

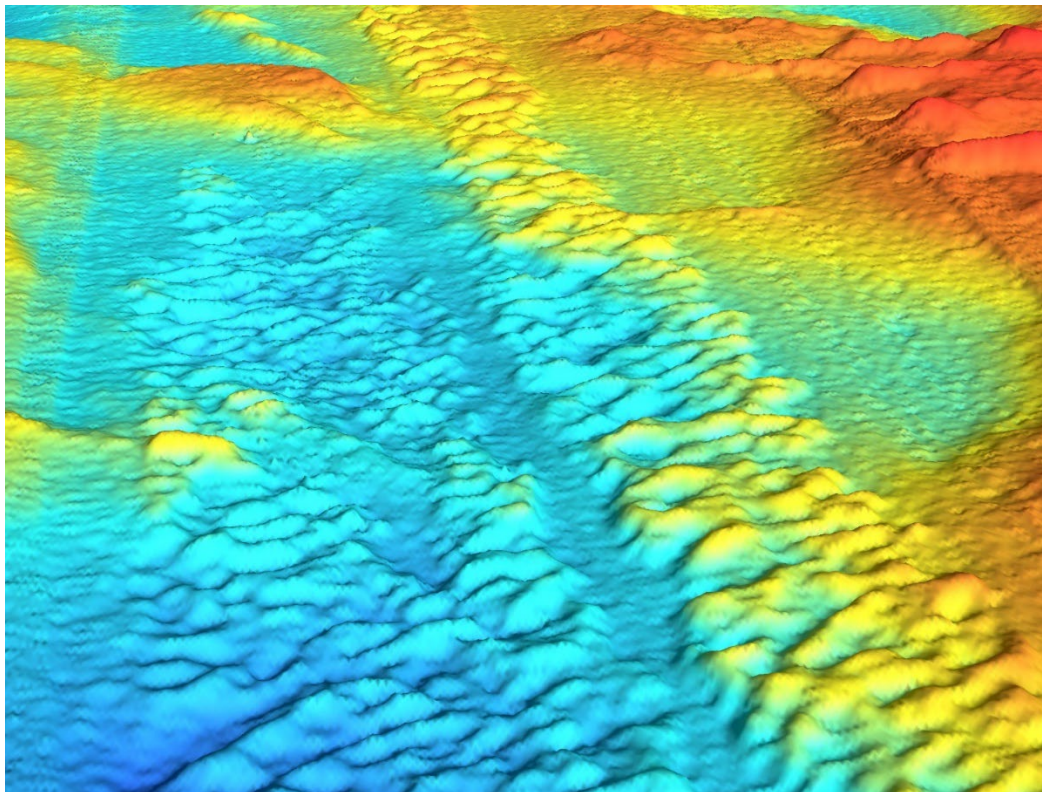


Pen Llŷn A'r Sarnau SAC Horse Mussel (*Modiolus modiolus*) reef MBES survey report (2024) and time series analysis (2005-2024)

NRW Evidence Report No: 851

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Crynodeb Gweithredol

Mae'r adroddiad hwn yn manylu ar waith arolygu Multibeam Echosounder (MBES) a wnaed gan Hydrofix ar ran Binnies UK Limited fel rhan o'u darpariaeth o waith i Cyfoeth Naturiol Cymru (CNC) yn ystod haf 2024 ym Môr Iwerddon, oddi ar arfordir gogleddol Pen Llŷn. Comisiynwyd y gwaith fel rhan o raglen fonitro barhaus i asesu iechyd gwelyau Marchfisglod (*Modiolus modiolus*) yn yr ardal.

Er mwyn cyflawni'r gwaith, gosododd Hydrofix system gaffael MBES lawn yn Pedryn, cwch CNC, wedi'i graddnodi yn unol â safonau'r diwydiant, a chael data bathymetreg a 'backscatter' llawn ar gyfer y ddwy ardal ddynodedig oddi ar Borthdinllaen. Yna cafodd y data ei brosesu a'i ddadansoddi i gynhyrchu arwynebau bathymetrig; mosaigau 'backscatter'; dosbarthiad gwely'r môr, gan gynnwys meintiau'r gwelyau cregyn gleision; a mesuriadau o'r biodwmpathau o gregyn gleision. Yna cafodd canlyniadau arolwg 2024 eu cymharu â setiau data blaenorol, a ddarparwyd gan CNC, o 2005, 2008 a 2015, a chafodd y rhain i gyd eu dadansoddi a'u hailbroseu i gynyddu eu gwerth i'r prosiect.

Mae'r data a gesglir yn cynrychioli'r data gorau o ran ansawdd sydd ar gael hyd yma dros ardaloedd yr arolwg, gyda dwysedd data uwch ac felly gwell eglurdeb nag a gafwyd yn flaenorol. Mae ôl-brosesu'r holl ddata llywio wedi sicrhau'r lefelau uchaf o gywirdeb lleoliadol, gan lwyddo i roi manwl gywirdeb o cm, ac mae'r data sy'n deillio o hyn yn rhagori llawer mwy ar fanylebau arolygu 1a gorchymyn y Swyddfa Hydrograffig Rhyngwladol (IHO) a argymhellwyd.

Mae'r dadansoddiad bathymetreg a 'backscatter' yn awgrymu bod y gwelyau cregyn gleision o bosibl yn dirywio, gyda maint yr arwynebedd i'w weld yn lleihau ers 2005/2008, a strwythur mewnol y gwelyau yn lleihau'n sylweddol rhwng 2015 a 2024. Ceir tystiolaeth sy'n awgrymu bod rhywfaint o arwynebedd y gwelyau a nodwyd yn 2024 yn cynrychioli ardaloedd sy'n marw neu sydd eisoes wedi marw, ond bydd angen cadarnhau hyn gyda gwaith arolygu pellach (fideo crog, archwiliad deifwyr, ac ati).

Executive summary

This report details the Multibeam Echosounder (MBES) survey works performed by Hydrofix on behalf of Binnies UK Limited as part of their provision of works to Natural Resources Wales (NRW) during the summer of 2024 in the Irish Sea, off the north coast of the Llŷn Peninsula. The works were commissioned as part of an ongoing monitoring programme to assess the health of known Horse Mussel (*Modiolus modiolus*) beds in the area.

In order to perform the works, Hydrofix rigged the NRW vessel Pedryn with a full MBES acquisition system, calibrated as per industry standards, and acquired full coverage bathymetry and backscatter data over the two designated areas off of Porthdinllaen. The data was then processed and analysed to produce bathymetric surfaces; backscatter mosaics; a seabed classification, including the extents of the mussel beds; and measurements of the mussel bioherms. The results from the 2024 survey were then compared to previous datasets, provided by NRW, from 2005, 2008 and 2015, all of which were analysed and reprocessed to increase their value to the project.

The data collected represents the highest quality data so far made available over the survey areas, with higher data density and thus better resolution than previously achieved. Post processing of all navigation data has ensured the highest levels of positional accuracy, with cm scale accuracies achieved, while the resulting data far exceeds the International Hydrographic Office (IHO) order 1a survey specifications prescribed.

The analysis of the bathymetry and backscatter suggests that the mussel beds are possibly in a state of decline, with the areal extent appearing to decrease since 2005/2008, and the internal structure of the beds diminishing significantly from 2015 to 2024. There is evidence to suggest that some of the bed extent identified in 2024 represents areas that are dying off or are already dead, however this will need to be confirmed with further survey works (drop-down video, diver inspection, etc.).

Introduction

In June 2024, Hydrofix Limited (Hydrofix) were commissioned by Binnies on behalf of Natural Resources Wales (NRW) to complete multibeam bathymetry and backscatter survey over two adjacent survey blocks near Porthdinllaen, on the north coast of the Llŷn Peninsula in North Wales. Provision of equipment and surveyors to conduct the survey was part of a wider, multi-phase project undertaken by Binnies and Hydrofix to provide technical guidance on likely costs involved in various market options for obtaining the survey data; design, commission and fabrication of an over-the-side pole mount for Pedryn; the survey works themselves; and the reporting and analysis of both the contemporary survey data and legacy data from previous surveys in order to facilitate NRW's requirements to obtain the data required over the survey areas.

The aim of the survey was to map the extents and internal structure of Horse Mussel (*Modiolus modiolus*) beds across the two survey blocks, and subsequently provide comparisons to previous datasets recorded in the same area in 2005, 2008 and 2015. The survey was divided over two blocks, henceforth referred to as Area A and Area B; the survey boundaries were defined in the *Modiolus_reefs.shp* file provided by NRW. The vertices, as WGS84 Lat/Long coordinates, for the two areas are provided in Table 1 and Table 2.

Point ID	Longitude (decimal degrees)	Latitude (decimal degrees)
1	-4.622393677	52.97163732
2	-4.614837504	52.96713144
3	-4.626361263	52.95924341
4	-4.610126439	52.94638145
5	-4.675637113	52.90919951
6	-4.699040276	52.92908663
7	-4.622393677	52.97163732

Table 1 – Area A survey area definition

Point ID	Longitude (decimal degrees)	Latitude (decimal degrees)
1	-4.531845363	53.03792573
2	-4.518655552	53.02241611
3	-4.518515432	53.00110818
4	-4.543111245	52.98645686
5	-4.575067729	52.99988925
6	-4.56806369	53.02219813
7	-4.531845363	53.03792573

Table 2 – Area B survey area definition

A nominal line plan, with 75m line spacing, was designed during the preceding Phase 1 Technical Assessment; survey lines were orientated roughly NE-SW, along the longer axis of both blocks, both to maximise the amount of online time and to sail into/ with the prevailing tidal currents. Data was to be recorded with a 200% overlap, i.e. every position on the seafloor was to be ensonified by at least two separate passes; this was to remove the reliance on the nadir beams in, and thus optimise, the backscatter data, while providing bathymetric coverage to meet the required IHO 1a specifications.

The survey was conducted using the NRW vessel Pedryn (see Table 3), operating a nominal 12 hour work day and berthing in Pwllheli marina; transit times between the berth and survey areas were around 90 minutes, however the logistic challenges related to finding a suitable mooring, fuelling and tidal limitations meant it was the most suitable base for the vessel.

Area A was treated as the priority area for acquisition; the existence of Horse Mussel beds in the area has been known about longer, and has hence been the focus of more survey and study than that of Area B, and is the focus of the comparative analysis to the legacy datasets, as mandated in the contract documentation.

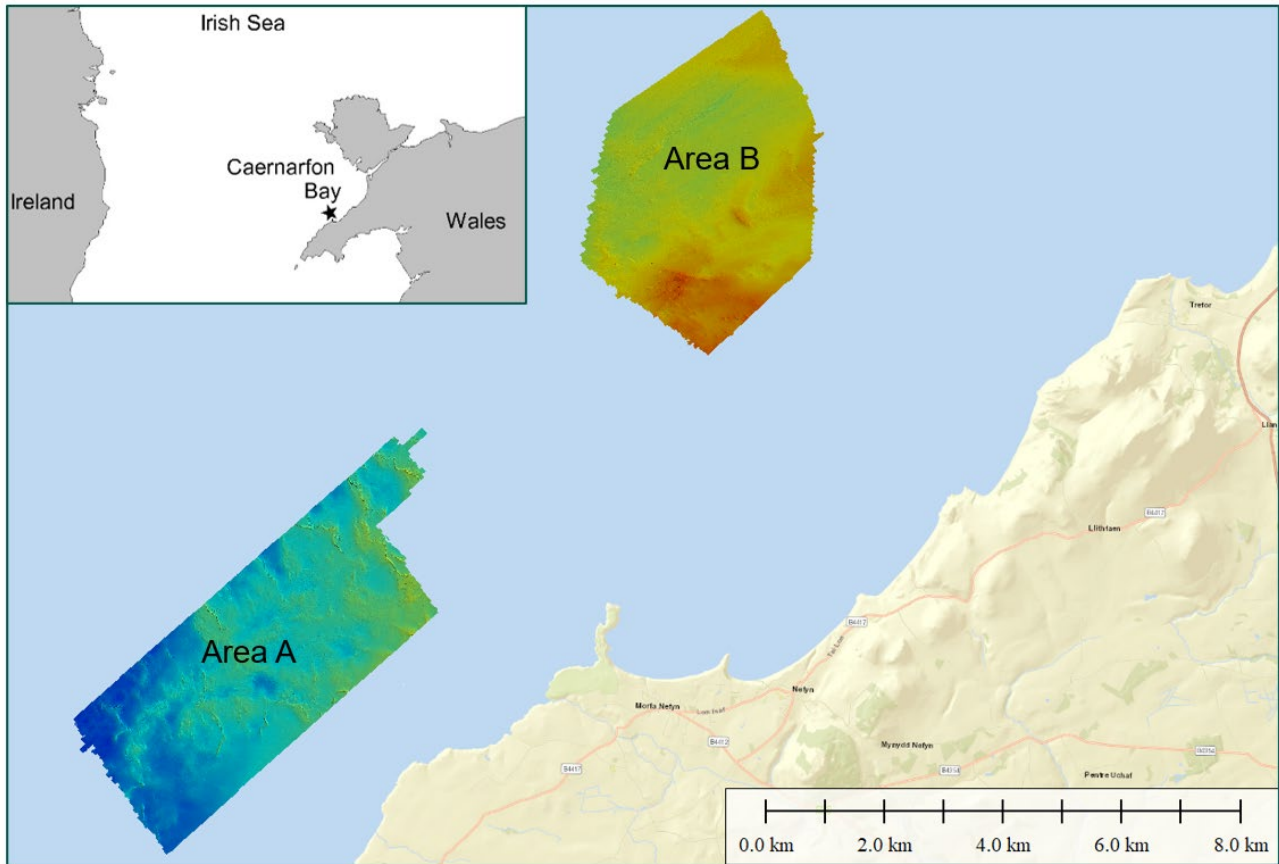


Figure 1 – Overview map of the survey areas, with inset of wider location

Survey Equipment

Vessel

The NRW vessel Pedryn, a dive support/ survey RHIB, was used for the duration of the survey. Although Pedryn has been used for towed Sidescan Sonar survey before, this is the first time a vessel mounted MBES system has been deployed on the vessel. Prior to commencing survey, a custom over-the-side survey pole was manufactured and fitted to allow the survey sensors to be mounted over the port side, immediately aft of the wheelhouse. The survey pole pushes out over the gunwale and rotates down into the water, allowing the MBES unit to be lowered for survey and raised for transit, allowing the vessel to transit at up to 25kts. A T-bar mounting for the dual GNSS antennas was bolted on top of the survey pole when in the lowered position, and unmounted and stowed adjacent to the wheelhouse when transiting.



Figure 2 – Pedryn, prior to fitting of the survey pole

Vessel Particulars	For Pedryn
Name	Pedryn
Length	12m
Beam	3.5m
Draft	1m
Propulsion	Twin Jet Drive
MCA Category	Cat 2 (60 miles)

Table 3 – Vessel details for Pedryn



Figure 3 – Survey pole and antenna T-Bar in recovered and stowed position



Figure 4 – Survey pole and T-Bar in deployed position

Hardware

The following equipment was mobilised aboard Pedryn:

- Norbit iWBMS Multibeam
- Applanix WaveMaster II INS (integrated in Norbit unit)
- NAVISTAK mini
 - Laptop
 - Network Switch
 - 4G Antenna and Modem
 - Eaton UPS
- Valeport Swift SVP

A Norbit iWBMS multibeam sonar was mounted to the survey pole; the unit has an integrated Applanix Wavemaster II INS unit, providing a tightly coupled position and orientation solution for the sonar. Position and heading information was derived from dual Trimble 540AP GNSS antennas, mounted on a 2m baseline on the antenna T-Bar. The multibeam, INS and antennas are all interfaced through the Norbit SIU topside unit. Both this and the 4G antenna/ modem were interfaced through the network switch to the acquisition laptop. The Valeport SVP was used to obtain full water column Speed of Sound (SoS) profiles, and connected to the laptop via Bluetooth.

Software

The MBES unit was controlled through the Norbit WBMS GUI; in addition to controlling the sonar settings, the GUI also manages a POSMV session to interface the INS

measurements, as well as an NTRIP client, over which RTK corrections were streamed from Trimble’s VRSNow service. The Norbit GUI was in turn interfaced with BeamworX’s NavAQ acquisition software, which was principally used to record survey and monitor acquisition; sonar data was also recorded directly through the Norbit GUI, to provide the option of re-calibrating the backscatter settings during processing if needed. Valeport’s Ocean software was used to download, analyse and export the SoS profiles from the SVP. Navigation data was post-processed using Applanix’s POSPac MMS software.

Software	Version
Norbit GUI	11.3.2
BeamworX package	2024.1.1.3
Valeport Ocean	1.2.2.3
POSPac MMS	8.7.7961.26193

Table 4 – Software version details

Project Geodesy

As per the project specifications, all project data is presented the projected WGS84 UTM30N coordinate system, with heights given referenced to Chart Datum. The geodetic parameters are provided in Table 5 and Table 6.

Parameter	Value	EPSG code
Ellipsoid	WGS84	7030
Datum	World Geodetic System 1984 ensemble	4326
Area of Use	Worldwide	-
Semi Major Axis	6378137	-
Inverse Flattening	298.257223563	-
Vertical Datum	Chart Datum	-
Unit	Metres	-

Table 5 – Geodetic Parameters

Parameter	Value
Area of Use	6 W to 0°E
Latitude of Natural Origin	0° (Equator)
Longitude of Natural Origin	3° W
Scale Factor at Natural Origin	0.9996
False Easting	500,000

Parameter	Value
False Northing	0
EPSG code for projected WGS84 CRS	32630

Table 6 – Geodetic Projection Parameters

As a terrestrial source of RTK corrections was employed during the survey (Trimble’s VRSNow service), the coordinates obtained were in the ETRS89 CRS. In order to transform the coordinates to WGS84, a 7-parameter epoch specific transformation was applied during acquisition in the BeamworX vessel configuration, both in the online acquisition software and in the offline processing suite; the parameters are shown below in Table 7.

Parameter category	From Value (ETRS89 / ETRF2000)	To Value (WGS84 / ITRF2020)	Shift X (m)	Shift Y (m)	Shift Z (m)	Rotation X (")	Rotation Y (")	Rotation Z (")	Scale (ppm)
CRS	ETRS89 (ETRF2000)	WGS84 (ITRF2020)	-	-	-	-	-	-	-
Spheroid	GRS1980	WGS84	-	-	-	-	-	-	-
Semi major	6378137.0	6378137.0	-	-	-	-	-	-	-
Flattening	298.257222101	298.257223563	-	-	-	-	-	-	-
Epoch	-	2024.5	-0.05755	-0.05550	0.10495	-0.00288	-0.01740	0.02812	-0.00414

Table 7 – ETRS89 to WGS84 coordinate transformation parameters. Rotation values are in arcseconds.

To convert ellipsoidal heights to relative to Chart Datum, a regional VORF model, obtained from the UKHO, was applied throughout BeamworX.

Mobilisation and Calibration

Vessel mobilisation and calibrations were performed between the 10-12th of June 2024; a summary of events are presented in Table 8.

Date	Activity	Notes
10/06/2024	Mobilisation	All equipment physically rigged to vessel. T-Bar taken to local marine services to enlarge bolt holes for antennas. All offsets measured and input into software. System powered up and checked alongside.
10/06/2024	Calibration	Static position check
10/06/2024	Mobilisation	Sea trials of new survey pole
10/06/2024	Calibration	GAMS calibration
11/06/2024	Calibration	Patch test, control point verification
12/06/2024	Calibration	Tuning of backscatter setting prior to beginning of acquisition

Table 8 – Mob/Cal Timeline

Offsets

As the Wavemaster II IMU is mounted within the Norbit iWBMS, the internal offsets are known from manufacturer specifications and are automatically applied within the Norbit GUI. The only principal offset that required measuring was that from the sonar measure point (defined as the top centre of the mounting bracket) to the base of the primary GNSS antenna, to allow the INS to accurately position the sonar phase centre.

Two additional measurements were taken; the sonar to vessel Centre of Rotation (CoR) and the sonar draft. The offset to the CoR is used to improve the quality of the heave calculations; the CoR is an approximate point (and also liable to change on a small boat such as Pedryn) and was estimated to be immediately behind the wheelhouse, along the ship's midline and level with the waterline. The draft measurement is necessary for BeamworX to position the sonar head within the SoS profile and thus accurately compute ray tracing for each ping. A measurement of the draft was taken by measuring the full length of survey pole while it was out of the water, then deploying the pole and measuring the distance down to the water line, and taking the difference.

All measurements were made by tape measure; in the case of measurements involving the sonar and antenna phase centres, measurements were taken to designated physical measure points and the published offsets from measure point to phase centre for the unit added on. The measured offsets at mobilisation are given in Table 9.

On the 22/06/2024, a Hydrofix 770mm extension flange was fitted to survey pole, to increase the draft of the sonar. This was done to push the sonar into less turbulent water away from the surface and the vessel hull, and thus improve the data quality (particularly the backscatter), which was becoming limiting to survey operations due to the amount of vessel movement and turbulence around the sonar. The updated offsets can be seen in and Table 10; all measurements below are phase centre to phase centre, relative to the

vessel's reference frame (which, due to the integrated IMU, is identical to that of the sonar head).

Offset	Forward (m)	Starboard (m)	Down (m)
Sonar to Primary Antenna	-0.828	0.000	-3.212
Sonar to CoR	0.000	1.800	0.400
Sonar draft	N/A	N/A	0.400m

Table 9 – Physical Offsets at mobilisation

Offset	Forward (m)	Starboard (m)	Down (m)
Sonar to Primary Antenna	-0.828	0.000	-3.982
Sonar to CoR	0.000	1.800	-1.170
Sonar draft	N/A	N/A	1.170

Table 10 – Physical offsets after installation of pole extension (22/06/2024 onwards)

Static Position Check

To confirm that the INS was providing an accurate position fix and that all offsets and geodetic parameters were entered correctly, a position check was performed against an independent system while the vessel was berthed at Pwllheli marina. A Trimble SPS855 was employed as the independent system; the antenna was mounted to a survey pole, which was then attached to the antenna T-Bar so that the SPS855 antenna was roughly level with the ship's antennas, and the horizontal and vertical offsets from the ship's primary antenna to the SPS855 measured. A BeamworX raw file was then logged to record the position provided by the vessel system, while the Trimble system logged series of observations, each for a duration of 10 seconds.

The data logged by the Trimble SPS855 was recorded as OSGB36 coordinates and ODN heights; these point locations were averaged, then this averaged point was transformed back to ETRS89 using the OSTN15/OSGM15 models before being transformed to WGS84 UTM30N coordinates using a 14-parameter time-dependant transformation. All transformations were performed in Blue Marble's Geographic Calculator software (version 2023 SP1).

Once converted to WGS84 UTM30N coordinates independently of the vessel based acquisition system, the SPS855 point was compared to the average location provided by NavAQ from the vessel based system. The results are presented in Table 11.

	Easting (m)	Northing (m)	Elevation (m)
Trimble SPS855	405341.626	5860499.669	57.356
Trimble SPS855 SD	0.005	0.014	0.009
Vessel system	405341.613	5860500.777	57.286
Vessel system SD	0.026	0.036	0.011
SP8S55 – Vessel Difference	0.013	-1.108	0.076
	Horizontal (m)	-	Vertical (m)
Measured Antenna Offset	1.080	-	0.070
Calculated Antenna Offset	1.108	-	0.076
C-O Offset	0.028	-	0.006

Table 11 – Static Position Check results

As the vessel was berthed such that it's heading was southerly, meaning that the Primary Antenna was slightly north of the SPS855 antenna, these results show that the two systems agree within 30mm of each other; this is within the accuracy of RTK measurements alone, and also critically lies within the standard deviations of the two measurement sets.

Control Point Verification

In order to confirm that the Trimble SPS855 system was providing an accurate position (and thus suitable to validate the onboard system), the antenna was set up over an OS trig pillar located on Pen Garm (Secondary Block Number SH62, Station Number T031), on the edge of Pwllheli. A series of 1 second observations were made continuously over a period of 1 minute to produce a single position for the receiver; multiple 1 minute periods were recorded, and the positions (recorded as OSGB36/ODN) of the points averaged. This average position was then compared to the published position for the pillar and benchmark (Ordnance Survey, 2024), which is summarised in Table 12:

	Easting (m)	Northing (m)	Elevation (m)
Trimble SPS855 position	237048.759	335372.007	72.354
Trimble SP855 SD	0.002	0.002	0.004
Offset to benchmark	0.000	0.000	0.813
OS Published position	237048.750	335372.000	71.542
SP855 – OS difference	0.009	0.007	-0.001

Table 12 – Control Point verification results

The results show millimetric differences between the recorded and published position and elevation for the trig pillar, confirming that the SPS855 system was producing accurate results.

GAMS Calibration

A GNSS Azimuth Measurement System (GAMS) calibration was performed using the in-built functionality of the Norbit GUI. The calibration uses data collected by both the primary (aft) and secondary (fore) GNSS antennas, while the vessel is manoeuvred through a series of figure-of-eight manoeuvres. The system uses the positions obtained from each antenna to calculate the offset (baseline) between them, which subsequently allows the vessel heading to be accurately calculated by the INS. The results (relative to the ship/sonar reference frame) from the GAMS procedure are presented in Figure 5; the results were then applied in the Norbit GUI.

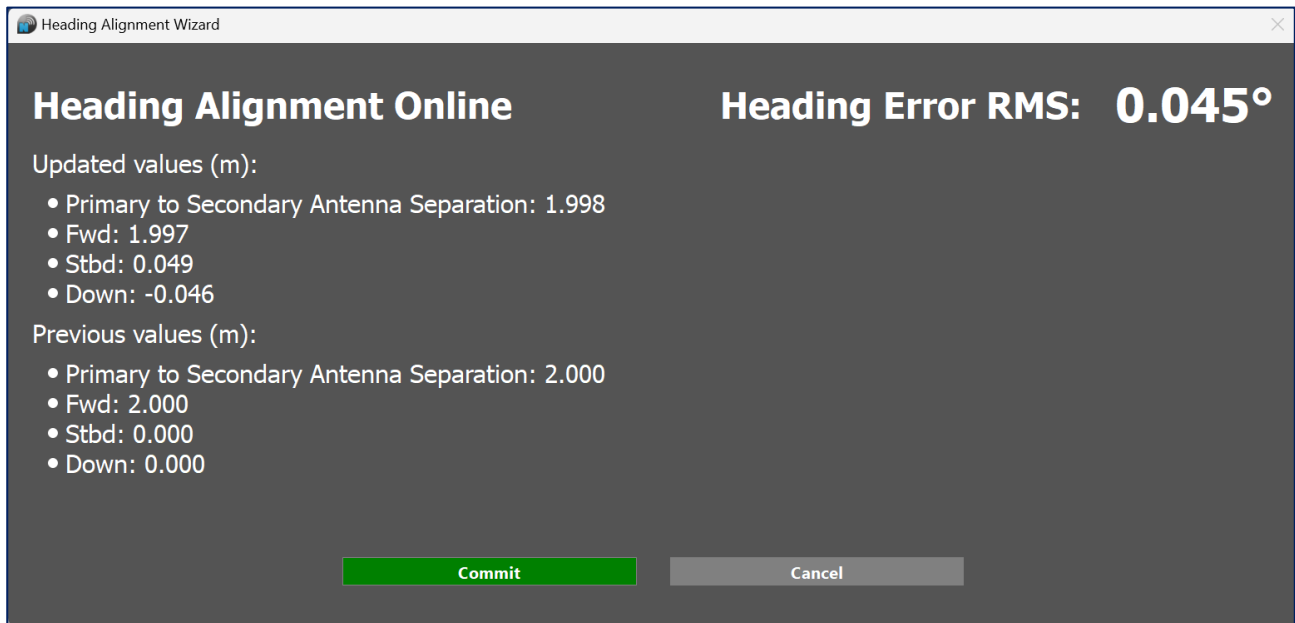


Figure 5 – GAMS alignment results from mobilisation (10/06/2024)

A second GAMS calibration was performed after the pole extension was fitted, due to the reconfiguration of the sonar mounting. The results, subsequently applied to the system, are presented in Figure 6:

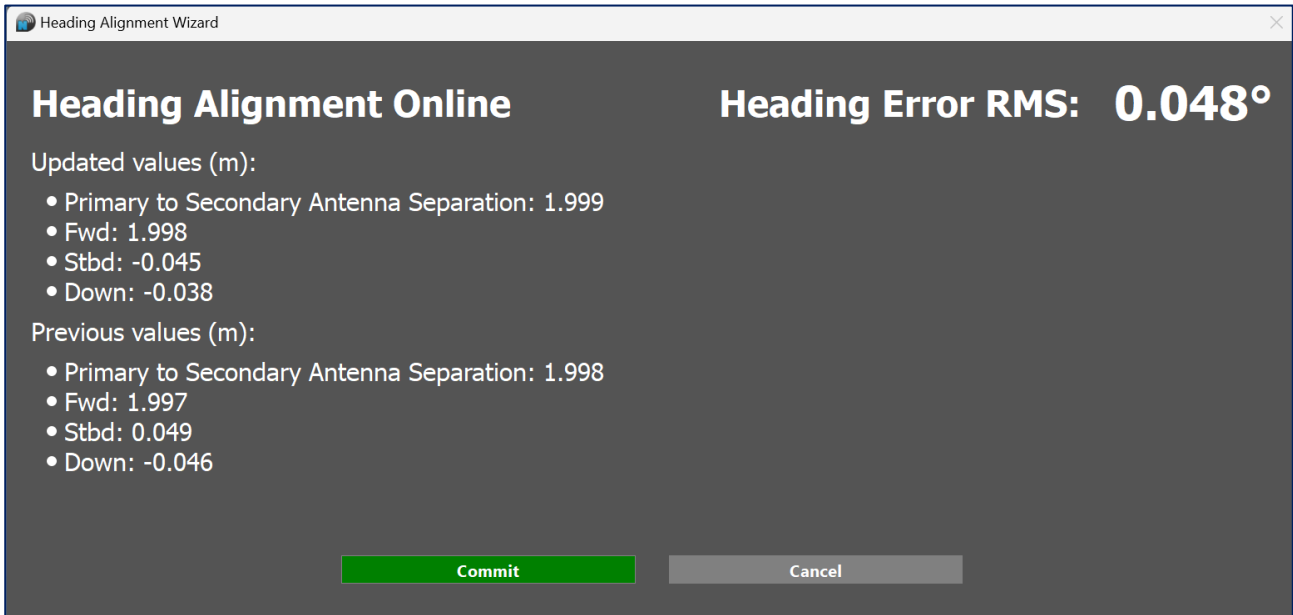


Figure 6 - GAMS alignment results following pole extension installation (22/06/2024)

Patch Test

In order to calculate the angular offsets between the INS and the sonar, an industry standard patch test was performed over an area of seafloor containing both a flat area and a feature with significant vertical offset to the surroundings; the general procedure is shown in Figure 7. A latency test was not performed as all data was synced using GPS time.

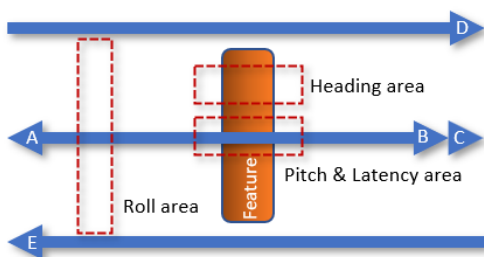


Figure 7 – Nominal Patch Test line planning

Offset to resolve	Line combination
Roll	A and B
Pitch	A and B
Heading	B and D (or A and E)

A total of three patch tests were performed. The initial mobilisation test was carried out over Holden's Reef in Tremadog Bay, near Barmouth, in water depths of 11-13m; the site was selected as providing suitable bathymetry to conduct the test while remaining accessible when weather prevented transit to the survey area. The second and third patch test were both performed over a steep ridge feature on the northern end of Area A and was a revalidation of the first patch test, after the sonar was removed and then reattached

to the pole on 19/06/2024, while the third patch test was performed after the pole extension was fitted and the second GAMS calibration performed on the 22/06/2024. The data was processed using BeamworX Autopatch software; see Enclosures A-C for full reports. The results for each patch test have been applied in the data processing to the relevant subsets of acquisition data; while the results of the second patch test were not statistically significantly different to the first, the test was performed in survey water depths and produced a better alignment than the results from the first test, so have been used for the period from the 19th to 22nd of June. All of the results are summarised below.

Test date	Roll Offset	Roll SD	Pitch Offset	Pitch SD	Heading Offset	Heading SD
11/06/2024	-0.026	0.017	0.16	0.19	0.31	0.08
19/06/2024	-0.028	0.019	0.19	0.03	0.49	0.15
22/06/2024	-0.040	0.012	0.12	0.06	0.22	0.10

Table 13 – Patch test results throughout project

Backscatter Tuning

To ensure that backscatter amplitudes were balanced across the full swath and that the signal did not become saturated (and thus result in loss of information) at any point, the vessel was sailed over each survey block before acquisition started on the block. Data was not recorded, but the live waterfall display in the Norbit GUI was monitored while the backscatter settings were adjusted. In the case of Area A, a final adjustment of -2dB was made during the first acquisition line (HM_MBES_A_001) when it became apparent the signal was becoming saturated in the deepest water on the east end of the block. Final values used for both acquisition areas are presented below.

	Static Gain	Spreading	Absorption
Area A	-76.5dB	51	140dB/km
Area B	-83.5dB	51	176dB/km

Table 14 – Backscatter settings for each acquisition area

Operations Summary

HSEQ

All survey operations were completed without accident or incident.

Timeline Overview

Following the initial mobilisation and calibration, all survey data was collected between 12/06/2024 and 01/07/2024, with all survey equipment demobilised on 02/07/2024. During this time, there was a total of 10 days of acquisition, with the remaining time as weather standby or stand down. Area A was acquired first as the priority area for comparison to previous datasets, followed by Area B. A summary timeline is presented in Table 15, for more specific details please refer to the DPRs; all survey works were performed by James Willcock (JW) and Iain Bones (IB) of Hydrofix.

	Operation	Summary
12/06/2024	Acquisition	Acquire HM_MBES_A_001-006
13/06/2024	Weather Standby	-
14/06/2024	Weather Standby	JW departs site
15/06/2024	Weather Stand Down	-
16/06/2024	Weather Standby	JW returns to site
17/06/2024	Acquisition	Acquire HM_MBES_A_007-012
18/06/2024	Weather Standby	-
19/06/2024	Acquisition	Second patch test, acquire HM_MBES_A_013-020
20/06/2024	Acquisition	Acquire HM_MBES_A_021-030
21/06/2024	Weather Standby	-
22/06/2024	Acquisition	Third patch test, reshoots and infill, JW handover to IB
23/06/2024	Acquisition	Acquire HM_MBES_A_031-036, calibrate backscatter for Area B, acquire HM_MBES_B_056, 052-053, infill
24/06/2024	Acquisition	Acquire HM_MBES_B_021-026, 044, 047-051, 056
25/06/2024	Acquisition	Acquire HM_MBES_B_027-031, 038-043, 046-047, infill
26/06/2024	Acquisition	Acquire HM_MBES_B_013-020, 032-037, infill
27/06/2024	Weather Stand Down	-
28/06/2024	Weather Stand Down	-

	Operation	Summary
29/06/2024	Weather Stand Down	-
30/06/2024	Weather Stand Down	IB handover to JW
01/07/2024	Acquisition	Acquire HM_MBES_B_001-012, infill and reshoots
02/07/2024	Demob	All Hydrofix equipment removed from Pedryn and returned to office

Table 15 – Acquisition time line summary

Vessel And Survey Pole Performance

Broadly speaking, Pedryn performed well during the survey, although the pending fibreglass repairs to the hull contributed to a limited weather window during the acquisition period. No issues were noted with powering the survey system from the ship’s batteries via the inverter, meaning it was not necessary to utilise a generator at any point.

At survey speeds, the vessel can be unstable in certain wave conditions with roll in excess of $\pm 10^\circ$ over short periods observed when only slight sea conditions (0.5m Hs) were seen on site, resulting in limited periods of reduced quality data being recorded (see Figure 8).

This was generally only an issue with swell on the beam of the vessel, however prevailing conditions on site resulted in side seas for much of the survey.

While the pole extension reduced the artefacts seen in the data, it only widened the weather window, rather than eliminating the issue. Minor motion artefacts persist in the data, despite post processing of the navigation solution, however the density of data collected ensures that the effect is largely cosmetic (see Figure 8). This is likely due to slight movement of the survey pole when underway, especially with the extension fitted.

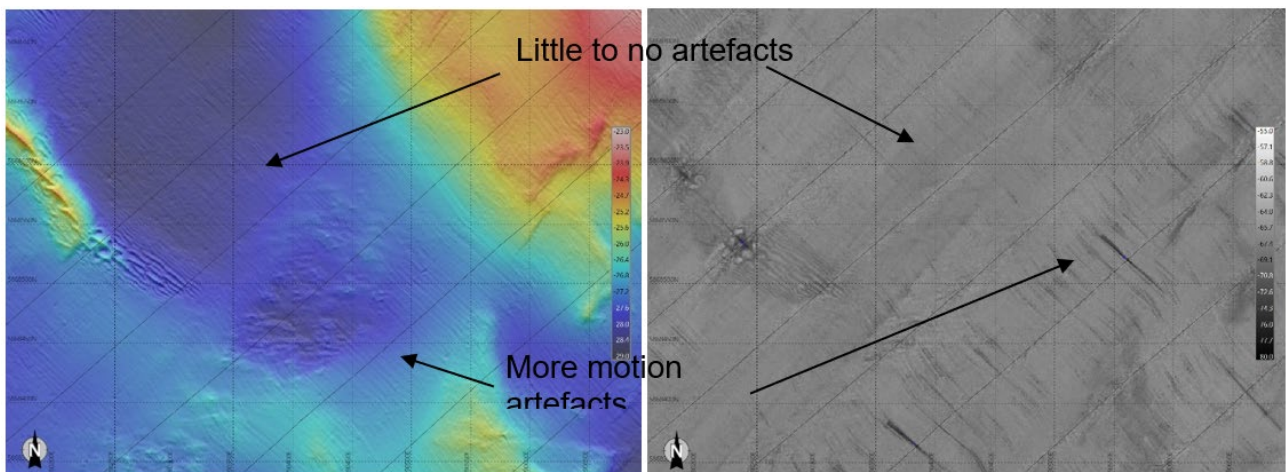


Figure 8 – Side-by-side motion noise in Area A data, in both bathymetry (left, coloured by elevation, referenced to Chart Datum) and backscatter (right, coloured by intensity value (dB)) data. Backscatter data is more heavily affected, while effects are visible but negligible in the bathymetry.

There is enough room in the wheelhouse for the topside equipment for single sensor acquisition, operated by one surveyor. However, if considering multi-sensor deployment (e.g. MBES and SSS), space is likely to become tight. If wishing to engage in more/ longer surveys, the seating arrangement would also need to be considered for improvement. As part of the mobilisation, some sea trials were performed on the new survey pole to ensure that it was suitable. The pole was deployed just outside of Pwllheli marina and the vessel manoeuvred at speeds steadily incrementing at ~0.5kts at a time, until a speed of 6kts was reached (this was considered the highest speed through the water likely to take place with the survey arm deployed). At all points during the trials, and during subsequent survey, the pole was held steady by the *Stauff*[™] clamps and never triggered the quick release pin. The pole appeared rigid, with no evidence of vibration, though a small wobble was observed in the T-bar during higher degrees of vessel motion; this was ameliorated by securing it, by rope, to the railing on top of the wheelhouse which has the added benefit of acting as a safety line to prevent loss overboard when moving the T-bar between the survey pole and the storage cup.

Sea trials were repeated after the extension flange was fitted; without additional securing, a noticeable (and intolerable) amount of movement was observed in the survey pole once a ~4kt vessel speed was reached. Ratchet straps were attached fore (to the port side railing) and aft (to the A-Frame) as stays and tightened, after which pole appeared stable at normal survey speeds.

The pole extension used (770mm) was excessive for the requirements of MBES survey on Pedryn and was only used due to the necessity to extend the operational weather window and its ready availability in Hydrofix stores. As well as the additional force generated through the pole (requiring the ratchet stays), extra lashing was likewise needed when the pole was recovered to prevent excessive bouncing of the MBES unit during transit. When the pole was recovered with the 770mm extension attached, it also prevented the port side engine hatch being fully opened.



Figure 9 – Extended survey pole in recovered position. Note that it now puts the sonar head in line with the engine hatch (left of photo).

The existing configuration allows for shallow water acquisition and easier deployment in calm waters. Hydrofix recommends that for further open water MBES survey, particularly when actively acquiring backscatter data, NRW consider using a 400-500mm long

extension flange on the existing pole. Longer ratchet straps will likely be required in order to secure the stays to a more suitable attachment point (i.e. a forward cleat).

In addition to the above points, based on observations during this first deployment of the equipment, Hydrofix makes the following recommendations for ongoing maintenance and operational improvements:

- Ensure two people are available to deploy and recover the pole, especially when moving the T-Bar between the storage cup and the survey pole until it is secured with at least two bolts (at which time only one person is needed to secure additional bolts).
- Check all bolts and fittings and tighten as needed.
- Check for any remaining rough edges and file down. Pad the ends of the T-Bar adjacent to the antenna mounts to prevent injury, especially for the person going forward during deployment and recovery of the T-Bar.
- Avoid overtightening of the *Stauff*TM clamps and monitor any stress marks; some appeared after the first day (especially on the port-most clamp), however they did not appear to worsen during the survey period. Recommend trialling using a torque wrench to establish a quantified tightness on the clamps. Carry spares onboard. Recommend replacing the individual washer type plates on the bolts with a single plate between both bolts.
- In addition to spare *Stauff*TM clamps, consider creating a dedicated tool and spares box for use with the survey pole, containing 13 and 17mm sockets, spanners and spare nuts & bolts.
- A better attachment mechanism for the antenna T-Bar should be considered; tightening/loosening of bolts over the side is less than optimal and likely to result in lost tools, bolts and nuts.

Tack welding of the bolts into the survey pole could be considered, but may not be possible due to the combination of steel bolts and aluminium pole; NRW should consult their skippers or a marine engineer as to the best course of action. A more significant alteration to allow a quick fit/ release mechanism could be considered.



Figure 10 – The Stauff™ clamps used to hold the survey pole in position. Note the discoloured stress marks, particularly on the outer clamp on the left of the photo.

Processing and Results

Processing Methodology

Navigation Processing

All INS data was post processed using Applanix's POSPac software. Navigation and motion data from the vessel was loaded into the software along with RINEX data obtained from the Aberdaron station of the Ordnance Survey's OSNet service to provide updated base station data, and automatically downloaded satellite ephemeris data.

Once the updated base station data was applied, the GNSS Inertial Processor tool was applied to the data to refine and smooth the online navigation solution, ensuring PPK navigation solutions with millimetric scale positioning accuracies on all three axes. The results were the output as SBET files that could be loaded with the raw MBES data from the matching timeframe.

MBES processing

All raw files recorded in NavAQ were subsequently loaded offline into BeamworX Autoclean. The files were loaded with the relevant vessel configuration (ensuring the correct angular and draft offsets were applied for the pole configuration in use at the time of recording), processed SVP profiles (any spikes removed and values applied either spatially or temporally as most appropriate) and the relevant SBET file (to update the navigation solution stored in the raw files).

Once all files were loaded, the data was cleaned using a selection of in-built automated filters (each employing differing methods of statistical analysis of the data). Further manual editing was employed in spatially limited areas, both to remove extraneous noise as well as to accept points that may have been erroneously removed by filtering.

Once the bathymetry was completely cleaned, a small amount of data interpolation was employed to ensure that there were no holes when the data was sampled at a 1m grid interval to ensure the best resolution possible. Interpolation was principally limited to a small number of isolated, individual cells; the exception were three patches of data in Area B, resulting from a loss of communication with the IMU while online; as a result, there was a gap in orientation data that could not be bridged in post-processing. Data was edited while trying to preserve representative seabed levels, then the subsequent gaps were filled using interpolated points.

Once the bathymetric data processing was completed, the backscatter data was processed using the Backscatter Processor tool with Autoclean. Snippets were selected as the data source; this refers to a time window centred around the bottom detection point, meaning the intensity data used in the analysis corresponds to that coming from the seafloor, rather than deriving a single value from the full record, as in the Per Beam Intensity method.

The raw backscatter values were clipped above -50dB and below -80db to limit the effects of the motion related noise and interpolated AVG applied.

All gridded data was output from Autoclean as .xyz ASCII files with gridding was at 1m bin size, with the data point plotted at the cell centre, and the mean value taken for the cell.

Data Quality

Overall, the data quality was high, and exceeded the requirement to meet IHO 1a specifications; the only exception is the previously described areas where interpolation was necessary in the northern end of Area B, as the required hit count was not met. Whilst the accuracy requirements were met to conform to IHO Special Order, the data cannot be said to be fully Special Order compliant due to the sparsity of data on a 1m grid; Special Order mandates feature search for 1m cubic objects, which IHO guidelines state need to be sampled by 5 good (i.e. after all processing) pings. A total of 0.04% of cells in Area A and 0.03% of cells in Area B fail to meet this Special Order criteria. However, as presented in subsequent sections, the data is more than suitable for the analysis required and represents the highest quality data so far available over the survey areas. Key statistics for each area are presented in Table 16 and Table 17.

Statistic	Mean	Min	Max
THU	0.334m	0.184m	0.674m
TVU	0.071m	0.051m	0.144m
Vertical span (95% confidence interval)	0.040m	0.000m	1.760m
Hit Count	35	1	606

Table 16 – Key statistics, Area A

Statistic	Mean	Min	Max
THU	0.252m	0.119m	0.460m
TVU	0.067m	0.051m	0.106m
Vertical span (95% confidence interval)	0.030m	0.000m	1.240m
Hit Count	38	1	1316

Table 17 – Key statistics, Area B

Accuracies and hit counts are higher for Area B due to the shallower water across the block, resulting in higher ping rates, shorter ranges and smaller beam footprints. Max THU values in Area A, in particular, are higher, due to the increased ranges employed on the first day of acquisition whilst targeting 200% overlap. Note that the minimum span value of 0m is owing to those cells with only 1 ping in them, while the max vertical span is skewed by those cells covering steep slopes.

Analysis of the data immediately after the first day's acquisition (12/06/2024) suggested the planned 200% overlap shooting plan was not workable as full overlap of adjacent lines was not being achieved, whilst the degree of refraction and noise on the outer beams was proving detrimental to the bathymetry data. The former issue was exacerbated by the vessel's autopilot, which exhibited a consistent tendency to steer ~2-3m to the port of the planned line, meaning that the planned 75m line spacing was actually closer to 70-80-70m when shooting adjacent lines in opposite directions. The latter issue, which naturally propagates over longer ranges (i.e. is most pronounced in the outer beams), was worsened by the high degree of vessel movement.

Considering the above analysis, and the fact that the nadir artefact in the backscatter data appeared negligible, it was decided with NRW stakeholders to continue with the planned 75m line spacing, but acquire data with a narrower swath and thus a more conventional (~15-20%) overlap. This allowed the accuracies of the individual beams to be kept high, while any loss of hit count from cells only being ensonified in a single pass was largely offset by the higher ping rates possible with decreased ranges whilst maintaining the planned acquisition schedule. The only detrimental effect to the data is the increased backscatter values present along the nadir of the vessel track. However following discussions on site with NRW representatives, it was decided that the effect was minimal and did not inhibit visual interpretation of the backscatter data, and was preferable to either compromising bathymetric data quality (which was deemed of higher importance), or requiring additional coverage and thus increased acquisition time.

In similar fashion, the 75m line spacing proved to be too wide to acquire high quality data in the shallowest areas of Area B, again owing to the amount of refraction effects seen with beams, this time due to the high swath angles necessary to achieve the swath width. In this case, additional lines were added ad-hoc to the acquisition, to ensure full coverage of the area was achieved at the required standards, while recording all data over the shallower areas around high tides, to maximise the achievable swath width. In this case, the addition of 8 additional, partial length lines did not significantly impact the acquisition time.

Analysis

Following the processing of the bathymetric and backscatter data, gridded data was output as .xyz files and imported into Blue Marble's Global Mapper software (v. 25.1) for all subsequent analysis.

Identifying Mussel Bed Extents in 2024 Data

Both the bathymetry and backscatter data were visually inspected to identify any suspected mussel beds; this was aided by comparison to previous datasets and shapefiles provided by NRW of the previously identified bed extents. Mussel beds were principally identified from the bathymetry data; the beds form a distinctive morphology, consisting of irregular, hummock shaped bedforms relatively short in length, giving a characteristic "lumpy" or "stippled" appearance in the bathymetric data. These were differentiated from sand waves, which are of a similar scale, but tend to be more linear.

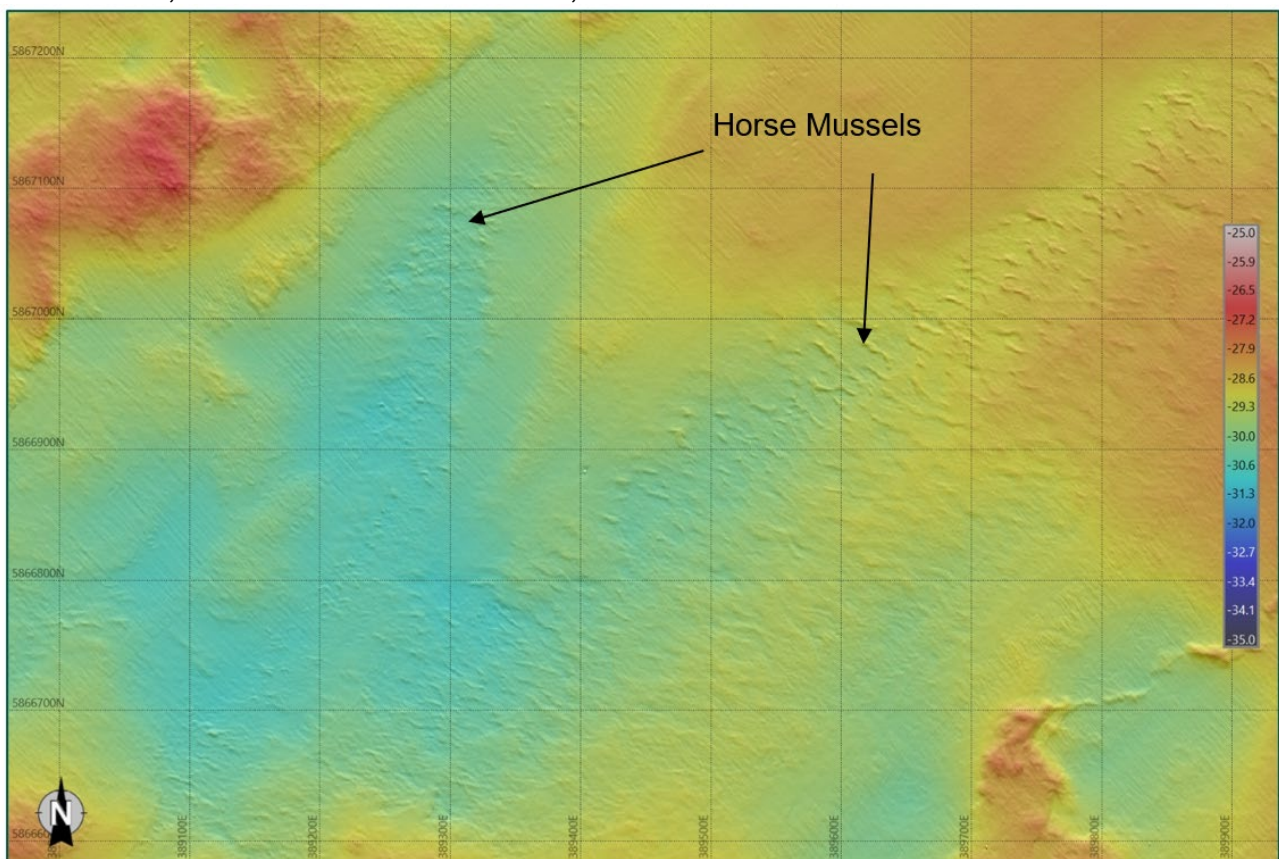


Figure 11 – Typical morphology of Mussel bed in bathymetric data. Taken from Area A, coloured by elevation, vertically referenced to Chart Datum.

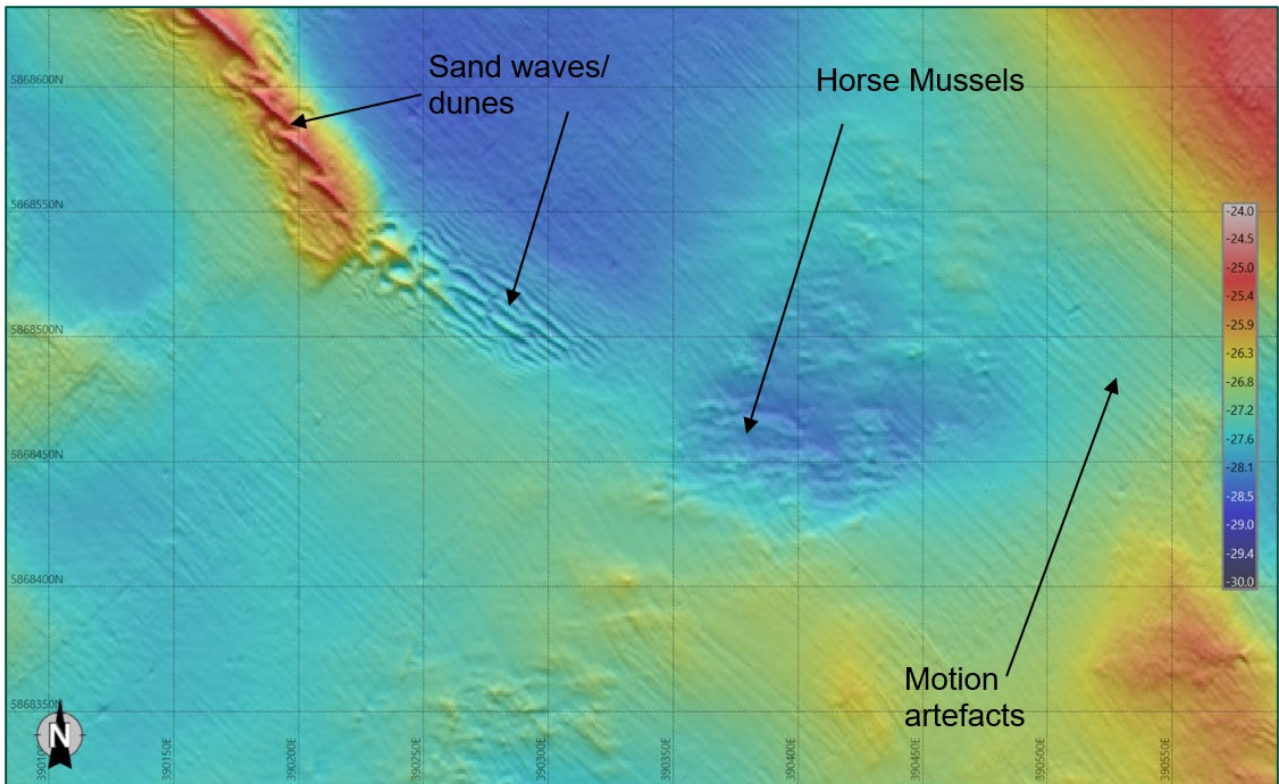


Figure 12 – Example bathymetry from Area A, showing the difference between mussel bed, sand waves/dunes and artefacts from vessel motion. Coloured by elevation, referenced to Chart Datum.

Although patches of the identified mussel beds can be delineated in the backscatter, large areas cannot be clearly identified from the intensity data. This is despite the backscatter clearly identifying changes in the seabed, including large scale (such as the moraine ridges and paleo-river features) and small scale (sand waves, individual boulders) features. This implies that the mussel beds produce a similar intensity of backscatter signal to the substrate on which they are growing, consisting of varying mixtures of gravel and sand (Lindenbaum, et al., 2008).

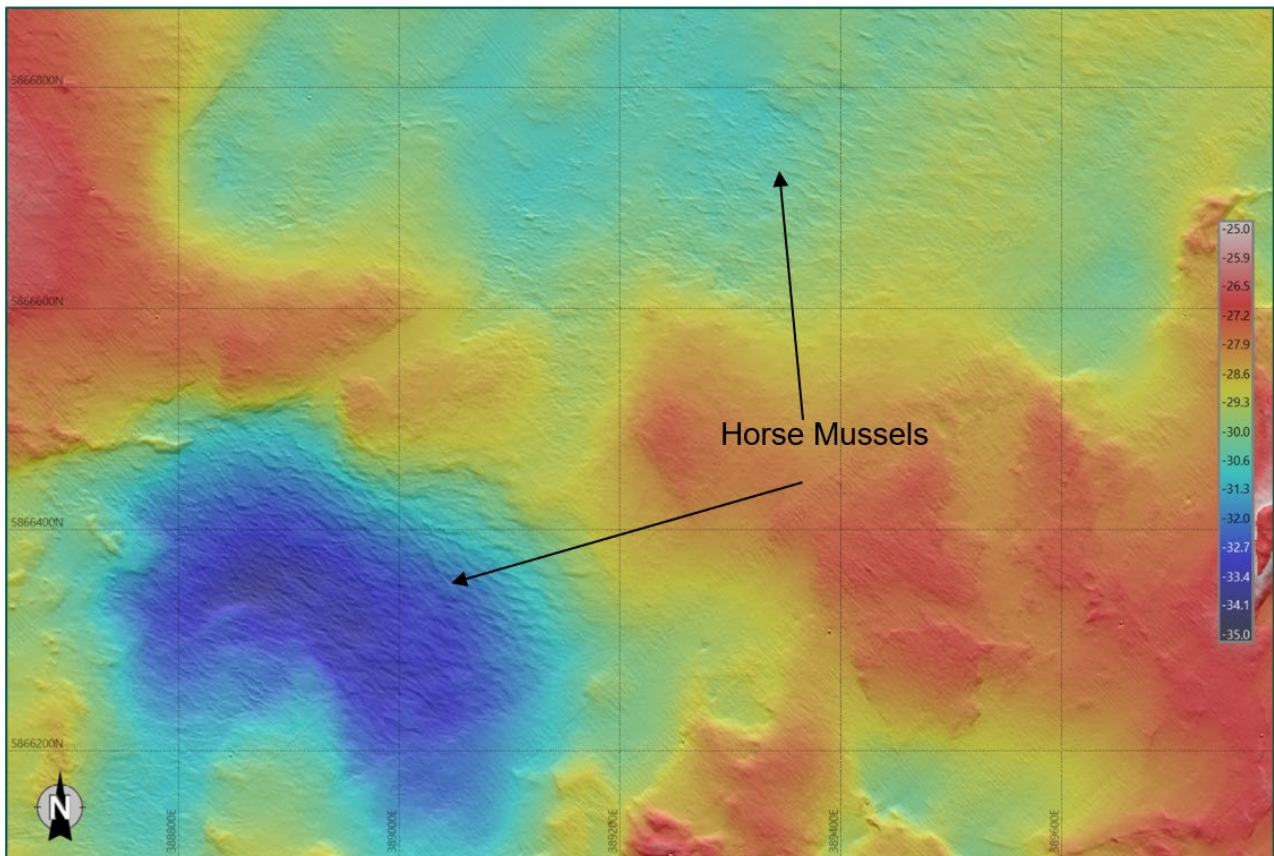


Figure 13 – Portion of Area A bathymetry, with Mussel beds visible in the southeastern and northern portions of the image. Coloured by elevation, referenced to Chart Datum.



Figure 14 – Backscatter data over the same area as Figure 13. Mussel extent in the SE is clearly visible, however the northerly portions cannot be delineated. Coloured by intensity value (dB).

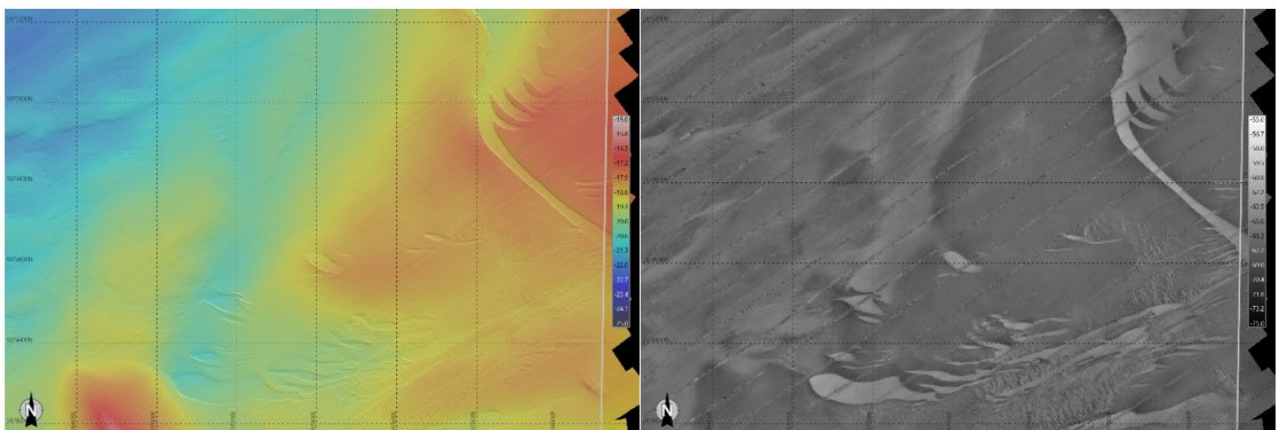


Figure 15 – Side-by-side of large scale features in Area B, in both bathymetry (left, coloured by elevation, referenced to Chart Datum) and backscatter (right, coloured by intensity value (dB)) data. Features are clearly visible in the backscatter, sometimes more so than in the bathymetry.

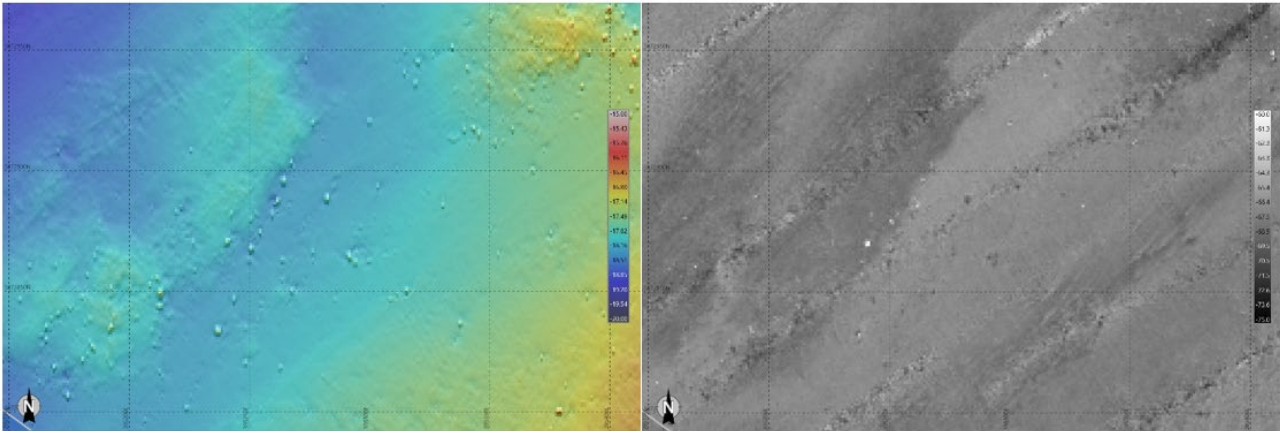


Figure 16 - Side-by-side of boulders in Area B, in both bathymetry (left, coloured by elevation referenced to Chart Datum) and backscatter (right, coloured by intensity value (dB)) data. Although not all boulders are picked out in the backscatter, a number appear as bright spots.

As the boundary drawing was a qualitative process, differing user interpretation may vary. In particular, it seems apparent that the beds are generally in decline; as a result, the boundaries in the 2024 data are much less distinct than they have been in previous data sets, with the beds tending to gradually thin out, rather than having a clear cut perimeter. Similarly, there are some areas where beds were previously identified, where some irregularity in the bed can be seen in the data, however it is not definable as a mussel bed on the 2024 data alone, and were it not for the previous data, these areas would not be considered as having mussel bed formations. The assumption in this case is that the reef structure has died off to such an extent that there is little or no remaining living fauna.

Internal Structure

Measurements of the crest height and distance between crests within the mussel beds were obtained by taking cross-sections through areas of the mussel beds in the point cloud data. The full density data ensured the best possible resolution for making the measurements. Cross sectional profiles were between 0.5-1m thick, depending on the local point cloud density, to ensure enough points were included to make accurate measurements. Note that in the absence of geophysical data to delineate the bottom of the mussel beds from the underlying substrate, the height of the crests has simply been measured as the vertical distance to the surrounding seabed level. In cases where the bioherms are growing on an overall slope, the height above the seabed was estimated based on the average of the height of the seabed on either side of the crest. Figure 17 below shows a representative example of a 1m thick slice, showing the estimate bed level beneath the crests, the crest height measured, and the wavelength from peak to peak.

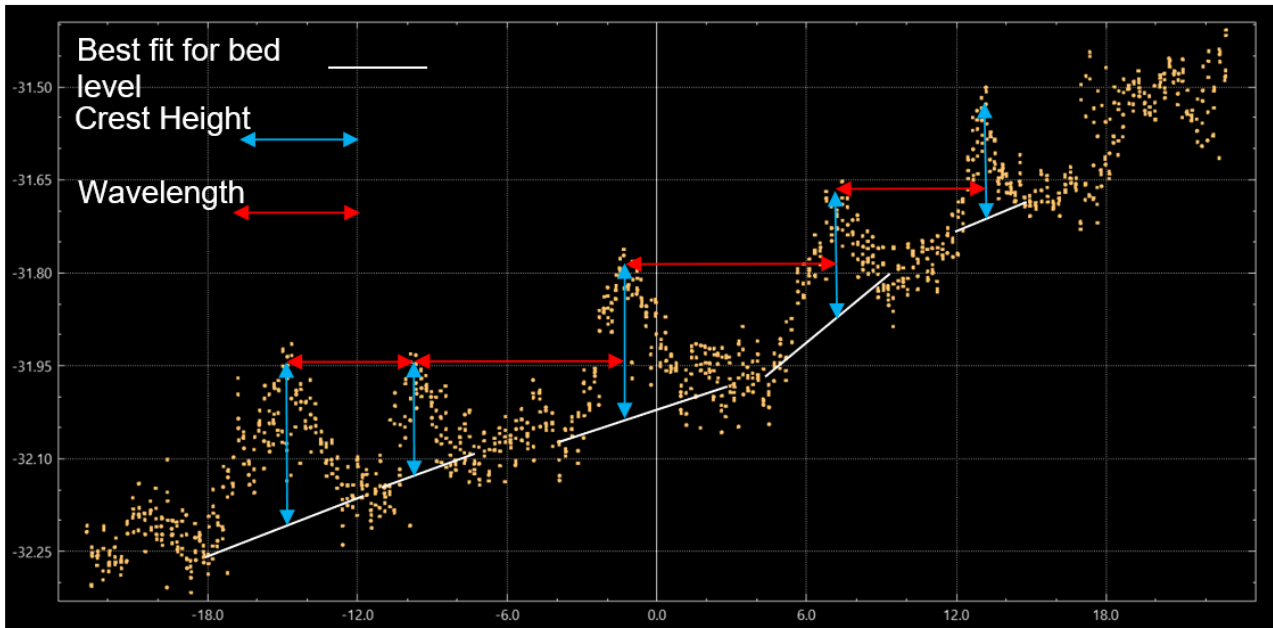


Figure 17 – Cross section of point cloud in mussel bed, illustrating measurement technique

Area	Sample size (number of crests)	Crest Height (m)	Crest Height Standard deviation (m)	Wavelength (m)	Wavelength Standard deviation (m)
1	25	0.114	0.046	6.88	2.02
2	19	0.143	0.067	6.89	3.55
3	11	0.096	0.029	6.22	1.19
4	10	0.085	0.021	6.92	2.63
5	8	0.085	0.026	6.64	2.36
6	17	0.091	0.021	7.19	2.21

Table 18 – Summary statistics of bioherm measurements

It was only possible to take consistent, accurate measurements on a relatively limited proportion of the identified bed extents; any crests smaller than 3-4cm high could not be reliably measured from the point cloud, as this began to fall within the limits of the TVU of the data set (and thus the vertical spread of the point cloud data), and of the amplitude of the residual motion artefacts seen within the data. This meant that although the beds could be delineated on a large scale, due to the relatively coherent structure of the bioherms, individual small scale measurements could not be made. It should therefore be considered that the results shown in Table 18 are skewed towards the larger bedforms present.

In general, while Table 18 suggests a fairly consistent set of values, particularly for the wavelength, the large standard deviations show that there is significant variation within the sampled measurements. This is particularly true of the crest heights in Areas 1 and 2, where crest heights range from 4-20cm (Area 1) and 3-26cm (Area 2).

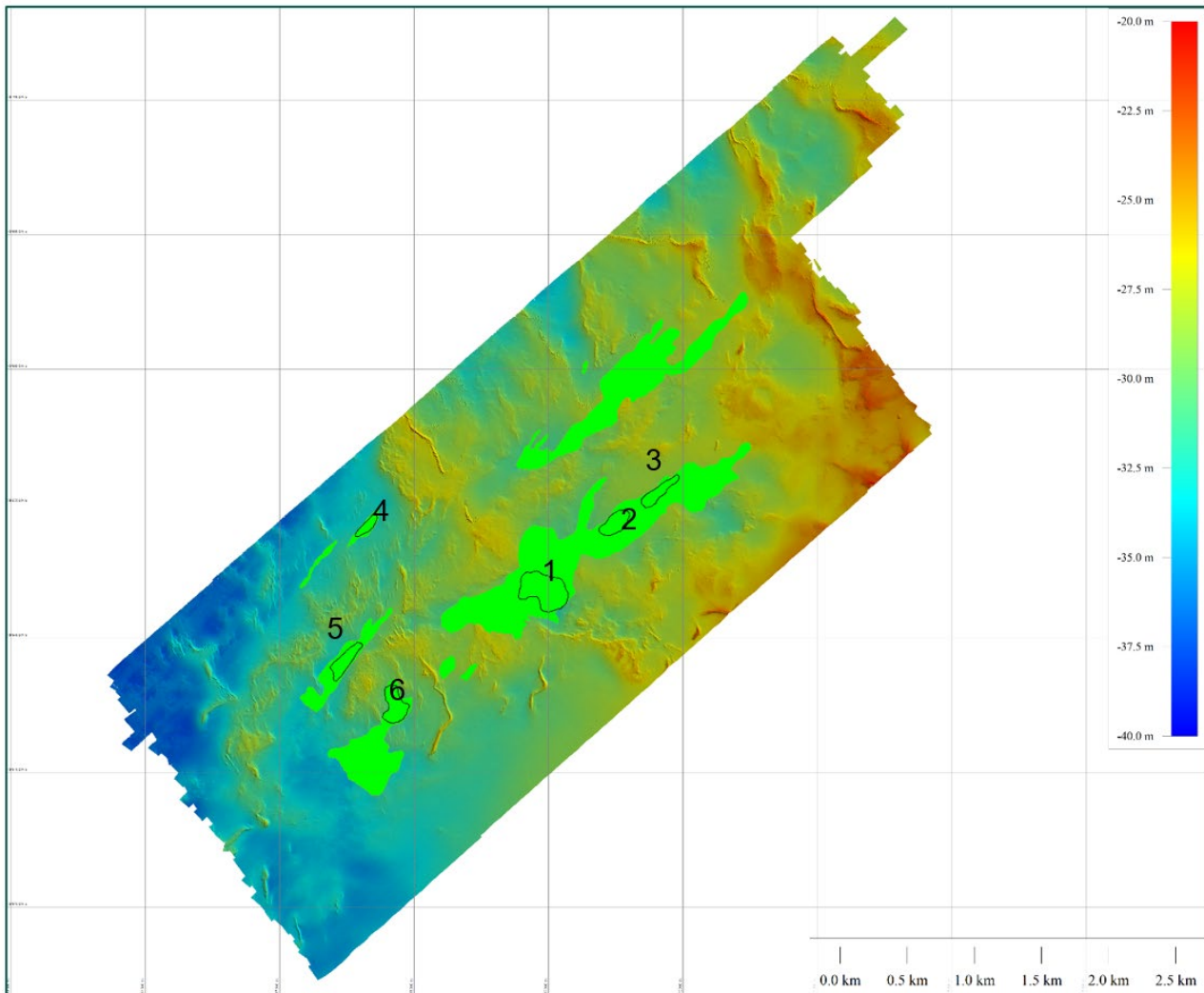


Figure 18 – Map of Area A illustrating areas in which bed structure measurements were taken. Identified bed extents shown in green, measurement areas defined by black lines.

Seabed Classification

A manual seabed classification was performed in Global Mapper, using both the backscatter and bathymetry data to delineate boundaries in the seabed composition. The seabed has been classed into 4 categories and are characterised based broadly on the known makeup of the seabed from previous literature (Lindenbaum, et al., 2008). Note that without specific ground truthing, this characterisation is purely speculative:

- Group 1- Moraine. Group 1 is characterised by rough, uneven bathymetry and mottled backscatter; the varying backscatter values don't necessarily correspond to the variations in bathymetry, likely due to varying grain size proportions and sizes within the moraine. The group also includes large, linear ridges which are stable over time, i.e. non-migratory.

- Group 2- Dunes and Ripples. Group 2 is characterised by ripple and dune structures that migrate over time, as seen between the different survey datasets. They are clearly defined in the bathymetry, due to height variation in their structure, and are often visible in the backscatter data.
- Group 3- Lag Gravel. Group 3 is characterised by a flat, featureless, homogeneous appearance, both in the backscatter and bathymetry data.
- Group 4- Unknown. Group 4 is an additional class, used to identify areas seen in the backscatter as lower intensity than the surroundings, but with no corresponding features in the bathymetry that would help class it into one of the other categories. The backscatter values within these relatively small areas is fairly consistent, lacking the variations seen within Group 1.

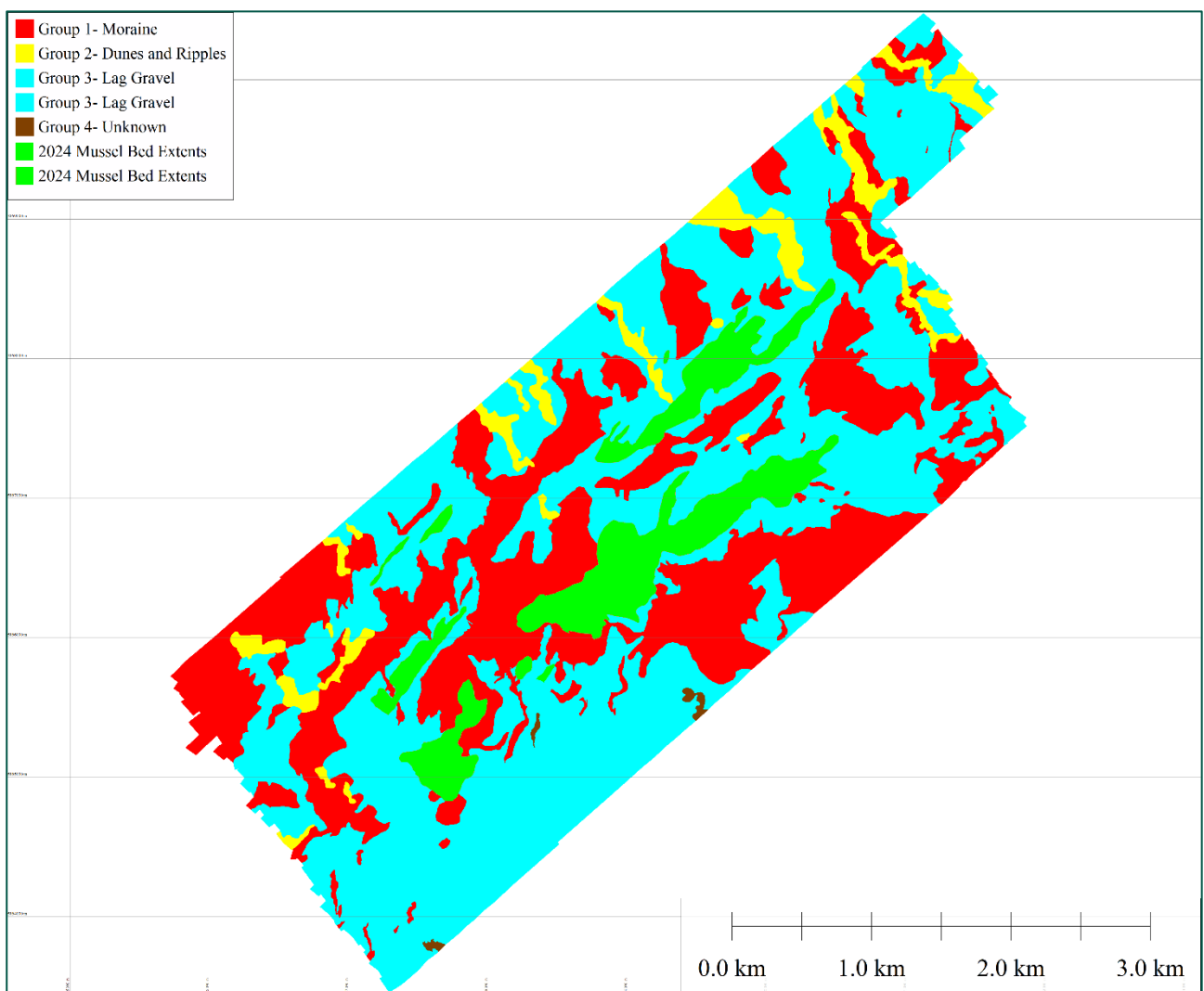


Figure 19 – Seabed classification of Area A, including mussel bed extents

Previous Datasets

Hydrofix was provided with the following legacy data, both as gridded products and as point cloud files. Through re-gridding of the data from the point cloud files, it was possible to increase the resolution of some of the legacy data. The result are summarised below in Table 19.

Year of Survey	Provided Grid Resolution	Point File Format	Re-Gridded Resolution
2005	5m	.all	2m
2008	0.5m*	.all	0.5m*
2015	2m	.gsf	1m

*Table 19 – Summary of legacy data formats and resolutions, both provided and re-gridded. *Data is unevenly spaced. Minimal spacing is 0.5m but there are significant gaps at this resolution which has been interpolated when surfaced in Global Mapper*

Gridded data was loaded into Blue Marble’s Global Mapper software as an Elevation Grid From 3D Point Data, using the Triangulated Irregular Network (TIN) methodology. With the exception of the 2008 data (see above), the No Data distance criteria was kept at the minimal 0.5m, to ensure no additional interpolation. The No Data distance was increased to 2.2m for the 2008 data to interpolate over the larger gaps between points.

Further to the information in Table 19, the following observations are worth noting:

- The 2015 contains a relatively small number of holes when gridded at 1m, but they are largely single, isolated cells
- When the 2015 data is re-gridded at 1m using the mean value and plotting at cell centre, there is a better match between the 2015 and 2024 data; the originally provided grid file for 2015 consistently sits around 10-15cm above the 2024 data, suggesting it was gridded on shallowest value for the cell, instead of mean.
- Overall, there is cm scale agreement, both horizontally and vertically, between the 2015 and 2024 datasets. This provides both further confidence in the accuracy of the 2024 data, and makes these two datasets best for direct comparisons.
- The 2008 gridded data sits around 2.5m deeper than the 2024 and 2015 data. This suggests it’s vertically referenced to ODN, rather than Chart Datum.
- The 2008 dataset clearly contains periods of IMU dropouts (where pings have not been positioned for angular motion of the vessel) and period of poor navigation fix, manifesting as metre scale vertical deviations, which become obvious when compared to the other datasets. These issues are prevalent in lines in the SE section of Area A.
- The 2005 data (both the provided 5m gridded data and the re-gridded 2m dataset) sit around 0.4m deeper than the 2015 and 2024 data. This is likely due to inaccuracies introduced by tidally correcting the data from buoy observations.
- Without additional metadata/ survey reports, it is not possible to resolve the ambiguities related to vertical referencing and gridding methodology mentioned above.

The following reprocessing was undertaken in order to obtain the higher resolution grid files:

2005 Data

- Point file data was loaded into Autoclean. GNSS heights were used, to remove any ambiguity as to the vertical reference employed (if this method was not employed, values tended towards those of the deeper 2008 data).
- A single height shift of -52.11m was applied to transform the GNSS ellipsoidal heights to Chart Datum (the single value corresponds to the average VORF value across Area A, differences across the area are centimetric).
- The supplied tide file site3_1.tid was applied to tidally correct the data.
- Auto Height fitting was used to help reduce remaining vertical offsets.
- Basic filtering was applied to reduce noise. Some noise remains in the data but for the scope of comparisons here, further processing was not deemed necessary.
- Mean elevation data was gridded at 2m grid size at cell centre.

Note that some gaps exist within the data due to insufficient raw coverage. These have been interpolated to some extent when surfacing in Global Mapper, but larger holes remain.

2015 Data

- Point file data was loaded into Autoclean.
- Pre-processed data was re-gridded at 1m and examined, before output at 1m interval, mean elevation, at cell centre.

2008 Data

Given the existing density of points in the gridded data and issues with positioning quality that could not be overcome from reprocessing the point files alone, it was decided not to reprocess the data and use the gridded data as provided.

Change Over Time

In general, the suggestion from the data available here is that the mussel beds are in decline across the survey area; horizontal extent appears to have reduced and internal structure is shrinking, suggesting that there is a process of decline across the remaining beds. The loss appears to be more significant between 2015 and 2024 than 2005-2015; while there has been a steady decrease in areal extent between 2005-2024, the 2015-2024 period appears to be marked by an increase in reduction in the internal structure of the beds. Although out of the scope of this reporting, and data is not available for 2005 and 2008, the degree of decline seen in Area B between 2015 and 2024 is similar to Area A.

Area A Extent Change

In order to make comparisons between the extents of the beds over time, the process of picking the bed extents was repeated for the 2015 and 2005 datasets. The extents seen in the 2008 data appear broadly unchanged from the 2005 data, and given the overall better quality of the 2005 data, the boundaries were only picked in the 2005 data. It is understood that the shapefiles provided by NRW for the existing extents are an amalgam of multiple datasets over various survey periods; in general, when compared to even the 2005 data (where the extents are greatest), the provided shapefiles appear to overestimate the extents. In order to maintain consistency in the analysis presented here, it was therefore decided to re-pick the 2005 data, rather than use the provided shapefiles.

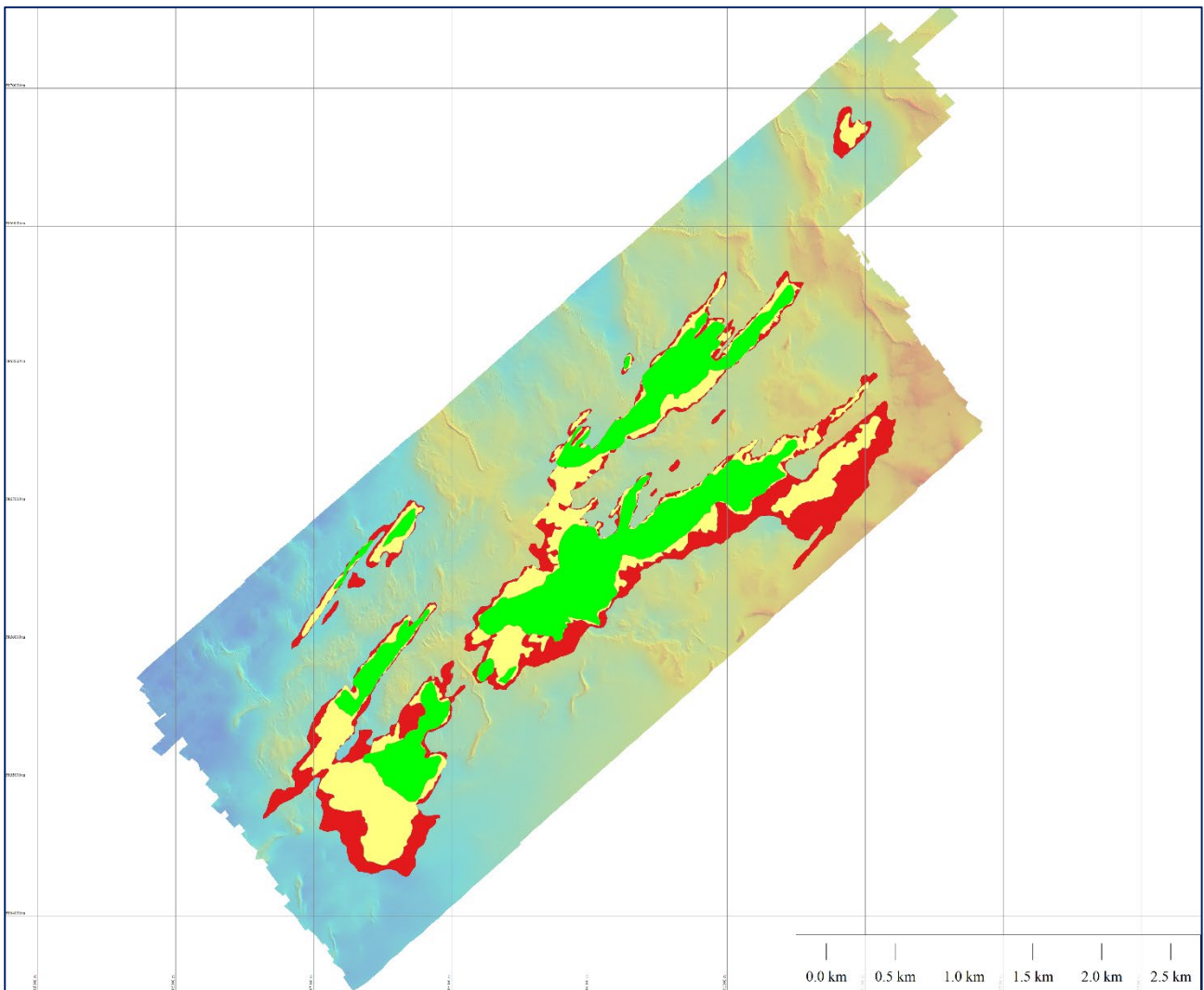


Figure 20 – Identified extents of mussel beds over time, overlaid on 2024 bathymetric coverage for context.
Red= 2005 extents, Yellow= 2015 extents, Green= 2024 extents

Measurement	2005	2015	2024
Total Area	3.95km ²	2.70km ²	1.54km ²
Percentage reduction	N/A	31.65%	49.97%

Table 20 – Comparison of Mussel Bed areal extents

Figure 20 indicates that the extents of the beds have been decreasing since 2005, with the 2024 data in particular showing that once continuous beds have split into smaller, separate areas. Table 19 suggests there has been a fairly steady areal decrease over the last ~20 years of around 0.13km² per year. However, when the loss is considered as a percentage of the total area, the rate of decrease is greater between 2015-2024 than 2005-2015. This rate of increase could be seen as less dramatic if we take the extents in 2008 to be the same as 2005, and assume that all losses to the beds have occurred since 2008.

Area A Difference Grids

In order to visualise the changes between the datasets, difference grids were employed in Global Mapper; elevation values from the older of two surfaces were subtracted from the newer within the Combine/Compare Terrain tool, to ensure that negative values in the resulting Elevation Difference grid represented reductions in bed level over time, while positive values represent increases. As well as providing quantification of the changes over time, the difference grids provide a good visual representation of the changes over time.

Volumetric Change

Attempts were made to calculate the volume differences between the datasets using the Volume statistics in Autoclean, however it was not possible to get accurate results; as previously described, the 2005 data are vertically offset to the 2015 and 2024 data, likely as the result of using tidal corrections based on buoy data rather than RTK/PPK positions. Although it is possible to apply a single static shift based on the average difference between the 2005 and other datasets, this still leaves a degree of uncertainty. Given that an average vertical difference of 1cm results in a total volume difference of nearly 40,000m³ calculated volume over the total 2005 bed area, this uncertainty remains too significant; even when comparing the 2015 and 2024 datasets, there is an average difference of ~4cm between the two; without knowing for certain the origin of this offset, the volumetric results cannot be treated as indicative.

Also, as previously discussed, there is also evidence from the difference grids to suggest that as the crests reduce in size, the troughs infill; this seems logical as it is unlikely the material is removed a significant distance. If this is the case, the overall volume would remain the very similar.

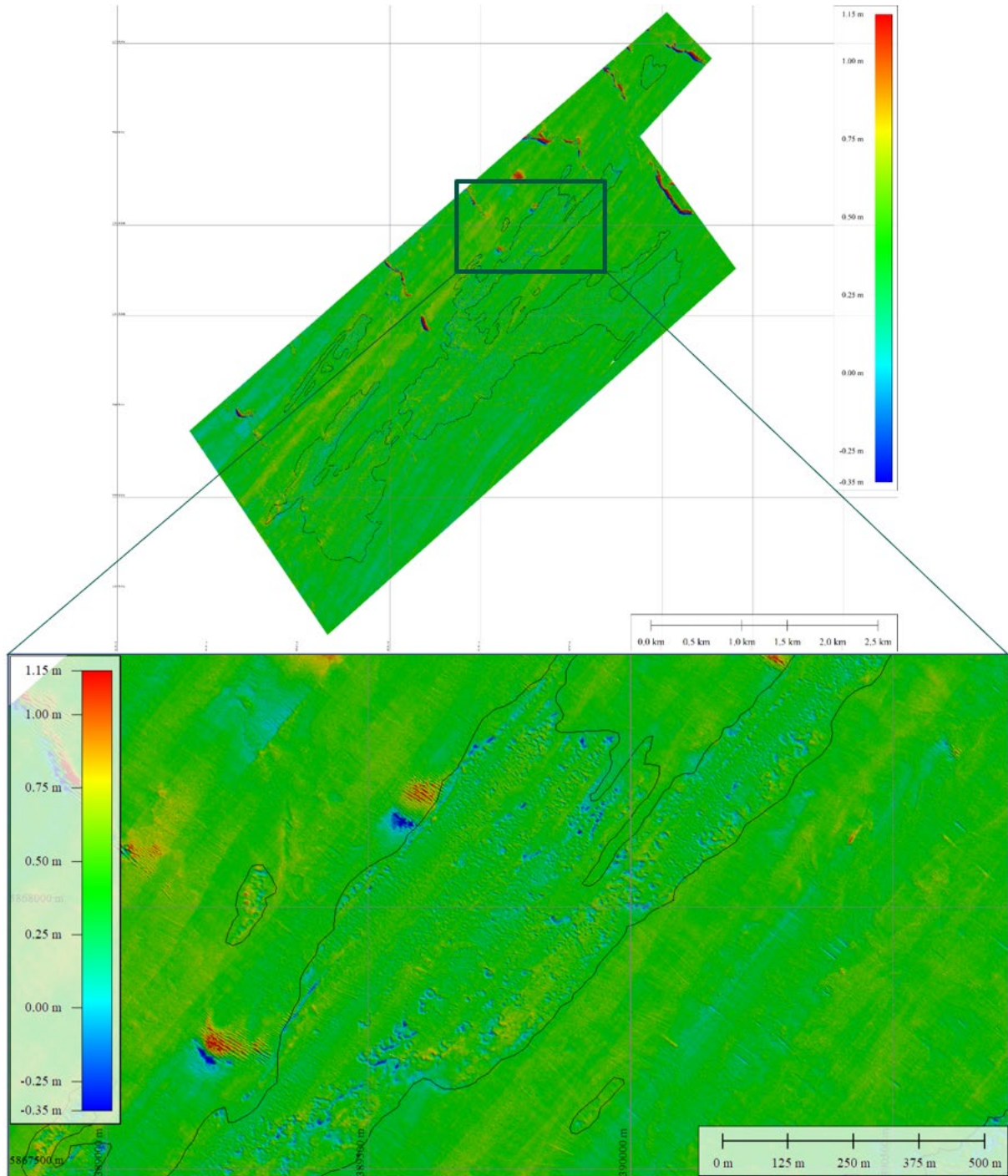


Figure 21 – 2005 to 2015 difference grid detail. Blue shades denote decreases in bed level over time, red shades denote increase. 2005 mussel bed extents are shown by the black lines. Note that due to the average 0.4m difference between the two surfaces, the colour scale has been skewed accordingly so green represents no change.

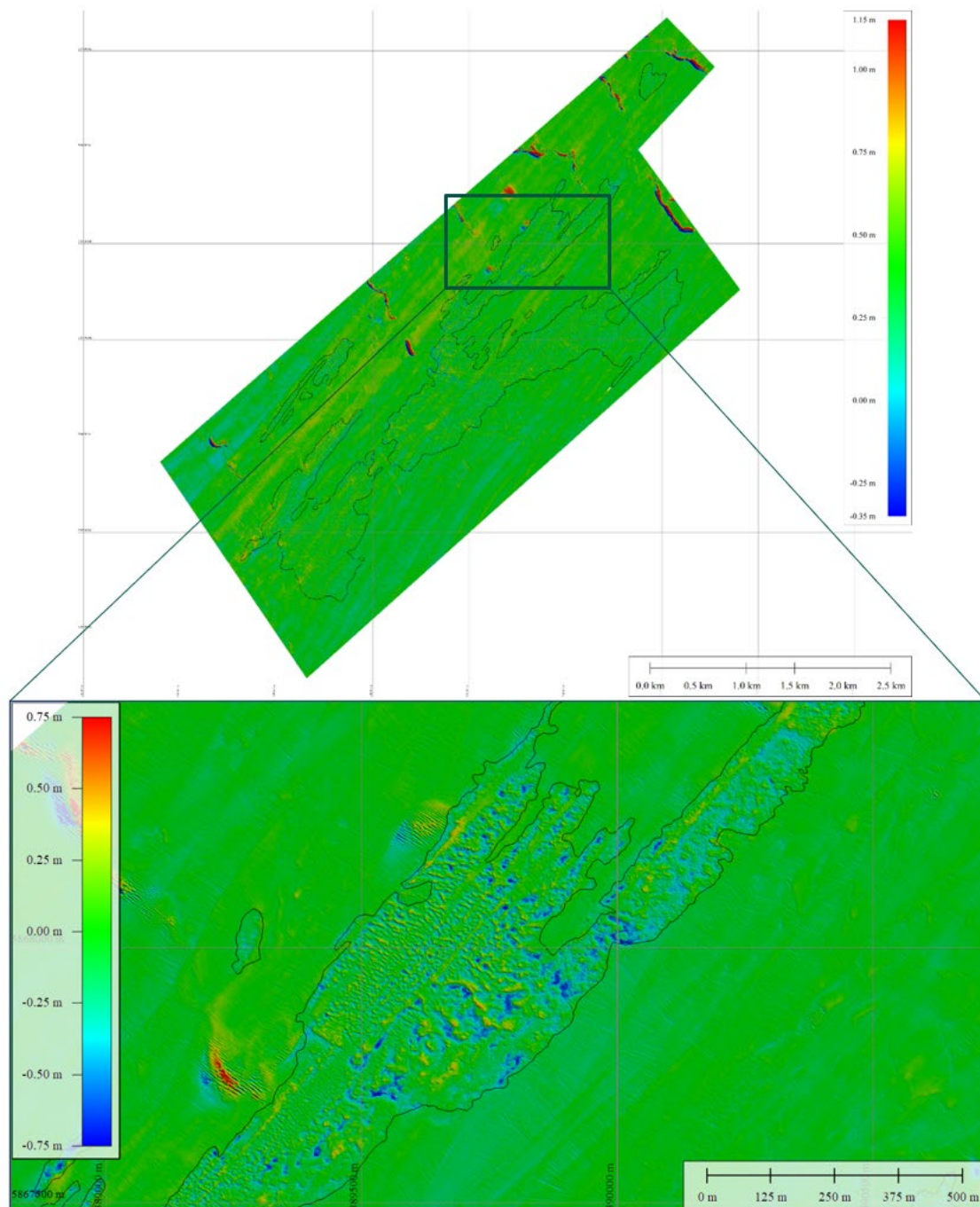


Figure 22 – 2015 to 2024 difference grid detail. Blue shades denote decreases in bed level over time, red shades denote increase. 2015 mussel bed extents are shown by the black lines.

Figure 21 and Figure 22 show the same detail of the difference grids generated for the 2005-2015 and 2015-2024 data respectively, and exemplify the broader trends observed. Figure 21 shows areas of loss around the perimeter of the mussel bed, while the inner areas appear largely stable. This suggests that while the area covered by the mussel bed

has decreased from 2005 to 2015, the structure of the remaining bed has been largely unchanged. Figure 22 shows both the losses around the periphery continuing, but also losses toward the centre of the bed, suggesting that not only are the areal extents decreasing, the internal structure is also reducing in size. Note that the small localised increases in bed levels represent a general flattening out of the bed, suggesting that as the crests of the bioherm diminish, the surrounding troughs are infilling.

Conclusions

The data delivered by Hydrofix represents the best MBES data currently available to NRW over the survey areas; a higher density of data was collected than the previous surveys, at high accuracy levels, allowing the vast majority of noise and artefacts to be removed. The data collected ties in very closely with the 2015 dataset, allowing for ready comparison; earlier datasets as presented to Hydrofix have issues that limit their usefulness to a lesser or greater degree.

Analysis of the data shows that the areas identified as mussel beds are both smaller in overall extent and in terms of internal structure in 2024 than the previously, and that this decrease in area has been ongoing since at least 2005/2008. The suggestion from the data presented here is that the mussel beds are in a state of decline, and that further complementary survey is needed to confirm the results shown here.

Deliverables

Deliverable	Format	File name
Full Point Cloud	ASCII text (.xyz)	H23034_WGS84_UTM30N_CD_point_cloud_R0.xyz
Gridded Bathymetry Data	ASCII text (.xyz)	H23034_WGS84_UTM30N_CD_gridded_R0.xyz
Backscatter Mosaic	GeoTiff (.tiff)	H23034_WGS84_UTM30N_CD_backscatter_R0.tiff
Bathymetry Difference Grids	ASCII text (.xyz)	H23034_WGS84_UTM30N_CD_2024_2015_difference_R0.xyz H23034_WGS84_UTM30N_CD_2015_2005_difference_R0.xyz
Seabed Classification and Mussel Bed Extents	ESRI Shape file (.shp)	H23034_WGS84_UTM30N_CD_2024_Classification_R0.shp H23034_WGS84_UTM30N_CD_2024_Extents_R0.shp H23034_WGS84_UTM30N_CD_2015_Extents_R0.shp H23034_WGS84_UTM30N_CD_2005_Extents_R0.shp

References

Lindenbaum, C., Bennell, J. D., Rees, E. I., McClean, D., Cook, W., Wheeler, A. J., & Sanderson, W. G. (2008). Small-scale variation within a *Modiolus modiolus* (Mollusca):

Bivalvia) reef in the Irish Sea: I. Seabed mapping and reef morphology. *Journal of the Marine Biological Association of the United Kingdom*, 1(88), 133-141.

Ordnance Survey. (2024). *Ordnance Survey Online Triangulation Station Directory*. Retrieved September 09, 2024, from Ordnance Survey:
<https://www.ordnancesurvey.co.uk/gps/legacy-control-information/triangulation-stations>

Appendices

Appendix A

Patch Test data collected 11/06/2024

AutoPatch (V2024.1.1.3) Calibration Report - 26 - 07 - 2024 14:53:51

TRANSDUCER ALIGNMENT CALIBRATION	
Current User	NAVISTAK1
Project Folder	D:/H23034/Autopatch
Number of Raw Files	9
Project	NRW Mussel Beds
Surveyor	JW
Job	H23034
Vessel	Pedryn

RAW FILE LIST					
Date	Start	End	Heading	Speed	File Name
11 - 06 - 2024	10:43:31	10:45:42	137.6°	1.7	NoLine_20240611_114331.0001.bwxraw
11 - 06 - 2024	10:46:55	10:49:56	321.3°	1.3	NoLine_20240611_114655.0001.bwxraw
11 - 06 - 2024	10:51:28	10:53:29	135.4°	1.7	NoLine_20240611_115128.0001.bwxraw
11 - 06 - 2024	10:54:35	10:57:11	322.5°	1.4	NoLine_20240611_115435.0001.bwxraw
11 - 06 - 2024	10:59:33	11:01:21	137.0°	1.9	NoLine_20240611_115933.0001.bwxraw
11 - 06 - 2024	11:02:26	11:04:48	318.1°	1.4	NoLine_20240611_120226.0001.bwxraw
11 - 06 - 2024	11:06:17	11:08:51	138.6°	1.8	NoLine_20240611_120617.0001.bwxraw
11 - 06 - 2024	11:09:35	11:12:37	313.6°	1.5	NoLine_20240611_120935.0001.bwxraw - NOT USED
11 - 06 - 2024	11:13:31	11:16:20	137.1°	1.6	NoLine_20240611_121331.0001.bwxraw

Post-Processing Trajectory	
File:	Not Used

OFFSET LOCATIONS			
Description	Starboard[m]	Forward[m]	Up[m]
COG	0.000	0.000	0.000

COMPUTATION SETTINGS	
Positioning System	Norbit-Pos
Heading System	Norbit-MRU[Attitude]
Pitch/Roll/Heave System	Norbit-MRU[Attitude]
Height Mode	Use Position and Heave

SOUND VELOCITY PROFILE		
From Internal Records		
125 records		
Min Speed = 1504.75m/s	Min Cast Depth = 0.50m	Min Survey Depth = 10.60m
Max Speed = 1505.05m/s	Max Cast Depth = 12.79m	Max Survey Depth = 15.10m

MRU ALIGNMENT			
Name	Roll	Pitch	Heading
Norbit-MRU[Attitude]	0.000 °	0.000 °	0.000 °
Motion[Sensor1(grp 102)]	0.000 °	0.000 °	0.000 °

VALID DATA GATES		
	Minimum	Maximum
Depth	10.60	15.60
Sector	-65.30°	65.40°

ADJUSTMENTS
No Adjustments were made

DATA PAIRING & ROLL AREA SETTINGS	
Parameter	Value
Min. Roll-Pitch Overlap	80
Max. Heading Overlap	60
Line Heading Margin	30
Line Speed Margin	1
Roll Calibration Area Placement	Automatically, based on seabed features

CALIBRATION OFFSET RESULTS					
Roll-Pitch	Hdg	Roll	Pitch	Heading	
1 - 2	1 - 5	-0.013°	0.25°	0.18°	
1 - 2	1 - 9	-0.016°	0.25°	0.35°	
1 - 2	3 - 5	-0.013°	0.23°	0.20°	
1 - 2	3 - 7	-0.013°	0.23°	0.18°	
1 - 4	1 - 5	-0.050°	0.40°	0.35°	
1 - 4	1 - 9	-0.052°	0.20°	0.39°	
1 - 4	3 - 5	-0.050°	0.17°	0.15°	
1 - 4	3 - 7	-0.051°	0.18°	0.28°	
2 - 3	1 - 5	-0.003°	0.33°	0.42°	
2 - 3	1 - 9	-0.004°	0.30°	0.45°	
2 - 3	3 - 5	-0.002°	0.34°	0.30°	
2 - 3	3 - 7	-0.007°	0.30°	0.25°	
3 - 4	1 - 5	-0.037°	0.07°	0.34°	
3 - 4	1 - 9	-0.035°	0.39°	0.31°	
3 - 4	3 - 5	-0.038°	0.06°	0.32°	
3 - 4	3 - 7	-0.040°	0.02°	0.32°	
6 - 7	1 - 5	-0.026°	-0.12°	0.35°	
6 - 7	1 - 9	-0.026°	-0.12°	0.37°	
6 - 7	3 - 5	-0.025°	-0.14°	0.39°	
6 - 7	3 - 7	-0.025°	-0.24°	0.25°	
	PRESET	0.083°	1.08°	-1.02°	
	AVERAGE	-0.026°	0.16°	0.31°	ADVISED MOUNTING ANGLES
	SDEV	0.017°	0.19°	0.08°	

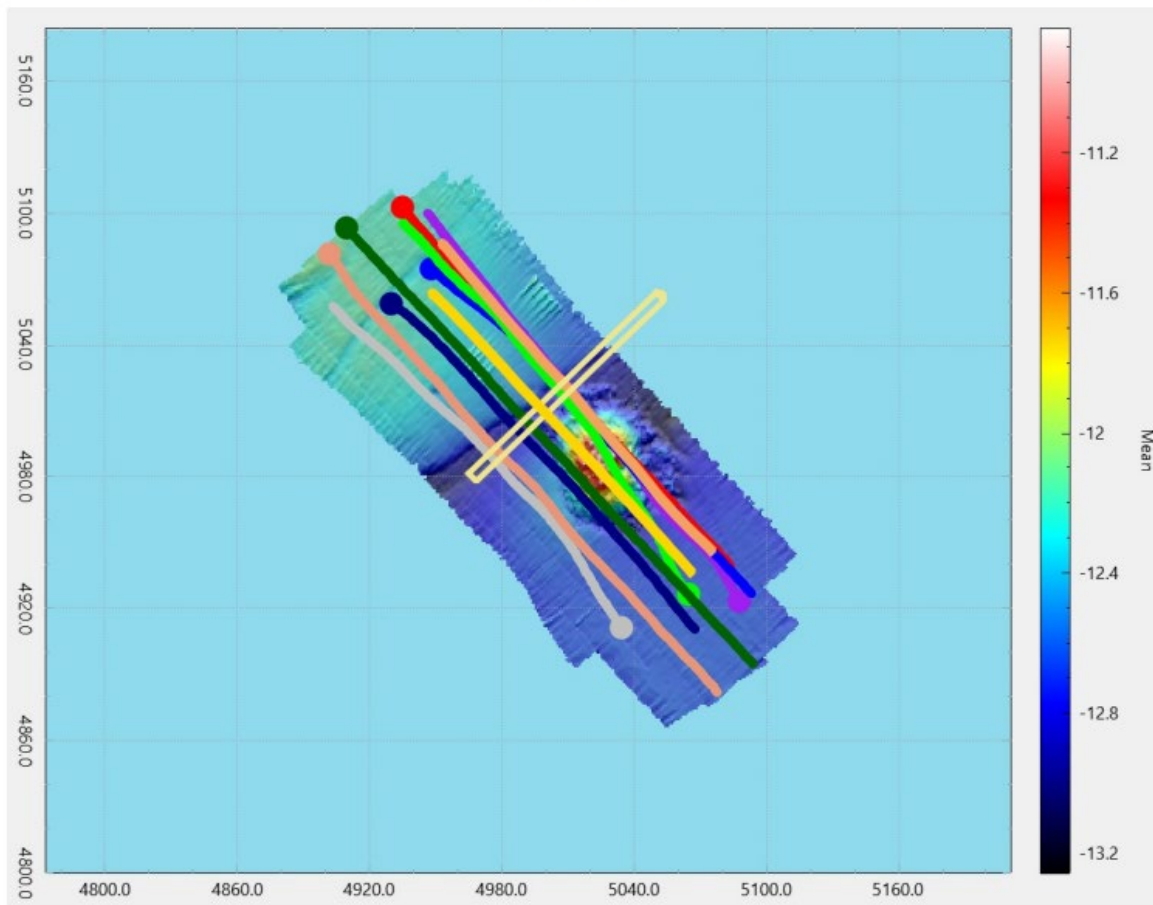
MOUNTING ANGLE SIGN CONVENTION	
Roll	Positive when Transducer center beam points towards port
Pitch	Positive when Transducer center beam points towards bow
Heading	Positive when Transducer is rotated clockwise around vertical axis of vessel

Note: All angles are absolute w.r.t. the vessel reference frame

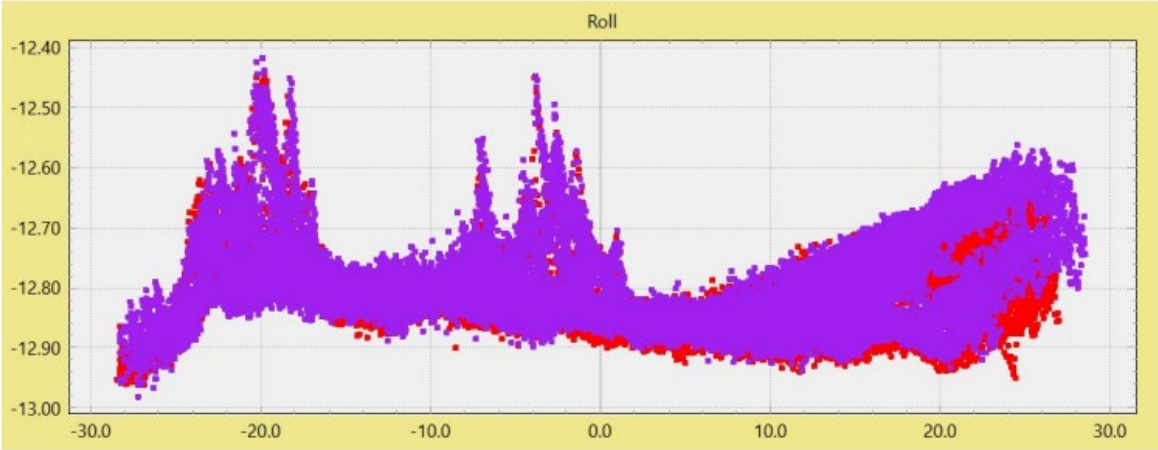
ACCURACY	
Average Error	2.894 cm/m2

WARNINGS	
There are no warnings to report	

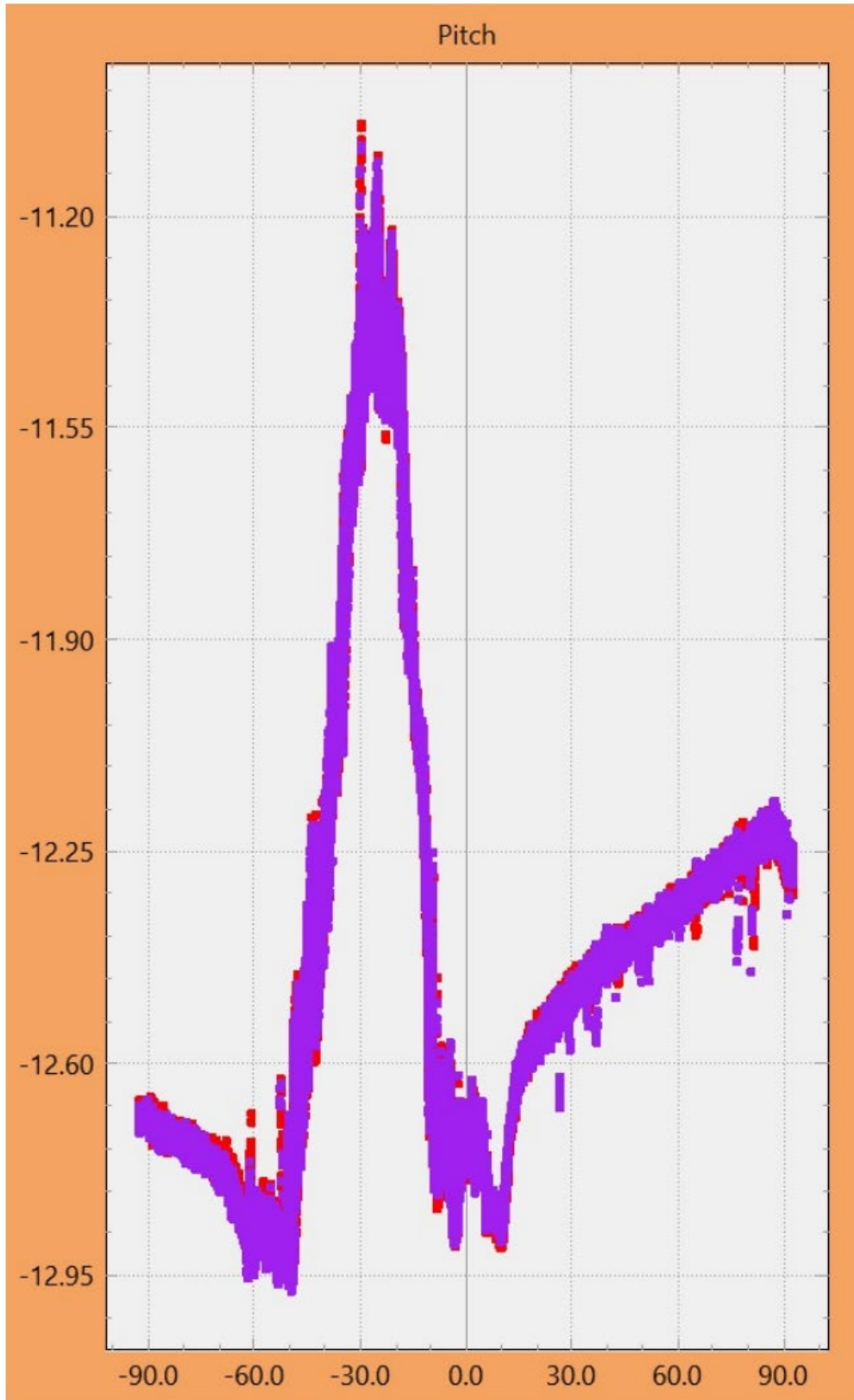
Chart View



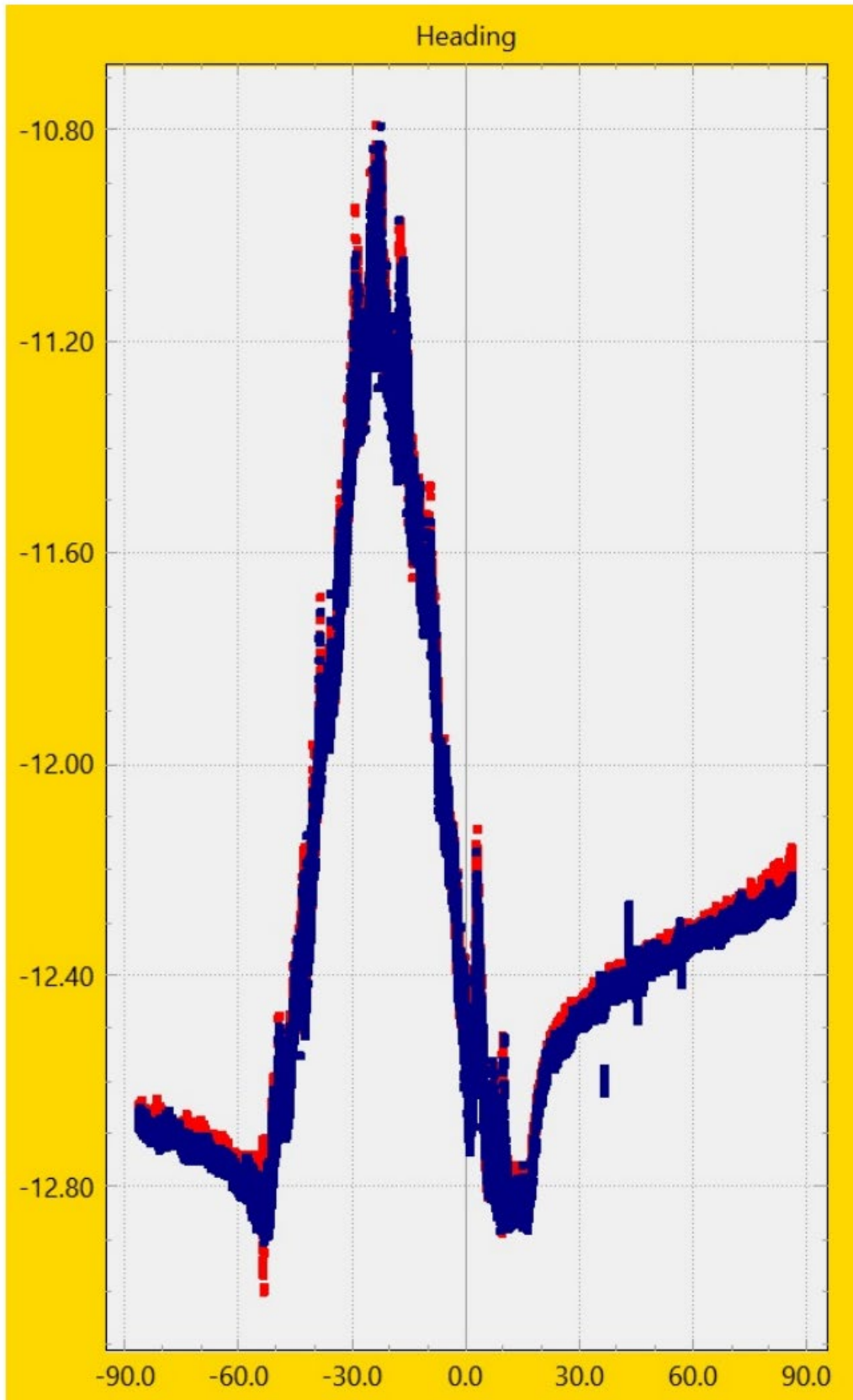
Roll Slice View



Pitch Slice View



Heading Slice View



Appendix B

Patch Test data collected 22/6/2024

AutoPatch (V2024.1.1.3) Calibration Report - 26 - 07 - 2024 14:49:01

TRANSDUCER ALIGNMENT CALIBRATION	
Current User	NAVISTAK1
Project Folder	D:/H23034/Autopatch
Number of Raw Files	10
Project	NRW Mussel Beds
Surveyor	JW
Job	H23034
Vessel	Pedryn

RAW FILE LIST					
Date	Start	End	Heading	Speed	File Name
19 - 06 - 2024	10:01:40	10:03:11	237.1°	1.3	NoLine_20240619_110140.0001.bwxraw
19 - 06 - 2024	10:04:05	10:05:51	71.4°	1.0	NoLine_20240619_110405.0001.bwxraw
19 - 06 - 2024	10:08:28	10:09:43	273.7°	1.7	New Line_20240619_110828.0001.bwxraw
19 - 06 - 2024	10:10:55	10:12:11	93.0°	1.8	New Line_20240619_111055.0001.bwxraw
19 - 06 - 2024	10:13:45	10:15:34	276.4°	1.6	New Line_20240619_111345.0001.bwxraw
19 - 06 - 2024	10:17:13	10:18:37	89.5°	1.9	New Line_20240619_111713.0001.bwxraw
19 - 06 - 2024	10:20:36	10:21:44	276.3°	2.2	New Line1_20240619_112036.0001.bwxraw
19 - 06 - 2024	10:23:34	10:24:41	100.5°	1.7	New Line1_20240619_112334.0001.bwxraw
19 - 06 - 2024	10:26:36	10:28:02	277.4°	1.9	New Line2_20240619_112636.0001.bwxraw
19 - 06 - 2024	10:29:13	10:30:01	94.6°	2.4	New Line2_20240619_112913.0001.bwxraw

Post-Processing Trajectory	
File:	Not Used

OFFSET LOCATIONS			
Description	Starboard[m]	Forward[m]	Up[m]
COG	0.000	0.000	0.000

COMPUTATION SETTINGS	
Positioning System	Norbit-Pos
Heading System	Norbit-MRU[Attitude]
Pitch/Roll/Heave System	Norbit-MRU[Attitude]
Height Mode	Use Position and Heave

SOUND VELOCITY PROFILE

From Internal Records		
390 records		
Min Speed = 1500.14m/s	Min Cast Depth = 0.52m	Min Survey Depth = 25.90m
Max Speed = 1500.57m/s	Max Cast Depth = 39.25m	Max Survey Depth = 32.90m

MRU ALIGNMENT			
Name	Roll	Pitch	Heading
Norbit-MRU[Attitude]	0.000 °	0.000 °	0.000 °
Motion[Sensor1(grp 102)]	0.000 °	0.000 °	0.000 °

VALID DATA GATES		
	Minimum	Maximum
Depth	25.90	32.90
Sector	-57.50°	57.60°

ADJUSTMENTS
No Adjustments were made

DATA PAIRING & ROLL AREA SETTINGS	
Parameter	Value
Min. Roll-Pitch Overlap	80
Max. Heading Overlap	60
Line Heading Margin	30
Line Speed Margin	1
Roll Calibration Area Placement	Automatically, based on seabed features

CALIBRATION OFFSET RESULTS					
Roll-Pitch	Hdg	Roll	Pitch	Heading	
2 - 9	2 - 4	-0.046°	0.25°	0.52°	
2 - 9	2 - 6	-0.089°	0.14°	0.17°	
2 - 9	2 - 10	-0.046°	0.25°	0.30°	
2 - 9	5 - 7	-0.064°	0.24°	0.59°	
2 - 9	7 - 9	-0.046°	0.25°	0.52°	
2 - 9	8 - 10	-0.078°	0.16°	0.39°	
3 - 4	2 - 4	-0.028°	0.22°	0.80°	
3 - 4	2 - 6	-0.021°	0.22°	0.58°	
3 - 4	2 - 10	-0.021°	0.22°	0.63°	
3 - 4	5 - 7	-0.021°	0.22°	0.56°	
3 - 4	7 - 9	-0.021°	0.21°	0.55°	
3 - 4	8 - 10	-0.017°	0.21°	0.35°	
3 - 6	2 - 4	-0.055°	0.23°	0.76°	
3 - 6	2 - 6	-0.053°	0.22°	0.56°	
3 - 6	2 - 10	-0.054°	0.17°	0.15°	
3 - 6	5 - 7	-0.053°	0.24°	0.59°	
3 - 6	7 - 9	-0.055°	0.23°	0.57°	
3 - 6	8 - 10	-0.054°	0.22°	0.39°	
4 - 5	2 - 4	-0.024°	0.18°	0.75°	
4 - 5	2 - 6	-0.023°	0.17°	0.47°	
4 - 5	2 - 10	-0.022°	0.17°	0.48°	
4 - 5	5 - 7	-0.024°	0.16°	0.62°	
4 - 5	7 - 9	-0.022°	0.17°	0.56°	

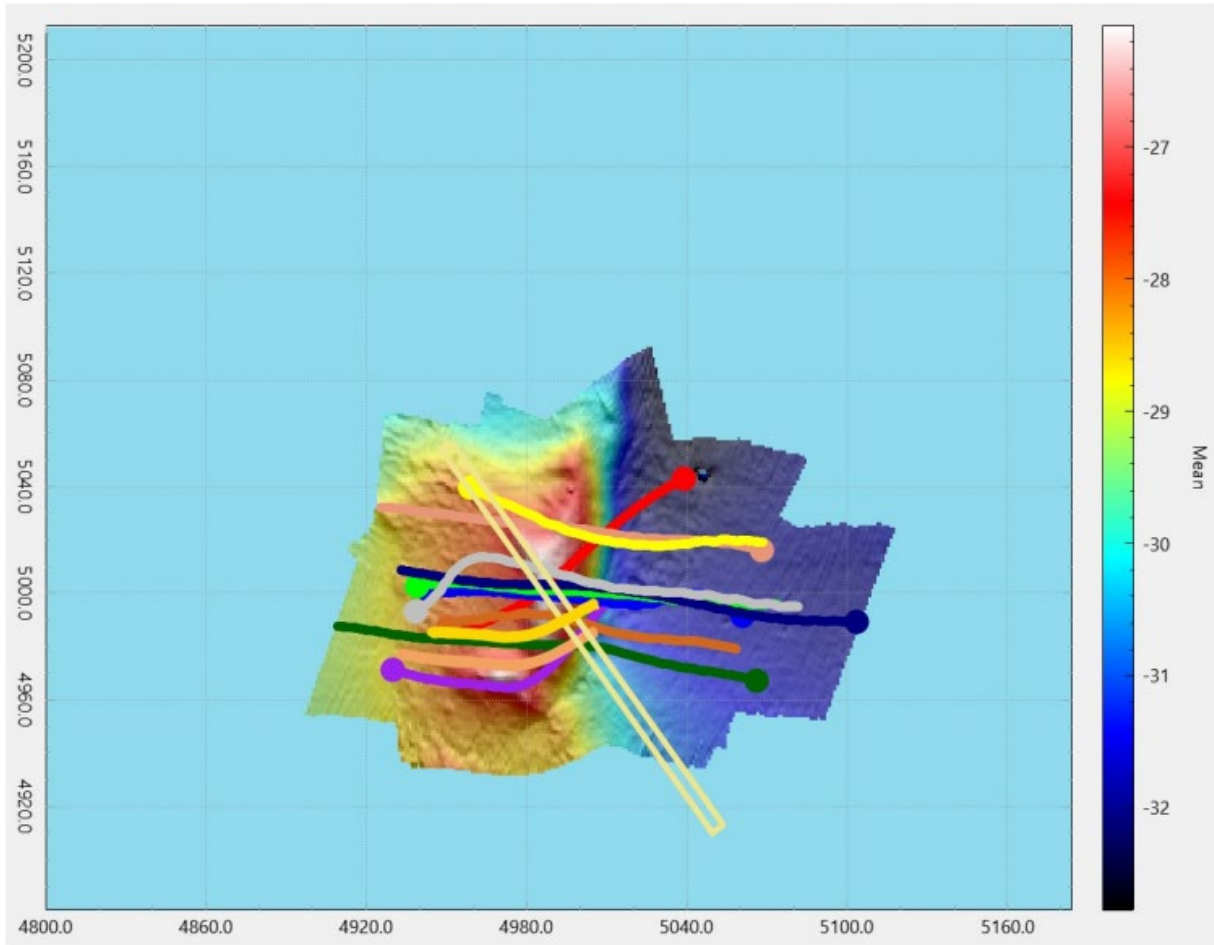
4 - 5	8 - 10	-0.019°	0.18°	0.34°	
5 - 6	2 - 4	-0.019°	0.17°	0.73°	
5 - 6	2 - 6	-0.017°	0.16°	0.38°	
5 - 6	2 - 10	-0.017°	0.16°	0.29°	
5 - 6	5 - 7	-0.019°	0.17°	0.59°	
5 - 6	7 - 9	-0.020°	0.17°	0.55°	
5 - 6	8 - 10	-0.017°	0.16°	0.36°	
5 - 10	2 - 4	-0.012°	0.13°	0.52°	
5 - 10	2 - 6	-0.010°	0.21°	0.46°	
5 - 10	2 - 10	-0.011°	0.21°	0.54°	
5 - 10	5 - 7	-0.012°	0.15°	0.65°	
5 - 10	7 - 9	-0.010°	0.17°	0.53°	
5 - 10	8 - 10	-0.010°	0.24°	0.26°	
7 - 8	2 - 4	-0.010°	0.15°	0.50°	
7 - 8	2 - 6	-0.009°	0.17°	0.46°	
7 - 8	2 - 10	-0.010°	0.17°	0.33°	
7 - 8	5 - 7	-0.011°	0.18°	0.56°	
7 - 8	7 - 9	-0.013°	0.18°	0.56°	
7 - 8	8 - 10	-0.005°	0.25°	0.24°	
9 - 10	2 - 4	-0.028°	0.19°	0.62°	
9 - 10	2 - 6	-0.029°	0.18°	0.27°	
9 - 10	2 - 10	-0.023°	0.15°	0.32°	
9 - 10	5 - 7	-0.024°	0.23°	0.44°	
9 - 10	7 - 9	-0.024°	0.16°	0.59°	
9 - 10	8 - 10	-0.028°	0.15°	0.35°	
	PRESET	-0.260°	0.16°	0.31°	
	AVERAGE	-0.028°	0.19°	0.49°	ADVISED MOUNTING ANGLES
	SDEV	0.019°	0.03°	0.15°	

MOUNTING ANGLE SIGN CONVENTION	
Roll	Positive when Transducer center beam points towards port
Pitch	Positive when Transducer center beam points towards bow
Heading	Positive when Transducer is rotated clockwise around vertical axis of vessel
Note: All angles are absolute w.r.t. the vessel reference frame	

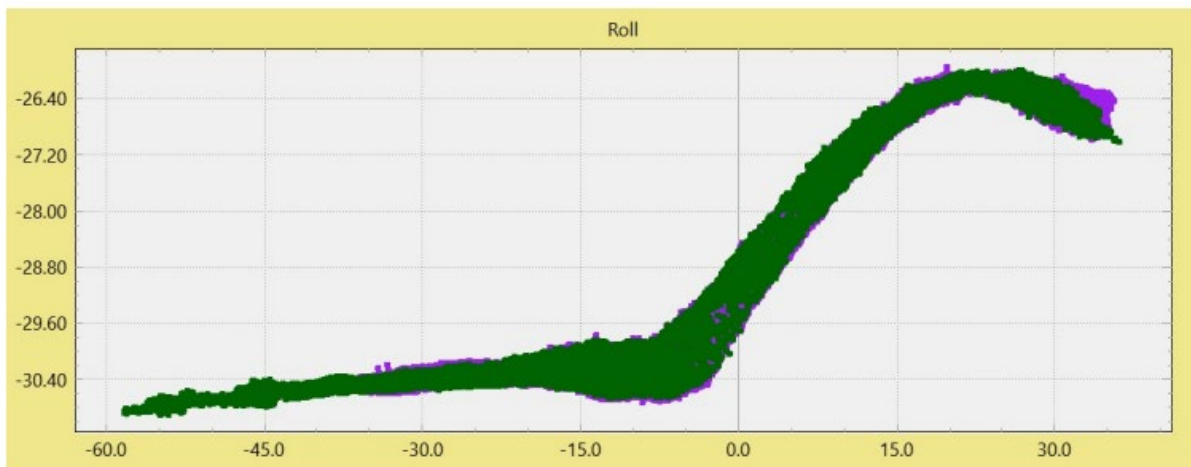
ACCURACY	
Average Error	2.041 cm/m2

WARNINGS	
The difference between the profile and the average sound velocity at the transducer is 1.2 m/s	
Sound Velocity beam angle correction is used	

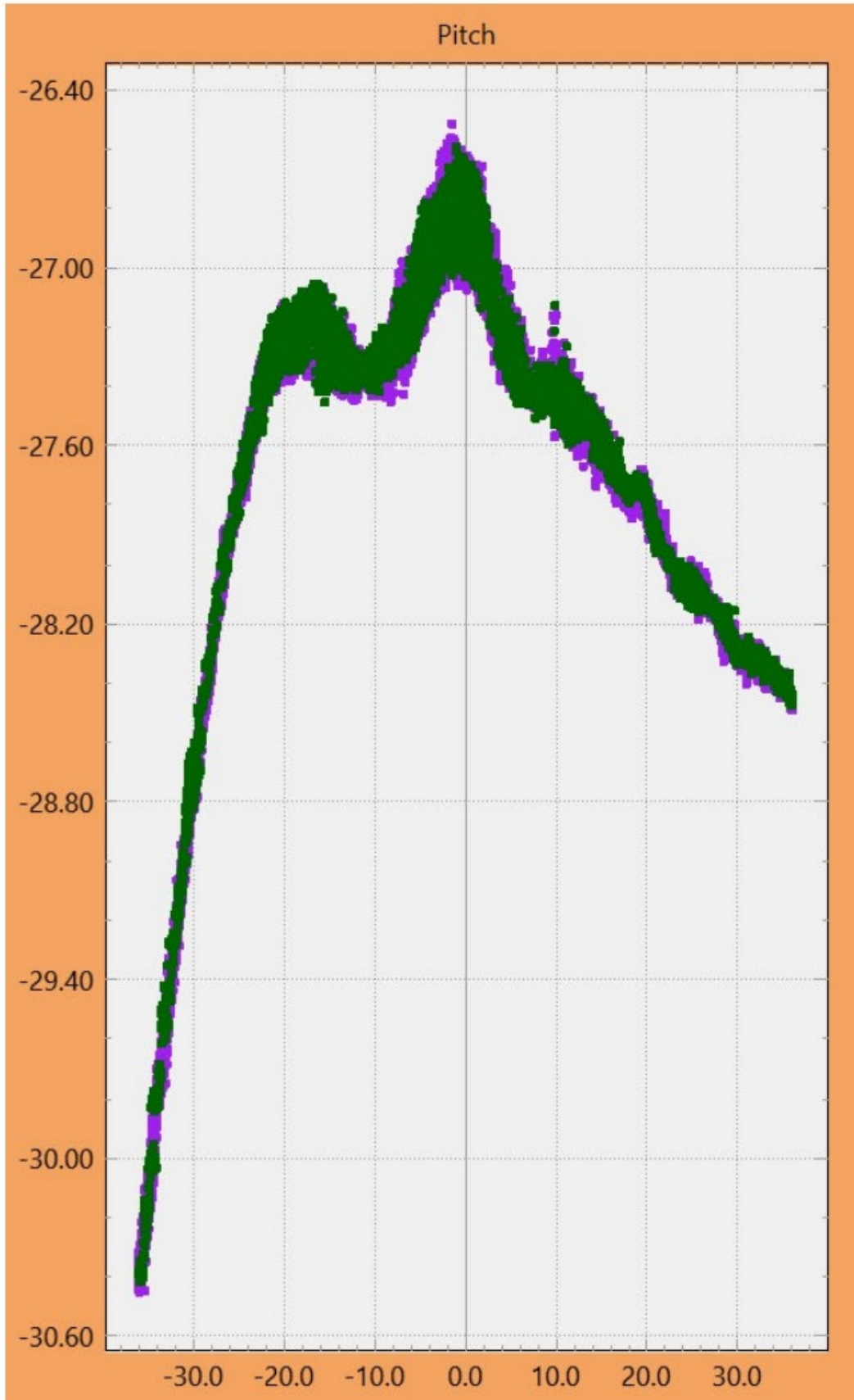
Chart View



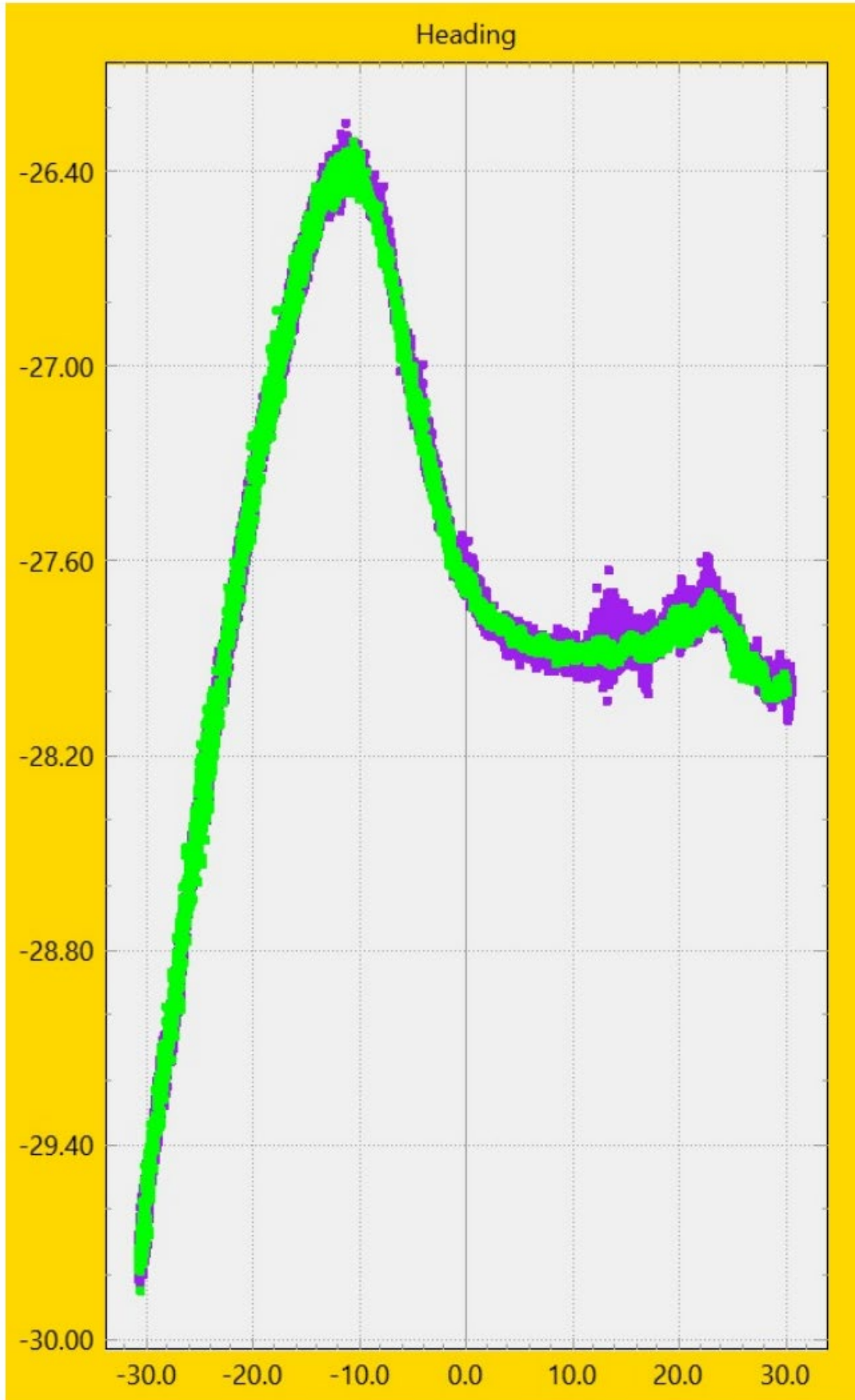
Roll Slice View



Pitch Slice View



Heading Slice View



Appendix C

Patch Test data collected 22/6/2024

AutoPatch (V2024.1.1.3) Calibration Report - 26 - 07 - 2024 14:52:31

TRANSDUCER ALIGNMENT CALIBRATION	
Current User	NAVISTAK1
Project Folder	D:/H23034/Autopatch
Number of Raw Files	8
Project	NRW Mussel Beds
Surveyor	JW
Job	H23034
Vessel	Pedryn

RAW FILE LIST					
Date	Start	End	Heading	Speed	File Name
22 - 06 - 2024	13:09:21	13:10:18	284.2°	2.2	Patch Test 1_20240622_140921.0001.bwxraw
22 - 06 - 2024	13:12:51	13:14:27	94.4°	1.9	Patch Test 1_20240622_141251.0001.bwxraw
22 - 06 - 2024	13:16:58	13:18:15	277.0°	1.9	Patch Test 1_20240622_141658.0001.bwxraw
22 - 06 - 2024	13:21:05	13:22:22	92.3°	1.8	Patch Test 1_20240622_142105.0001.bwxraw
22 - 06 - 2024	13:25:59	13:27:15	277.0°	1.6	Patch Test 2_20240622_142559.0001.bwxraw
22 - 06 - 2024	13:29:54	13:31:24	97.9°	1.8	Patch Test 2_20240622_142954.0001.bwxraw
22 - 06 - 2024	13:34:14	13:35:13	277.5°	2.4	Patch Test 3_20240622_143414.0001.bwxraw
22 - 06 - 2024	13:36:31	13:38:00	97.2°	1.8	Patch Test 3_20240622_143631.0001.bwxraw

Post-Processing Trajectory	
File:	Not Used

OFFSET LOCATIONS			
Description	Starboard[m]	Forward[m]	Up[m]
COG	0.000	0.000	0.000

COMPUTATION SETTINGS	
Positioning System	Norbit-Pos
Heading System	Norbit-MRU[Attitude]
Pitch/Roll/Heave System	Norbit-MRU[Attitude]
Height Mode	Use Only Position

SOUND VELOCITY PROFILE		
From Internal Records		
312 records		
Min Speed = 1501.95m/s	Min Cast Depth = 0.30m	Min Survey Depth = 24.70m
Max Speed = 1502.99m/s	Max Cast Depth = 31.22m	Max Survey Depth = 31.60m

MRU ALIGNMENT			
Name	Roll	Pitch	Heading

Norbit-MRU[Attitude]	0.000 °	0.000 °	0.000 °
Motion[Sensor1(grp 102)]	0.000 °	0.000 °	0.000 °

VALID DATA GATES		
	Minimum	Maximum
Depth	24.70	31.60
Sector	-50.20°	50.30°

ADJUSTMENTS
No Adjustments were made

DATA PAIRING & ROLL AREA SETTINGS	
Parameter	Value
Min. Roll-Pitch Overlap	80
Max. Heading Overlap	60
Line Heading Margin	30
Line Speed Margin	1
Roll Calibration Area Placement	Automatically, based on seabed features

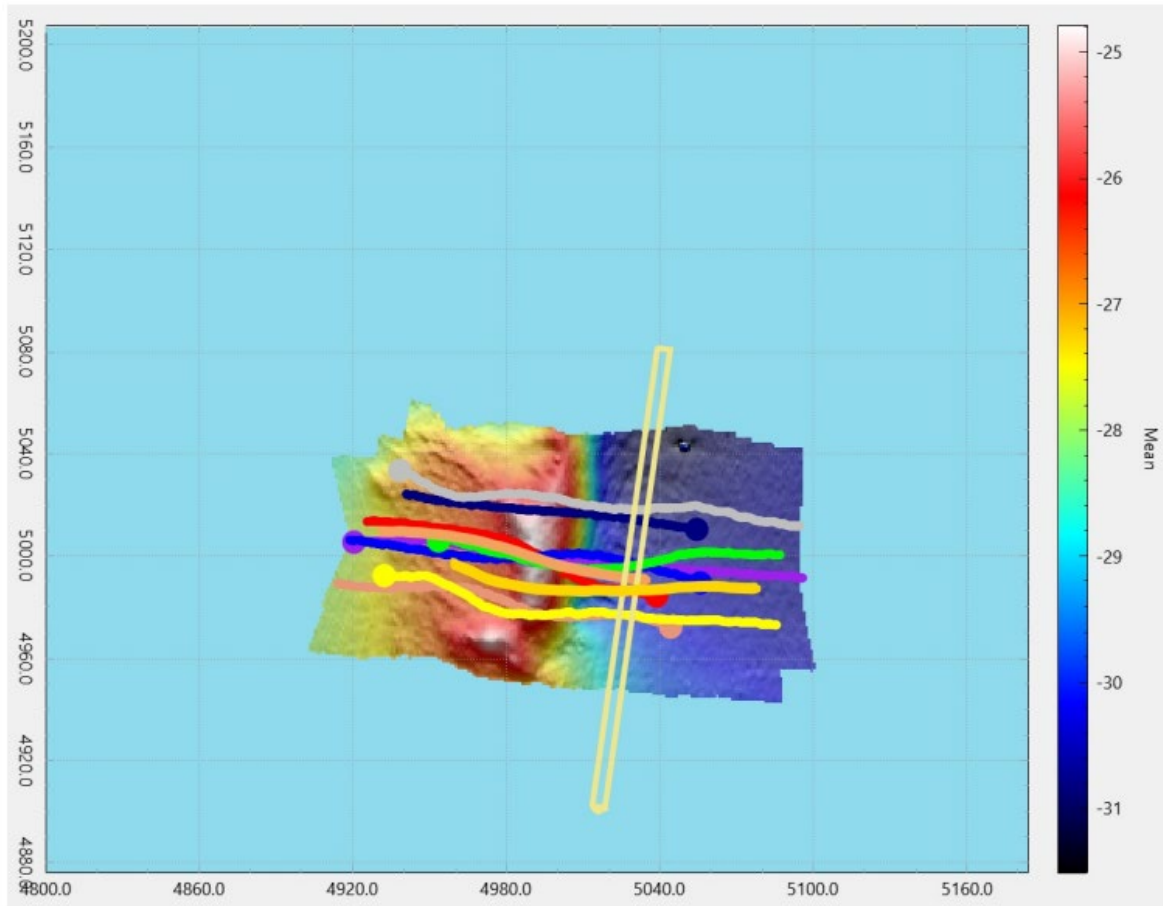
CALIBRATION OFFSET RESULTS					
Roll-Pitch	Hdg	Roll	Pitch	Heading	
1 - 2	4 - 8	-0.037°	0.05°	0.20°	
1 - 2	5 - 7	-0.039°	0.05°	0.11°	
1 - 2	6 - 8	-0.041°	0.05°	0.31°	
2 - 3	4 - 8	-0.021°	0.10°	0.30°	
2 - 3	5 - 7	-0.023°	0.10°	0.22°	
2 - 3	6 - 8	-0.023°	0.10°	0.27°	
5 - 6	4 - 8	-0.052°	0.11°	0.24°	
5 - 6	5 - 7	-0.057°	0.10°	0.05°	
5 - 6	6 - 8	-0.052°	0.12°	0.25°	
7 - 8	4 - 8	-0.046°	0.22°	0.28°	
7 - 8	5 - 7	-0.049°	0.21°	0.05°	
7 - 8	6 - 8	-0.044°	0.20°	0.36°	
	PRESET	-0.028°	0.19°	0.49°	
	AVERAGE	-0.040°	0.12°	0.22°	ADVISED MOUNTING ANGLES
	SDEV	0.012°	0.06°	0.10°	

MOUNTING ANGLE SIGN CONVENTION	
Roll	Positive when Transducer center beam points towards port
Pitch	Positive when Transducer center beam points towards bow
Heading	Positive when Transducer is rotated clockwise around vertical axis of vessel
Note: All angles are absolute w.r.t. the vessel reference frame	

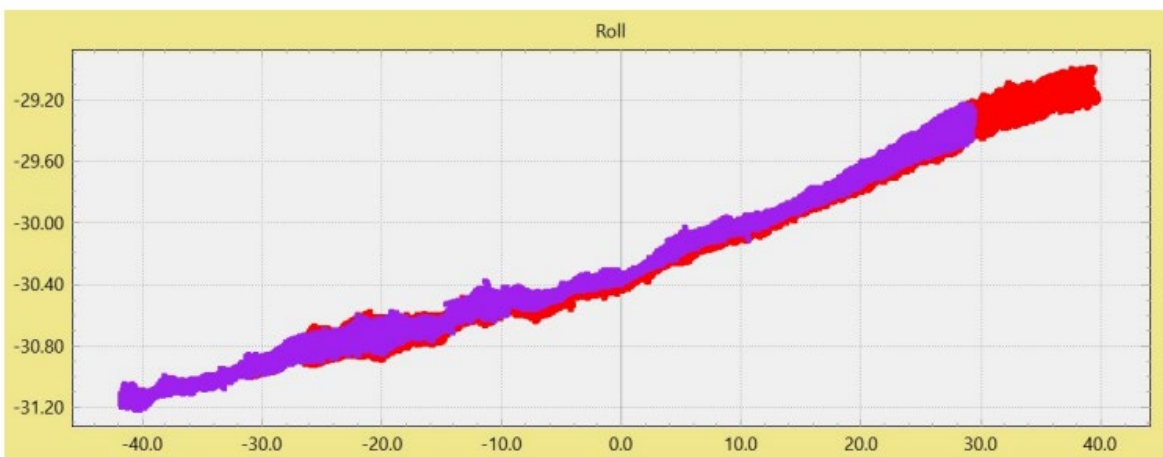
ACCURACY	
Average Error	2.073 cm/m2

WARNINGS
Sound Velocity beam angle correction is used

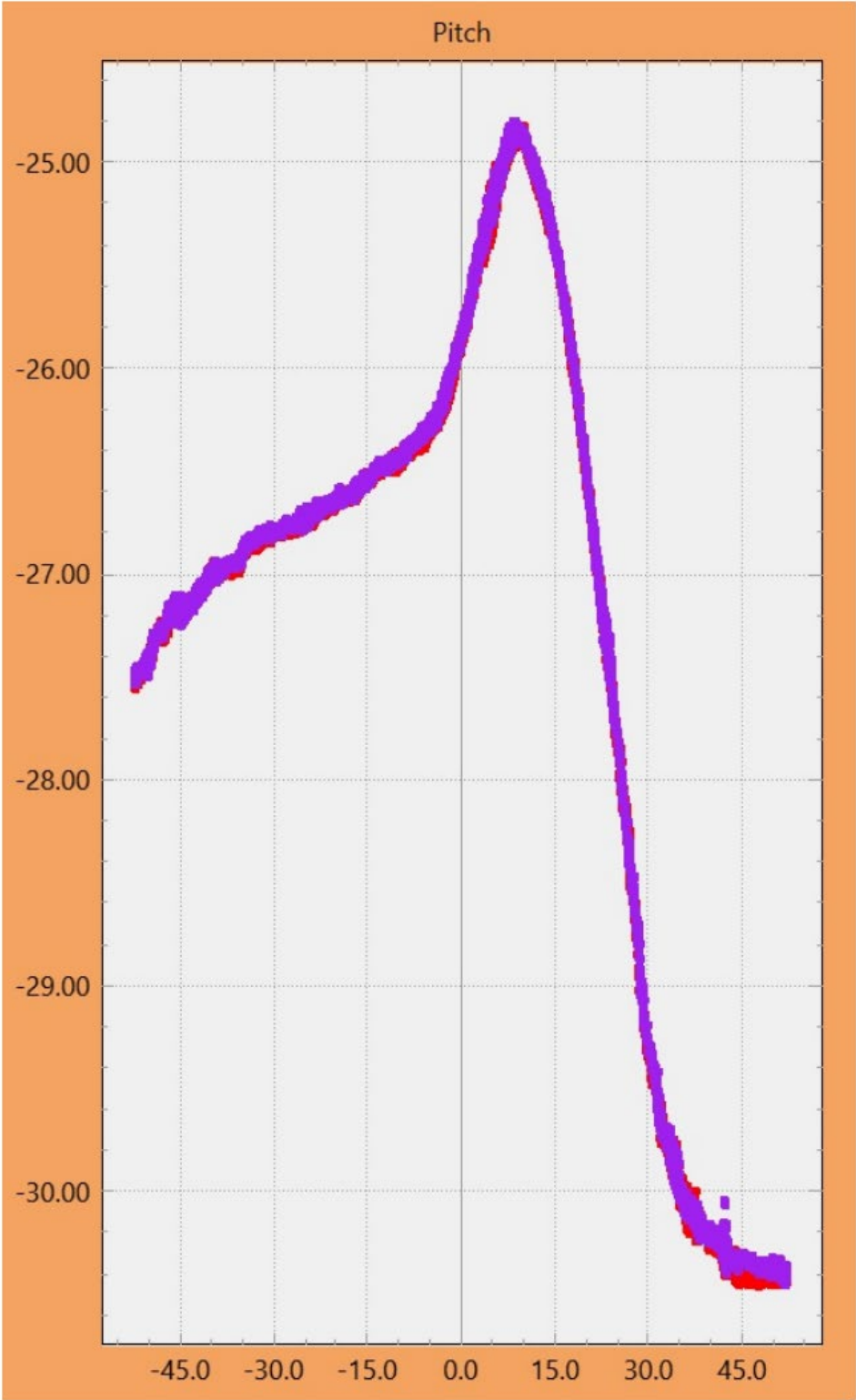
Chart View



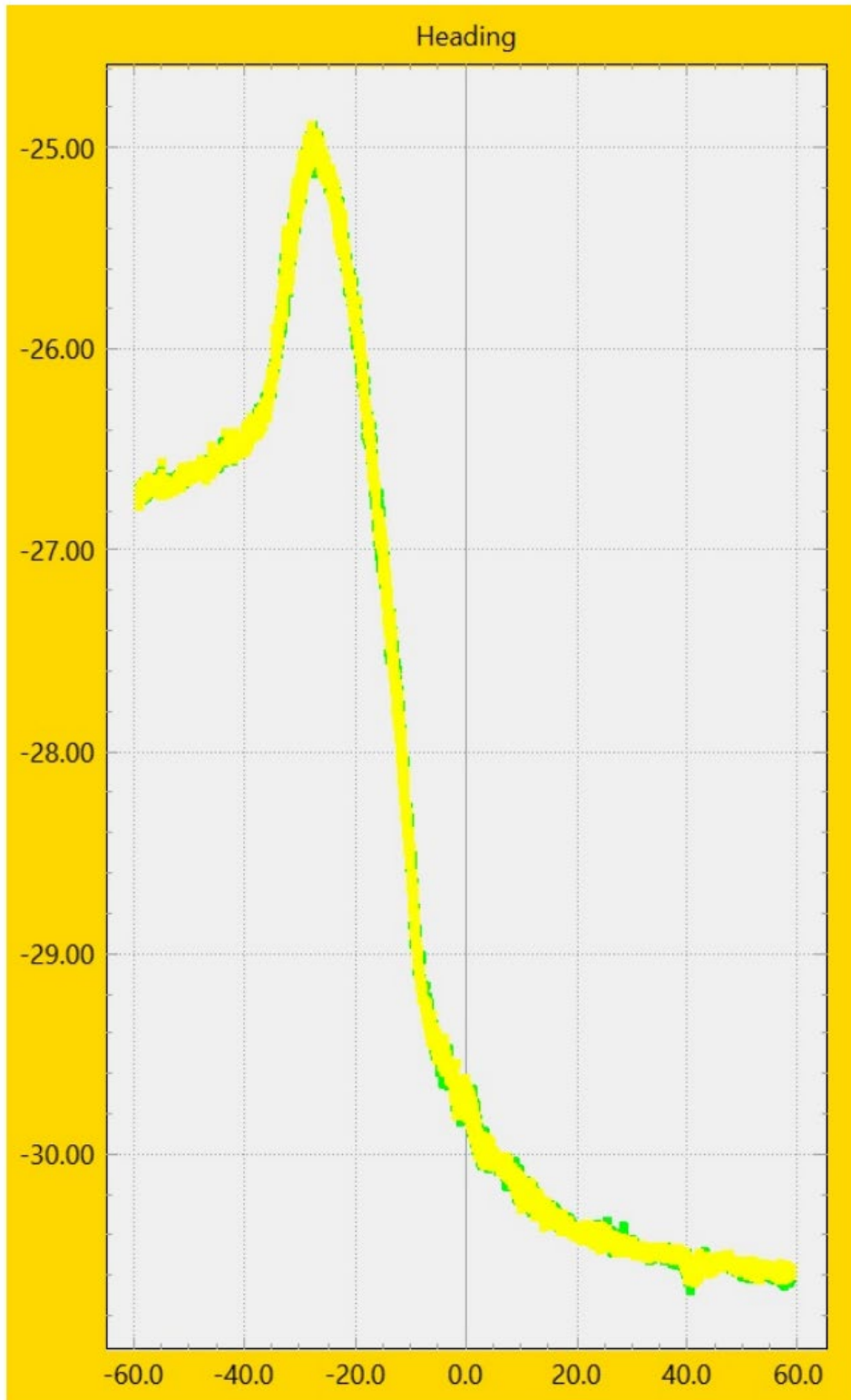
Roll Slice View



Pitch Slice View



Heading Slice View



Data Archive Appendix

Data outputs associated with this project are archived on server-based storage at Natural Resources Wales.

The data archive contains:

[A] The final report in Microsoft Word and Adobe PDF formats: NRW Evidence Report No. 851

[C] A series of GIS layers on which the maps in the report are based with a series of word documents detailing the data processing and structure of the GIS layers

[D] A set of raster files in ESRI and ASCII grid formats. (E.g. Backscatter Mosaic in GeoTiff .tiff, Full point cloud MBES data in ASCII text. xyz, Gridded bathymetry data in ASCII text. xyz)

Metadata for this project is publicly accessible through Natural Resources Wales' Library Catalogue <https://libcat.naturalresources.wales> (English Version) and <https://catllyfr.cyfoethnaturiol.cymru> (Welsh Version) by searching 'Dataset Titles'. The metadata is held as record no NRW_DS161323.

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