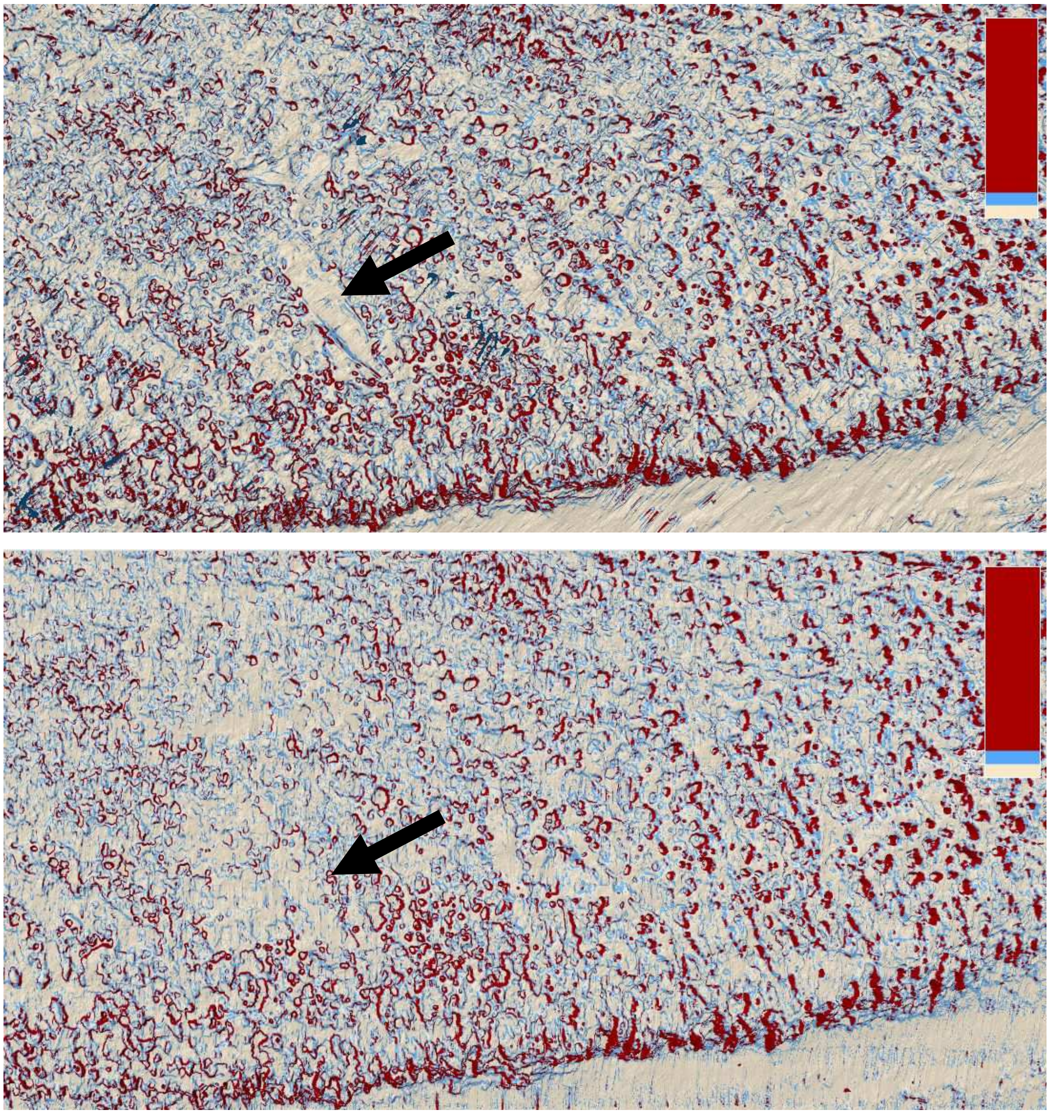


Figure 17: Slope magnitude derived from 2010 bathymetry (top) and 2019 bathymetry (bottom). Arrow highlights depression associated with grounded vessel. Red areas represent slopes > 10°.

Backscatter

From a backscatter perspective, mosaics were created for each of the 3 primary frequencies adopted for the 2019 survey. The 170kHz mosaic provides perhaps the best indication of coarser sediments related to the path the vessel took during the grounding event.

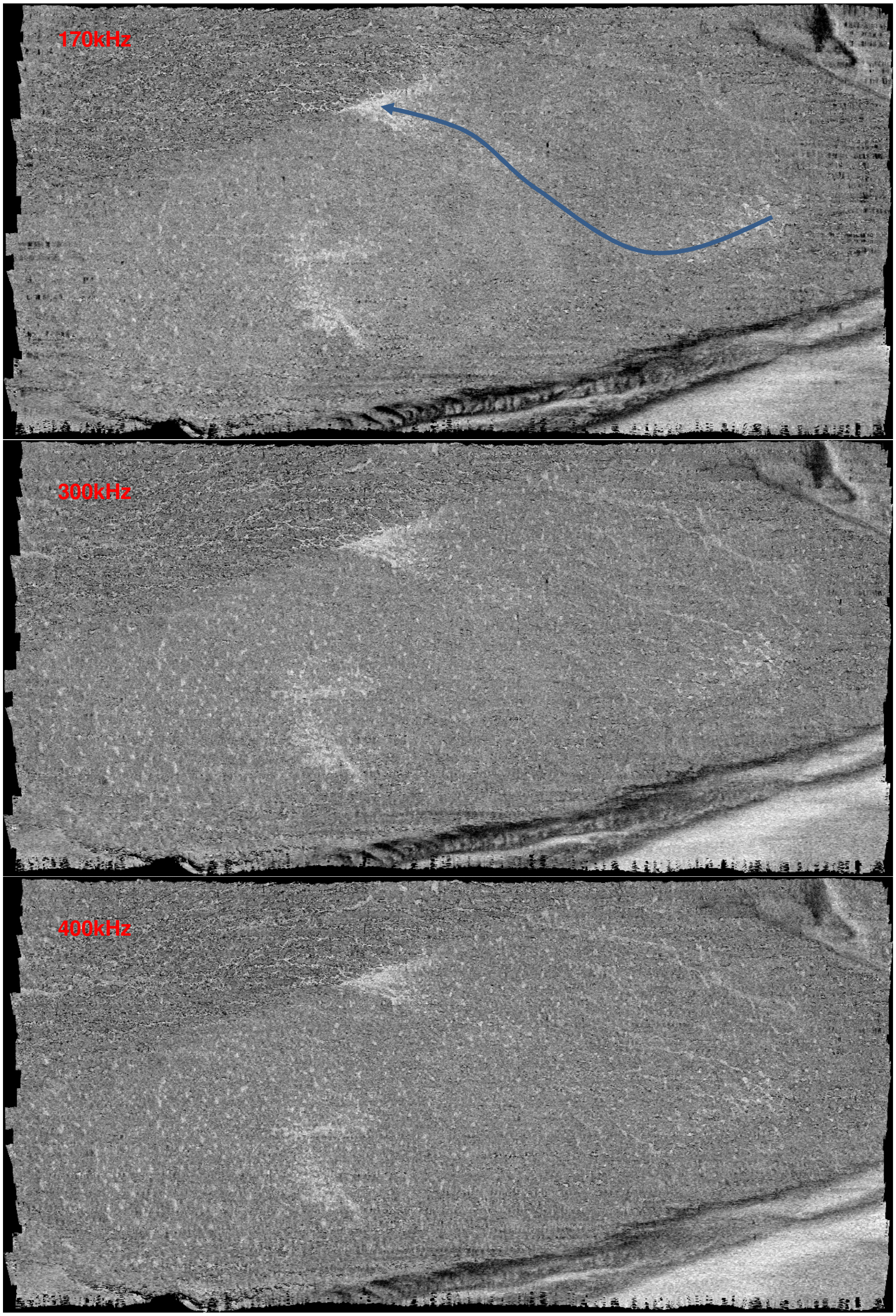


Figure 18: Backscatter mosaics for the 3 different frequencies. Blue arrow in 170kHz mosaic shows higher backscatter region corresponding to vessel path during grounding.

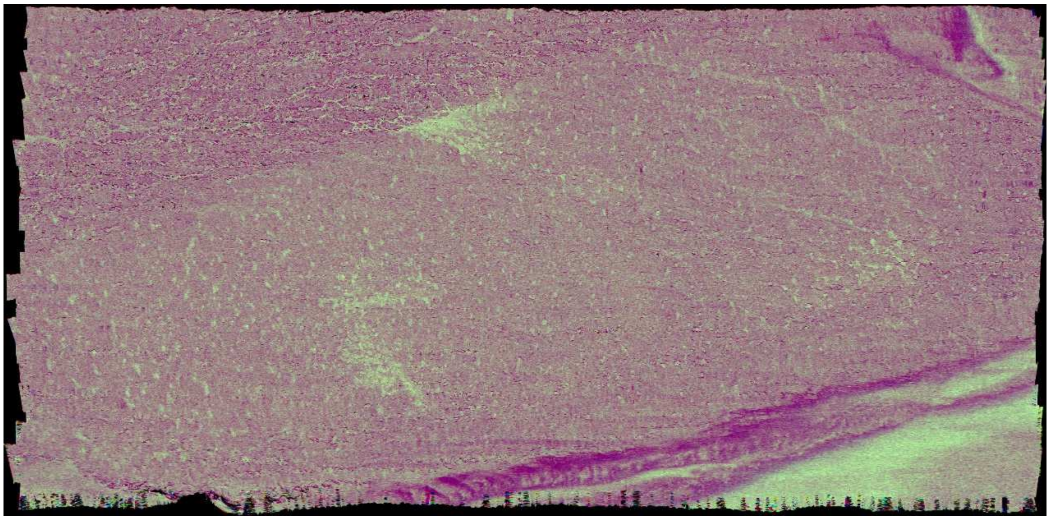


Figure 19: Multispectral image of Douglas Shoal built from 3 frequency mosaics.

In terms of seabed characterisation, the Angle-Range Analysis (ARA) technique was applied to the 300kHz frequency backscatter data. This technique stems from work done by Luciano Fonseca at the University of New Hampshire (e.g., Fonseca, et al., 2009)[1]. As a brief summary of the technique, backscatter data from a MBES system is fully corrected for all parameters that affect the intensity of the returns from the seabed (radiometric, geometric, etc.) such that the processed data most closely reflects the "true" intensity of the seabed. Then, Angle-Range curves are extracted across 30-ping sections (or patches) of the seabed on a per line basis. These curves (port and starboard) are compared to empirically derived responses of the seabed for different sediment types as defined in the Jackson Model[2] within the QPS FMGT software. A raster version of the Phi grain size results is one of the data products from FMGT, and this can be mapped to a colour scale to show sediment characteristics across the survey area.

The figure below shows the gravel sediment locations overlain on ARA automated characterisation results. Good correspondence exists between the two independently acquired data sets, suggesting that the ARA acoustic technique might be useful in future monitoring efforts (e.g., tracking gravel signature over larger areas or targeting areas that should be investigated with more intensive diving/sampling programs).

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[1] Fonseca, L., Brown, C., Calder, B., Mayer, L., and Rzhanov, Y. Angular Range Analysis of Acoustic Themes from Stanton Banks, Ireland: A Link between Visual Interpretation and Multibeam Echosounder Angular Signatures. Applied Acoustics, 2009, v70, pp 1298-1304.

[2] Jackson DR, Winebrenner DP, and Ishmaru A. Application of the Composite Roughness Model to High-frequency Bottom Backscattering. J. of Acoustic Society of America, 1986; v. 79(5), pp. 1410–22.

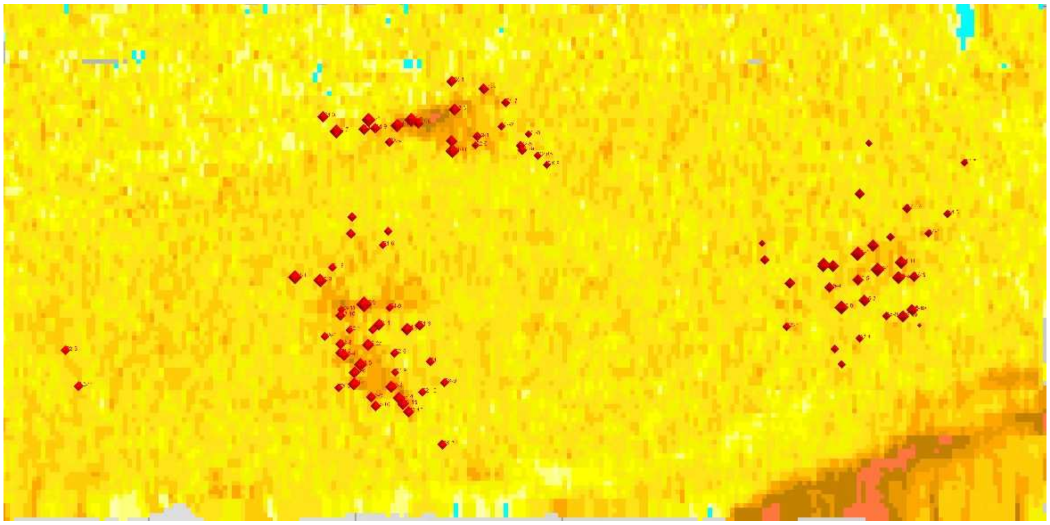

Figure 20: ARA raster image of Phi grain size layer overlain by ground-truth gravel sediment samples (red diamonds). The yellow pixels represent different Sand size divisions whereas the orange pixels represent Gravel size divisions. The size of the red diamonds reflects the percentage of gravel size sediments in the sample (larger diamonds = larger percentage of gravel).

Subbottom Profiler

Surprisingly, the SBP data didn't provide much additional information on seabed types or location of sand vs. gravel sediment sizes. It was expected that good acoustic penetration would occur across the sand areas, with a well-defined reflector at the sand/reef (hard ground) interface. Penetration and definition of an underlying reflector would be less pronounced / absent across the gravel areas.

In reality, an underlying reflector is largely absent across most areas and acoustic penetration is only subtly different between the sand and gravel regions. These observations are highlighted in the figures below.

Across Area A, acoustic penetration occurs across areas where sand is present (dark pixels in backscatter mosaic) and is essentially absent in gravel areas (bright pixels in mosaic). As noted for slope analysis of MBES data, grounding areas are flatter than normal seabed across Douglas Shoal.

In Area C adjacent to the exposed reef, the seabed transitions from blocky across the reef to undulating across areas where sediment accumulation is present. Some acoustic penetration occurs adjacent to the reef.

Areas E and F show pronounced high backscatter regions where the vessel was grounded.

In Area E, SBP transects occur north and south of the highest backscatter patch and tend to show some acoustic penetration across areas interpreted to be gravel. However, the grounding site is mostly defined by a flatter seabed.

In Area F, flatter seabed again defines the grounding area. Acoustic penetration may be slightly greater in the berm area noticeable in the 2010 bathymetry data set but changes within the SBP data are very subtle.

It's possible that more focussed tuning of the SBP system (e.g., to the uppermost 1-2m of sediment) would better delineate seabed types (in terms of Sand vs. Gravel areas). However, as the data presently stands much more seabed characterisation information exists within the MBES data than the SBP results.

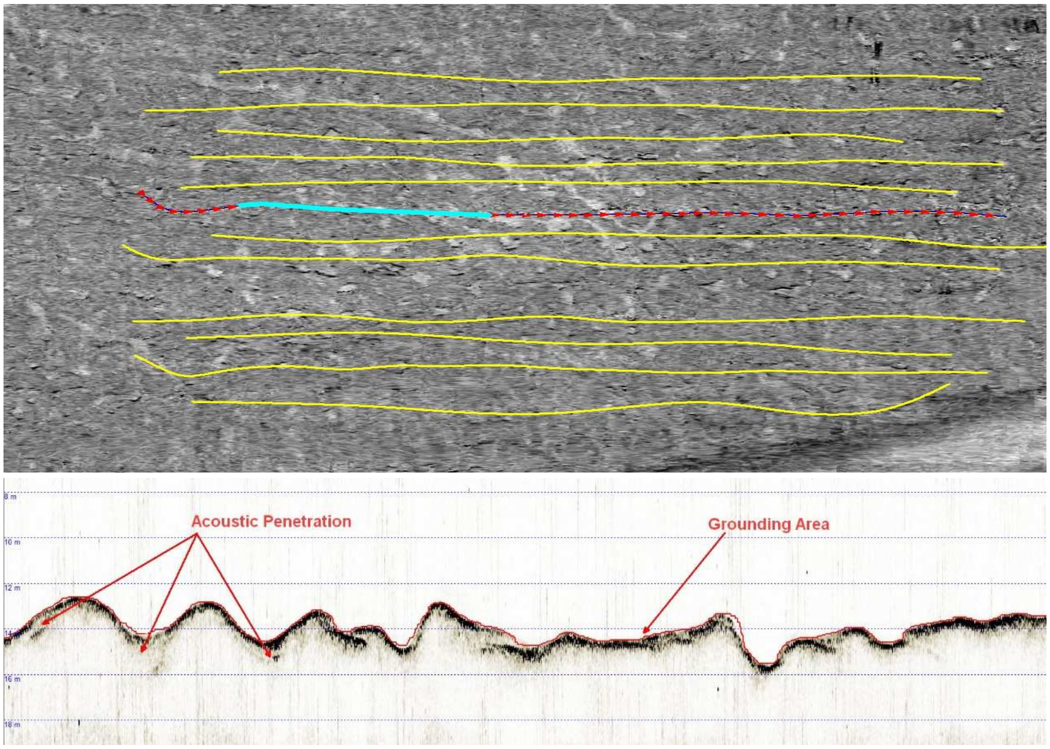

Figure 21: Area A. Backscatter mosaic in top panel and subbottom profile in bottom panel. Blue line marks extent of SBP data. Some acoustic penetration visible in sand areas outside of grounding site.

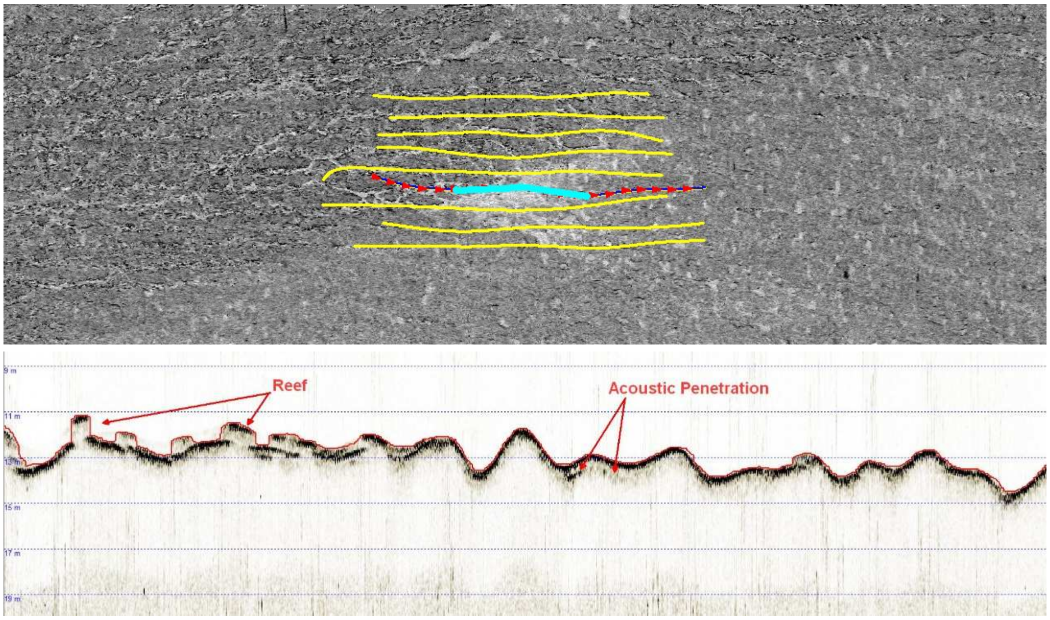

Figure 22: Area C. Backscatter mosaic in top panel and subbottom profile in bottom panel. Blue line marks extent of SBP data. Reef area defined by blocky seabed in SBP data. Some acoustic penetration apparent along the margin of the reef and seabed more undulating where sediment is present.

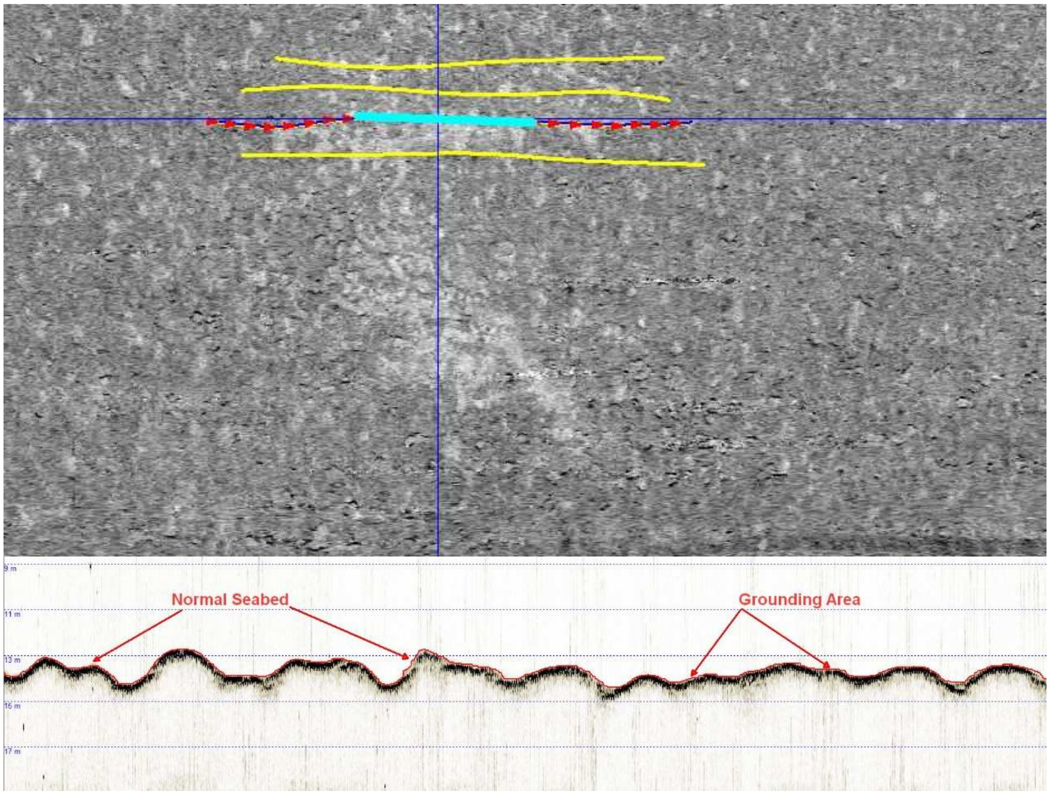

Figure 23: Area E. Backscatter mosaic in top panel and subbottom profile in bottom panel. Blue line marks extent of SBP data. Some acoustic penetration apparent in gravel areas but mostly the grounding area defined by flatter seabed.

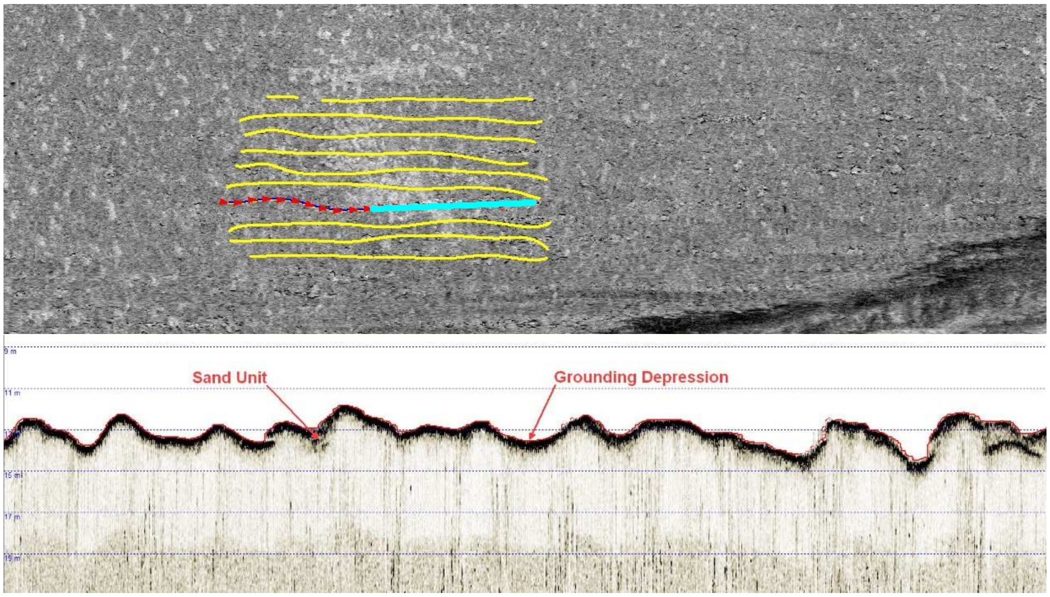

Figure 24: Area F. Backscatter mosaic in top panel and subbottom profile in bottom panel. Blue line marks extent of SBP data. Seabed is flatter around grounding area and depression still visible where vessel was stable. Perhaps more acoustic penetration around area of sediment berm as noted in 2010 bathymetry data set.

7.0 Summary

Assessment and monitoring of the grounding sites across Douglas Shoal benefits substantially from the inclusion of swath mapping data from a multibeam echo sounder. Both the bathymetry and backscatter data provide different insights into changes occurring through time.

The backscatter data in particular was useful for identifying the distribution of coarse (gravel) size sediment associated or created by the grounding event. Bright pixels in the backscatter mosaic highlighted the location of coarser sediments, and the Angle-Range Analysis technique showed good correspondence with sediment samples taken during diving missions. Future projects across Douglas Shoal should incorporate a geophysical survey in advance of any diving / sampling program to better focus those efforts on areas highlighted as acoustically different.

Results from the subbottom profiler survey were ambiguous. No clear acoustic penetration difference was discernible between sand and gravel areas. More focused tuning of the subbottom profiler system might produce a better delineation if the system is used in future monitoring projects.