An Roinn Comhshaoil, Aeráide agus Cumarsáide
Department of the Environment, Climate and Communications

INFOMAR
Integrated Mapping for the Sustainable Development of Ireland's Marine Resource

TC24_04 INFOMAR Survey Report
Area: Celtic Sea

For:
Marine Institute & Geological Survey Ireland

RV *Tom Crean*

September 2024

Prepared by Kevin Sheehan & INFOMAR Survey Team

Rialtas na hÉireann
Government of Ireland

Foras na Mara
Marine Institute

Geological Survey
Suirbhéireacht Gheolaíochta
Ireland | Éireann

Marine Institute Reference No:	Survey Report: TC24_04

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Issue	Date	Description	Author	Approved
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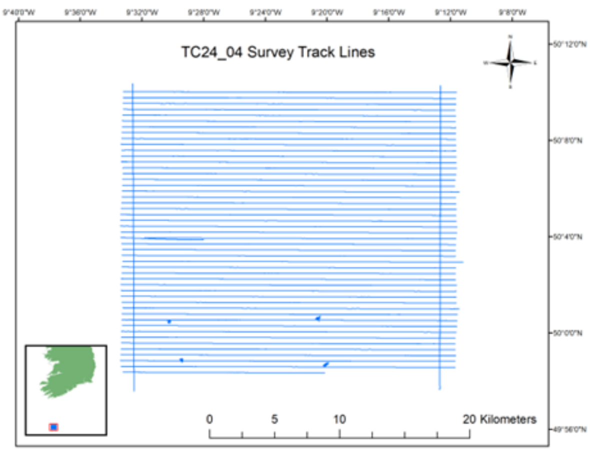
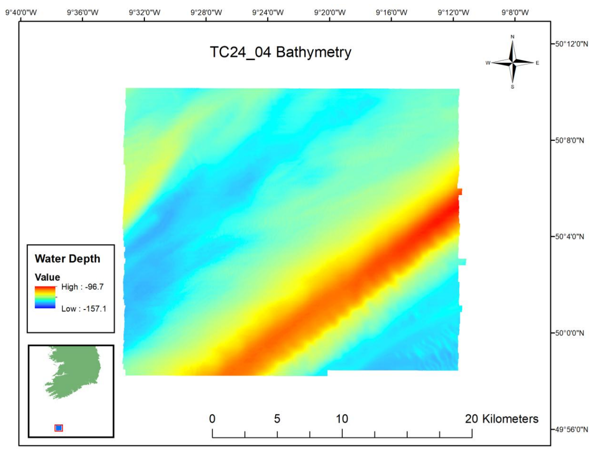
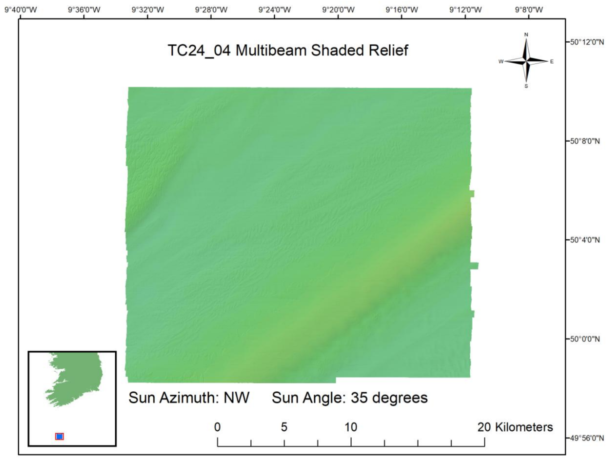
Executive Summary			
Survey Summary			
Survey Vessel:	RV *Tom Crean*	**Survey Leg:**	TC24_04
Mobilisation:	Cork	**Demobilisation:**	Cork
Survey Area:	Celtic Sea	**Start Date:** **End Date:**	14/09/2024 20/09/2024
Northwest Boundary	50° 10.101 N -9° 33.269 W	**Southeast Boundary**	49° 58.451 N -9° 11.644 W
UKHO Admiralty	0002 (1:1,500,000) & 1123 (1:500,000)		
Key References	TC24_04 Survey Leg Report & TC24_04 Executive Report		
Equipment Used	Kongsberg EM2040D MKII MBES, Knudsen 3260 Chirp sub-bottom profiler, SeaSpy magnetometer, AML MVP30-350, C-Nav 5000 GNSS, Seapath 380 R.		
Survey Statistics			
Minimum Water Depth (LAT)	96.7 m	**Maximum Water Depth (LAT)**	157.1 m
Area Covered:	565 km^2	**Survey Line Kilometres:**	1365 km
Operational Time:	62 %	**Weather Standby:**	0 %
Ground Truthing Stations:	0	**Wrecks**	4
H525 forms issues (wrecks)	4	**H102 forms issued (shoals)**	0
Survey Track Lines		**MBES Bathymetry**	



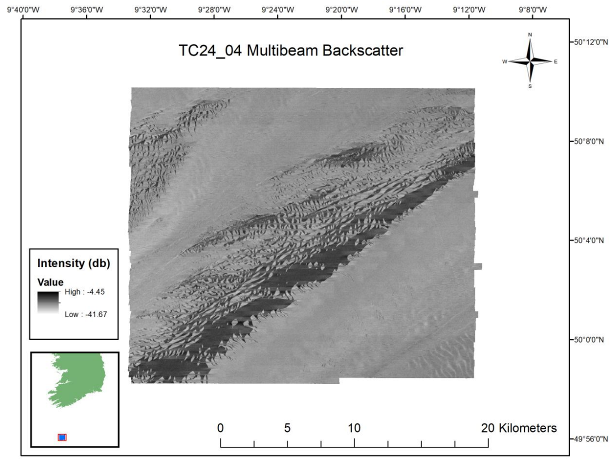


Survey Images

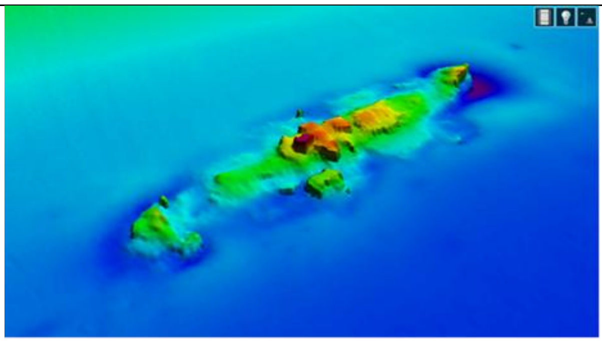
Shaded Relief



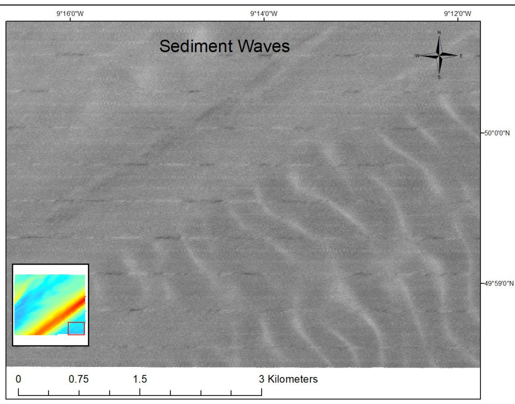
Backscatter



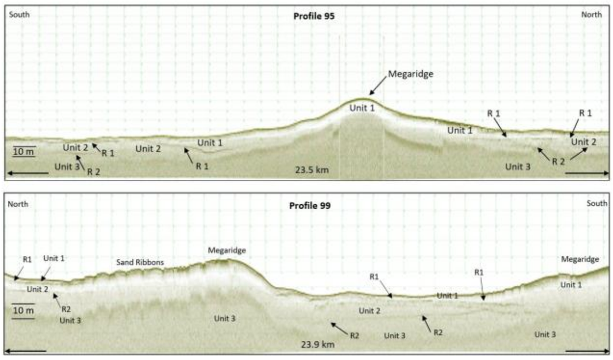
Wreck 3



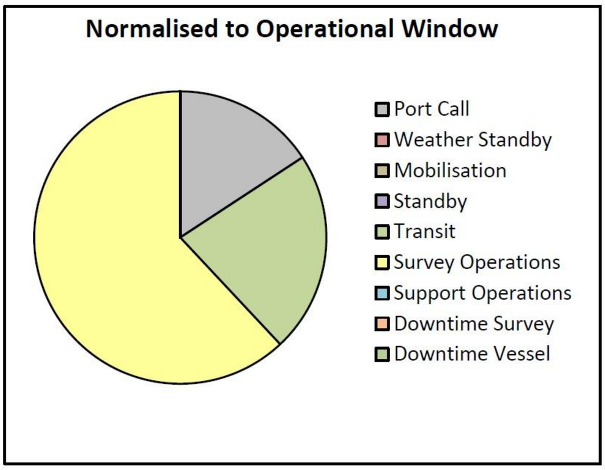
Backscatter Features



Chirp Profiles



Survey Statistics



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List of Acronyms Used Within This Report

Acronym	Full Name
AML	AML Oceanographic
CUBE	Combined Uncertainty and Bathymetry Estimator
DECC	Department of the Environment, Climate and Communications
DGNSS	Differential Global Navigation Satellite Systems
DPR	Daily Progress Report
FMGT	Fledermaus Geocoder Tool
GIS	Geographic Information System
GNSS	Global Navigation Satellite Systems
GSI	Geological Survey Ireland
HVF	Hips Vessel File
IHO	International Hydrographic Organisation
IMO	International Maritime Organisation
IMU	Inertial Measurement Unit
INFOMAR	INtegrated Mapping FOr the Sustainable Development of Irelands MArine Resource
INSS	Irish National Seabed Survey
ISU	INFOMAR Survey Unit
ITRF	International Terrestrial Reference Frame 2014 (ITRF2014)
LAT	Lowest Astronomical Tide
MVP	Moving Vessel Profiler
MBES	Multibeam Echo-Sounder
MI	Marine Institute
MGC	Motion Gyro Compass
MRU	Motion Reference Unit
NPWS	National Parks & Wildlife Service
PPE	Personal Protective Equipment
PPP	Precise Point Positioning
RTG	Real-Time Gipsy
RV	Research Vessel
SBP	Sub Bottom Profiler
SIS	Seafloor Information System
SVP	Sound Velocity Profiler
TPU	Total Propagated Uncertainty
UKHO	UK Hydrographic Office
UTC	Coordinated Universal Time
VORF	Vertical Offshore Reference Frame
WGS	World Geodetic System

1. Introduction

1.1 Project Overview and Objectives

Geological Survey Ireland (GSI) and Marine Institute (MI) conducted seabed mapping between 2003 and 2005 under the auspices of the Irish National Seabed Survey (INSS) and mapping continued from 2006 to present day under the INtegrated mapping FOr the sustainable development of Irelands MArine Resource (INFOMAR) programme. INSS, which commenced in 1999 under the GSI was one of the largest marine mapping programmes ever undertaken globally, with a focus on deep water mapping. INFOMAR is a joint venture between the GSI and the MI and is funded by the Irish Government through the Department of the Environment, Climate and Communications (DECC).

INFOMAR Phase 1, 2006 to 2015 focused on mapping 26 priority bays and 3 priority areas around Ireland and creating a range of integrated mapping products of the physical and biological features of the seabed in those areas. INFOMAR Phase 2, 2016 to 2026 intends to map the remainder of Ireland's entire seabed. Figure 1 shows the extent of the continental shelf mapped area under INSS and INFOMAR and the outstanding areas as of January 2024. Grey areas have already been mapped and blue and purple-coloured areas are unmapped. Coloured hatched areas are designated for mapping in 2024.

In 2018, the remaining survey area was split at the 30 nautical mile (NM) limit. The inshore survey fleet, managed by GSI is responsible for mapping inshore of 30 NM and the MI vessels are responsible for mapping the offshore. Operational requirements sometimes necessitate that MI vessels map inshore of 30 NM. Survey areas are defined into gridded survey units known as INFOMAR Survey Units (ISUs). ISUs are all 1000 km^2 in size and are uniquely identifiable by a letter on the x-axis and number on the y-axis. ISUs are coloured in a shade of blue, which indicates the modal water depth within that ISU. Colour scales are used, to denote the three depth bands: 50 to 100m, 100 to 150m and 150m plus.

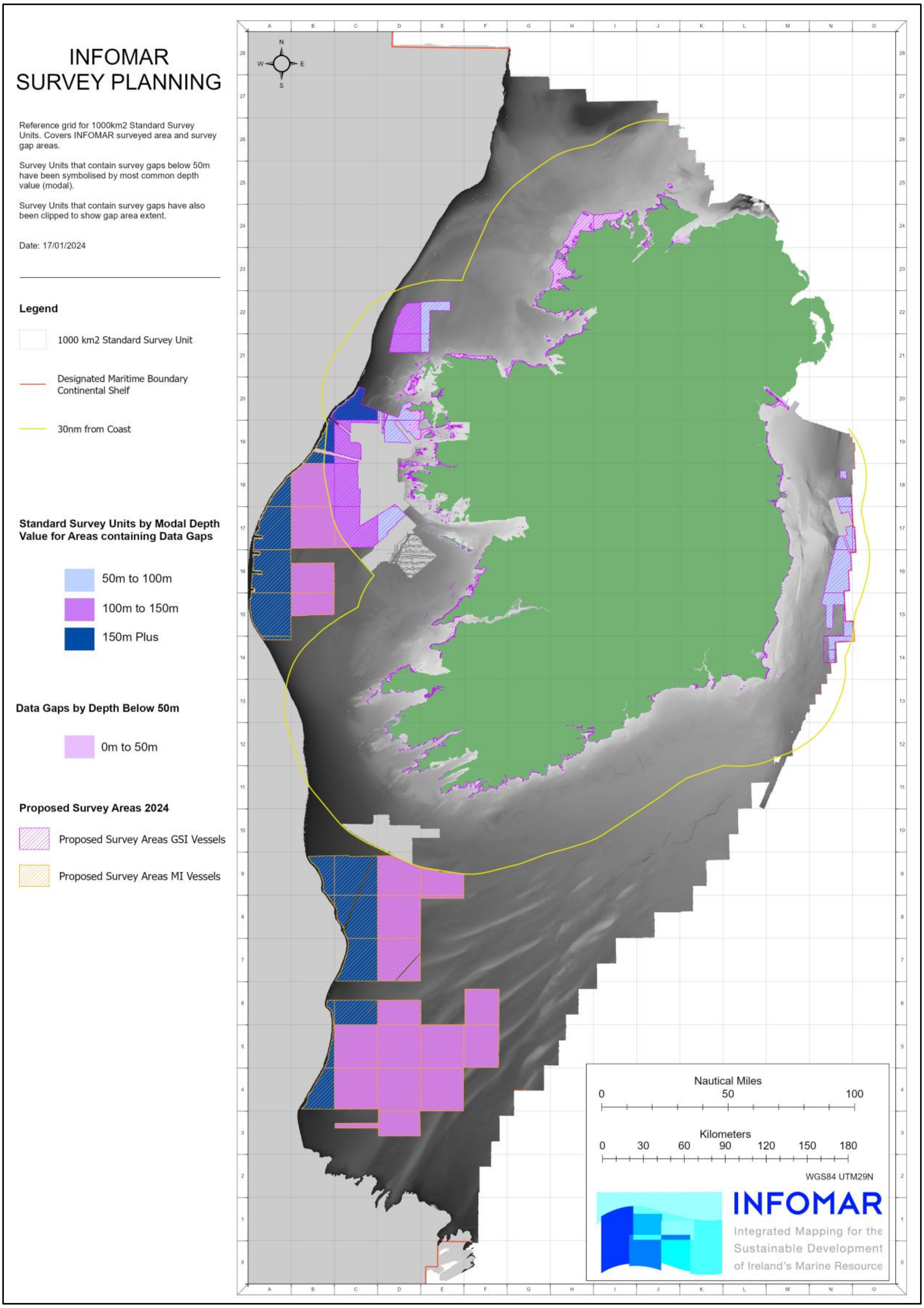


Figure 1: Survey coverage and 2024 designated operations areas.

Survey acquisition was conducted using the MI research vessel RV *Tom Crean* along with experienced personnel.

The scientific aims of the survey were to:

(i) Undertake a Multibeam Echo Sounder (MBES) hydrographic survey to the highest International Hydrographic Organisation (IHO) standard possible in the surveyed water depths.

(ii) Produce bathymetry, shaded relief and backscatter products to provide depth, seabed features and seabed hardness/roughness information.

(iii) Acquire Sub Bottom Profiler (SBP) data of the shallow sub-seabed to determine the existence of buried objects and ascertain the sub-seabed character.

(iv) Acquire magnetometer data to investigate the sub-seabed geology and provide information on man-made seafloor debris.

(v) Map in detail and provide hydrographic wreck reports for all encountered wrecks.

1.2 Proposed Survey Area

The 2024 INFOMAR Operations Plan was agreed between MI and GSI at the start of the year, circulated to stakeholders and published online at https://www.infomar.ie.

Figure 2 shows the designated mapping areas for 2024 in the Celtic Sea. Predicted survey coverage for the RV *Tom Crean* survey season was 5920 km^2 based on 74 charter days and from analysis of historical survey statistics.

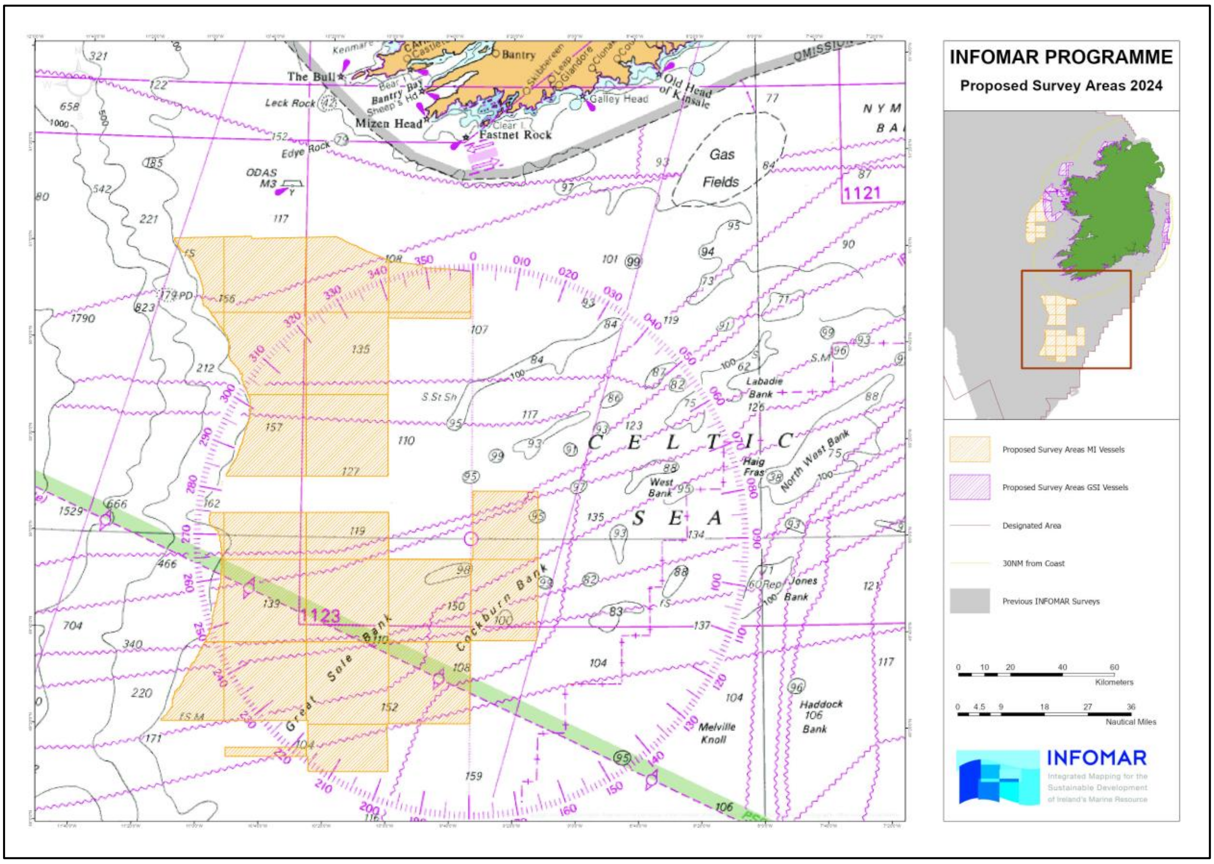


Figure 2: Proposed RV *Tom Crean* 2024 survey area in the Celtic Sea.

2. Operations & Survey Setup

Mobilisation took place in Cork, on 14th September. Survey acquisition was between 15th and 19th September. Kevin Sheehan of the MI acted as Party Chief. The survey team comprised skilled personnel from the Advanced Mapping Services team at the MI.

2.1 Survey Track Lines

The final survey track lines image in Figure 3 is produced in ArcGIS software, after export of an initial shapefile from Teledyne Caris HIPS & SIPS™ software. Data acquisition took place approximately 140 km south of Cape Clear Island.

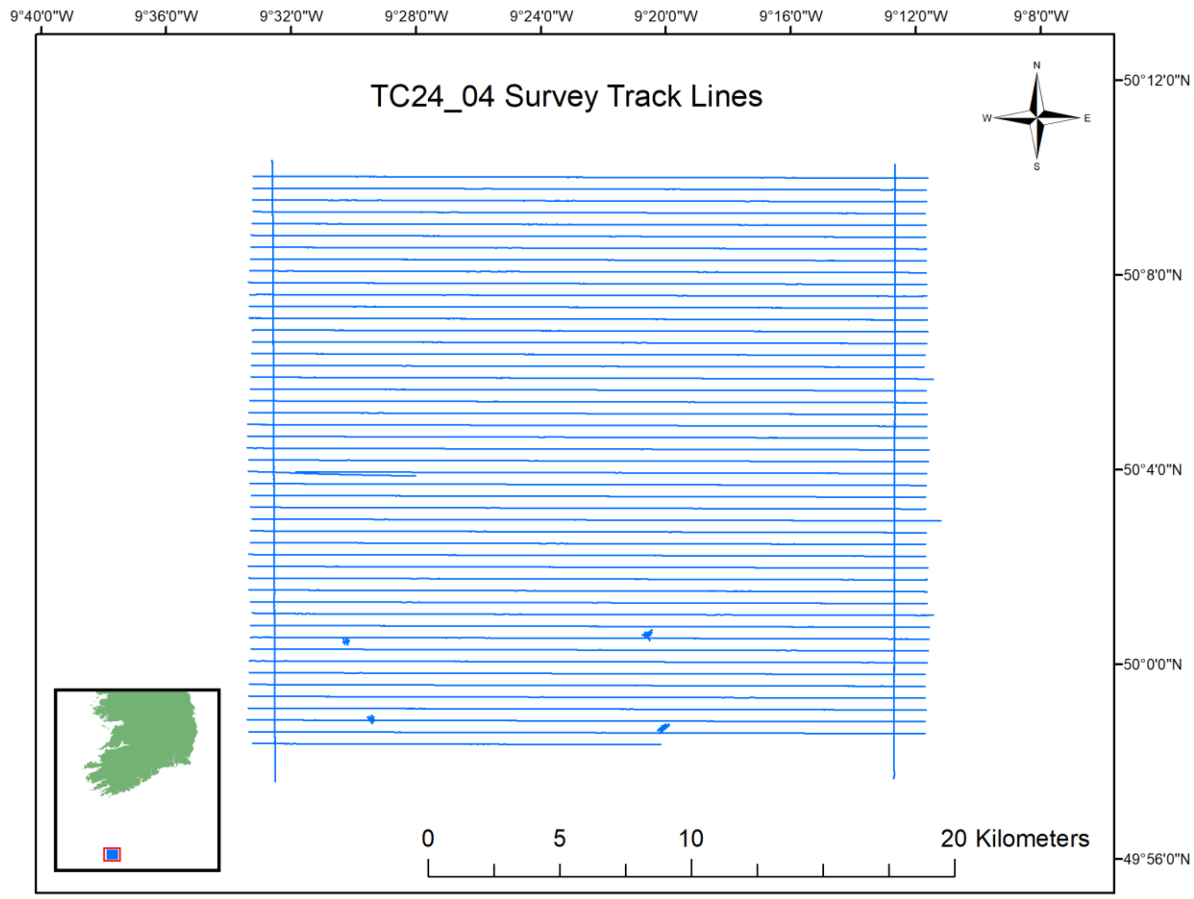


Figure 3: Survey track line plot produced in Teledyne Caris and ArcGIS software.

2.2 Summary of Events

A summary of the key events is presented in Table 1. Times are in Coordinated Universal Time (UTC). Daily Progress Reports (DPRs) were distributed to management and INFOMAR personnel daily.

Date and time	Activity
14/09/2024 00:00	Mobilisation Cork
14/09/2024 09:30	Transit to Survey Site

15/09/2024 05:00	Survey acquisition commenced in the Celtic Sea
19/09/2024 13:07	Acquisition completed. Transit to Cork for demobilisation
20/09/2024 16:01	Port Call Cork
20/09/2024 23:59	Demobilisation complete

Table 1: Summary of survey events.

2.3 Survey Personnel

Survey personnel, their affiliation and roles are listed in Table 2.

Name	Affiliation	Dates	Role
Kevin Sheehan	MI	14th – 20th Sept	Party Chief
Vera Quinlan	MI	14th – 20th Sept	Surveyor
Oisin Mcmanus	MI	14th – 20th Sept	Processor
Nicola O' Brien	MI	14th – 20th Sept	Surveyor

Table 2: Survey personnel details.

2.4 Health, Safety and Environment

All personnel joining the vessel were given a safety induction tour, which was recorded by the Second Officer. Medical, Personal Sea Survival and Personal Security certifications for all personnel were checked for validity prior to departure. Scientists signed on to the ship and signed the drug and alcohol policy and safety tour form. A Muster drill was held within 24 hours of joining the vessel. Magnetometer and Moving Vessel Profiler (MVP) operations were performed by vessel crew and without incident, with personnel wearing correct Personal Protective Equipment (PPE).

2.5 Marine Mammal Observations

National Parks and Wildlife Service (NPWS) published a *Code of Practice for the Protection of Marine Mammals during Acoustic Seafloor Surveys in Irish Waters* in 2007. An updated document titled "Guidance to Manage the Risk to Marine Mammals from Man-made Sound Sources in Irish Waters" was published in January 2014. Full details of both documents are published on the NPWS website: https://www.npws.ie/. The code and guidance are applicable to all SBP (pinger or chirp), MBES and sidescan sonar surveys in bays, inlets or estuaries and within 1500 m of the entrance of enclosed bays/inlets/estuaries.

2.6 General Survey Information

A summary of key survey statistics is contained in Table 3.

Total Line Length (km)	1310
New Area Covered (km^2)	565
Operational (%)	62
Transit (%)	22.3

Port Call (%)	15.8
Weather Standby (%)	0.0
Mobilisation (%)	0.0
Downtime Vessel (%)	0.0

Table 3: Key survey statistics.

The pie chart in Figure 4 illustrates the cumulative survey activity statistics taken from the final DPR. Survey data acquisition accounts for approximately 62% of the charter time.

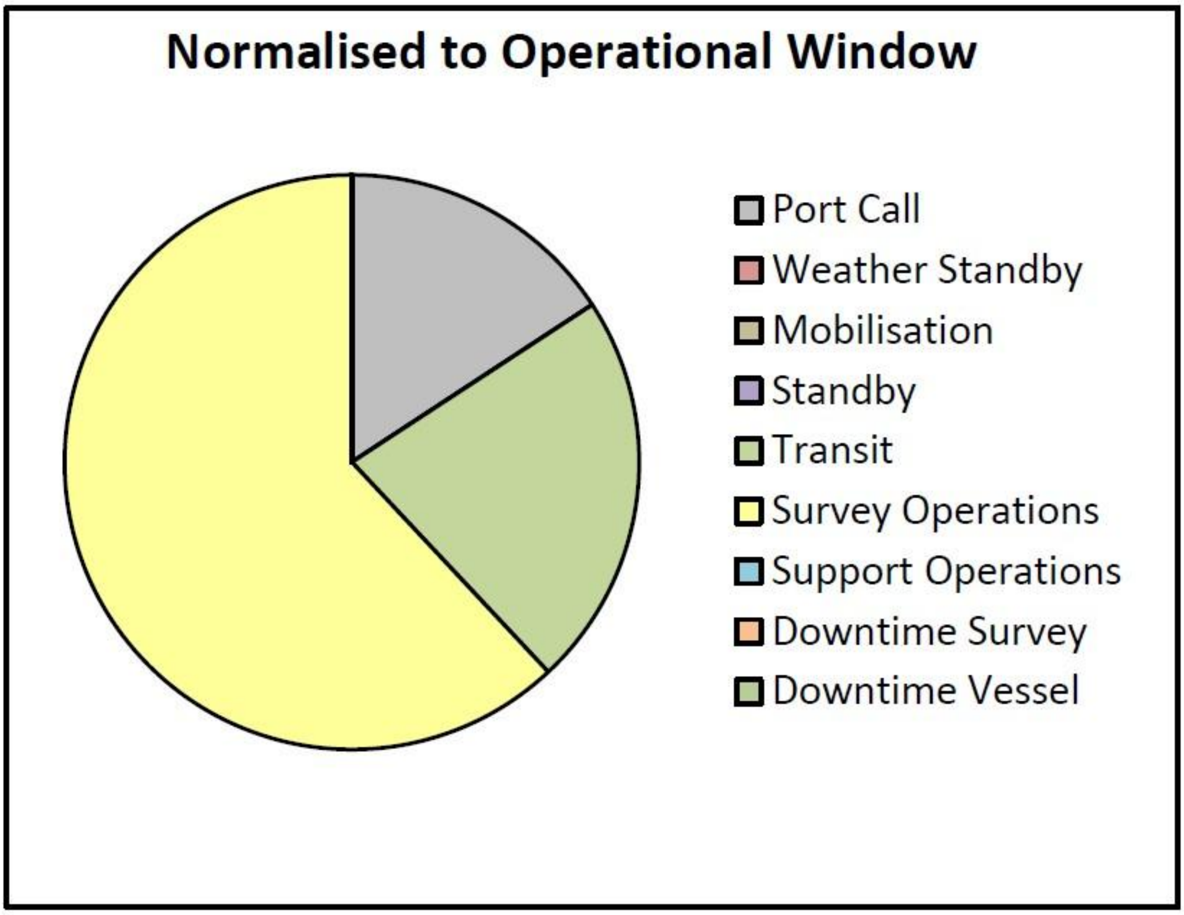


Figure 4: Survey statistics pie chart.

3. Survey Vessel Offsets, Equipment and Data Acquisition

The RV *Tom Crean* (Figure 5) is a multipurpose research vessel owned by MI and managed by P&O Maritime. The vessel has wet, dry and chemical laboratories, which are permanently fitted with standard scientific equipment and can accommodate 13 scientists with a maximum endurance of 21 days. It has a high-resolution dual head EM2040D MKII MBES system fitted on a retractable pole, hull-mounted Knudsen chirp source SBP, two C-NAV Differential Global Navigation Satellite Systems (DGNSS) units as primary navigation and a Seapath 380-R as secondary navigation. The vessel has two Motion Gyro Compasses (MGC) used within the Seapath 380-R as Inertial Measurement Unit (IMU) and as stand-alone International Maritime Organisation (IMO) type approved gyrocompass. All necessary geophysical and DGPS positioning equipment were pre-installed, calibrated and tested prior to commencement of survey activities.

Figure 5: The RV *Tom Crean*.

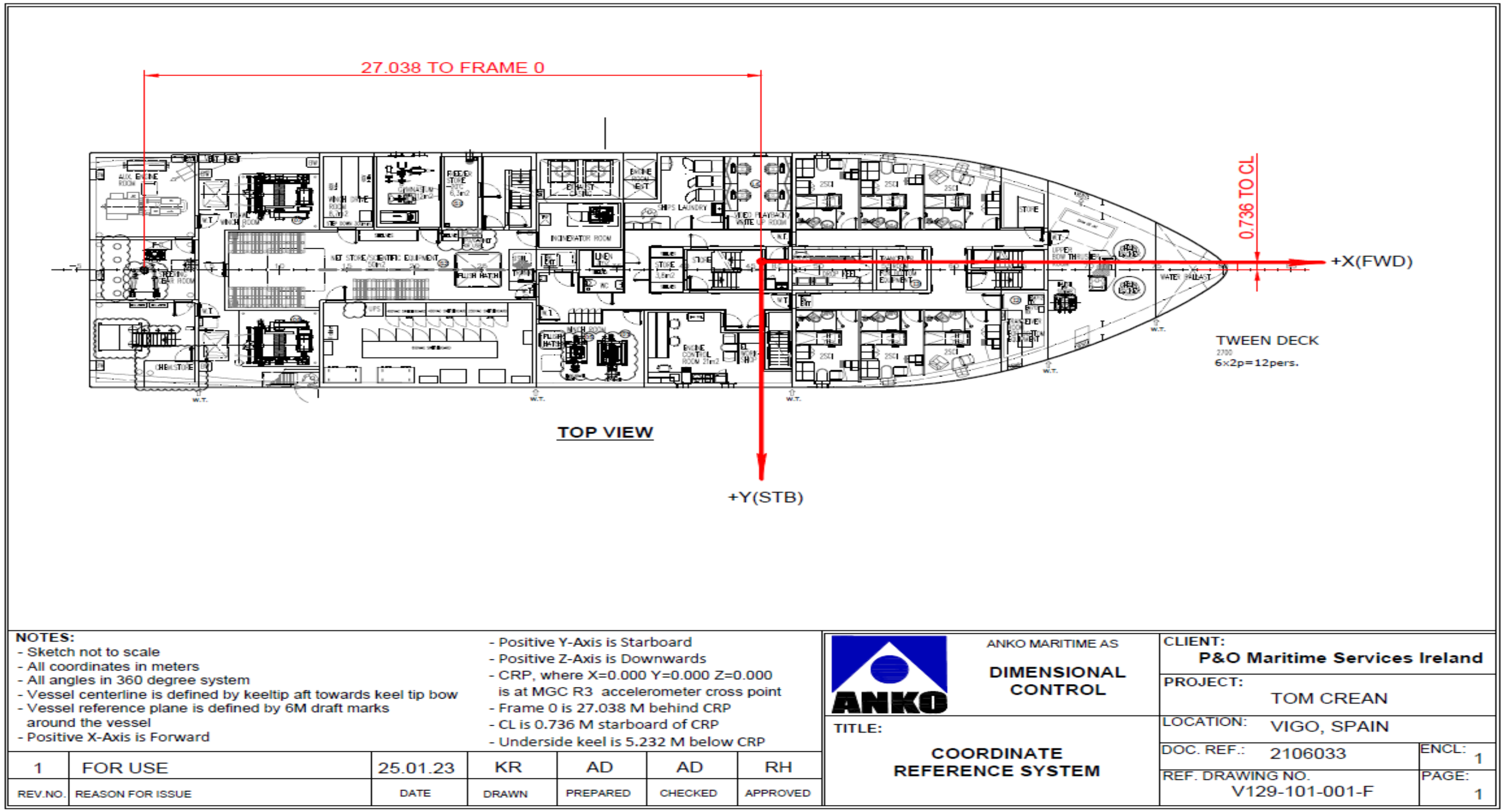
Detailed vessel information is contained in Table 4.

Parameter	Numeric
Length	52.8 m
Beam	14.0 m
Draught	5.2 m
Power Generation	2 x 1350 kw, 1 x 400 kw
Main Propulsion Motor	2000 kw
Speed	10 knots
Max Scientists	13
Crew	12
Endurance	21 Days
Other	DP1 Dynamic Positioning

Table 4: RV *Tom Crean* vessel information.

3.1 Vessel Offsets

Anko Maritime AS performed an offset survey of the RV *Tom Crean* in May 2022 while in dry dock in Vigo, Spain. The coordinate reference system is shown in Figure 6.



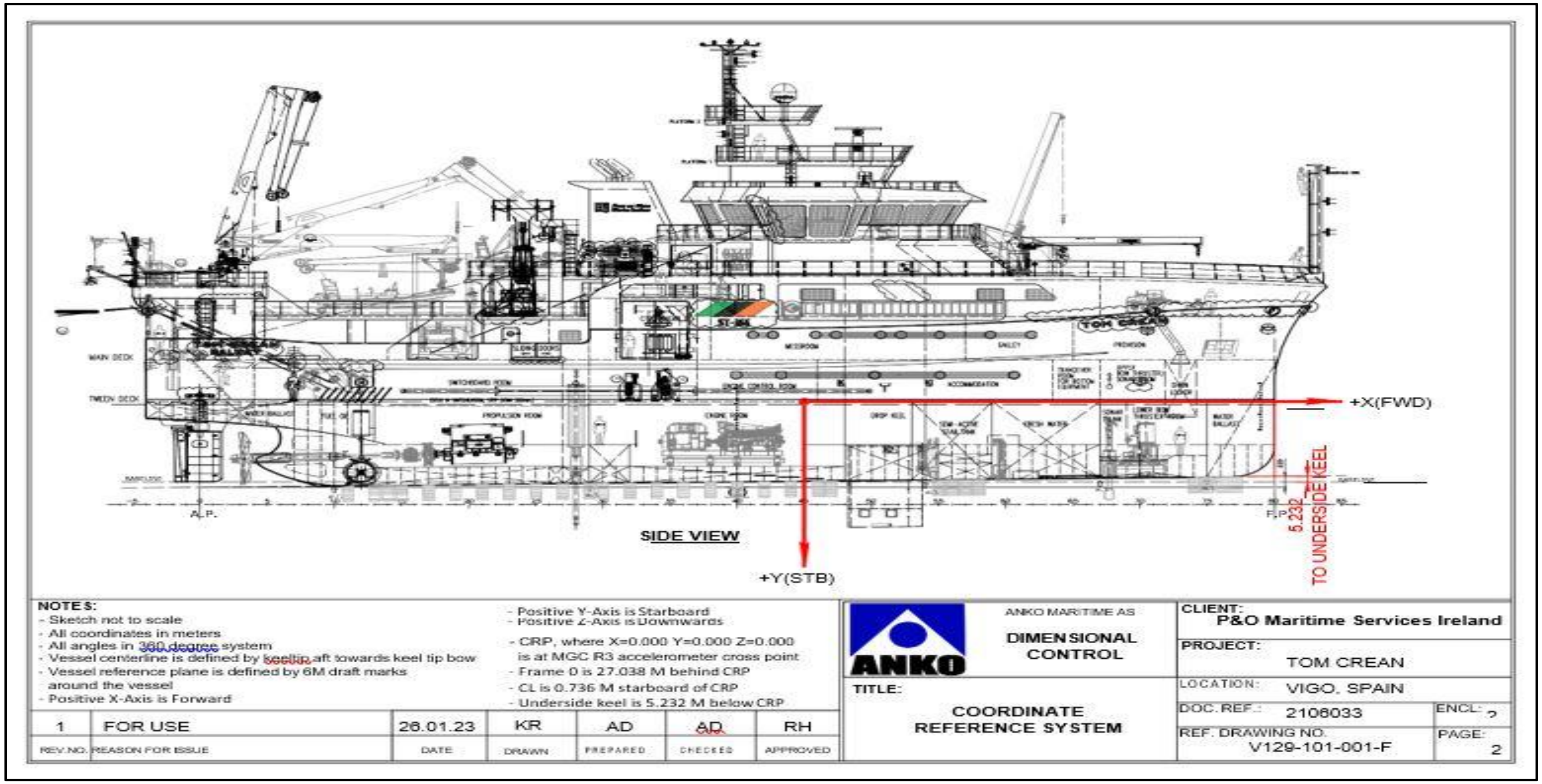


Figure 6: Coordinate Reference System.

Vessel offsets are presented in Table 5 below.

Item	Y (+ Stb)	X (+ Fwd)	Z (+ Down)	Description
MGC R3	0.000	0.000	0.000	Accelerometer Cross Point
MGC R2	0.492	-0.008	0.000	Accelerometer Cross Point
Seapath Aft	0.717	-4.229	-23.313	Geometrical Centre
Seapath Fwd	0.734	-1.729	-23.301	Geometrical Centre
CNAV Port No. 1	-0.144	-3.019	-23.462	Geometrical Centre
CNAV Stb No. 2	1.604	-2.975	-23.458	Geometrical Centre
Wind Sensor Stb	8.415	-0.355	-16.813	Geometrical Centre
Wind Sensor Port	-6.942	-0.396	-16.803	Geometrical Centre
2040 TX	0.728	8.654	6.343	Centre Face
2040 RX STB	1.077	8.776	6.177	Centre Face
2040 RX Port	0.388	8.798	6.177	Centre Face
TX Frame	0.520	3.298	5.131	Centre Face
RX Frame	0.821	3.405	5.128	Centre Face
ES38	0.748	4.863	5.259	Centre Face
ES333	0.432	4.408	5.260	Centre Face
ES120	0.662	4.469	5.259	Centre Face
ES70	0.980	4.471	5.260	Centre Face
ES18	0.746	3.999	5.262	Centre Face
ADCP	0.731	2.669	5.252	Centre Face
Ranger2	0.425	-10.340	8.060	Fully Extended
SU92	2.033	13.471	6.629	Fully extended
SubBottom profiler	1.043	9.707	5.248	Centre Face
TX712	0.737	12.125	5.227	Centre Face
RX712	0.732	10.704	5.231	Centre Face

Table 5: Vessel offsets.

Vessel inclinations are listed in Table 6 below.

Item	Roll	Pitch	Yaw
MGC R3	-0.27	-0.61	0.57
MGC R2	0.72	-0.25	0.35
Seapath	N/A	N/A	0.40
TX 2040	-0.02	-0.37	1.70
RX 2040 STB	-39.96	-1.82	1.68
RX 2040 Port	39.94	1.14	1.98
ES38	-0.17	0.52	0.45
ES333	0.13	0.44	-0.05
ES120	-0.16	0.79	-0.12
ES70	-0.14	0.33	-0.05
ES18	-0.11	0.18	-0.19

ADCP	-0.07	1.07	1.66
Ranger2	0.06	-0.69	-0.08
SU92	-0.10	-0.96	289.06

Table 6: Vessel inclinations.

3.1.1 Multibeam Patch Test

A patch test was conducted in Galway Bay on 6th March 2024. No changes were made to the angular offsets during this patch test. Figure 7 shows the angular and location offsets post patch test.

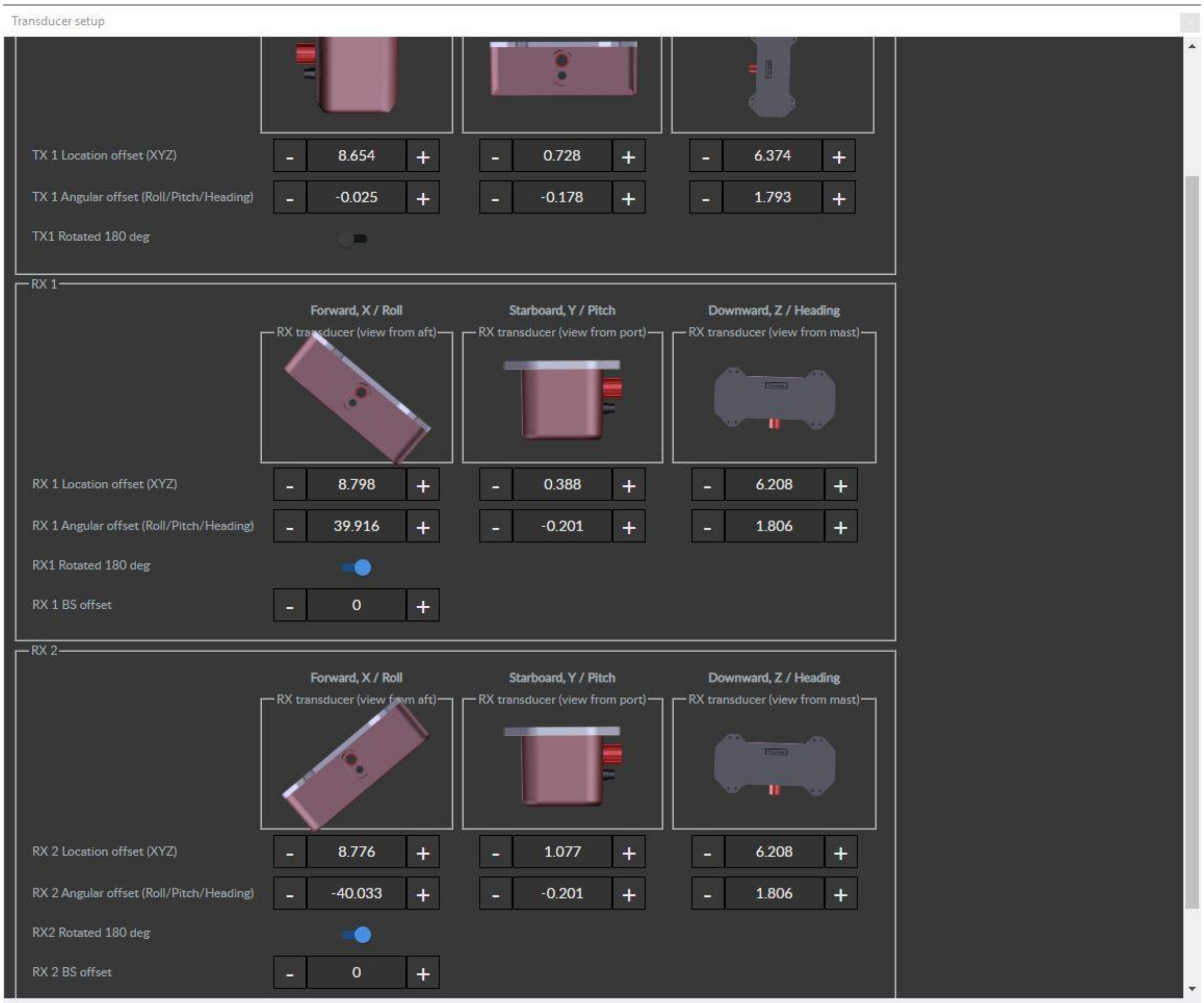


Figure 7: Angular and location offsets in SIS post patch test.

While most of the parameters above reflect those provided in the dimensional survey, pitch and heading angular offsets for Rx1 and Rx2 do not. This is because Kongsberg analysed the dimensional survey and questioned the validity of these specific parameters which are too far from the mounting frame standard angles. They recommended to use the pitch and heading of the Tx, which are usually more reliable than the Rx values when measured with total stations (due to longer baseline) and then adjust the Rx values based on patch test results. This was a key recommendation provided by Kongsberg prior to any patch test.

On RV *Tom Crean* both Rx have connectors pointing aft, i.e. they are reversed. Roll, Pitch and Heading calibration values found for the rotated Rx heads are therefore also inverted. This is shown in Figure 7 where observed offset convention is swapped for Rx heads resulting in differences between Pitch and Heading Installation Angles for Rx heads and for the Tx.

Figure 8 shows the line plan and MBES data for the pitch and heading calibration.

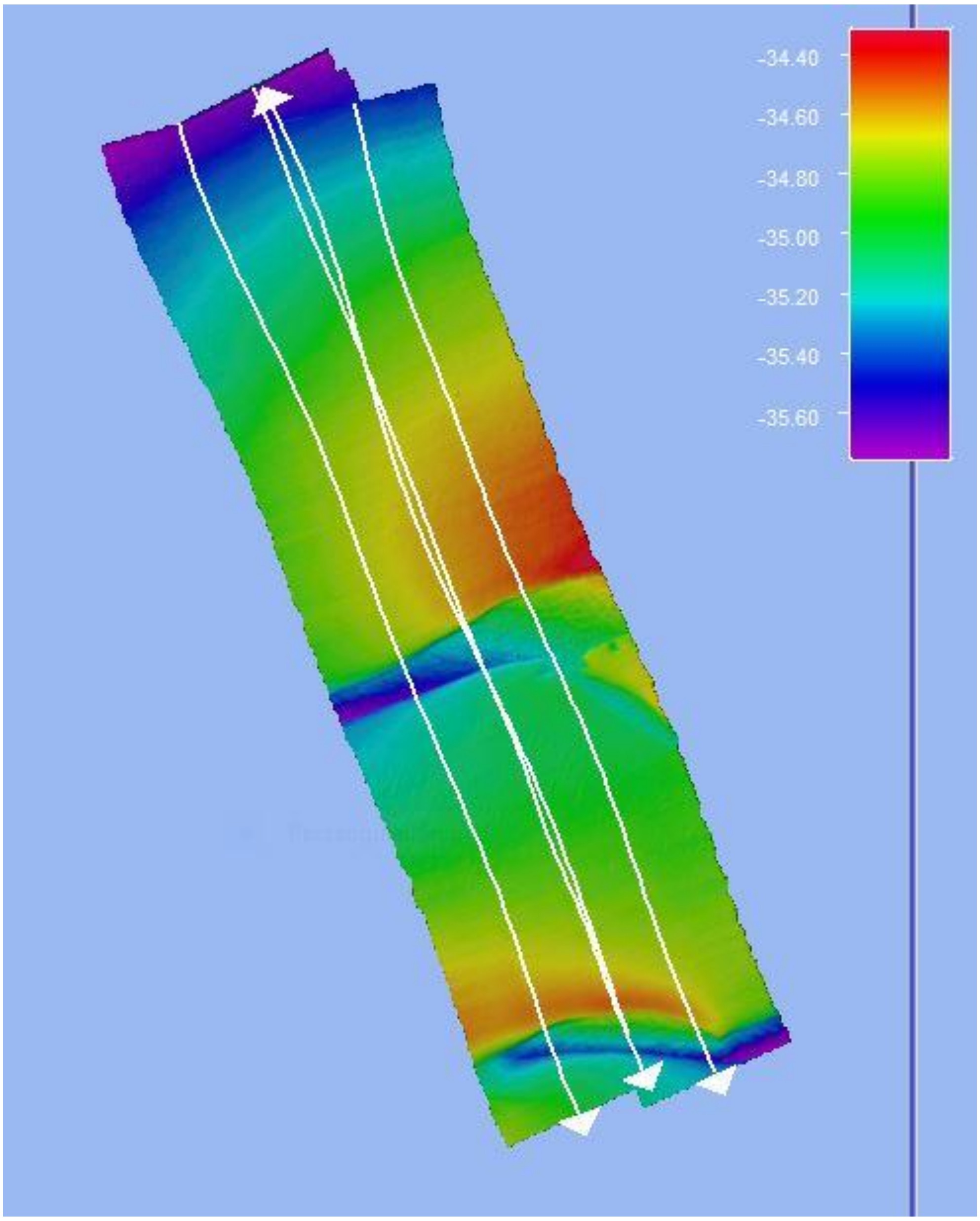


Figure 8: Pitch and heading patch test data.

Figure 9 shows the line plan and MBES data for the roll calibration.

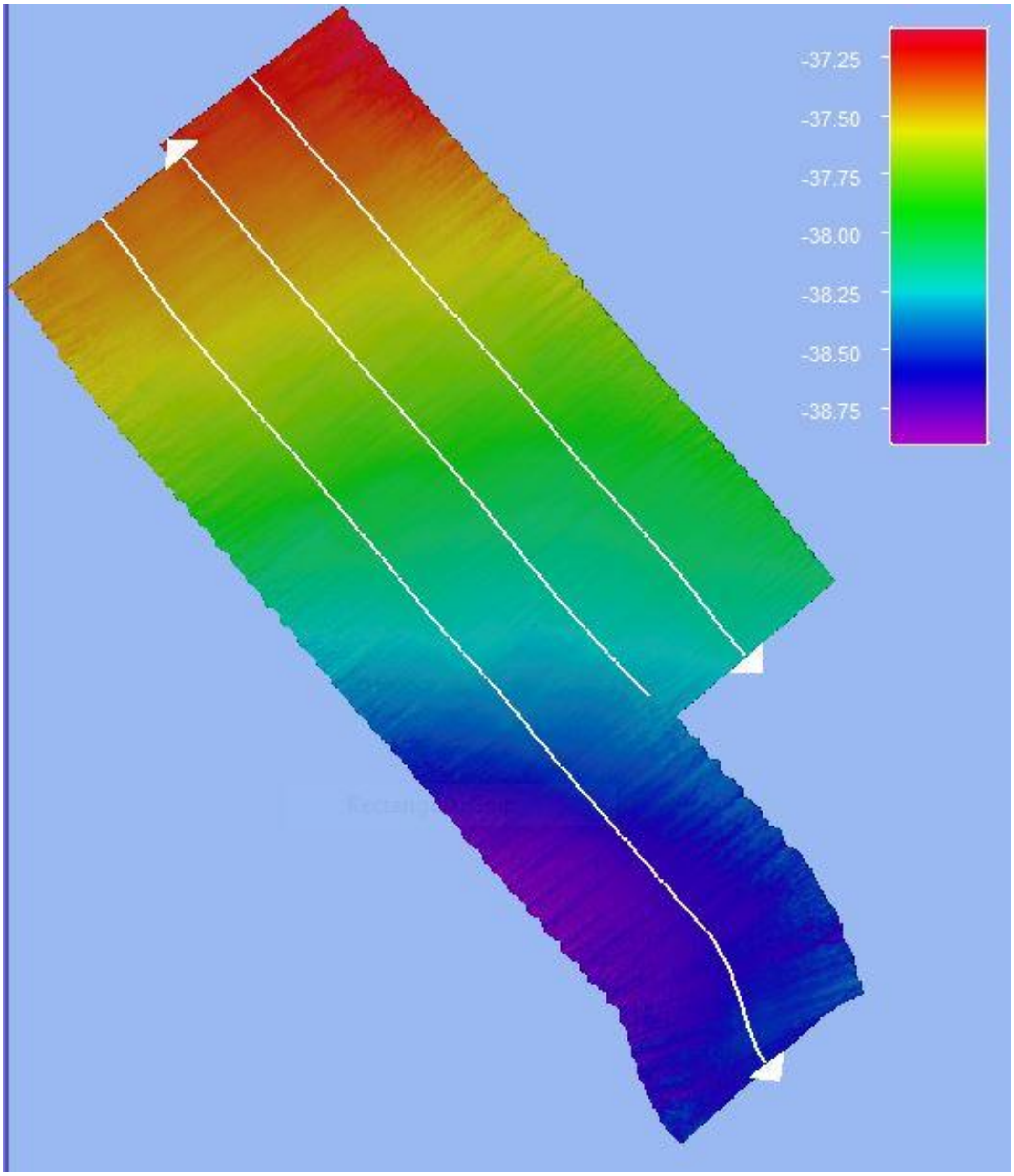


Figure 9: Roll patch test data.

3.2 Survey Equipment

Table 7 contains information on the survey equipment both permanently installed and available for mobilisation on board the RV *Tom Crean*.

System	Type	Comment
Multibeam Echo-Sounder	Kongsberg EM2040D MKII	200, 300 & 400 kHz
Sub-Bottom Profiler	Knudsen Chirp 3260	3.5 and 12 kHz
Sidescan Sonar	Edgetech 4200	100 and 500 kHz
Positioning	C-Nav DGNSS (two units)	Seapath 380-R secondary
Motion Gyro Compass	Seapath 380-R	2nd MGC as backup

USBL	Sonardyne Ranger 2	
Sound Velocity Profiler	Valeport SVP Mini	Valeport Midas as backup
Moving Velocity Profiler	AML MVP30-350	Sound Velocity
Realtime Sound Velocity	Valeport mini SVS	Sound Velocity
Magnetometers	SEASPY	Overhauser Effect

Table 7: RV *Tom Crean* available survey equipment.

3.2.1 Technical Issues

EM2040 Data Noise

A long term issue with noise on starboard side on EM2040 requires investigating.

3.3 Data Acquisition

3.3.1 Geodetic Parameters

Table 8 contains the geodetic parameters used.

Local Datum Geodetic Parameters	
Datum	ITRF2014
Spheroid	World Geodetic System 1984 (WGS-84)
Semi-Major Axis (a)	6378137.000 m
Semi-Minor Axis (b)	6356752.314 m
First Eccentricity Squared (e^2)	0.0066943800
Inverse Flattening (1/f)	298.257223563
Projection Parameters	
Grid Projection	Universal Transverse Mercator
Central Meridian Zone 29 (CM)	009º West
Origin Latitude (False Lat.)	00.0°
Hemisphere	North
False Easting (FE)	500000.0 m
False Northing (FN)	0.0 m
Scale Factor on CM	0.999600
Units	M

Table 8: Geodetic parameters.

3.3.2 Survey Datum, GNSS Tides and VORF Model

Table 8 above provides details of the vertical and horizontal datum applied during operations. GPS tides derived from high precision Differential Global Navigation Satellite Systems (DGNSS) do not require accounting for changes in vessel draft or vessel squat values, as recorded depths are related directly to the WGS84 Ellipsoid. Depth measurements were reduced to Lowest Astronomical Tide

(LAT) using DGNSS tidal measurements and by then applying the VORF (Vertical Offshore Reference Frame) model (LAT/WGS84 separation) as illustrated in Figure 10 below.

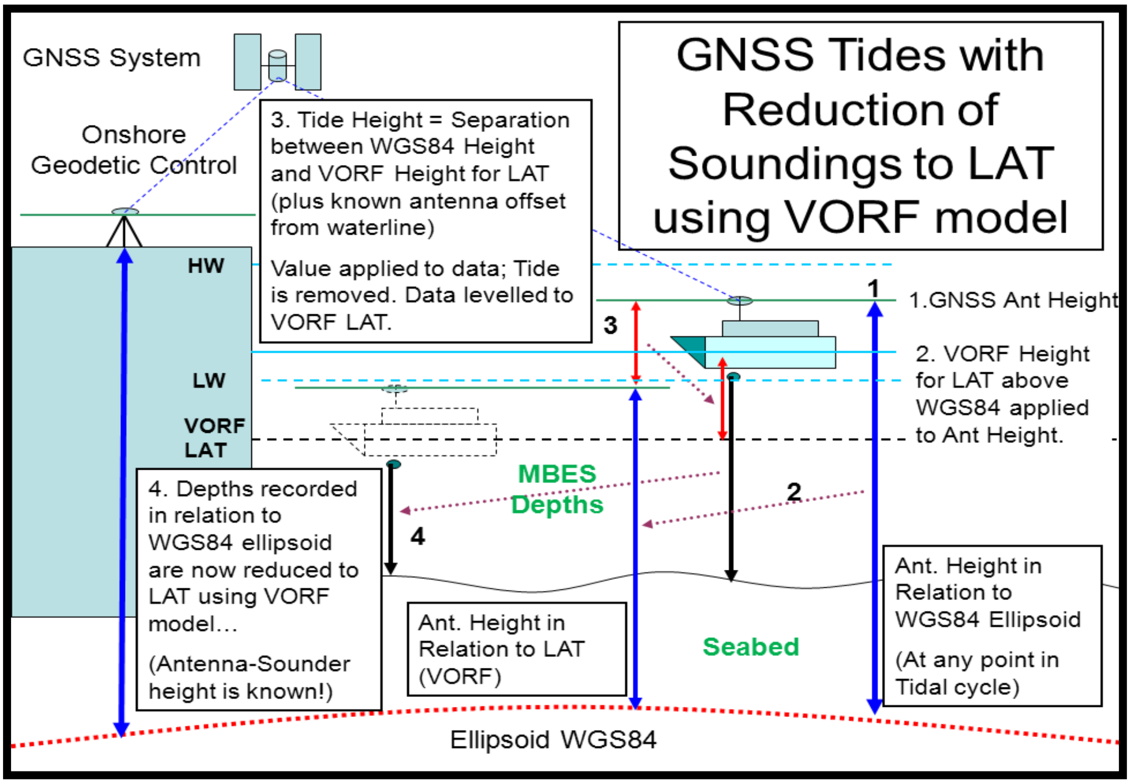


Figure 10: GNSS tides to LAT using VORF model.

3.3.3 Vessel Draft

A constant value of 0.35 was entered for the waterline in the installation parameters in SIS. This value was calculated from the dimensional survey during dry dock.

3.3.4 Acoustic Systems

A Kongsberg EM2040 MKII high resolution MBES mounted on a retractable pole was used for swath acoustic acquisition. First bottom returns from the MBES produce highly accurate bathymetric data. Additionally, backscatter acquired by MBES sonars contains important information about the seafloor and its physical properties. Backscatter provides valuable data to aid in seafloor classification and important auxiliary information for a bathymetric survey.

The configuration consists of dual RX transducers and a single TX transducer 1.5° beamwidth each when operating at 200 kHz frequency and 0.7° beamwidth each when operating at 400 kHz. The system operates at frequency ranges of 200, 300 or 400 kHz with 800 soundings per ping and allows coverage of up to 10 times water depth on a flat bottom. It has a maximum ping rate of 50 Hz. The 200 kHz frequency was used for this survey. Primary positioning was provided by C-Nav 5000 DGNSS.

Seapath 380-R provided secondary positioning. Kongsberg Motion Gyro Compass (MGC) R3 provided real time heading, heave, pitch, roll and velocity to the MBES system.

MBES data was recorded in kmall format using Kongsberg's Seafloor Information Software. Raw files were continuously backed up on the vessel server at EOL. Table 9 contains MBES metadata.

Descriptor	Metadata
Survey lines	Main lines, Cross lines, Patch Test and Wrecks
Data Files	133
Date Created	15-09-2024 to 19-09-2024
Dataset Size	80.9 GB
File Formats	kmall & kmwcd

Table 9: MBES metadata.

United Kingdom Hydrographic Office (UKHO) guidelines were implemented when carrying out wreck investigations. Three survey lines along the wreck's primary axis with high overlap and one or more lines across its secondary axis to ensure full wreck coverage along both axes were acquired. Water column data logging functionality in SIS was used throughout the investigation. Beam angles, survey speed, operational frequency and pulse length were configured for maximum resolution. Wrecks were reported to the UKHO using the standard UKHO "H-Forms". A total of four wrecks were surveyed in detail.

A Knudsen hull-mounted chirp source SBP operating at 3.5 kHz was used for sub-bottom profiler data acquisition. The range and phase settings were varied appropriately with water depth to maximise ping rate and resolution. The chirp source is most effective in high resolution investigations of the top 20 or 30 m sub-seabed and where sediments are fine and medium grained. The signal does not penetrate bedrock. The Chirp 3260 is a blackbox system that interfaces to a standard PC via a USB connection. SounderSuite Windows application software controls data acquisition. Raw data were recorded in native Knudsen format along with industry standard SEGY data. Positioning and MRU data were fed directly from the Seapath 380-R. QC was maintained by the online surveyors, with reference to the digital display; with power, range, gains, filter parameters and transmit pulse adjusted as required for optimal imaging. All data were backed up to the vessel server. Table 10 contains SBP metadata.

Descriptor	Metadata
Survey lines	All
Data Files	200
Date Created	15-09-2024 to 19-09-2024

Dataset Size	11.6 GB
File Formats	kea, keb & sgy

Table 10: SBP metadata.

3.3.5 Magnetometer

A Marine Magnetics Inc. SeaSPY towed Overhauser Magnetometer was used to acquire magnetic field data. The system comprises a towfish, tow cable, deck lead and transceiver interfaced to a standard Windows based PC. Acquisition parameters and QC were controlled via Marine Magnetics BOB™ software.

The magnetometer was towed 100 m behind the vessel at a depth of less than 5 m beneath sea surface. Magnetometer data from the towfish and GPS data from Seapath were input to the control PC via separate serial ports and synchronised. Initial QC was performed via real-time graphing of the magnetic field trace and by monitoring real-time GPS data. Magnetometer data were recorded in a database using BOB and output in proprietary BOB format as a mms file. The data were also output in text file format. Metadata is contained in Table 11.

Descriptor	**Metadata**
Survey lines	All
Data Files	2
Date Created	15-09-2024 to 19-09-2024
Dataset Size	0.47 GB
File Formats	mms & csv

Table 11: Magnetometer metadata.

3.3.6 DGPS Systems

C-Nav DGNSS provided the primary navigation. The C-Nav 5000 is a dynamic DGNSS Precise Point Positioning (PPP) system providing <0.1 metre horizontally and 0.2 metre vertically. It provides 66 channel tracking, including multi-constellation support for GPS, GLONASS and Galileo. C-Nav also provided a reliable GPS tide correction.

C-Nav has a range of QC output displays that were monitored in real-time including number of satellites in use, satellite attitude and angles, vertical accuracy, vessel speed, heading and precise position. GPS signal was always very good, and the system never lost the Real-Time Gipsy (RTG) solution. Navigation data were recorded in cnav5000 format using C-Nav software. One file per day was logged.

Seapath 380-R provided the secondary navigation for the MBES and primary navigation for the magnetometer. Seapath and C-Nav data were monitored continuously in Quality Integrated Navigation System (QINSy) software to ensure data integrity and comparison between the primary and secondary navigation systems remained within tolerance. DGPS metadata information is contained in Table 12.

Descriptor	Metadata
Survey lines	All
Data Files	7
Date Created	15-09-2024 to 19-09-2024
Dataset Size	0.87 GB
File Formats	cnav5000

Table 12: CNAV metadata.

3.3.7 Sound Velocity

An AML Oceanographic MVP 30-350 was the primary instrument for acquiring sound velocity profile data. A Valeport Mini Sound Velocity Profiler (SVP) instrument was available as backup. Both instruments are equipped with sensors that directly measure sound velocity. The dual benefit of the MVP is uninterrupted survey and greater frequency of casts. Fresh sound profiles were input to the MBES as required. A Valeport SVS sensor provided real-time sound velocity data at the MBES transducers.

MVP deployment was controlled from the vessel Dry Lab using Rolls Royce MVP software. The probe was continually towed in the water at between 2 and 6 metres depth and deployed to a maximum of c. 100 metres depth during casts. Sound velocity profiles in asvp format were sent to SIS where they were checked and extended for import into the MBES. Metadata is contained in Table 13.

Descriptor	Metadata
Survey lines	NA
Data Files	65
Date Created	15-09-2024 to 19-09-2024
Dataset Size	0.52 MB
File Formats	asvp

Table 13: Sound velocity metadata.

4. Online QC, Data Processing, Results and Interpretation

The hydrographic survey was performed to IHO survey standards. Rigorous standards for position, depth accuracy, feature search, feature detection and bathymetric coverage were achieved during data acquisition and processing. IHO Order 1a and Order 2 requirements are presented in Table 14.

	Order 1a (S-44)	Order 2 (S-44)
Description of Areas	Areas where underkeel clearance is considered not to be critical but features of concern to shipping may exist.	Areas generally where a general description of the sea floor is considered adequate.
Max THU allowable (95%C)	Total Horizontal Uncertainty (THU) 5m+5% of depth	Total Horizontal Uncertainty (THU) 20 m+10% of depth
Max TVU allowable (95%C)	Total Vertical Uncertainty (TVU) a = 0.5 metre b = 0.013 $\pm\sqrt{a^2 + (bxd)^2}$	Total Vertical Uncertainty (TVU) a = 1.0 metre b = 0.023 $\pm\sqrt{a^2 + (bxd)^2}$
Feature Search	100%	Recommended but not required
Feature Detection	Cubic Features > 2m (Depths < 40m) 10% depth > 40m	Not specified
Bathymetric Coverage	≤100%	5%

Table 14: IHO standards for hydrographic surveys

4.1 MBES Online Quality Control

4.1.1 Acquisition Parameters

Most of the important acquisition parameters are set in the Runtime module of SIS. Figure 11 shows the Runtime settings used. Max coverage parameters were changed depending on depth, seafloor hardness and weather conditions. Pulse type was set to FM. Frequency was set to 200 kHz, which maintained good signal to noise ratio. Swath coverage was set at 520 m and main lines were spaced at 450 m.

Max coverage, sector mode, detector mode, vessel speed and frequency were adjusted to attain maximum resolution for wreck inspections. Water Column data were acquired for all survey lines.

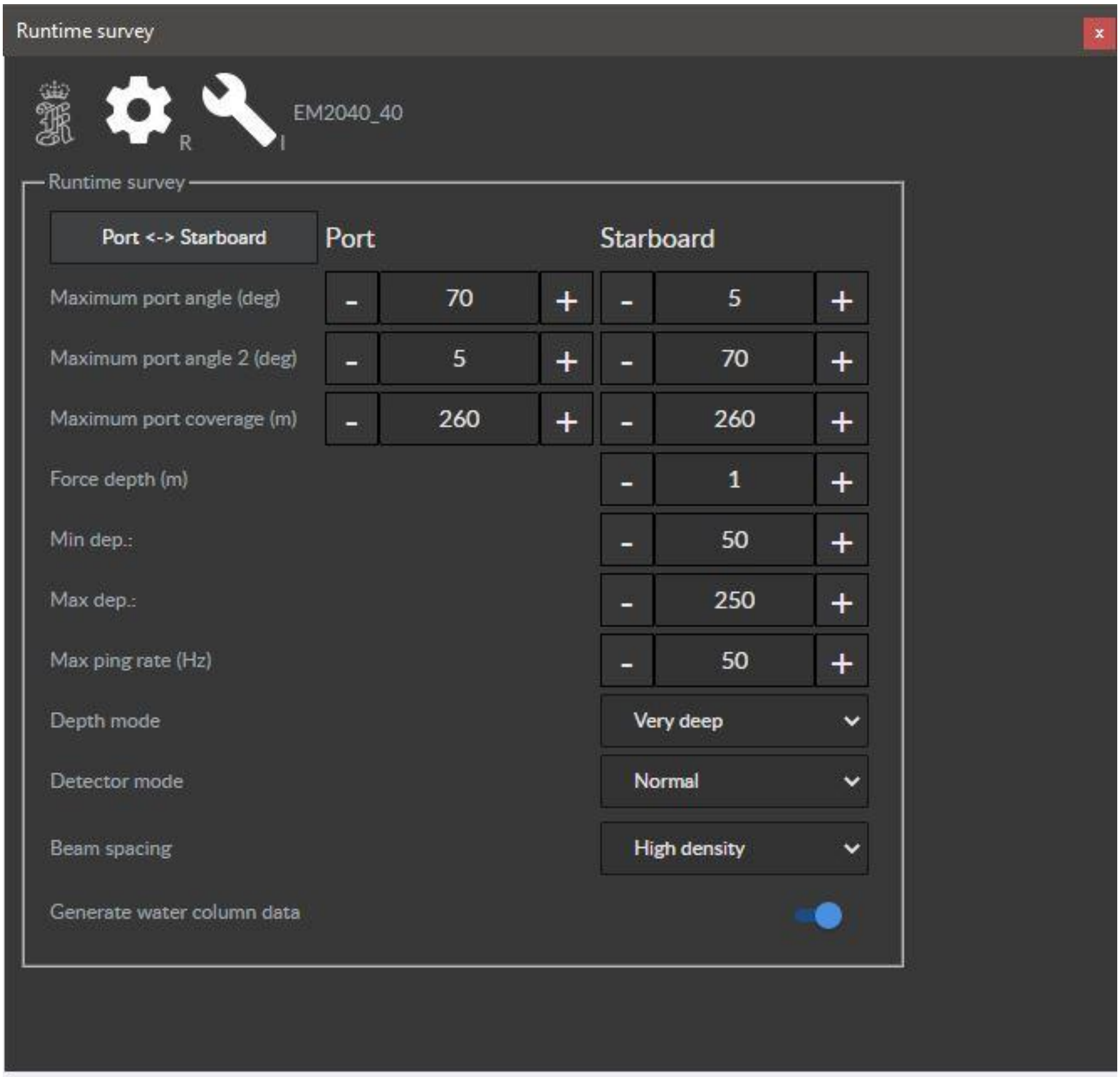


Figure 11: Runtime Survey parameters settings.

4.1.2 Cross Line Versus Main Line Statistics

Cross line data were acquired for QC of depth soundings. A total of two cross lines, comprising eight files were acquired for statistical analysis in QIMERA^{TM}. Cross line data were compared with main line data. All cross line data indicated that the soundings exceeded the 95% certainty required for Order 1a specification. Results of statistical analyses of two cross line files are presented in Tables 15 and 16.

Survey Line Files Used in Cross Check:

0095, 0096, 0097, 0098, 0099, 0100, 0101 and 0102.

Statistics for Cross Line 0095							
Beam Number	Count	Max (+)	Min (-)	Mean	Std Dev	Order 1a (%)	Order 2 (%)
1 - 51	220,464	0.858	0.813	0.037	0.163	100	100
51 - 101	220,310	0.736	0.714	0.031	0.169	100	100
101 - 151	220,213	0.738	1.022	0.009	0.167	100	100
151 - 201	220,116	0.744	0.862	-0.001	0.163	100	100
201 - 251	219,925	0.679	0.864	0.001	0.160	100	100
251 - 301	219,894	0.672	0.903	0.014	0.160	100	100
301 - 351	219,633	0.866	0.725	0.036	0.154	100	100
351 - 401	219,581	0.787	0.891	0.046	0.160	100	100
401 - 451	219,652	0.715	0.736	0.053	0.163	100	100
451 - 501	219,386	0.799	0.692	0.047	0.154	100	100
501 - 551	219,305	0.814	0.723	0.052	0.163	100	100
551 - 601	219,530	0.847	0.646	0.071	0.153	100	100
601 - 651	219,438	0.950	0.622	0.083	0.162	100	100
651 - 701	219,366	1.085	0.652	0.079	0.172	100	100
701 - 751	219,160	1.083	0.849	0.068	0.182	100	100
751 - 800	214,616	0.954	0.809	0.070	0.187	100	100

Table 15: MBES statistics for QC of cross line file 0095.

Statistics for Cross Line 0096							
Beam Number	Count	Max (+)	Min (-)	Mean	Std Dev	Order 1a (%)	Order 2 (%)
1 - 51	330,775	0.783	0.797	0.032	0.164	100	100
51 - 101	330,761	0.873	0.883	0.041	0.167	100	100
101 - 151	330,851	0.768	0.681	0.046	0.157	100	100
151 - 201	330,770	0.695	0.738	0.059	0.158	100	100
201 - 251	330,579	0.758	0.750	0.063	0.152	100	100
251 - 301	330,740	0.810	0.731	0.078	0.160	100	100
301 - 351	330,004	0.784	0.699	0.094	0.156	100	100
351 - 401	329,787	0.804	0.629	0.113	0.156	100	100
401 - 451	330,372	0.865	0.748	0.114	0.161	100	100
451 - 501	328,987	0.769	0.649	0.106	0.158	100	100
501 - 551	329,730	0.910	0.622	0.120	0.152	100	100
551 - 601	330,349	0.803	0.583	0.119	0.148	100	100
601 - 651	330,578	0.776	0.640	0.120	0.149	100	100
651 - 701	330,647	0.833	0.653	0.103	0.151	100	100
701 - 751	330,742	0.889	0.613	0.100	0.154	100	100
751 - 800	324,160	0.894	0.575	0.101	0.161	100	100

Table 16: MBES statistics for QC of cross line file 0096.

4.1.3 Feature Detection

The survey area is in water depths ranging from 97 to 157 m. Order 1a feature detection criteria are specified for depths less than 100m in IHO standards. Sounding density was analysed to demonstrate that vigorous survey standards exceeding those required by IHO were achieved.

The minimum standard for feature detection for an Order 1a survey are cubic features > 2 metres in depths up to 40 metres and cubic features >10% of depth beyond 40 metres. In 40 metres water depth 9 soundings are required in a 2 m^2 bin and in 100 metres water depth 9 soundings are required in a 10 m^2 bin. Feature detection criteria are not specified in the IHO standards for Order 2 surveys, where depths exceed 100 m.

The data were analysed for feature detection using a 5 m^2 bin size, i.e. half the bin size required in 100 m water depths for Order 1a. The plot in Figure 12 shows the data density results. Red indicates that less than 9 soundings were found within a bin and green indicates where 9 or more soundings were found within the 5 m^2 bin. Almost everywhere exceeded the 9 soundings per bin. Red areas are sporadic and limited to the outer fringes of coverage where adjacent data from other surveys has not been included in the data density calculations.

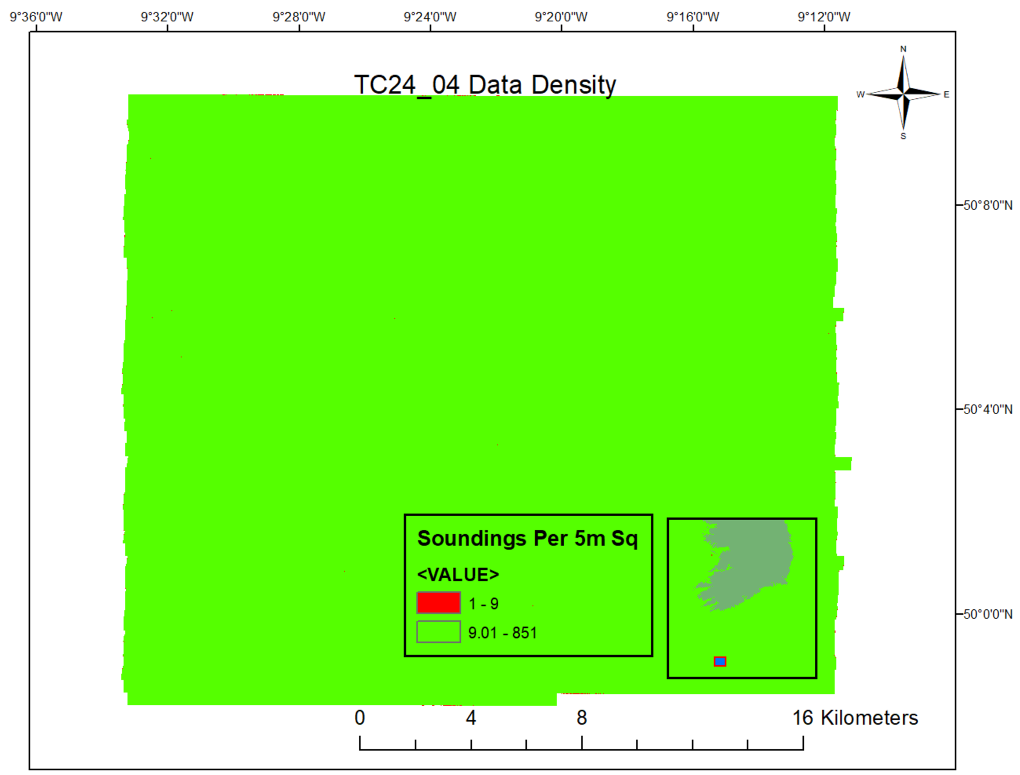


Figure 12: Sounding density traffic light plot.

Number of soundings per bin varied from 1 to 851.

4.1.4 Error Budget and Uncertainty Model

Manufacturer values for positioning and sounding errors were factored into the vessel error budget. Vessel offsets were established through an onshore dimensional control survey (see section 3.1). In addition, uncertainty levels over positions of soundings were improved through good sound velocity control while surveying. Calibration of the MBES through a standard patch test, combined with good online quality control, ensured that the vessel's error budget fell within IHO 1a specifications.

Table 17 below details standard deviation values applied in the calculation of the vessel's Total Propagated Uncertainty (TPU) model. TPU is an estimate of the uncertainty of any individual sounding, incorporating the uncertainty estimates of the component measurements (tide, sound speed, draft, range measurement, angle measurement, attitude, offsets etc). TPU is expressed as a separate value in horizontal and vertical planes. The uncertainty of each sensor was entered in the HIPS Vessel File (HVF) and the TPU calculated.

Heading Accuracy	0.02°
Heave	5 cm or 5 % Amplitude
Roll	0.01°
Pitch	0.01°
Pitch Stabilised	0.01°
Position Navigation	0.1 m
Timing Transducer	0.00 s
Timing Navigation	0.00 s
Timing Gyro	0.00 s
Timing Heave / Pitch / Roll	0.00 / 0.00 / 0.00 s
Sound Velocity Measured	0.1 m/s
Sound Velocity Surface	0.1 m/s
Offsets X / Y /Z	X=0.01 / Y=0.01 / Z=0.01
MRU Alignment	Gyro=0.1 / Pitch=0.1 / Roll=0.1
Vessel Speed	0.1
Vessel Loading	0.00
Vessel Draft	0.00 (Use of GPS tides)
Delta Draft	0.00

Table 17: Standard deviation values used in TPU calculation.

4.1.5 Sound Velocity Control

MBES data processors continuously monitored the effect of sound velocity variations on the acquired MBES data and advised on the frequency and geographical distribution of MVP casts. Sound velocity variations were also monitored by the Online Surveyors by QC of the SIS Cross Track window and

Numerical window. A composite MVP plot, created in Sound Speed Manager software is shown in Figure 13. Most profiles show a linear increase in sound speed with depth. Sound velocity ranges from 1495 m/s to 1515 m/s. A strong thermocline is evident between c. 35 m and 55 m water depth.

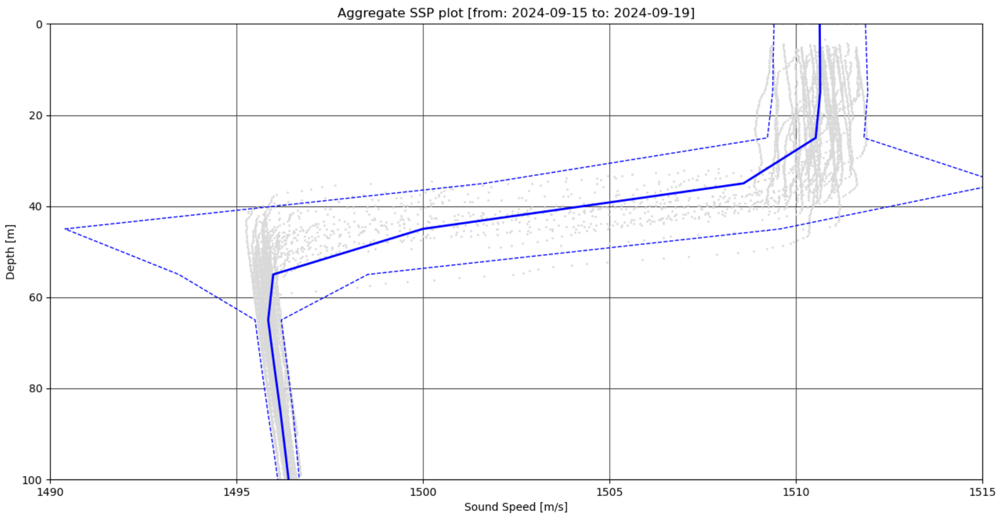


Figure 13: MVP aggregate profiles plot.

4.2 Post Processing Methods

4.2.1 Navigation

Navigation data were logged in standard C-Nav format. Real-time positioning data quality from C-Nav was of sufficient quality to exceed IHO Order 1a standard requirements. Vertical errors on the GPS heights were low (+/- 20 cm) and provided a robust solution for computation of GPS tide.

Navigation data and in particular GPS heights were de-spiked and smoothed in Caris HIPS. GPS tide was computed using the separation model between International Terrestrial Reference Frame (ITRF) datum and VORF LAT.

4.2.2 Depth Soundings Data Processing

Soundings were edited in Caris HIPS software against an existing chart background. Combinations of automated and manual processing procedures were applied by experienced data processors to remove systematic errors and obvious outliers. Uncertainty results were examined to ensure soundings fell within IHO specifications for Order 1a and Order 2 surveys. Processed and cleaned data were subject to final validation by an experienced and qualified hydrographer. The following is a simplified list of steps undertaken during sounding data processing:

1. Navigation data were checked and spikes removed.
2. GPS tides were computed using the UKHO's VORF model. This reduced the MBES depth soundings to LAT. GPS tide results were then checked for quality and consistency.
3. TPU values were calculated.
4. SVP data were applied to correct for refraction errors caused by water column heterogeneity. A range of SV algorithms were used to determine the most suitable method of applying SV corrections, for example: nearest in distance versus nearest in time.
5. Subset Editing was performed in CARIS to clean large "noise" spikes from the data. Additional delta draft and refraction corrections were applied to correct residual issues.
6. A CARIS Combined Uncertainty and Bathymetry Estimator (CUBE) base surface was created to allow CUBE automatic filtering.
7. Final verification of sounding consistency and absence of spikes was done using subset editing.
8. Final adjustments for residual tidal or refraction issues were addressed manually.
9. Bathymetry data were then exported as gridded data at multiple spatial resolutions (*.asc, *.xyz, *.bag, *.Geotiff) and as survey line point clouds. Ancillary exports included track line shapefile and XL QC reports.

4.2.3 Backscatter Mosaic Generation

Backscatter is a function of the hardness and roughness of the seafloor. Raw MBES data was put through the Geocoder engine in QPS Fledermaus^{TM} (FMGT) to produce backscatter mosaics at 5 and 10 m resolutions.

4.3 Survey Results and Data Interpretation

A preliminary interpretation of MBES data was used to assess bathymetry, seabed texture and seabed features. SBP data was used to assess the shallow geology.

4.3.1 MBES Images

MBES bathymetry grids and images produced at 5 and 10 m respectively were created in Teledyne Caris HIPS & SIPS^{TM} software. Shaded relief geotiffs were produced for NE and NW azimuths at 5 and 10 m resolutions. Backscatter mosaics were created at 5 and 10 m in QPS FMGT^{TM}. Geotiffs, mosaics and grids were imported into ArcGIS^{TM} and images (Figures 14 to 16) output for this report.

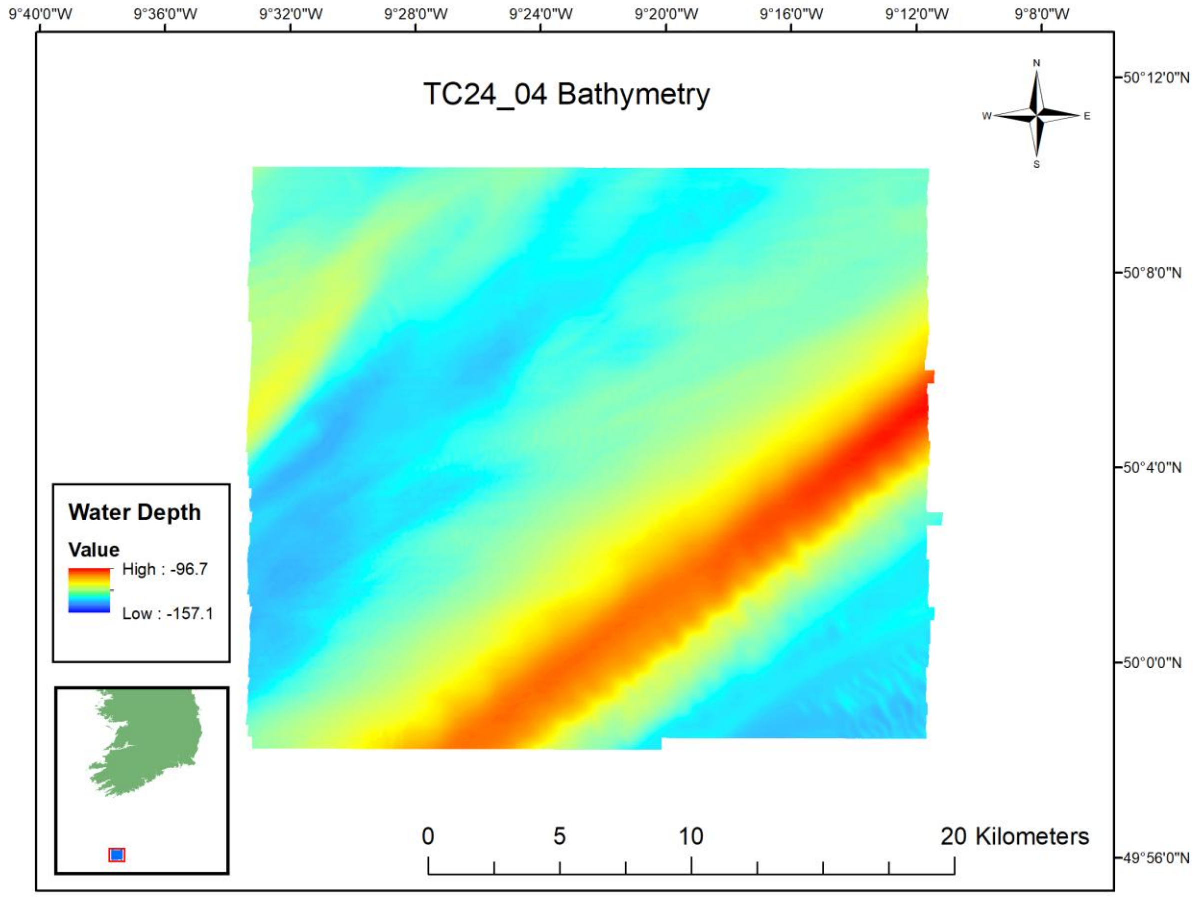


Figure 14: MBES bathymetry.

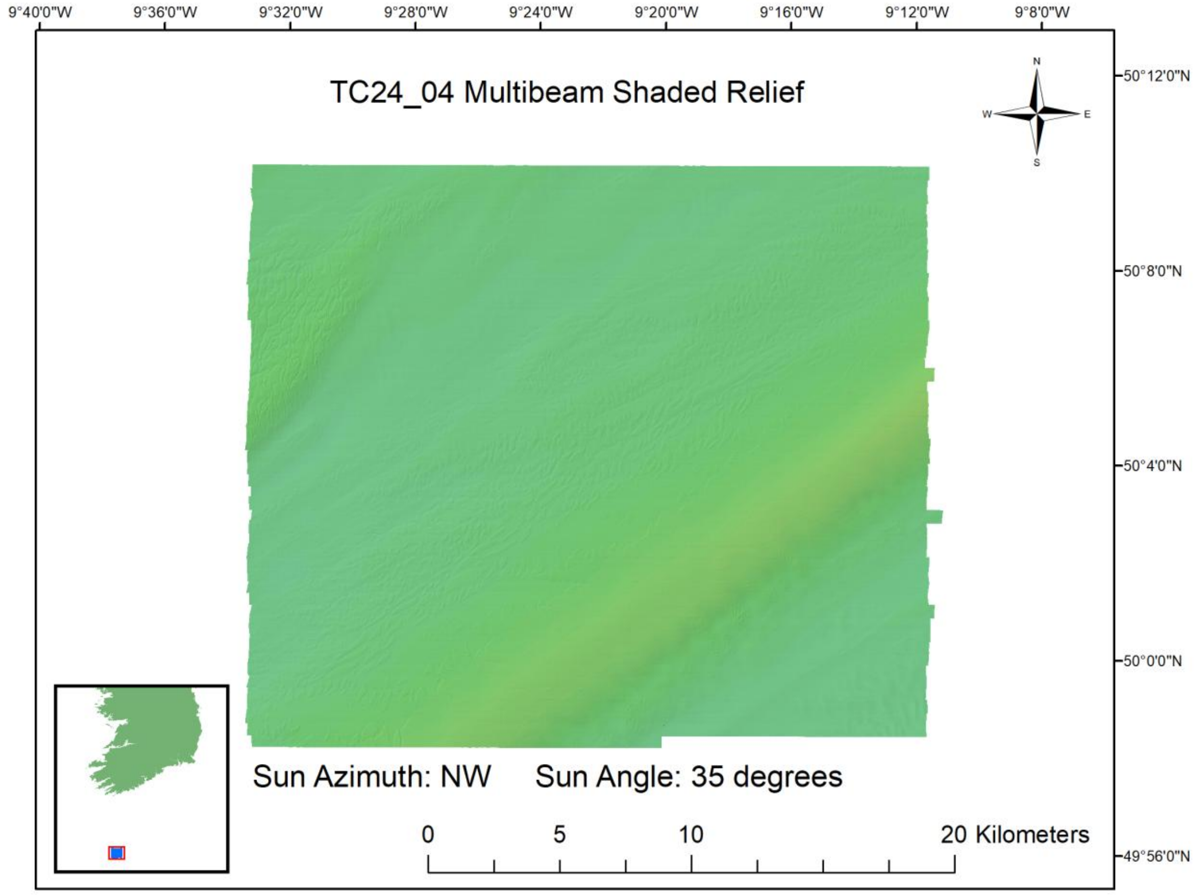


Figure 15: MBES shaded relief.

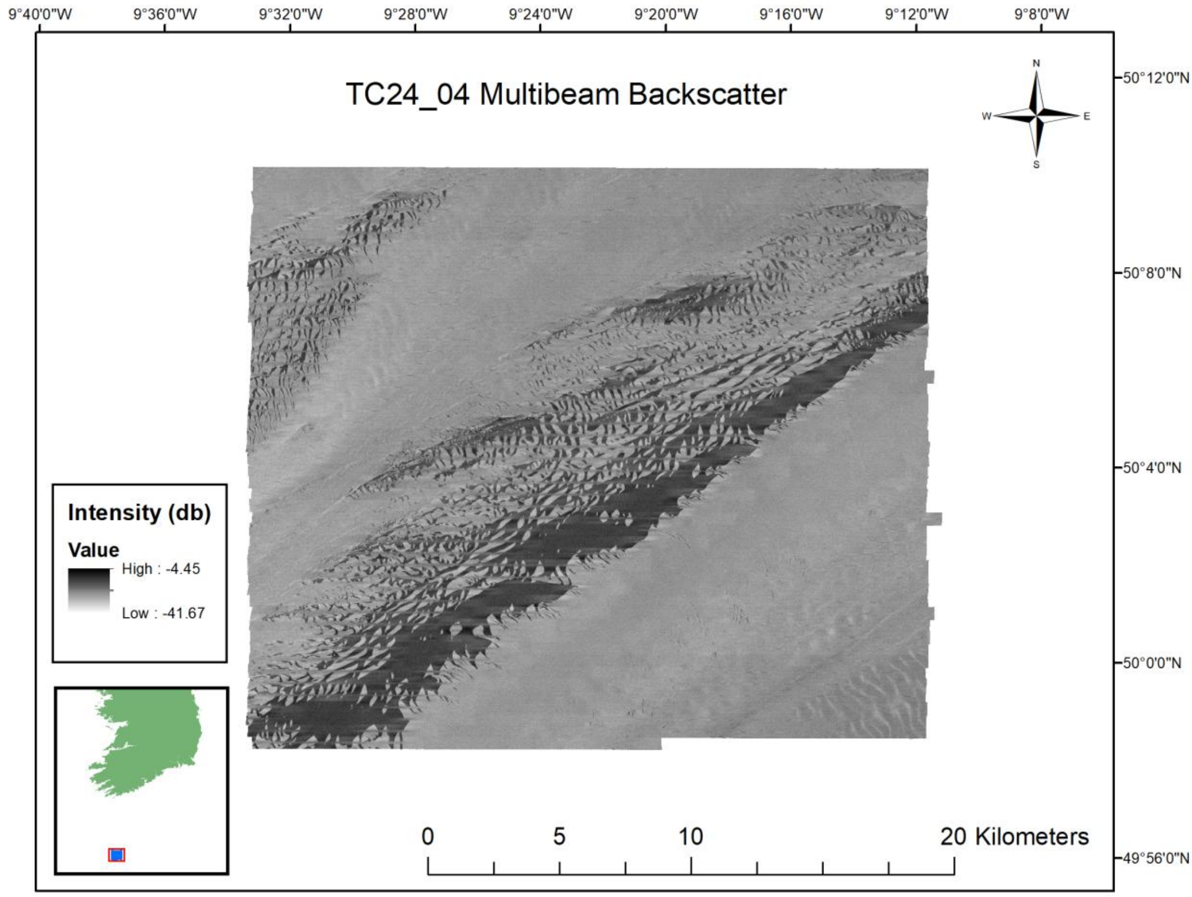


Figure 16: MBES backscatter mosaic.

4.3.2 Shallow Geology Analysis

Chirp SBP data quality and penetration varied due to environmental factors relating to sea state and sub-bottom conditions. Survey speed (4-9 knots) was dictated by the ability of the MBES to meet its data density and data quality requirements. This is usually faster than the optimal maximum speed of 4 knots for high quality SBP data acquisition. Sea state was very good throughout the survey. Overall SBP data quality was good.

Knudsen SounderSuite™ software recorded sub-bottom data in proprietary Knudsen kea and keb formats and sgy format. Data were imported into SonarWiz™ software and image files were output for this report. Cross line profiles 95 and 99 are selected for discussion here. Their geographical extents are shown in Figure 17 where the profiles extents are overlain on MBES backscatter data.

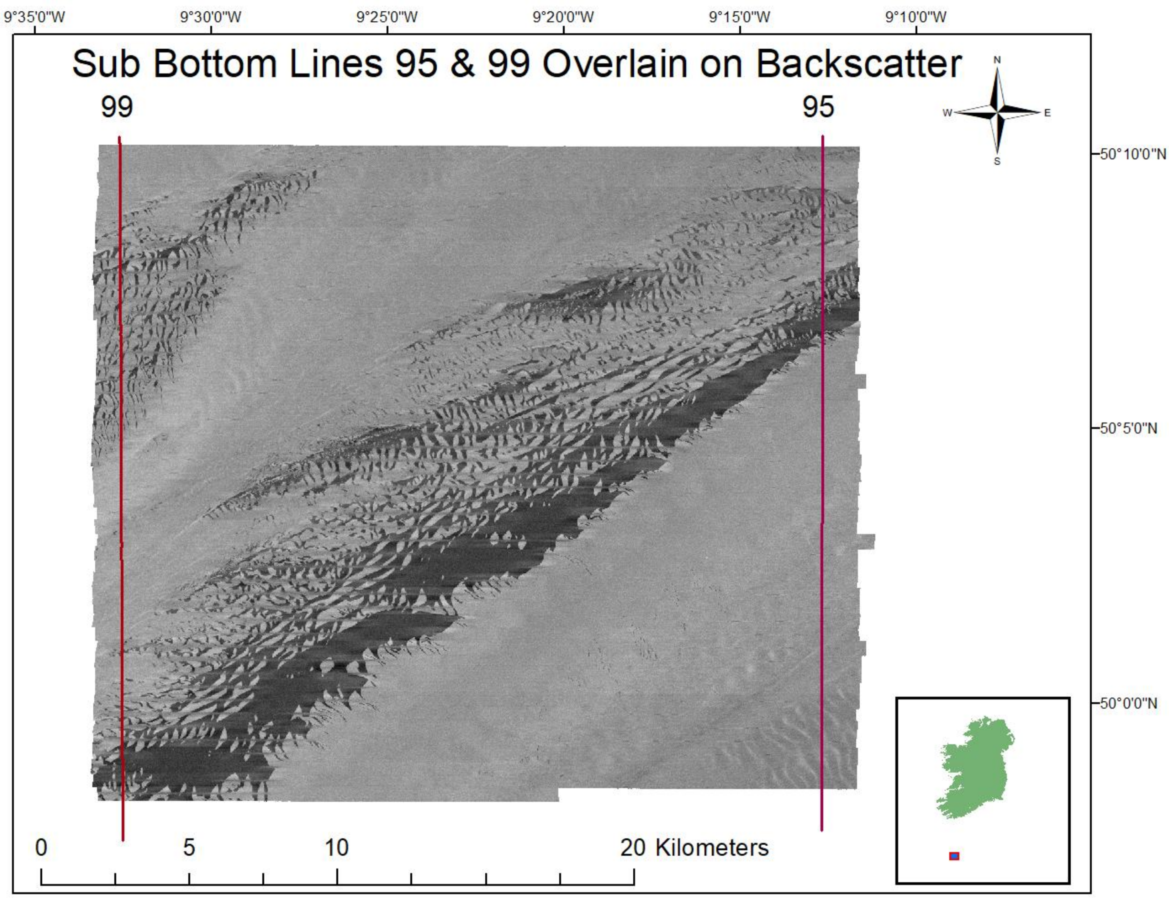


Figure 17: Extents of Profiles 95 & 99 overlain on backscatter.

Interpreted SBP images of profiles 95 and 99 are shown in Figures 18 and 19 respectively. Heave compensation, seabed tracking, AGC gain and bandpass filtering are applied to the data. Horizontal scale lines are at 10 m intervals. Note that the vertical scales are greatly exaggerated.

Profile 95 in Figure 18 is 23.5 km in length. The profile was acquired from south to north. Data quality is good. Seabed topography is dominated by a megaridge which has an amplitude of c. 40 m and width of c. 10 km. It should be noted that there is little or no signal penetration for the width of the megaridge.

Three sedimentary units are observed on the profile. Units 3 is the oldest. It has an unknown thickness. The top of Unit 3 is denoted by the horizon R2. R2 is observed at the northern and southern sides of the profile. Unit 2 overlies Unit 3. Unit 2 is c. 10 m to 15 m in thickness. Unit 2 is overlain by Unit 1 with R1 denoting the boundary between both units. Unit 1 has a maximum thickness of c. 20 m where the base of Unit 1 can be observed. Unit 1 is opaque in character.

Profile 99 in Figure 19 is 23.9 km in length. The profile was acquired from north to south. Data quality is good. Two megaridges are located on this profile, one in the north and one in the south.

The oldest unit observed is Unit 3. Its thickness is unknown. The top of Unit 3 is marked by reflector R2. R2 is gently sloping in character and is observed in the north and between both megaridges. Unit 2 overlies Unit 3. Where the base of Unit 2 is observed it has a maximum thickness of c. 15 m. Unit 1 overlies Unit 2, the boundary denoted by R1. The maximum thickness of R1 is unknown.

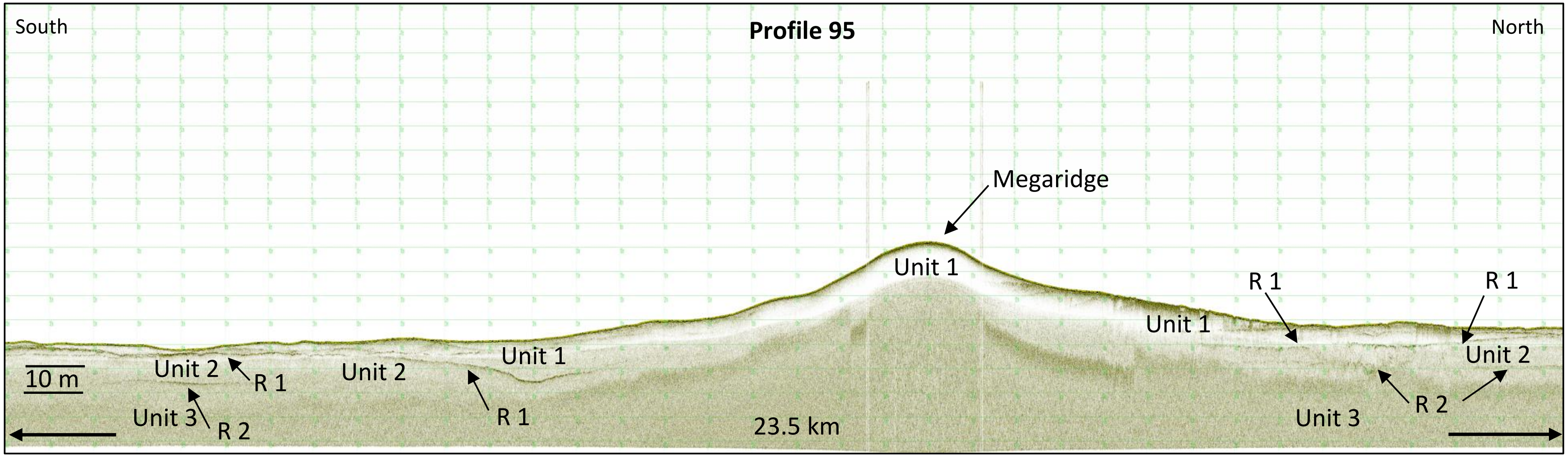


Figure 18: SBP interpreted image, line 95.

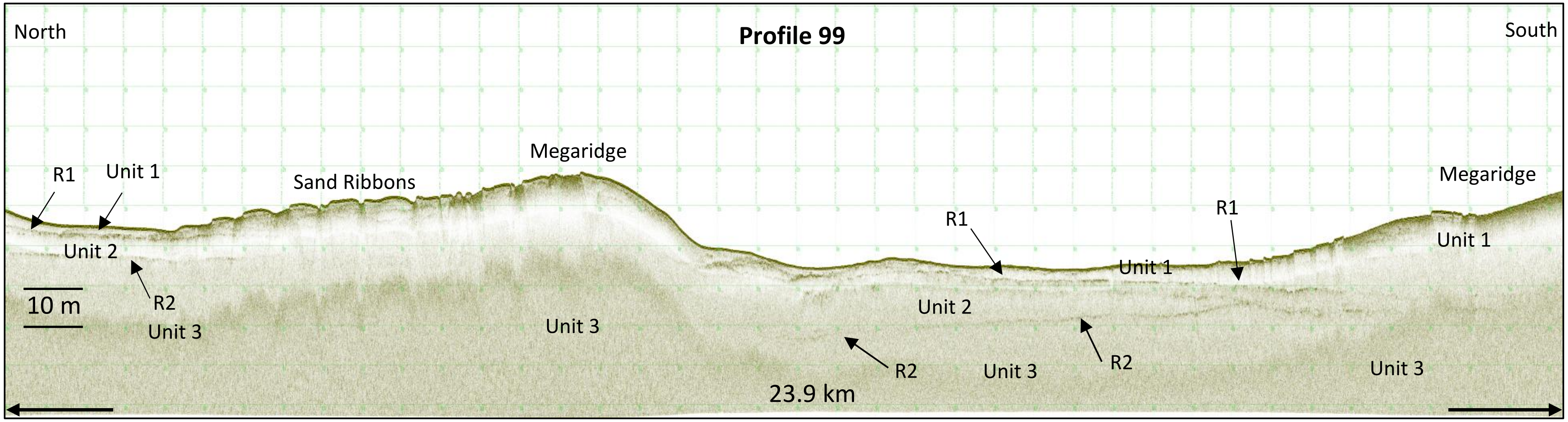


Figure 19: SBP interpreted image, line 99.

4.3.3 Bathymetry

Figure 20 is the colour coded MBES bathymetry image. Water depth varies from 96.7 to 157.1 m with greatest depths in the west. Shallowest depths are found on a megaridge crest, located in the southeast. Seabed gradients are gentle.

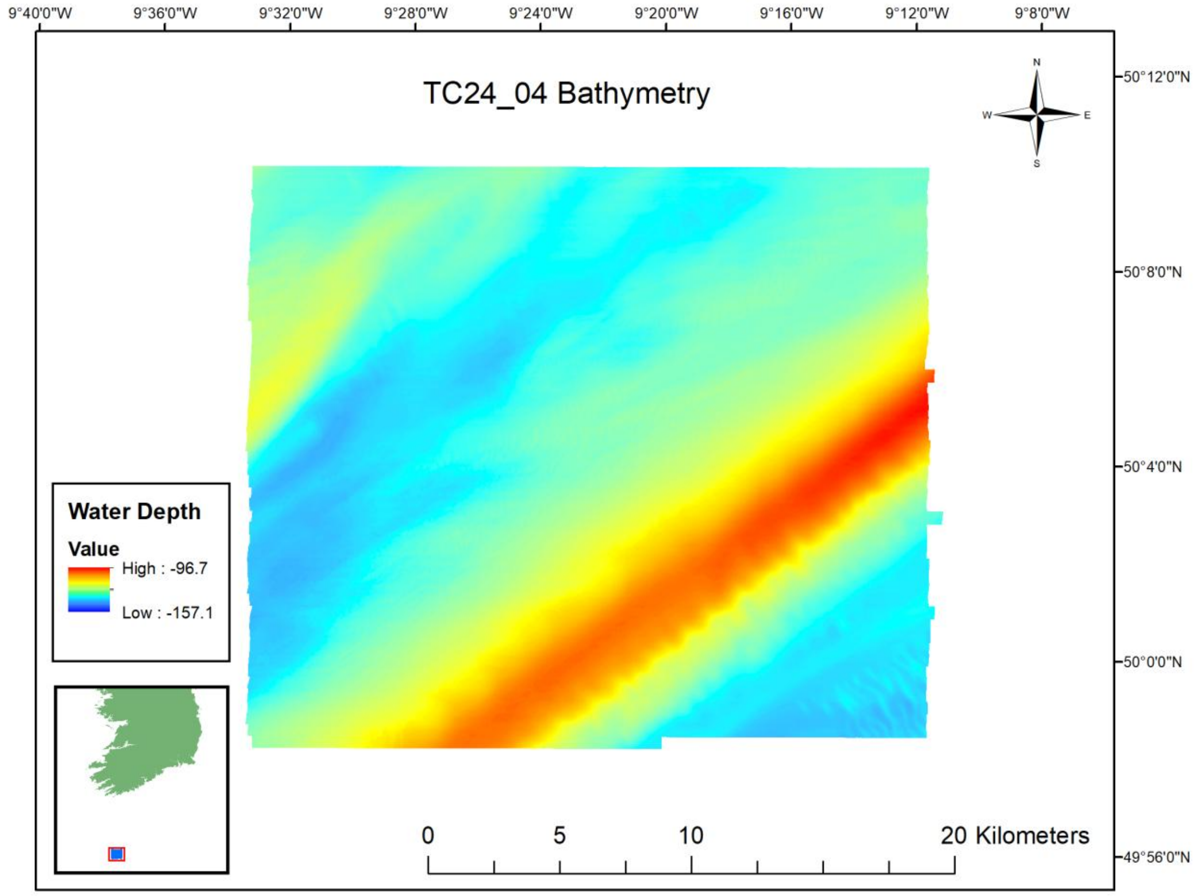


Figure 20: Colour coded MBES bathymetry.

Figure 21 shows bathymetry data from the southeast corner. Several sinuous sediment waves are observed on the data. Sediment waves have wavelengths of 300 to 500 m and amplitudes of up to 3 m approximately. They are orientated NW-SE.

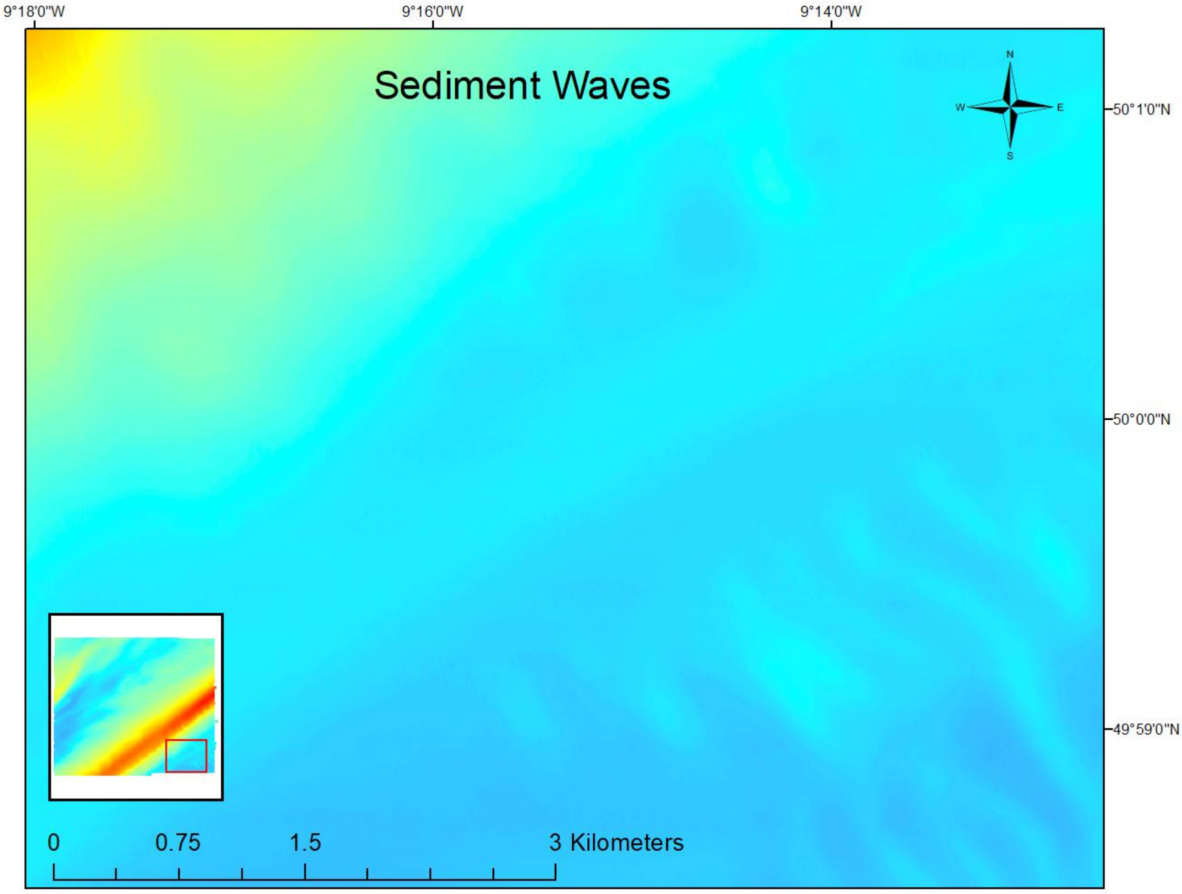


Figure 21: Sediment waves on bathymetry.

4.3.4 Seabed Texture

MBES backscatter is the strength of acoustic energy received by the sonar after a complex interaction with the seafloor. By analysing the amplitude of the returning sound waves, it is possible to extract information about bottom structure and hardness, allowing for identification of bottom types. Seabed reflectivity properties depend on the hardness and roughness of the seafloor surface. In simple terms, a strong return signal indicates a hard and/or rough surface, and a weak return signal indicates a soft and/or smooth surface.

Backscatter values referenced in this report are relative intensities. The convention used in the images is that dark coloured areas represent relatively higher backscatter intensity than light coloured areas. Backscatter intensity values vary from -4.5 to -41.7 db.

A backscatter mosaic gridded at 5 m is shown in Figure 22. The area is divided into low, moderate and high and mixed backscatter types. Mixed and high backscatter types are distributed in the centre. Moderate backscatter type is dominant in the southeast and north. Low backscatter is found in the northwest, east of an area of mixed backscatter.

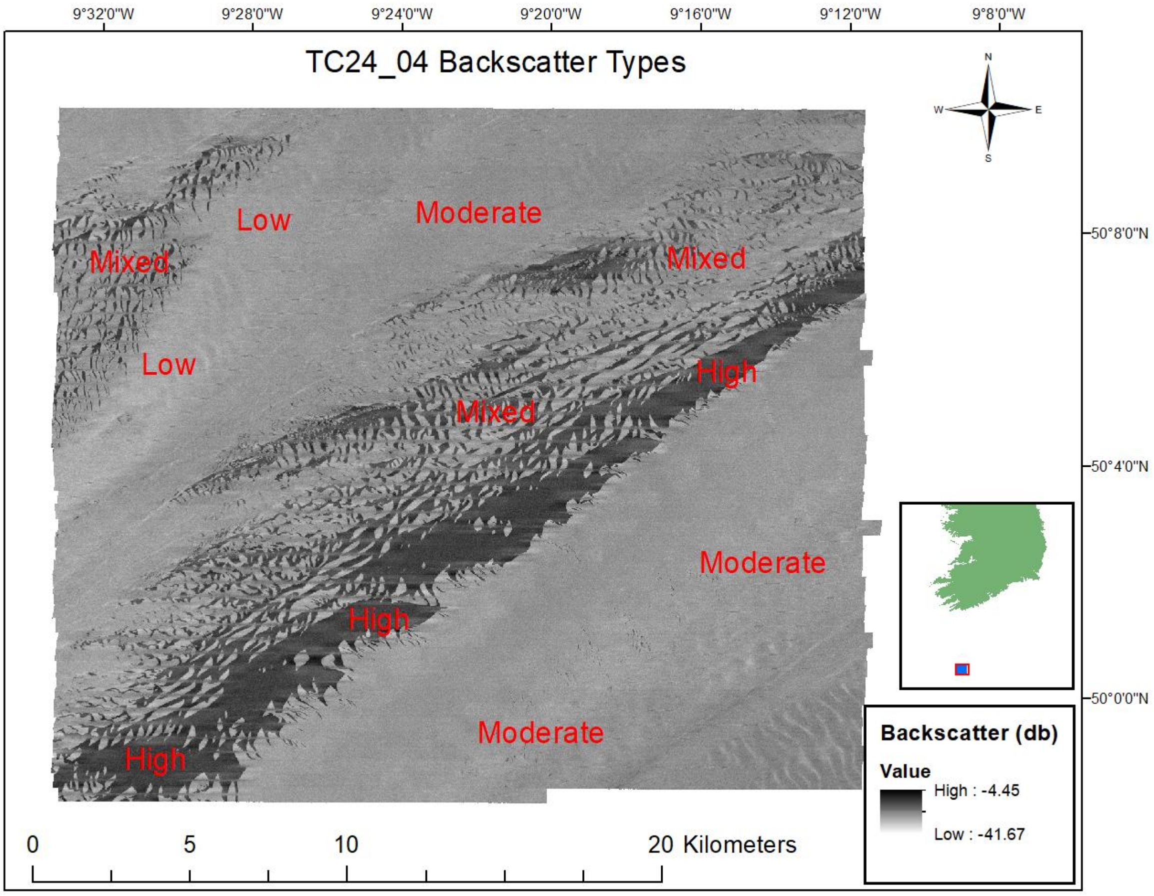


Figure 22: Backscatter distribution.

Figure 23 shows backscatter data from the southeast, where low intensity returns are dominant. Small channels filled with high backscatter sediments are located within the area. Channels are less than 1 m deep and widths less than 50 m. The channels are discontinuous with lengths in the order of 100's m. All channels have a NW-SE orientation.

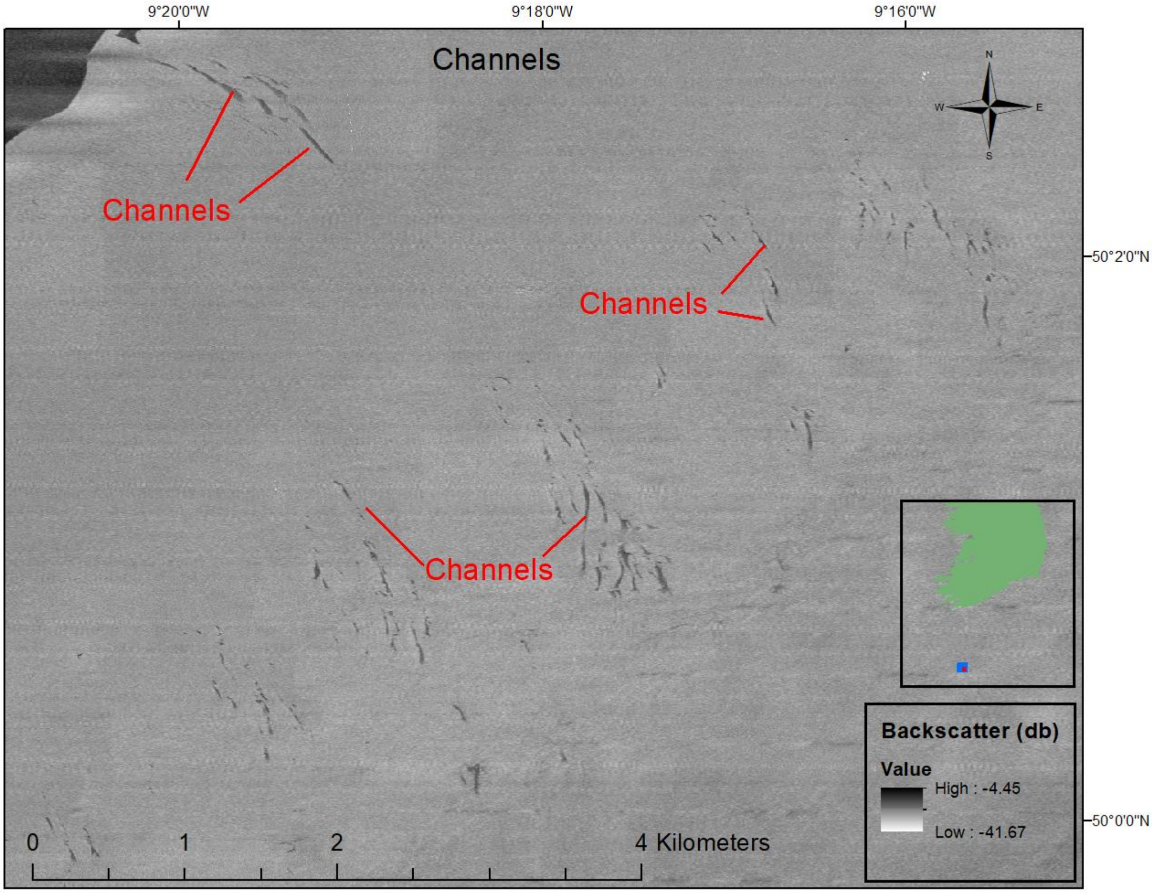


Figure 23: Channels in backscatter data in southeast.

Figure 24 shows the backscatter data for the southeast corner. It shows the area with sediment waves that are discussed above in Figure 21. The low backscatter areas in the image below correlate with the bathymetric lows.

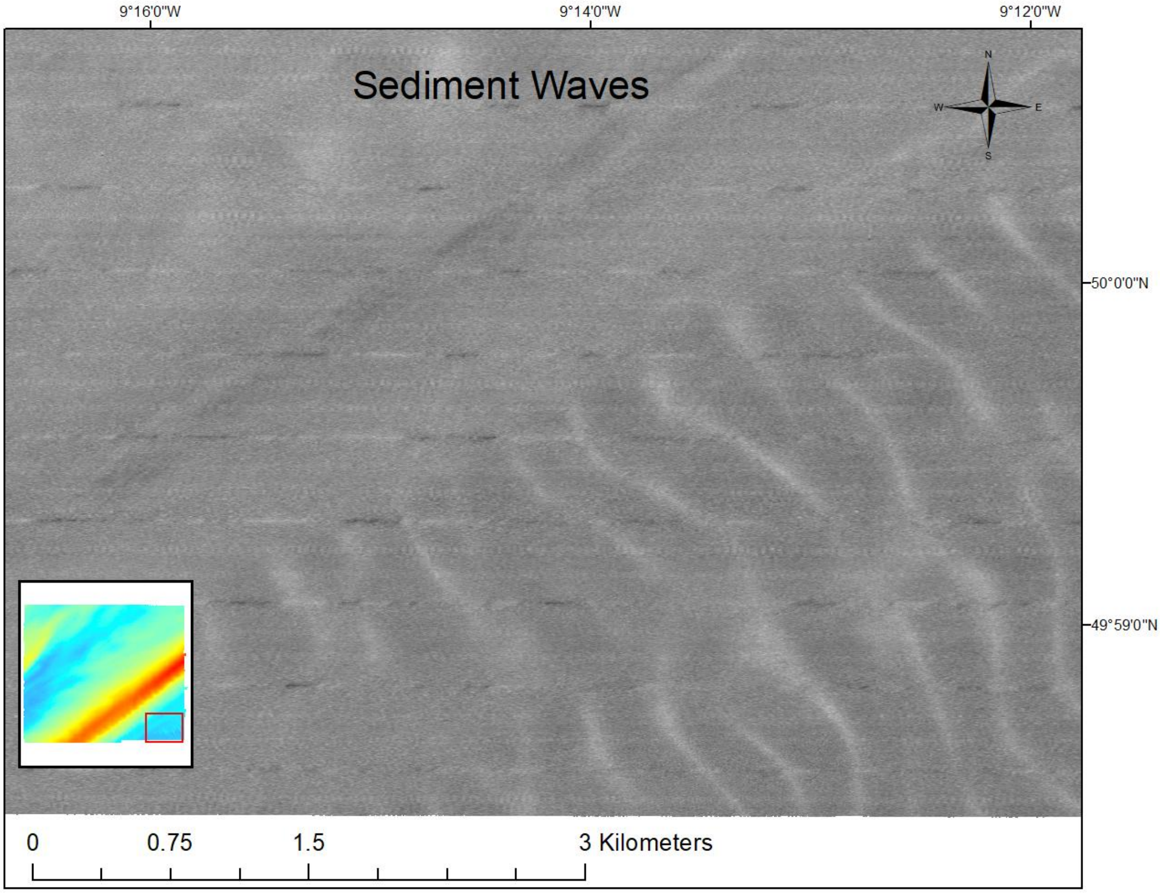


Figure 24: Sediment waves evident on backscatter.

4.3.5 Seabed Features

Description of seabed features are based on analysis of bathymetric, shaded relief and backscatter data. It is possible to make valid inferences on seabed character and composition by correlating these datasets. Shaded relief data are used to illustrate the features discussed in this section. Shaded relief imagery is produced in Teledyne Caris HIPS & SIPS^{TM} software by shining an imaginary sun at 35° angle over the depth colour coded MBES bathymetry dataset. Data illustrated below are gridded at 5 m, with sun illumination from the NE and a vertical exaggeration of 4.

Figure 25 is a MBES shaded relief image illustrating the megaridge in the southeast. A series of ribs are evident to the south of the megaridge crest. These ribs are usually associated with megaridges in the Celtic Sea. The ribs are orientated at right angles to the ridge crest. They have wavelengths of c. 1.2 km, amplitudes of up to c. 4.5 m and lengths of c. 2 to 3 km.

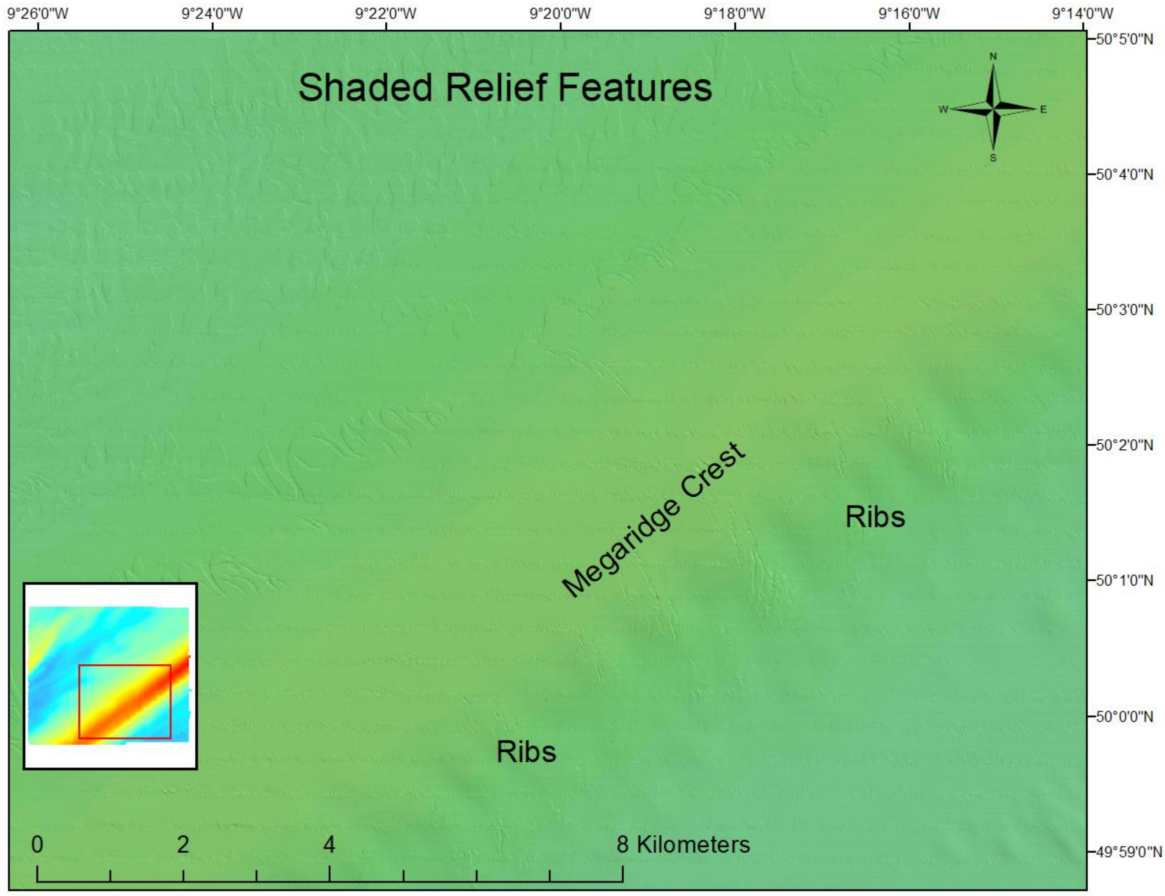


Figure 25: MBES shaded relief illustrating megaridge and associated ribs.

4.4 Ground Truthing

Ground truthing was not undertaken during this survey.

4.5 Wrecks

Four wrecks were mapped in detail. H525 forms were completed for all and sent to the UKHO. Admiralty charts will be updated in due course. Table 18 provides the wreck location and basic information.

Number	Latitude	Longitude	Length	Date
1	50° 00.403 N	-009° 30.096 W	39 m	19/09/2024
2	49° 58.811 N	-009° 29.275 W	57 m	19/09/2024
3	49° 58.662 N	-009° 19.986 W	122.2 m	19/09/2024
4	50° 00.574 N	-009° 20.528 W	31.7 m	19/09/2024

Table 18: Wreck metadata.

Figure 26 provides the location of the mapped wrecks.

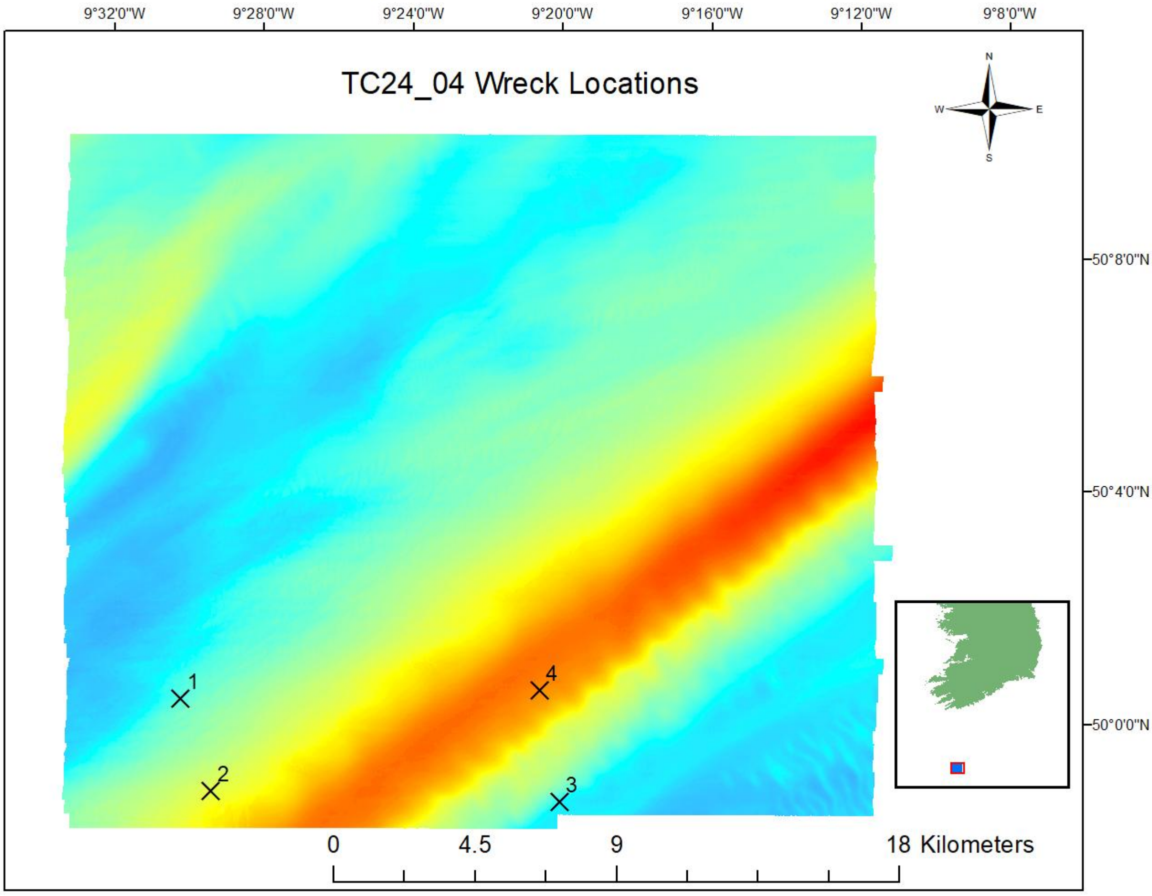
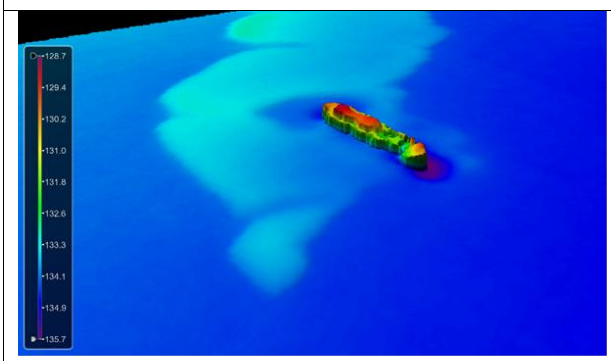
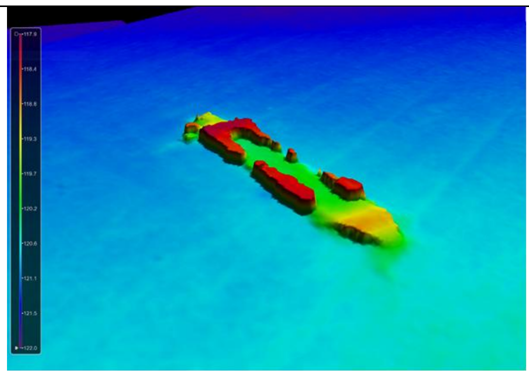


Figure 26: Wreck locations overlain on bathymetry.

Wreck images are provided in Table 19.

Wreck 1	Wreck 2
	
Wreck 3	Wreck 4

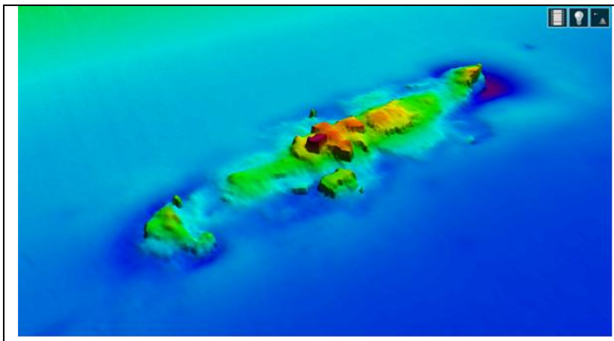
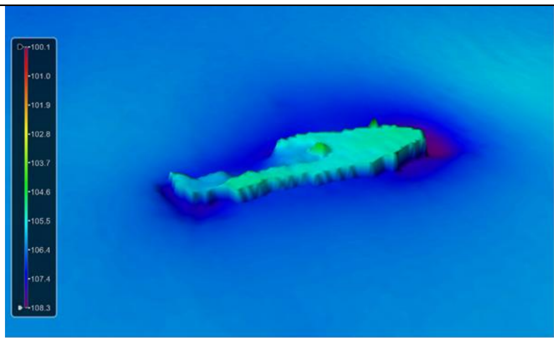
	

Table 19: Wreck Images.