Sabellaria monitoring trial: summary report

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Sabellaria monitoring trial: summary report

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Dit onderzoek is uitgevoerd in opdracht van het MONS-programma. MONS vormt de kennisbasis voor het Noordzeeoverleg

NOORDZEEOVERLEG

Contents

1 Introduction

Rijkswaterstaat (RWS) has asked TNO to prepare, coordinate and evaluate a monitoring campaign on *Sabellaria spinulosa* (Ross worm) biogenic reefs in the Brown Bank (also known as Brown Ridge and Bruine Bank (in Dutch)) as part of the MONS program (MONS ID56, monitoring reef-building species [1]).

The interest for this species is its ability to create conspicuous reefs that stabilize the seabed and potentially increase biodiversity by providing a habitat for a multitude of other species. In the greater North Sea these reefs are recognized to be under threat and worthy of protection. The results of this study will help answering the questions (i) to what extent the Brown Bank is suitable for *Sabellaria* reef establishment and (ii) what is the value of *Sabellaria* in this region in terms of enhancing biodiversity. Insights from this study will help RWS to develop more effective policy regarding the protection of the North Sea ecosystem. The main interest is in finding relatively large patches (>~1m^2) of *Sabellaria* on the seabed surface, and hence less on finding buried or smaller reefs (<~1m^2).

The goal of the campaign was to acquire the data needed to:
- Evaluate the presence of *Sabellaria* reefs in the Brown Bank area and in Wind Farm Zone IJmuiden Ver (IJVER).
- Evaluate the biodiversity (content) of *Sabellaria* hotspots.
- Study the abiotic environmental conditions of areas with *Sabellaria* hotspots.

This report describes the trial preparation (Chapter 2), trial plan (Chapter 3), trial results (Chapter 4) and preliminary conclusions, in particular regarding the goals of the campaign (Chapter 5).

Acknowledgements
Special thanks to the captain and crew of the Arca who supported the preparation and execution of the monitoring campaign. Also special thanks to Oscar Bos (WMR), Mirjam Snellen, Qian Li & Sebastiaan Mestdagh (TU Delft), Peter Hermans (Deltares), Leo Koop, Karin van der Reijden and Jakob Asjes (RWS - WVL) for useful input that helped the preparation of the expedition.

2 Trial preparation

2.1 Introduction

The size of the Brown Bank (Figure 2.1) and the speed of surveying are such that a complete survey of the region would take around 1500 h (65 days) consecutive hours of sonar survey, excluding the required hours needed for ROV (Remotely Operated Vehicle) scans and grab sampling. Because of time and financial constraints, only a small percentage of the Brown Bank could be surveyed during two work weeks of monitoring. To decide on the most suitable sub-regions the following actions where undertaken:

- Existing maps of relevant abiotic environmental properties were loaded into a single GIS project file.
- Various experts who were involved in previous research on *Sabellaria* in the North Sea were interviewed.
- Literature on *Sabellaria* monitoring projects that used acoustic remote sensing was collated and reviewed.

An overview of the inventoried historical data is provided in Section 2.2. Key insights from the interviews and literature survey are described in Section 2.3. Finally, sub-regions with the highest chance of hosting *Sabellaria* reefs are described in Section 2.4.

2.2 Availability of historical data

Various public datasets were identified that contain relevant information about the Brown Bank and IJVER regions. These datasets were imported into GIS (ArcMap 10.8.1) such that the information could be used to (i) select sub-areas to survey in detail during the trial and (ii) enable geo-specific comparison against data acquired during the trial on board of the vessel. An overview of the obtained data is shown in **Table 1**. Figures of the datasets for the Brown Bank and IJVER are shown afterwards. The data is presented in the ETRS89 UTM (grid zone 31N) coordinate system.

Note on IJVER data: The IJVER area was surveyed in full-coverage with different geophysical methods by the company GEOxyz at a high lateral resolution (cell size of 1m). The data is available on request via RVO, the Netherlands Enterprise Agency. All sonar data is provided as processed GIS files (GeoTIFF format) but also in the raw sonar format, which enables a more detailed evaluation. The RVO data includes:

- Full-coverage multibeam echosounder (MBES) bathymetry and backscatter data (Figure 2.2), acquired with a Reason Seabat 7150 at a frequency of 350 kHz. The data was processed and gridded (cell size of 1m).
- Full-coverage side-scan sonar (SSS) data, acquired with an Edgetech 5000 at frequencies of 400 and 900 kHz. The data was processed and gridded (cell size of 1m).
- Grain size-analysis and fotos of 49 sediment samples for ground-truthing of the acoustic data. Samples were taken with a Van Veen sampler.

Note on Brown Bank data: to the knowledge of the authors, the entire Brown Ridge has not yet been surveyed in full-coverage at a high resolution. Several research expeditions have taken place in the Brown Bank where only specific locations were surveyed. Within the

DISCLOSE project (Distribution, structure and functioning of low-resilience seafloor communities and habitats of the Dutch North Sea), Delft University of Technology (DUT; acoustics), the University of Groningen (video) and the Royal Netherlands Institute for Sea Research (seabed sampling) surveyed the northern part of the Brown Bank in 2017 and 2019 [2] (Figure 2.3). They used a Kongsberg EM 302 MBES at 30 kHz and a R2Sonic 2026 MBES at 90 kHz, 200 kHz and 450 kHz to acquire bathymetry and backscatter data (example shown in Figure 2.4 and Figure 2.5). In addition, they used a Kongsberg Pulsar SSS with a frequency of 550 kHz and a range of 100 m. The MBES data is available as processed and gridded GIS files (GeoTIFF format). The acquired SSS data has not been processed by the TU Delft because of poor navigation. The raw SSS and MBES files can be obtained from the TU Delft if required at a later stage of the project. During the same trials, boxcores and video tracks were acquired. The coordinates and interpretations of the video tracks are available, as shown in examples in Figure 2.4 and Figure 2.5, whereas the box-core locations could not be obtained in digital format prior to the trial (data resides at DUT but can be obtained). Extensive *Sabellaria* reefs found in 2017 had decreased in extent and density by 2019.

Other information relevant for the monitoring campaign concerns:

- **Currents:** Figure 2.6 shows the primary current direction for the North Sea Region[1]. Information on measured current speed available from *waterinfo.rws.nl*. Examples of commercial products or services that provide spatiotemporal maps of the currents in the Brown Bank and IJVER regions are NLTides (available via agents of the "*Dienst der Hydrografie*") and SVASEK (*https://www.svasek.nl/model-research/).*
- **Visibility underwater**: The underwater visibility is expected to be as good as it gets in the North Sea at the time of the trial (up to 5 m visibility is likely; personal communication with RWS). However, big storms may significantly but only temporarily reduce visibility (<~2m).
- **Tides**: Forecast models available for tide prediction at *tide-forecast.com* and *waterinfo.rws.nl*.
- **Wave height and wind:** Forecast models available at ECMWF: the (i) mean wave direction and height of total swell and (ii) wind and mean air pressure at 10 m above sea level.

Sand wave migration:

- Table 2 provides an overview of offshore bedform characteristics and associated net migration velocities.

[1] https://www.eea.europa.eu/data-and-maps/figures/north-sea-physiography-depth-distribution-and-main-currents

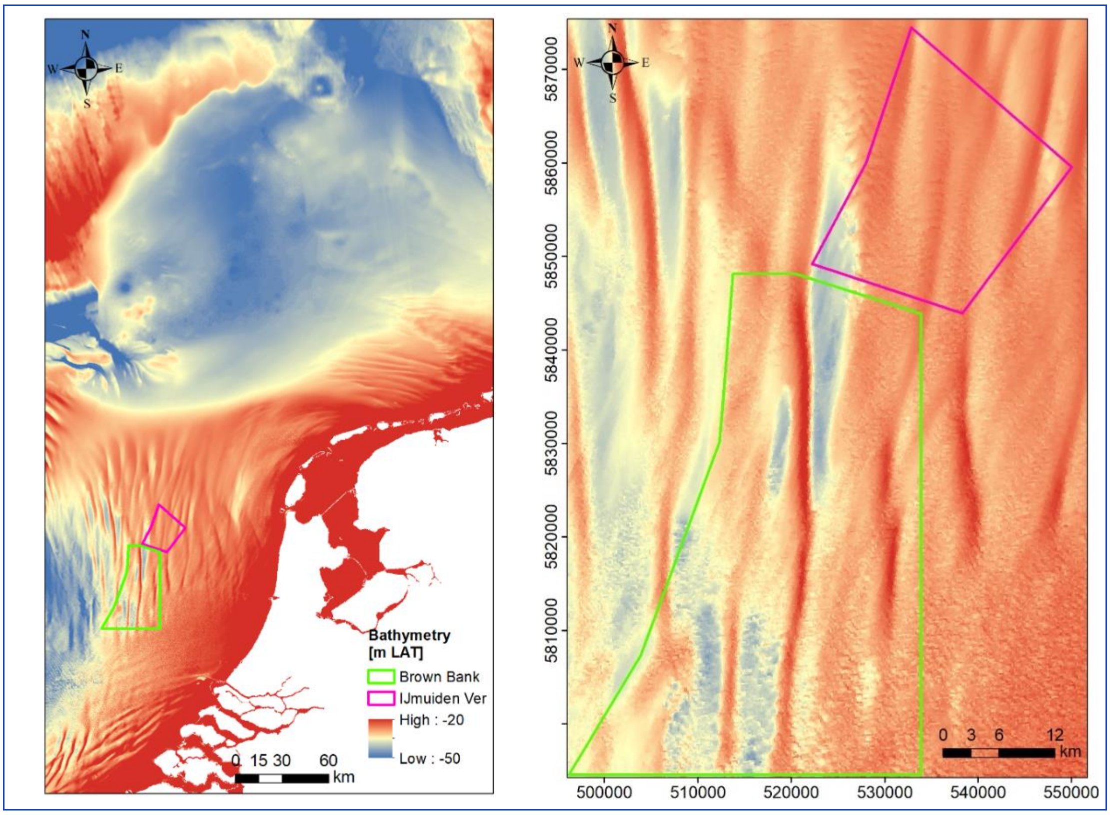

Figure 2.1: Bathymetry NCP and surrounding sea areas (left) and zoomed-in sections Brown Bank and IJVER (right), via EMODnet.

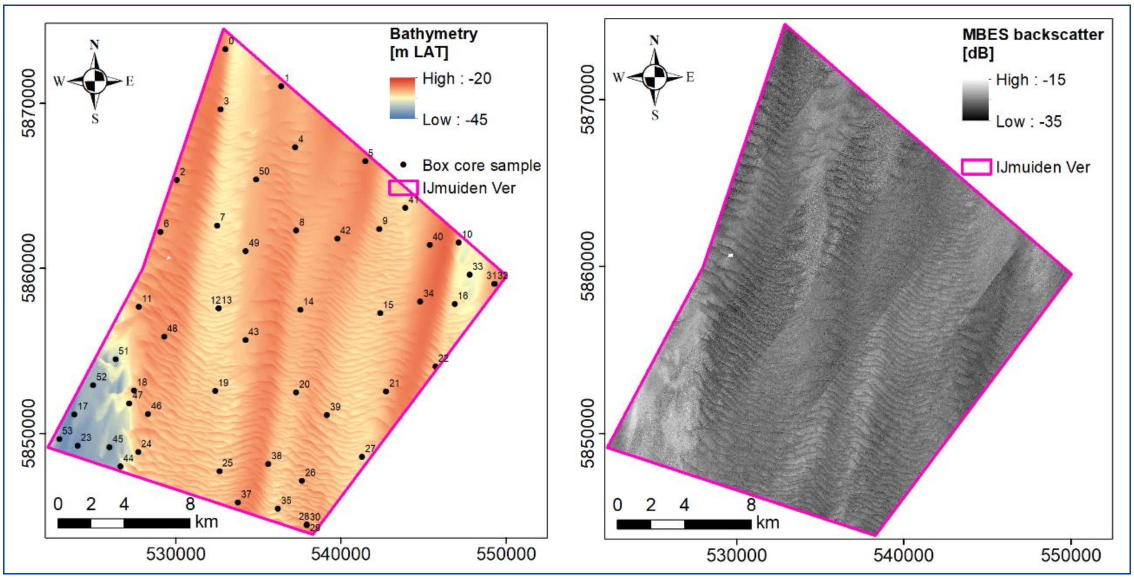

Figure 2.2: IJVER MBES bathymetry with sample locations (black dots) (left) and MBES backscatter (right).

Table 1: Existing data and data products useful for the monitoring campaign. NCS refers to the Dutch part of the North Sea.

Coverage	Data type [Unit]	Source	Resolution	Figure
North Sea	Bathymetry [m]	EMODnet [2]	~ 160 m x 160 m	Figure 2.1
NCS	5,7&16 class Folk sediment classification[-]	TNO – Geological Survey of the Netherlands (GDN) (not available online)	200 m x 200 m	Figure 2.7
NCS	Median grain size (d50) of the sand fraction (63-2000 µm) [µm]	TNO – GDN	200 m x 200 m	Figure 2.8
NCS	Mud content [% < 63 µm]	TNO - GDN	200 m x 200 m	Figure 2.8
NCS	Thickness of Holocene cover [m] Pleistocene subsurface layer [-]	TNO – GDN	No resolution specified, depends on data density and method. Source map published at 1:250,000.	Figure 2.9 Figure 2.10
NCS	Seabed shear stress [N/m^2] from the DCSM-FM model run by Deltares	Deltares [3]	1000 m x 1000 m	Figure 2.11
NCS	Probability *Sabellaria* occurrence [%] using random forest and logistic methods	Deltares [3]	178 m x 178 m	Figure 2.12
IJVER	Bathymetry [m]	RVO [4]	1 m x 1 m & RAW files	Figure 2.2
IJVER	MBES backscatter [dB]	RVO [4]	0.5m x 0.5m	Figure 2.2
IJVER	SSS backscatter [dB]	RVO [4]	Raw JSF	-
IJVER	Grab samples [-]	RVO [4]	49 Samples in area	Figure 2.2
Brown Bank	Bathymetry [m]	DISCLOSE [5], [6]	1 m x 1 m	Figure 2.3 Figure 2.4
Brown Bank	Backscatter [dB]	DISCLOSE [5], [6]	0.5 m x 0.5 m	Figure 2.5
Brown Bank	Video tracks [-]	DISCLOSE [5], [6]	1s	**Example in** Figure 2.5
Brown Bank	Grab samples.[-]	DISCLOSE [5], [6]	Unknown	-
Brown Bank	SSS backscatter (unprocessed)[dB]	Hydrographic Service [7]	Raw XTF	-

Table 2: Characteristics of offshore sandy bedforms. L denotes the wavelength, A is the amplitude, T is the time scale and c is the order of magnitude of migration [8].

Bed form	Related Flow	L [m]	A [m]	T	c
Ripples	Instant flow	~ 1	~ 0.01	h	~ 1 m/day
Megaripples	Storm surges?	~ 10	~ 0.1	Days	~ 100 m/year
Sand waves	Tide	~ 500	~ 5	Years	~ 10 m/year
Long bed waves	Unknown	~ 1500	~ 5	Unknown	Unknown
Tidal sandbanks	Tide	~ 5000	~ 10	Century	~ 1 m/year

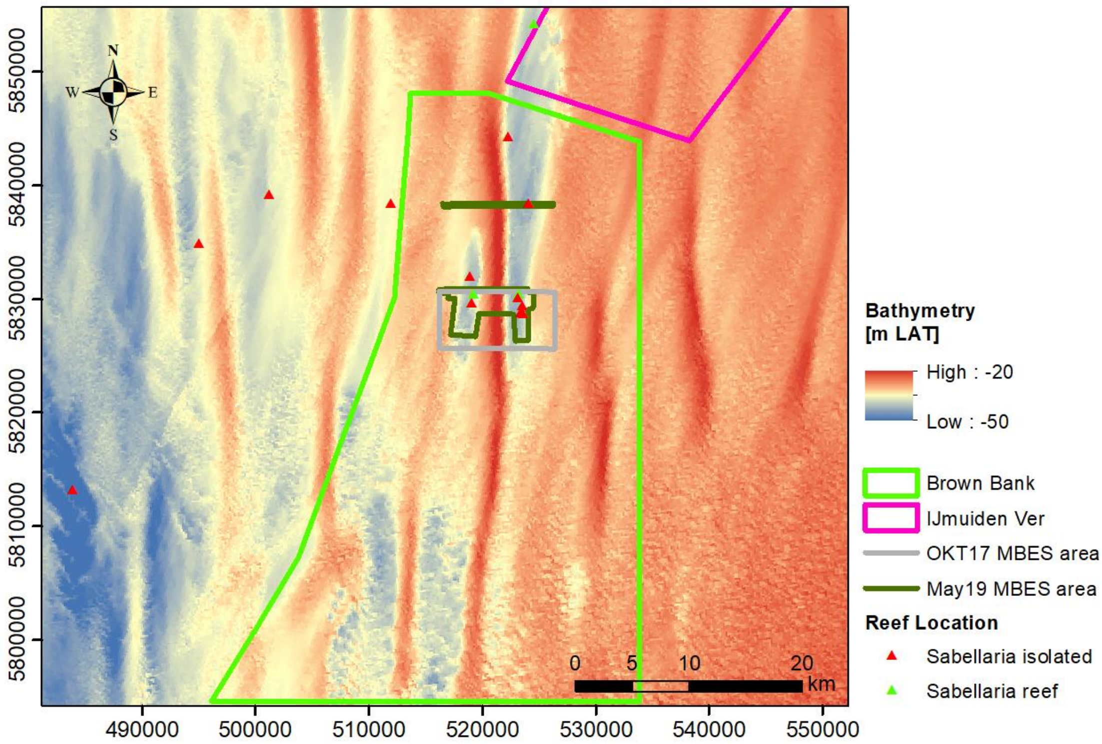

Figure 2.3: Brown Bank and surroundings, with outlines of DISCLOSE trial areas and locations where *Sabellaria* was detected (red markers) plotted on EMODnet bathymetry.

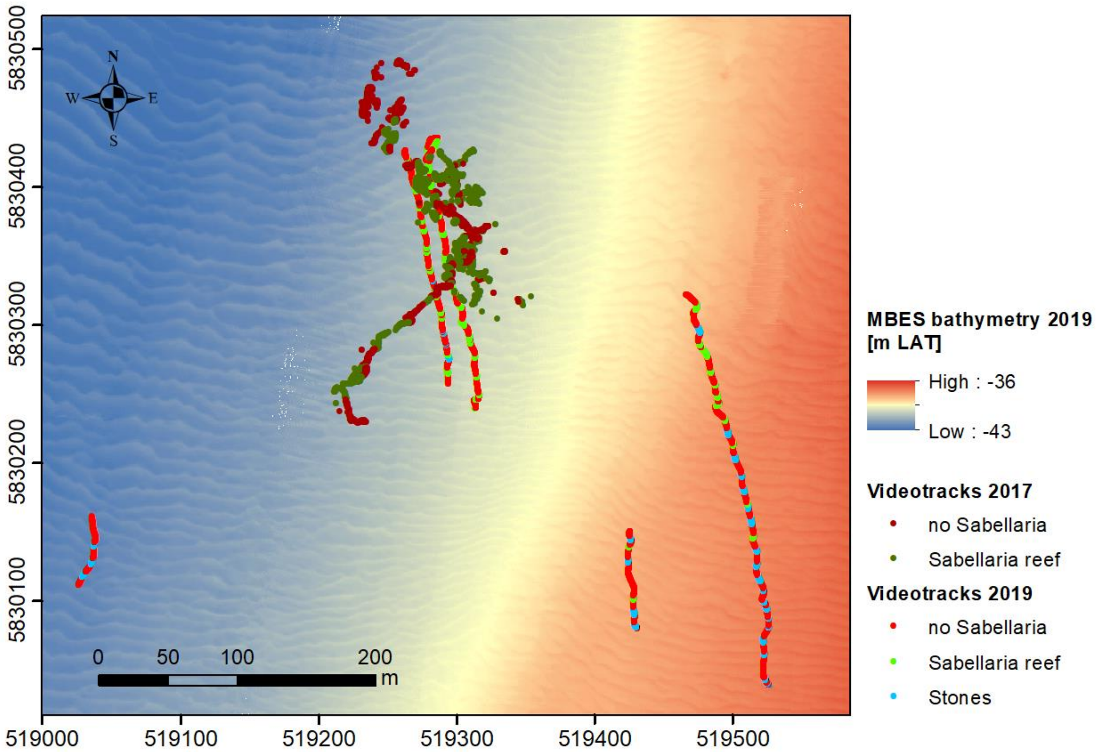

Figure 2.4: Example of DISCLOSE video recordings (2017 on top of 2019) plotted on high-resolution MBES bathymetry acquired in the DISCLOSE trial in 2019. Green dots show presence of *Sabellaria* reefs, and red dots show absence. In 2019 an additional class of stones (blue dots) was added.

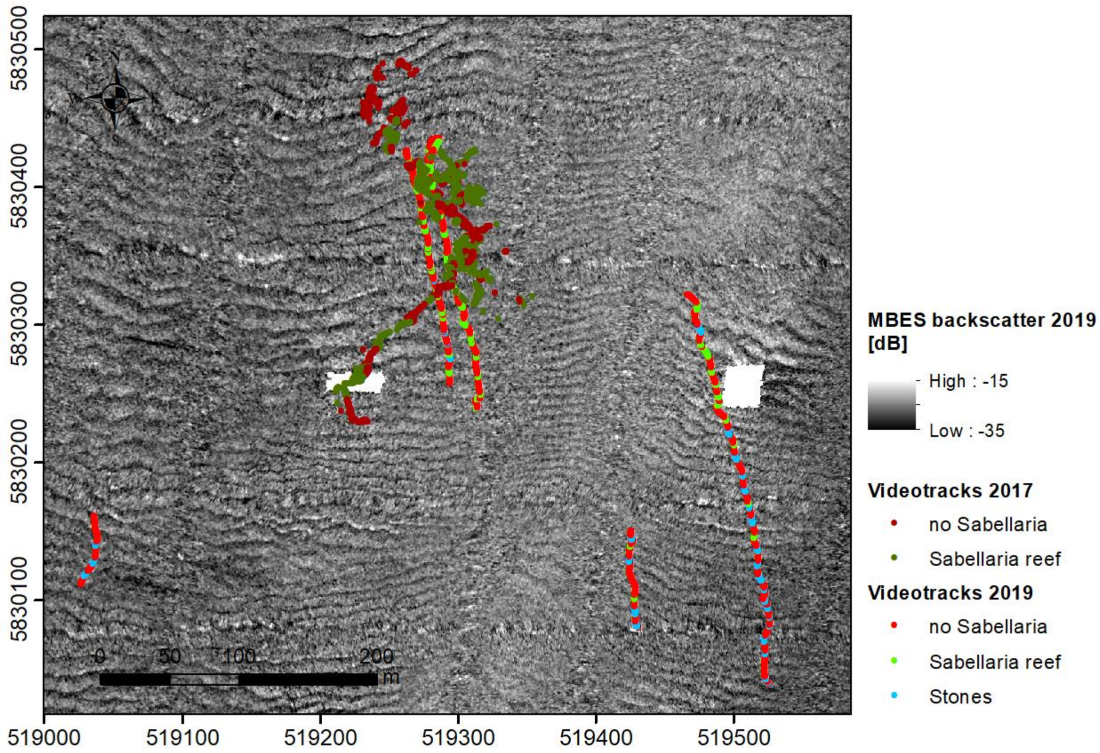

Figure 2.5: Example of combination of video recordings and high resolution MBES backscatter acquired with a Kongsberg EM302 at 30 kHz in DISCLOSE project in 2019. Green dots show presence of *Sabellaria* reefs and red dots show absence. In 2019 an additional class of stones (blue dots) was added. The white rectangular spots in the middle of the figure are data gaps and shouldn't be mistaken with the max backscatter value.

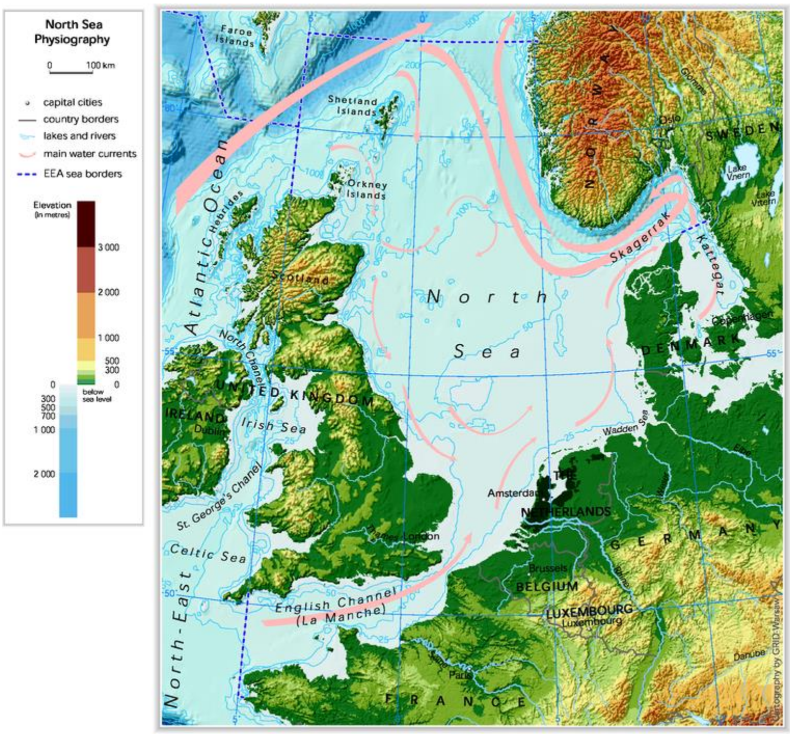

Figure 2.6: Overall water depth and main currents for the North Sea region and adjacent marine areas.

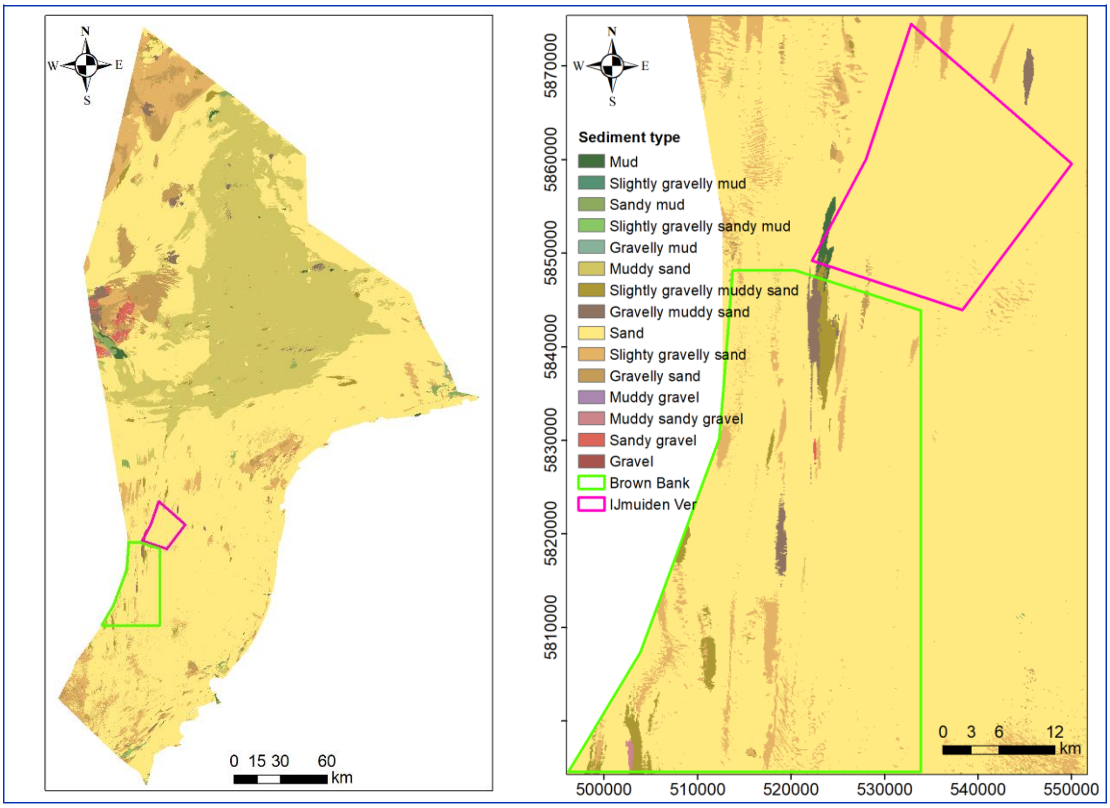

Figure 2.7: Folk 16 class of the NCS (left) and zoomed-in sections Brown Bank and IJVER (right). Folk 5 and 7 maps, with fewer classes, are available as well but not shown in the report.

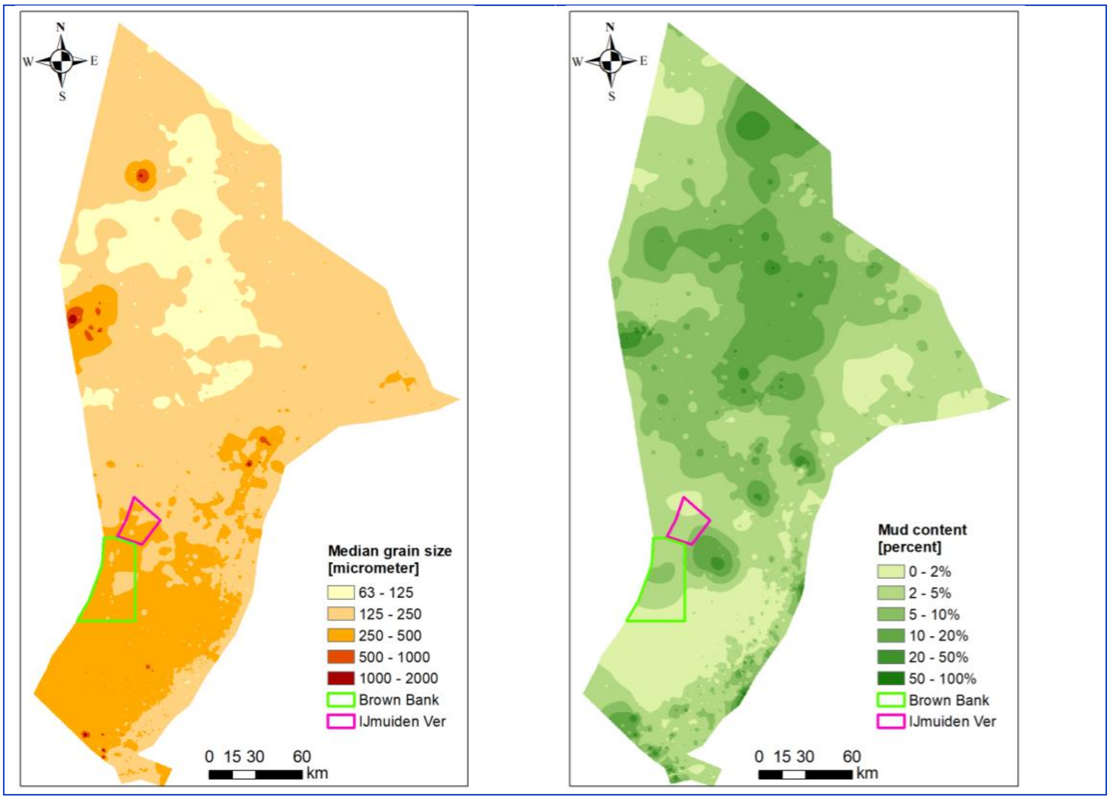

Figure 2.8: Median grain size (left) and mud content of the NCS (right).

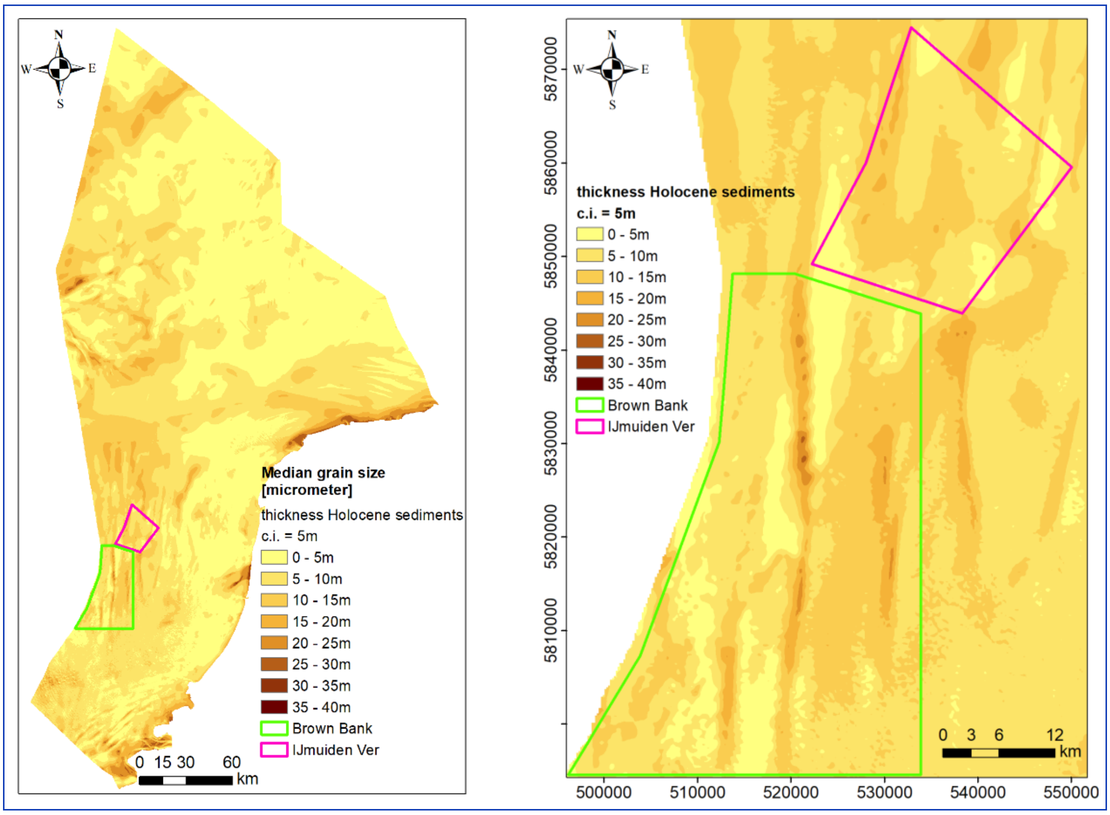

Figure 2.9: Thickness of Holocene cover of the NCS (left) and zoom-in sections Brown Bank and IJVER (right).

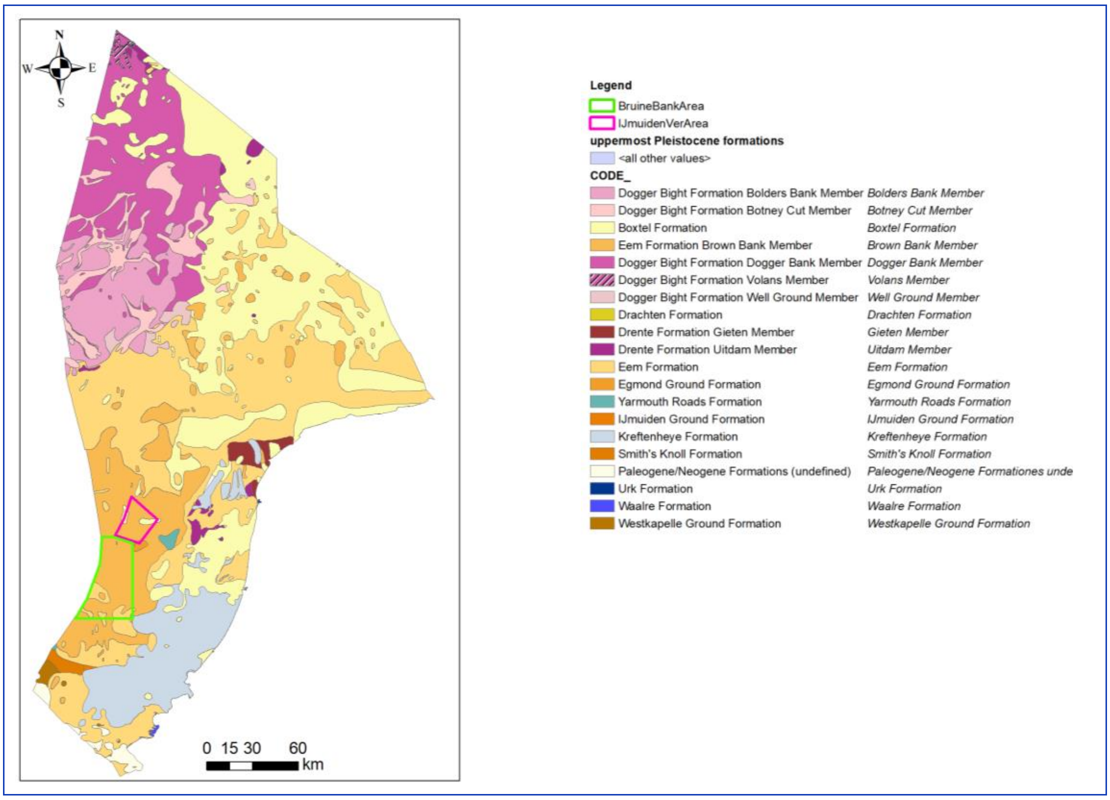

Figure 2.10: Top unit of Pleistocene subsurface sequence of the NCS (left) and zoomed-in sections Brown Bank and IJVER (right).

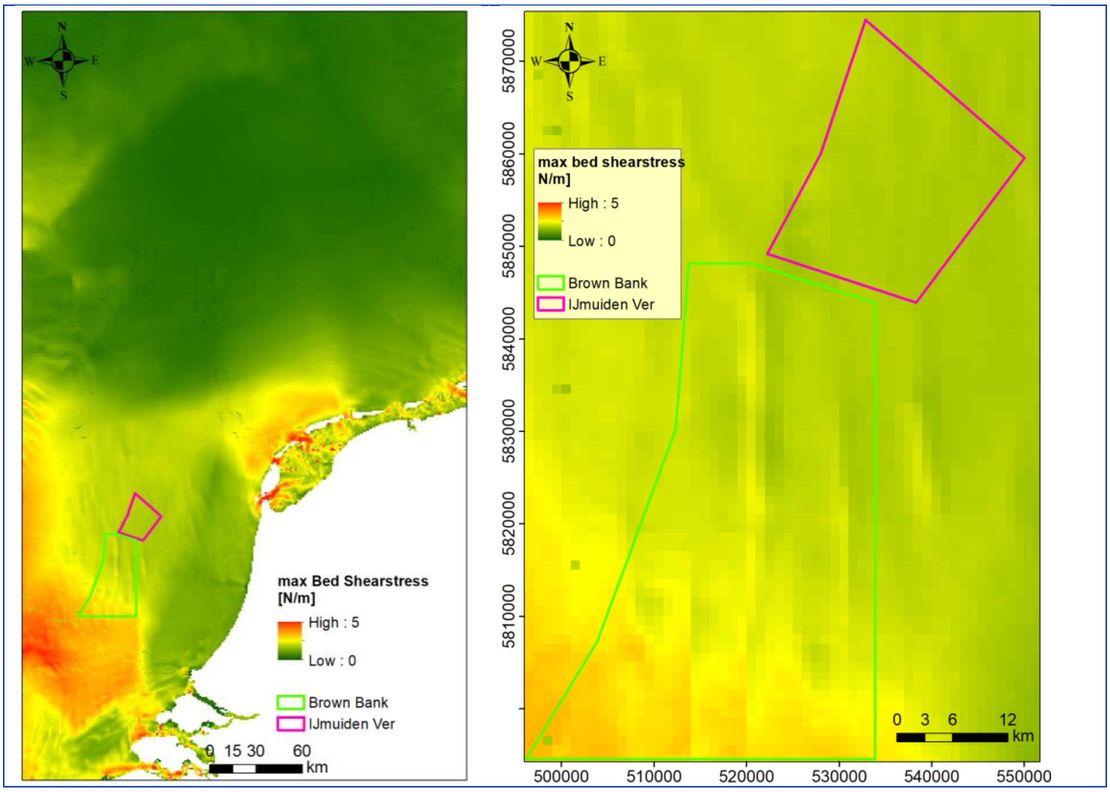

Figure 2.11: Seabed shear stress of the NCS (left) and zoomed-in Brown Bank and IJVER (right).

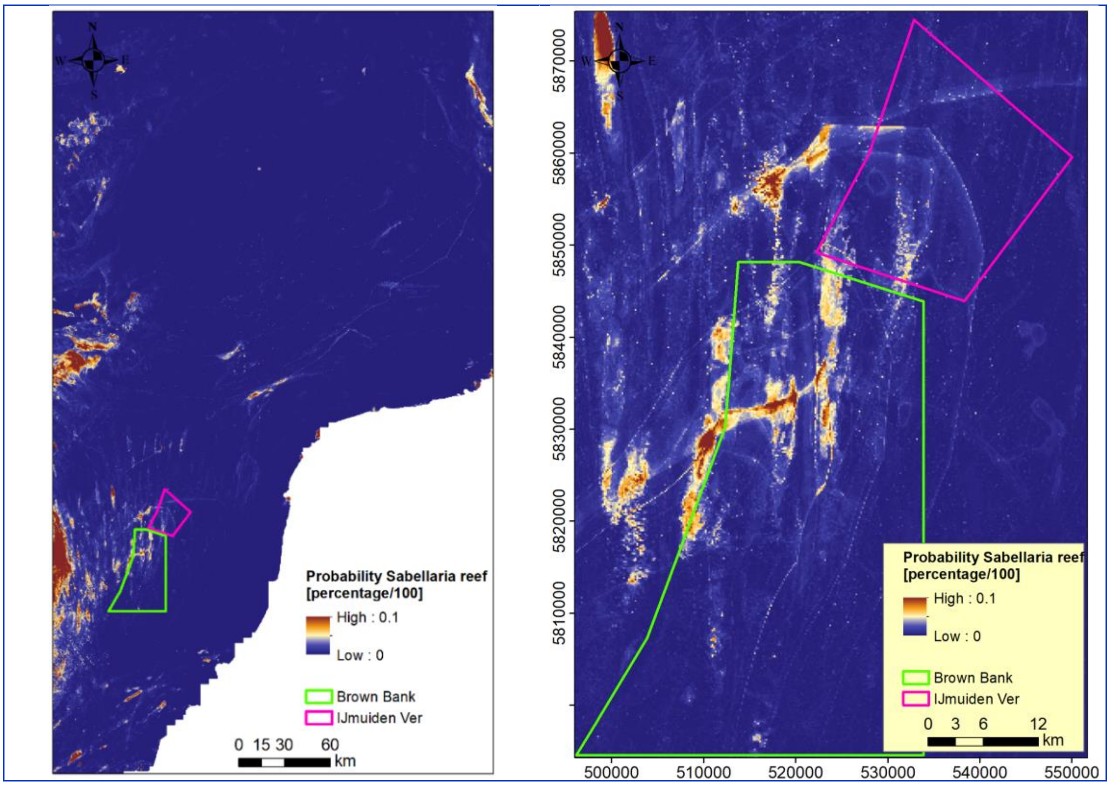

Figure 2.12: Modelled probability of *Sabellaria* occurrence for the NCS (left) and zoom-in sections Brown Bank and IJVER (right) using random forest. Results are also available for a logistic-based method, but these are not shown in the report.

2.3 Lessons learned from previous studies

As part of the preparation of the trial (i) various interviews were conducted with experts who participated in earlier *Sabellaria* monitoring campaigns and (ii) a literature survey was conducted. On the basis of these actions, the following insights, guidelines and hypotheses were identified:

- Tidal zones (dominant directions) and current strength are expected to influence the presence of *Sabellaria* due to its effect on sand particle suspension and seabed shear stress. The direction of the main current flow is SSW-NNE and NNE-SSW, where SSW-NNE direction is stronger. The Seabed morphology in the Brown Bank in combination with the main current direction and magnitude results in regions with spatially varying current speeds and sand particle suspension concentrations.
- The deep areas (troughs of sand banks) and the area where the bathymetry gently rises (lee side of tidal ridge SSW-NNE) are expected to have a higher chance of hosting *Sabellaria*.
- Up to this date Sabellaria was only found in the troughs of the sand banks [5]. Crest and slopes are expected to be less likely locations for significant *Sabellaria* presence
- In MBES images, spots of higher backscatter in the troughs of megaripples may be good indicators for the presence of *Sabellaria*. However, MBES backscatter doesn't allow a distinction between coarse material and *Sabellaria*. Therefore, SSS images allowing the detection of blotchy/patchiness patterns typical for *Sabellaria* are important.
- *Sabellaria* reef presence may be linked in part to bottom trawling, hence focus should not only be on sediment properties but also on morphological features. (In [5] it was argued that megaripples may. protect *Sabellaria* patches in troughs from bottom trawling).
- While morphology is likely relevant, also keep an open mind and consider the influence of other attributes (such as e.g. lithology, grain size, cohesion, turbidity, current direction,...). Disregarding these environmental parameters means potentially missing links that weren't observed before.
- *Sabellaria* is an opportunistic species with a relatively short lifetime. Patches come and go (few years lifetime and a year to build a reef). However, new patches tend to settle on older reefs.
- *Sabellaria* reefs are expected to be damaged by trawling [5], which has been extensive in both the Brown Bank and IJVER sub-regions.
- *Sabellaria* is expected to be guided by high bottom shear stress, hard substrate and the availability of mobile sand. Bedload of mobile sand is used as a resource to construct the reef structures.
- While the ross worm depends on suspended particles to build reefs, the mobility of the different types of megaripples also puts newly formed reefs at risk to burial, hence limiting the period over which the reefs can provide positive ecosystem effects. To assess the value of these reefs, the time period and area over which they can increase biodiversity needs to be constrained and understood.
- *Sabellaria* reefs have a positive effect on the ecosystem as the reefs provide shelter to benthic species which support the complete ecosystem bottom up. However, much remains unknown on the exact effect of the reefs on the ecosystem.

2.4 Selection of sub-regions

Seven sub-regions of interest (survey areas A, B, E, F and G) have been identified as areas with a high likelihood of hosting *Sabellaria* reefs and having sufficient historical data to help focus the search for the reefs during the two-week monitoring campaign.

<u>Survey areas A and B</u>
Survey areas A and B are chosen on the basis of DISCLOSE findings (see survey area A and B in Figure 2.13). Both areas overlap to a large extent with the surveyed area in the DISCLOSE project in 2017 and 2019. The reason for the high interest of this area is twofold: *Sabellaria* reefs were detected by existing video recordings, indicating the suitability of this area for their presence, and a third trial allows for a time-series investigation of *Sabellaria* evolvement and morphological variation. An example of ROV tracks with video recordings, given in Figure 2.4, shows the presence of *Sabellaria* reefs along the track with green markers.

<u>Survey area C</u>
Survey area C is selected to extend the survey areas A and B towards the south and to survey the crest of the sand bank. This survey area is more elongated in the W-E direction and therefore also allows us to sail longer track lines and reduce the number of vessel turns per covered area.

<u>Survey area D</u>
This survey area is primarily chosen to extend survey area A northward and to only cover the more promising trough of the sand bank where *Sabellaria* reefs were found during the DISCLOSE project. It is an optional survey area in case the data acquisition goes very smoothly and if findings during the trial show that it is valuable to extend area A.

<u>Survey Area E</u>
A preliminary desktop study using the MBES and SSS data acquired in the SW IJVER area has revealed an area close to the Brown Bank (see Figure 2.2) with features suggesting the presence of *Sabellaria* reefs (Figure 2.14). The low-frequency channel of the SSS shows the typical blotchy acoustic signature for *Sabellaria* reefs. This blotchy SSS pattern also corresponds to interesting elevated features in the bathymetry (and slope), which could reflect the presence of elevated *Sabellaria*. In addition, the high MBES backscatter close to these pattern indicates a flat seabed with hard substrate. Hard-substrate areas in the vicinity of megaripples providing sediment influx are a promising settling ground for *Sabellaria*.

<u>Survey Area F</u>
Survey area F was selected on the basis of DISCLOSE results. As shown in Figure 2.3, *Sabellaria* was solely found in the troughs of the sand banks and not on the more dynamic crests. Survey area F was placed in the widest part of the eastern trough. This makes it possible to sail longer W-E track line while extending narrow swale area D northward. It would allow a better supported conclusion about the suitability of the entire trough for hosting *Sabellaria*.

<u>Survey Area G</u>
This area was chosen to cover an additional and also unexplored trough of the Brown Bank. It is around 30 km from the previously found locations of *Sabellaria* and provides additional insights about the distribution of *Sabellaria* in the entire Brown Bank region.

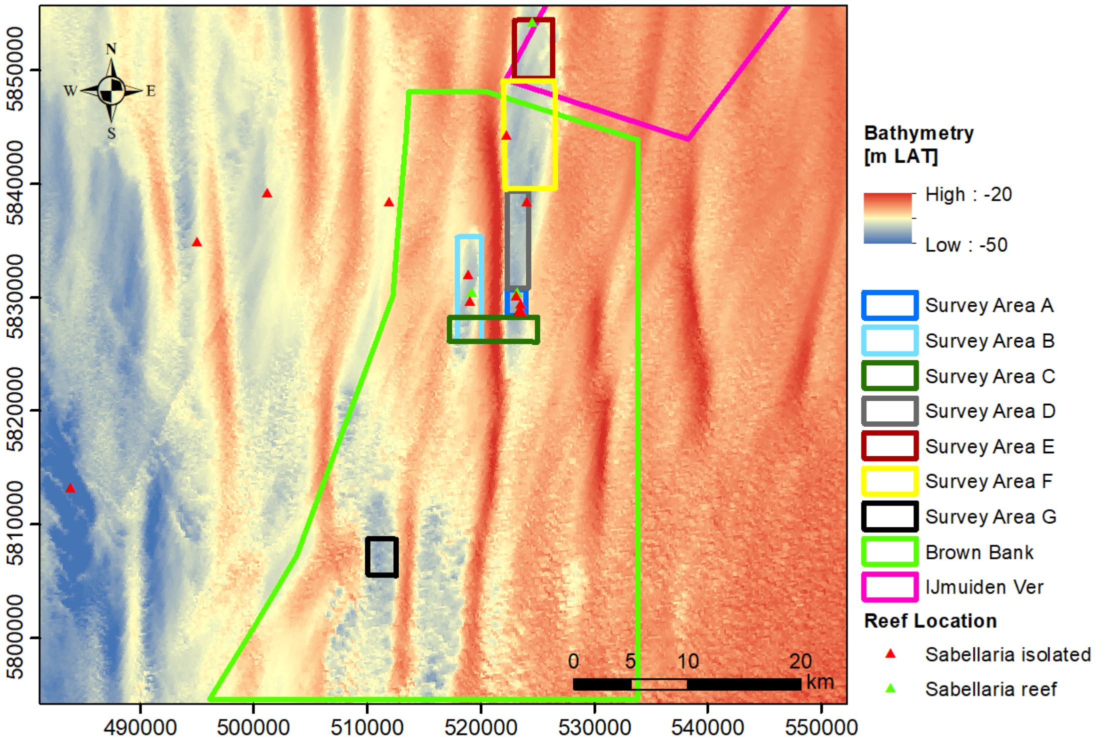

Figure 2.13: Overview of selected main survey areas in the Brown Bank and IJVER regions.

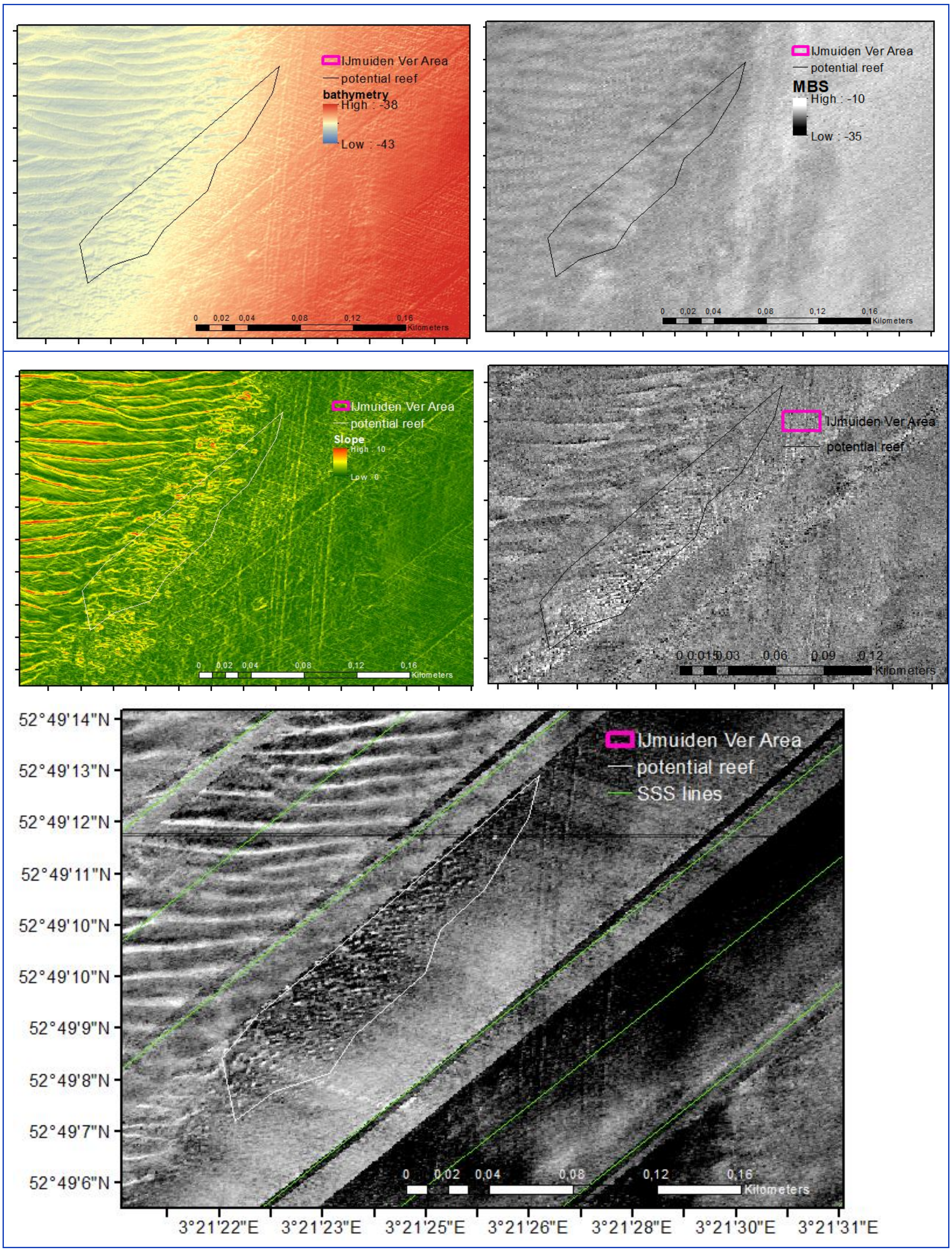

Figure 2.14: Selected area in IJVER (SW-NE outline) that could potentially contain *Sabellaria* reefs. This example region is located in survey area E. (Top left) MBES bathymetry, (Top right) MBES backscatter mosaic, (Middle left) MBES bathymetry slope, (Middle right) SSS high-frequency backscatter mosaic and (bottom) SSS low-frequency backscatter mosaic.

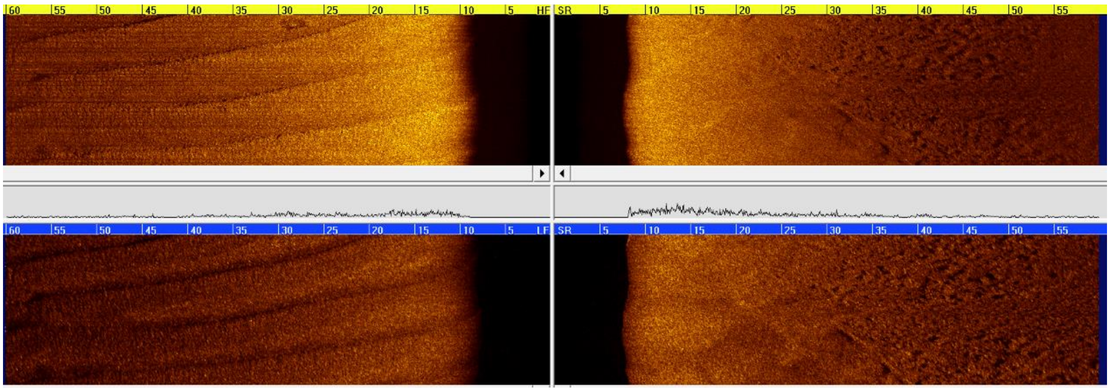

Figure 2.15: SSS waterfall display showing the typical *Sabellaria spinulosa* pattern (right side). The image is from the same location as the outlined section in Figure 2.14.

3 Trial plan

3.1 Introduction

This chapter outlines the trial plan, describing the hardware and software used, data management approach, crew responsibilities, safety measures, list of experiments and monitoring strategy.

3.2 Hardware

The following hardware is available on the vessel MS Arca, used for the monitoring campaign and provided by RWS:

- A hull-mounted Kongsberg EM 2040C dual head MBES, operating between 200 and 400 kHz. It is operated via the QPS acquisition software Qinsy.
- A Klein 5000 SSS (Figure 3.1), operating at 455 kHz, towed via a winch and cable behind the Arca and operated using Klein acquisition software. The SSS has a wing improving stability and making it possible to maintain a constant flying height above the seabed. Positioning of the SSS is done using cable length or USBL (ultra-short baseline, a method of underwater acoustic positioning.
- A Kongsberg EA440 single-beam echosounder (SBES) with a dual frequency of 24 kHz and 210 kHz.
- As a positioning system, the Septentrio AsteRx-U Fg GNSS receiver, with correction of Fugro Marinstar G4+ for the PPP solutions.
- A CTD-probe to measure electrical conductivity, temperature and pressure for sensor calibration, deployed by a crane (Figure 3.2).
- A SVP (Sound Velocity Probe) to measure the sound speed profile in the water column
- Boxcorer for seabed sampling (Figure 3.2).
- One acoustic locator which can be connected to the ROV, SSS or boxcorer.
- SSS and MBES acquisition computer (fixed stations from RWS).

A Saab Seaeye Panther Remotely Operated Vehicle (Figure 3.3) maintained by Bluestream is available for the visual inspection of the seabed and of benthic species present on the seabed. The ROV is equipped with:

- A high-resolution camera SUB-C 4k resolution which is placed on a pan-and-tilt unit on the front top of the ROV. The lighting is placed at the sides of the camera.
- No Doppler velocity log for keeping is present on this model; hence, positioning is done manually.
- Horizontal station keeping is ensured using proper trimming of the ROV mass lower in centre of gravity; no INS (Inertial Navigation System) used, to allow 360 degrees of orientation.
- A forward looking sonar for obstacle avoidance.
- A compass for determining the ROV heading.
- A pressure sensor for computing the ROV depth.
- An altimeter for determining the ROV flying height.
- An acoustic locator connected to the USBL of the vessel.

Packing list TNO:
- One laptop per staff member and one screen for data processing and interpretation, required software (described in Secction 3.3) for data processing on TNO computers;
- 2 2TB hard drives;
- Safety shoes.

Packing list Waardenburg Ecology (WE):
- Laptop & hard disk for data storage;
- PPEs (Personal Protective Equipment);
- GoPro + light + holder for on boxcorer **(not used).**

Packing list Eurofins (EF):
- Backup boxcorer, sieves;
- Jars for storing macrozoobenthos, formalin, labels;
- Jars for storing sediment samples;
- Laptop;
- PBMs.

Figure 3.1: Klein 5000 SSS, operating at 455 kHz, and attached wing.

Figure 3.2: CTD-probe (left) and boxcorer (right).

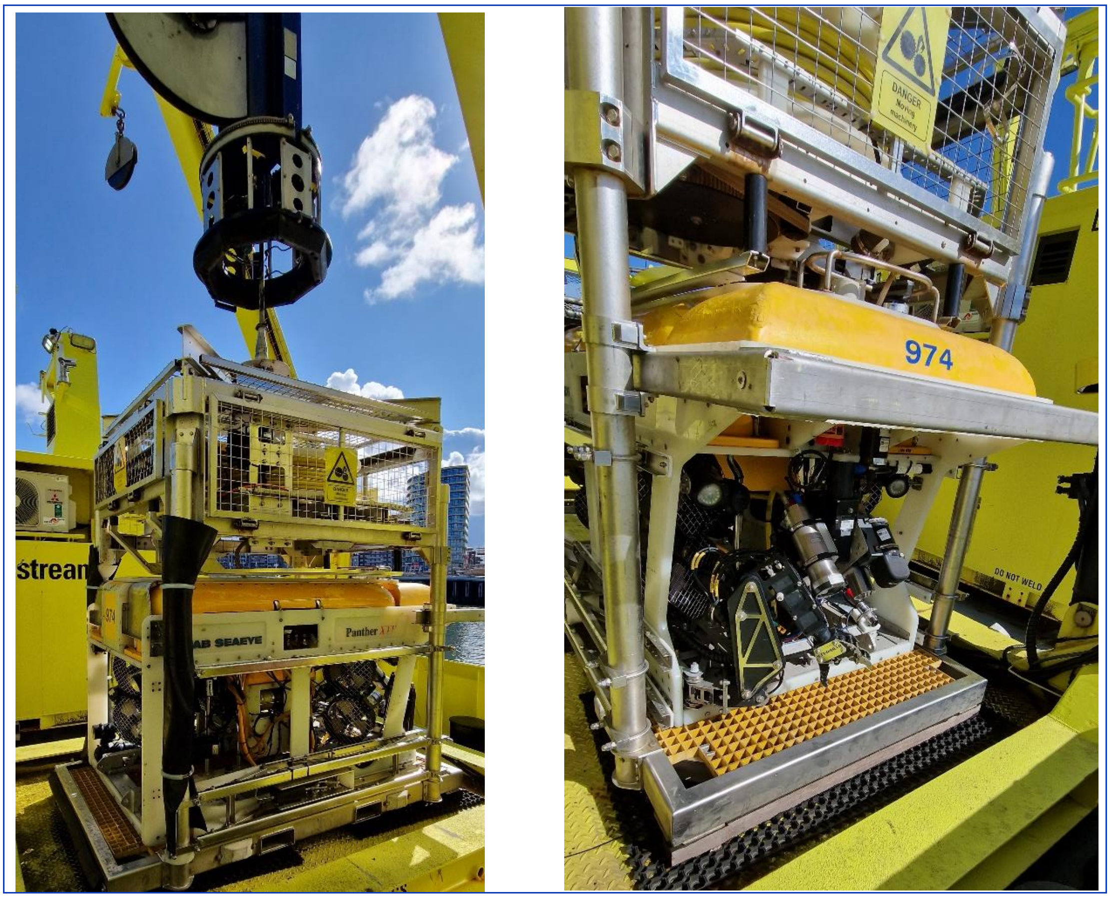

Figure 3.3: Sab Seaeye ROV.

3.3 Software

The following software is available for the trial:

Acquisition software:

- Acoustic transponder: attached to SSS, boxcorer & ROV.
  - File output: ROV and boxcorer: log files with position and depth; SSS: position and depth integrated into towfish position via acquisition software Sonar Pro.
- MBES: Qinsy (QPS) provided by RWS, installed on MS Arca survey desktop.
  - File output: Storage in .DB and .QPD files generated by the Qinsy acquisition software. The storage of both bathymetry and backscatter data is enabled.
- SSS: Klein acquisition suite provided by RWS, installed on MS Arca survey desktop and TNO laptop.
  - File output: Storage in .SDF (Klein format) and XTF (standard format) files.
- SBES: Acquisition software provided by RWS, installed on MS Arca survey desktop.
  - File output: Storage in .SEGY (standard seismic file format) files.
- ROV: Realtime video labelling software provided by RWS, installed on MS Arca survey desktop.
  - Usage: used to create video overlays and .xlsx export logs in real-time.
  - File output: 4K .mp4 video files, .xlsx log files.

Processing Software

- MBES bathymetry: Qimera (QPS) provided by TNO, installed on TNO laptop.
  - Usage: reading bathymetry data, ray-tracing (i.e. signal propagation), georeferencing, filtering, mosaicking, visualisation, export.
  - File output: QPD (point cloud, metadata), GeoTIFF (gridded bathymetry map).
- MBES backscatter: FMGT (QPS) provided by TNO, installed on TNO laptop.
  - Usage: reading backscatter data, attenuation and gain compensation, beam pattern correction, angular-response correction, slope correction, georeferencing, mosaicking, export.
  - File output: GeoTIFF (gridded backscatter map).
- SSS: Sonar Pro provided by TNO, installed on TNO laptop.
  - Usage: Allows very quick visualisation of SSS backscatter in a waterfall display. However, does not allow more advanced processing.
  - File output: PNG.
- SSS: Sonar Wiz provided by RWS, installed on TNO laptop.
  - Usage: reading SSS backscatter, georeferencing, layback correction, bottom tracking, gridding, export.
  - File output: GeoTIFF and GeoPNG.
- MATLAB scripts.
  - Usage: survey planning, computing sound-absorption coefficient.
  - File output: /.
  - File output: coordinates and values.
- ArcGIS Desktop provided by TNO and installed on TNO laptop.
  - Usage: plotting (overlaying) gridded sonar data, computing bathymetry derivatives, accurately georeferencing SSS data, selecting suitable ground-truth locations, plotting acquired ground-truth data.
  - File output: PNG.

3.4 Data management

During the trial, TNO takes the lead in the data management. The following activities are part of the data management strategy:
- A *"master .xlsx spreadsheet"* is maintained during the trial. It contains an overview of the completed tests.
- All tests acquired during the trial are checked for completeness and a data quality check is done to ensure the logged data meets the expected quality.
- A backup of the raw and processed sonar and video data is made on a secondary hard disk to minimize the risk of data loss.
- All sonar data remains on the MS Arca while transitioning from the first to the second survey week.
- All team members keep notes of important events during the trial. TNO takes responsibility to collect the relevant notes.

3.5 Crew overview and responsibilities

The following crew from TNO, WE and EF is present during the trial:
- **First trial week:** Joël Cuperus, Angela Dekker, Timo Gaida, Cecile van Stappen.
- **Second trial week:** Joël Cuperus, Rianna Vlierboom, Timo Gaida, Bas Binnerts.

Regarding responsibilities:
- Timo is responsible for guidance of the SSS and MBES data acquisition (hence communication with the RWS survey team) and for processing and interpreting the SSS and MBES data. This work is supported by Cecile and Bas.
- Joël is responsible for the ROV analyses and general communication to the MS Arca crew.
- Angela or Rianna is responsible for the boxcore sampling.

Project management supporting trial execution from shore: Helga van der Jagt (WE), Lies Leewis (EF) and Daniele Piras (TNO).

3.6 Safety measures

The following safety precautions are taken:
- The safe deployment of all devices depends on the weather conditions. In particular, operating the SSS, ROV and boxcorer requires safe working conditions on deck of the MS Arca. Safe working conditions are defined by the MS Arca personnel.
- The crew is in possession of an RWS-compatible safety and health certificate.
- The crew gets a familiarization training on the MS Arca upon boarding, and acts in compliance with the RWS-prescribed safety procedures.
- The crew wears the required PBMs when needed.
- An RI&E (risk inventory and evaluation) is produced by WE.
- As the boxcorer is a potentially dangerous instrument, the experienced WE\EF + RWS crew takes care of deployment, recovery and decoupling of the kettle. Sampling is the responsibility of WE\EF. The hazardous chemicals formaldehyde and borax are used on board. A safety leaflet for each chemical is available. The chemicals are only used by WE/EF staff using safety goggles and gloves, and sample conservation is done outside or in a vent.

3.7 List of experiments

Table 3 shows the list of experiments conducted during the trial, indicating the date, goal, sub-area and sensors used. A complete list of all boxcore samples and ROV tests can be found in Appendix B. Note that during the preparation of the trial, only the areas and generic monitoring strategy were detailed. The list of planned experiments is therefore the same as the actual, completed experiments. The location of sub-areas is shown in Figure 4.1. Information about the acquired data per experiment and area is given in Table 4.

Table 3: Concise overview of experiments conducted during the two-week monitoring campaign. Area Bsub indicates a small area located in area B.

#	Date	Goal	Sub-Area	Sensors
1	21 Aug	Calibration line	A and B	MBES+SSS
2	21/22 Aug	Map area, validate SSS and MBES, revisit DISCLOSE area	A	MBES+SSS+ROV+BOX
3	22 Aug	Optimize SSS settings and deployment strategy	A	SSS
4	22/23 Aug	Map area, validate SSS and MBES, revisit DISCLOSE area	B	MBES+SSS+ROV+BOX
5	23/24 Aug	Map area, validate SSS and MBES, validate sonar pattern in IJVER	E	MBES+SSS+ROV+BOX
6	24 Aug	Optimize SSS settings on detected *Sabellaria* reef	B	MBES+SSS
7	28/29 Aug	Map area, validate SSS and MBES, investigate additional sand-bank trough	G	MBES+SSS+ROV+BOX
8	29/30 Aug	Map area, validate SSS and MBES, extend DISCLOSE area to the north	F	MBES+SSS+ROV+BOX
9	30/31 Aug	Map area, validate SSS and MBES, achieve full-coverage of one sand-bank trough	B	MBES+SSS+ROV+BOX
10	31 Aug	Highly detailed SSS mapping of area with elevated *Sabellaria* reefs	B (Bsub)	SSS

3.8 Monitoring strategy

In this section the monitoring strategy is detailed. This strategy serves as a guideline because a certain amount of improvisation and flexibility is usually required in field trials. Lessons learned during the trial need to be incorporated and the plan needs to be adaptive to deal with setbacks (bad weather, equipment failure, human error).
The highest priority for the start of the trial is to find acoustic reef indicators in the sonar data (SSS and/or MBES) and validate to what extent these indicators represent *Sabellaria* reefs, using ground-truthing from ROV video recordings. As soon as this is established, the following activities are prioritized:

- Acoustically map the distribution of *Sabellaria* in the identified sub-areas.
- Further verify the validity of the acoustic indicators using the ROV video recordings.
- Obtain boxcores with sediment-entrained benthos from areas with a high *Sabellaria* density to assess the biodiversity gain of *Sabellaria* presence.
- Obtain boxcores in areas with distinct acoustic backscatter patterns to link the backscatter strength to associated sediment type.

For safety reasons, the strategy is to do the acoustic survey (MBES and SSS) during the night and to use daylight conditions to do the ROV video tracks and box-coring, in 12-hour shifts. Depending on the success of the methods and on metocean conditions a prioritisation of activities is made every day and adapted if needed. Decisions are made with the full team. In the morning, the TNO, WE and EF crew use maps made with processed sonar data to make a plan for the ROV tracks and boxcore locations, focussing efforts on areas where the sonar data shows features that are expected to be indicative for *Sabellaria* presence.

Additional notes regarding the sonar data acquisition:

- A CTD (Conductivity, Temperature and Depth) measurement is taken before and after the survey during the first day to evaluate potential variations in the water parameters. If variations are present, whichhave a significant effect on the sound absorption, this schedule is kept. The sound absorption needs to be quantified for optimal MBES backscatter processing. A SVP is taken before the start of every sonar survey. If significant changes of the sound speed are expected, typical sound speed artifacts are observed in the bathymetry data or the SVP sensor mounted on the MBES head shows significant variation (typically 2m/s) more SVPs should be taken.
- The acoustic data is acquired by RWS surveyors in collaboration with TNO. The data processing and preliminary interpretation is carried out by TNO on board of the MS Arca. After a certain number of sonar data files have been acquired, the data is copied to TNO laptops to carry out the processing. While the copied data files are being processed, RWS surveyors will continue to acquire MBES and SSS data.
- The survey and sonar (MBES, SSS) settings are provided in the Appendix A.
- It is recommended to switch on the SBES in areas of interest, and to store the data, since it provides additional information, in particular where buried structures may be present just below the seabed.

Additional notes regarding the ROV video data acquisition:

- The USBL system provides the location of the ROV with an accuracy of up to a few m, which is good enough for the ROV pilot to navigate to the georeferenced hotspots of interest as identified in the sonar data provided by TNO. After reaching the starting point of a predefined set of points on the seabed, the ROV pilot navigates the ROV as accurately as possible from the starting to the end point following the predefined transect as shown on a navigation chart.
- The WE\EF crew takes responsibility for the analysis of the camera feed. Locations are registered by the Cruise leader of the Rijksrederij, which manages, crews and maintains specialized vessels and makes them available to RWS.
- The RWS vessel needs to be stationary positioned on the up-current side to avoid the risk of the ROV tether getting stuck in the propellor of the vessel.
- The max current speed at which the pilot can still effectively control the ROV is ~1.8 knots. As the current speed can be higher in the designated area, the operation of the ROV is limited to periods when the current doesn't exceed this value.
- Keep the speed of the ROV between 0.18 and 0.35 knots to ensure good image quality (avoid image blurring by moving too fast). A sailing speed of 0.27 knots is ideal.
- Start the transect when the ROV is flying stable above the seabed.
- Straight tracks against the current are preferred as these ensure the best visibility as disrupted seabed sediment will disperse behind the ROV, not beneath it.
- In case of strong currents, the navigation of the ROV will get increasingly compromised; minimising the tether length will significantly improve manoeuvrability. Under such conditions, very long track lines will require the ship to be relocated multiple times. A max tether length of 25-30 m is recommended.

- Data management for the ROV runs is done using an Excel file that is automatically generated during real-time logging, by a manually filled .xlsx (by WE\EF) filled in on board and by storing all videos on a hard disk. Regarding the video capture of the ROV track an overlay is added to the video image, containing the:
  - Location name and transect (Dive) number;
  - Position (using EPSG 4258, i.e. ETRS89);
  - Date (dd/mm/yyyy) and time in UTC (hh:mm:ss);
  - Heading (degrees);
  - Depth below water (m) and height above seabed (m).
- A first analysis of the video is done in real-time by WE\EF during the survey to locate the margins of observed *Sabellaria* reefs, with mapped extents of *Sabellaria* allowing (i) successful box coring of the *Sabellaria* patches and (ii) proper calibration of the visually detected *Sabellaria* in the SSS data during the trial.

A detailed analysis of the video data will be done post-trial. The following classification scheme has been decided upon.
Habitat characterisation according to the Wentworth scale:
- Sand[2] type
  - Sand/silt with <25% shell/gravel coverage;
  - sand/silt with 25-50% shell/gravel coverage;
  - sand/silt with >50% shell/gravel coverage;
- presence of stones (6-25 cm);
- presence of boulders (>25 cm);
- presence of peat.

Occurrence of *Sabellaria*, aligning with [5]:
- Height
  - flat (≤5 cm);
  - elevated (>5 cm).
- Coverage
  - low-coverage reef (<20%);
  - medium coverage (20-50%);
  - high coverage (>50%).

furthermore, other characteristics are noted:
- presence of *Lanice* conchilega;
- presence of *Loimia* ramzega.

If the quality of the video images is poor, only presence of *Sabellaria* is noted.

A 5 seconds fixed time window will be apprehended for the classification. Only detections within laser lines are considered. It is important to note that the ROV pilot steers towards *Sabellaria* patches within the camera view, and hence that the detection results cannot be directly used to map the arial percentage cover with *Sabellaria*.

[2] Sand here implies fine to coarse Sand wrt Wentworth classification scheme; as visual inspection does not allow for accurate discrimination between sand sub categories (boxcore analysis is used for this)

Additional notes regarding the box coring:

- No more than 60 sediment samples can be analysed during the two weeks of expedition time. The following procedure is adopted in line with RWS procedures[3]:
  - A boxcore is taken.
  - The water on top is gently taken off.
  - Pictures are taken of both the top view (including reference scale) and a sliced side view. When taking the picture, add a scale on top of the boxcore for post-analysis scaling of features.
  - For each boxcore, a 500 mL jar is filled with the top few centimetres of the sample.
    - If a few centimetres are not enough to fill the required amount for the grain-size analysis a thicker interval can be subsampled. In general the amount depends on the coarsest particle in substantial proportion and varies from 100 g for 2 mm to 500 g for 10 mm [9].
    - However, if layering exist, sediment from multiple layers shouldn't be mixed.
    - If a thin veneer of mud covers a coarser (sand or gravel) layer, the mud layer and coarse layer should be subsampled separately.
    - If sediment layering exists, take another sample from a second layer and take a photo of the layering.

No more than 10 macrozoobenthos samples can be analysed. If *Sabellaria* reefs are found, the focus is on taking benthos samples from these locations. The RWS protocol is followed (RWSV 913.00.B200). For a sample to count as a zoobenthos reef, it is important that it is actually reef-like[4]. Pictures need to be taken of the sample. The aim of the macrozoobenthos samples is to gain insights in biodiversity of *Sabellaria* reefs.

Locations of both samples types are registered by the Meetleider Rijksrederij. Pingers are attached to the boxcorer to get exact sampling positions under water using the RWS USBL system. Data entry for the boxcorer will be done by WE\EF, listing pictures, sample depths, locations, times, redox layer depth[5] and other relevant specifics.

Since large-scale MBES backscatter data is acquired, which is a good indicator for variation in sediment composition, the box coring is also used to ground-truth grain-size variability suggested by the backscatter maps. This helps to create a sediment map and thus to describe the general habitat of *Sabellaria*. At least one sample per uniform backscatter patch should be taken, so that the occurring range of backscatter values in the area are well sampled. More samples increase the significance of the statistical analysis and could be taken if all other trial goals are completed.

[3] Sampling: RWSV 913.00.B200 (Versie 8, dd 01-09-2021, MACEV_S540) Bemonstering van Macrozoöbenthos en sediment in het litoraal en sublitoraal in mariene wateren. Sediment analysis: RWSV A1.064 (Versie 9) Bodem - Deeltjesgrootteverdeling van de minerale fractie 16 - 2000 um

[4] A Sabellaria reef sample was characterized as a sample with >20% Sabellaria coverage.

[5] Redox layer depth is the oxygenated sediment layer. The anoxic layer is visible as a grey/black stripe in the sediment.

4 Results

4.1 Introduction

This chapter provides an overview of the acquired data and results per sub-region. Furthermore, key lessons learned during the trial are summarized. All data is presented in the ETRS89 UTM (grid zone 31N) coordinate system.

4.2 Summary of results

Figure 4.1 shows an overview of the area covered during the trial, displaying the measured MBES bathymetry data and boxcore locations (indicating if *Sabellaria* was found in the sample). Data acquired with the towed SSS was collected for the same survey tracks.

The following data was acquired during the trial:
- ~45 km^2 was mapped with the MBES & SSS.
- 45 bo cores were taken, 36 of which were used for grain-size analysis and 9 for benthos analysis. 19 samples contained *Sabellaria* (42%). Pictures where taken of all boxcores.
- 26 video tracks were recorded, representing a total distance of 13,4 km.
- An SVP was taken at the beginning of each sonar survey and when needed also in the middle or at the end of the survey.
- Only 4 CTDs were taken over the two weeks of trial, since the water parameters did not change significantly over time and across space; hence, variability in the sound absorption was negligible.

Note on the MBES bathymetry and backscatter results:
- The MBES bathymetry and backscatter data was processed and gridded into 1x1 m and 0.25x0.25 m cells using QPS Qimera 2.5.4 (MBES) and FMGT 7.10.3 (backscatter). The data quality after this initial processing was already good, though additional processing may still be needed later in the project.
- Each MBES backscatter map presented in this chapter is shown with the same range of backscatter levels (-10 to -30 dB). As all data was acquired with the same MBES and the same processing steps were applied, the backscatter results for different sub-regions can be compared relatively easily.

Notes on the SSS backscatter results:
- The SSS data were processed and grided into 0.2 m grid cells per single-track line using Sonar Wiz 7.
- The georeferencing quality of the processed SSS was observed to be poor (up to 10 m inaccuracy). A high georeferencing error limits the possibility to compare the SSS data with the ROV tracks, the acquired MBES data or historical datasets. During the trial and for this report, the SSS data was manually georeferenced using the georeferencing tool of ArcGIS. Features visible in both the MBES bathymetry and SSS image were used to align the SSS data with the highly accurate MBES data (positioning accuracy of few cm). This process is only valid for a limited part of the image, since the positioning error varies with range and ping. Depending on the method selected to post-process the acquired SSS data, the georeferencing of the SSS may need to be improved and automated.

High-quality georeferencing of the SSS data will be particularly important for data fusion and for a multi-layer modelling approach.

Notes on the ROV video results:

- The ROV video recordings were supplemented with a preliminary classification done in real-time during the ROV activities, primarily focussing on the presence of *Sabellaria* in the video footage.
- The presence (both small and larger patches) and absence of *Sabellaria* was documented by WE through real-time labelling. The labelled presence or absence of *Sabellaria* is interpolated on a regular time interval of 5 s.
- The distance between the laser lines visible in the video footage is 50 cm.

Notes on the box-coring results:

- The boxcores were also assigned a first classification during the trial, denoting if *Sabellaria* was present (labelling yes in case at least a lump was found (expert assessment WE/EF).

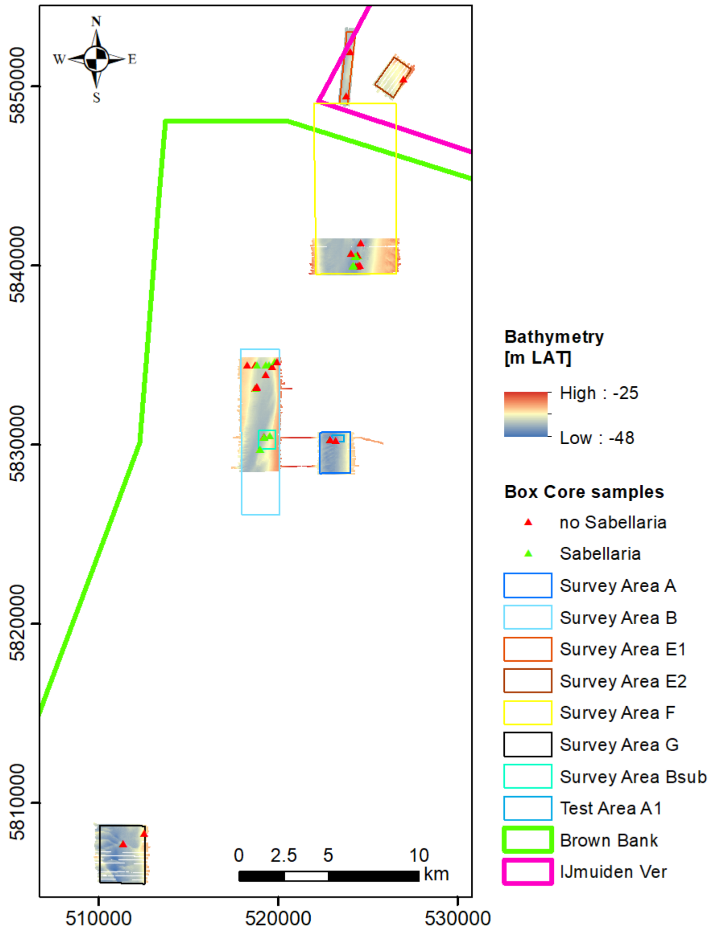

Figure 4.1: Overview of acquired MBES bathymetry and boxcores in the Brown Bank and IJVER regions (coordinate system ETRS89 UTM 31N). Displayed MBES bathymetry is representative of the extent of MBES backscatter and SSS backscatter coverage as well. The 26 video tracks are not shown.

4.3 Configuration tests for SSS

While the SSS was used in earlier projects aimed at finding *Sabellaria*, the following environmental conditions were expected to have an influence on the optimal deployment strategy of the SSS:

- Strong bathymetric variability (sand dunes) requiring the continuous manual adjustment of the depth of the tow fish to avoid collision, which in practice will lead to variable flying height of the sensor above the seabed.
- Local bathymetric variability (megaripples), creating shadow zones that may degrade signal-to-noise ratios (SNRs) or even cause blind zones in the SSS data. In addition, the slope of the megaripples influences the signal amplitude. Slopes facing the sonar increase the backscatter and can be mistaken with coarse sediments or potentially Sabellaria patches.
- Strong currents and variable current directions, causing cribbing of the tow fish and thus decreasing both SNR and georeferencing accuracy.

The following parameters can be optimized to maximize the deployment of the SSS:

- Optimal flying height of the tow fish.
- Optimal line spacing (determined by the minimum and maximum range at which SSS is of sufficient quality).
- Optimal track line orientation, minimizing georeferencing errors due to cribbing and data-coverage loss because of the negative influence of megaripples on data quality.
- Optimal survey speed, finding a balance between data quality and coverage.

Since the survey speed varied with wave and current direction, it was difficult to assess its influence. The minimum survey speed to allow stable operation of the SSS (enough tension on the cable) was around 4.5 knots. The other three variables were investigated and preliminary results are shown below.

The following tests were conducted:

- 7.5 m flying height, range 75 m, track-line orientation W-E (default settings);
- 5.0 m flying height, range 75 m, track-line orientation W-E;
- 7.5 m flying height, range 150 m, track-line orientation W-E;
- 15.0 m flying height, range 150 m, track-line orientation W-E;
- 7.5 m flying height, range 75 m, track-line orientation N-S.

The following configuration proved to provide the best results, with good SSS image quality up to ~75 m range (best result in terms of survey efficiency, data quality and hence *Sabellaria* mapping capability):

- A flying height of 7.5 m;
- A track-line orientation parallel to the megaripples (i.e., W-E in the Brown Bank area);
- A track-line spacing of 100 m.

The track line spacing of 100 m was chosen to have a relatively good overlap of the SSS data and also be in alignment with the MBES coverage (> 100%). In general, a spacing of 50 to 75 m would be more favourable to cover the nadir region but it would drastically increase the survey time.

Two notes on alternative configurations tested:

- A flying height of 5 m with a range of 75 m was found to be a useful configuration as well; however, the acoustic shadow behind the megaripples becomes larger and therefore hides to some extent the presence of *Sabellaria* within troughs (Figure 4.2). In addition, it reduces the coverage and therefore the survey efficiency.
- A range of 150 m increases the coverage rate but, as clearly seen in Figure 4.3, the images have lower resolution. Particularly towards the outer parts of the swath, the SNR drops rapidly yielding a blurry image.

Sailing track lines N-S (i.e. perpendicular to megaripple orientation) achieves a lower image quality (Figure 4.4). While this is true for areas with mega ripples, it doesn't hold for flat areas.

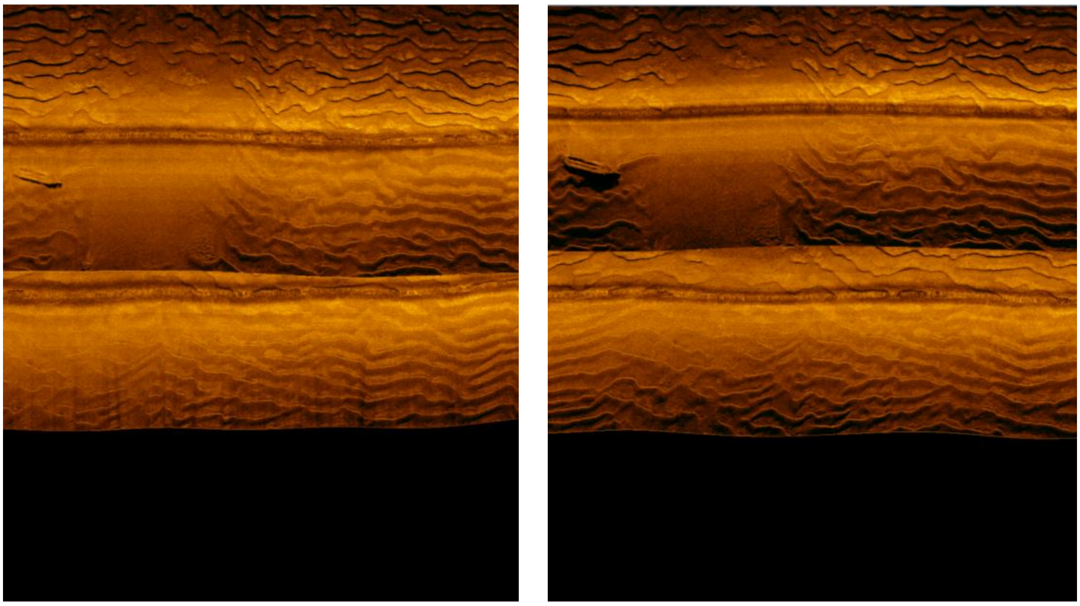

Figure 4.2: SSS images obtained from setting test showing *Sabellaria* findings around ship wreck. The constant parameter in these images is a range of 75 m. The survey speed varied between 4.7 and 6.7 knots. Two tracks lines are visible, where the top track line is plotted on top. The stripe going from left to right marks the track of the SSS. Ship wreck can be used as the reference, (Left) top track line: flying height 7.2 m; bottom track line flying height 8.5 m. (Right) top track line: flying height 5 m; bottom track line: flying height 5.5 m.

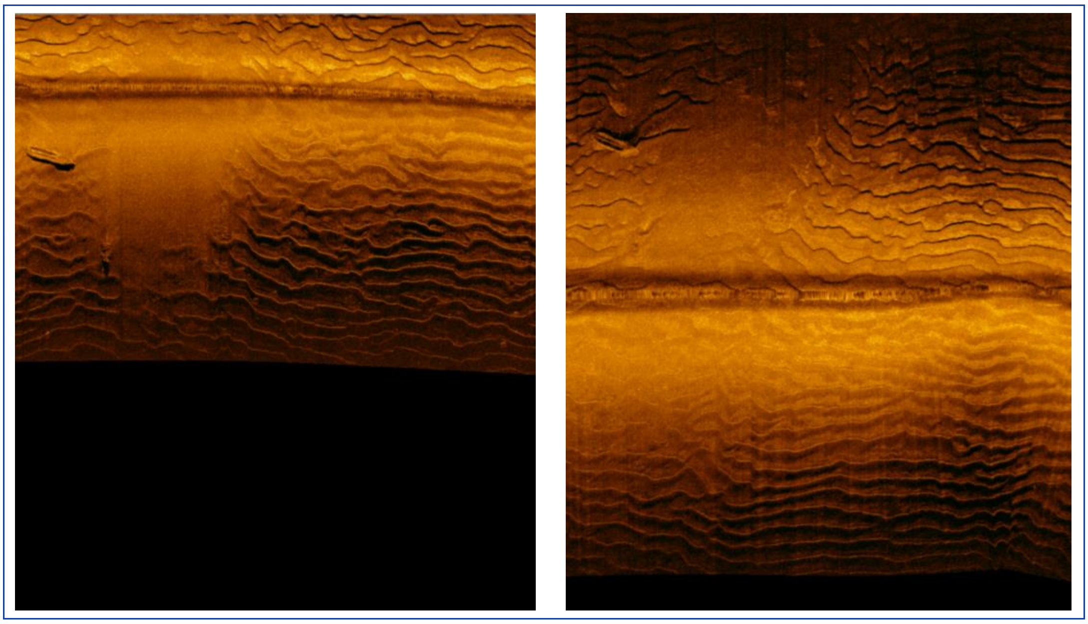

Figure 4.3: SSS images obtained from setting test showing *Sabellaria* findings around ship wreck. The constant parameter in these images is a range of 150 m. (Left) flying height 7.5m. (Right) flying height 14 m.

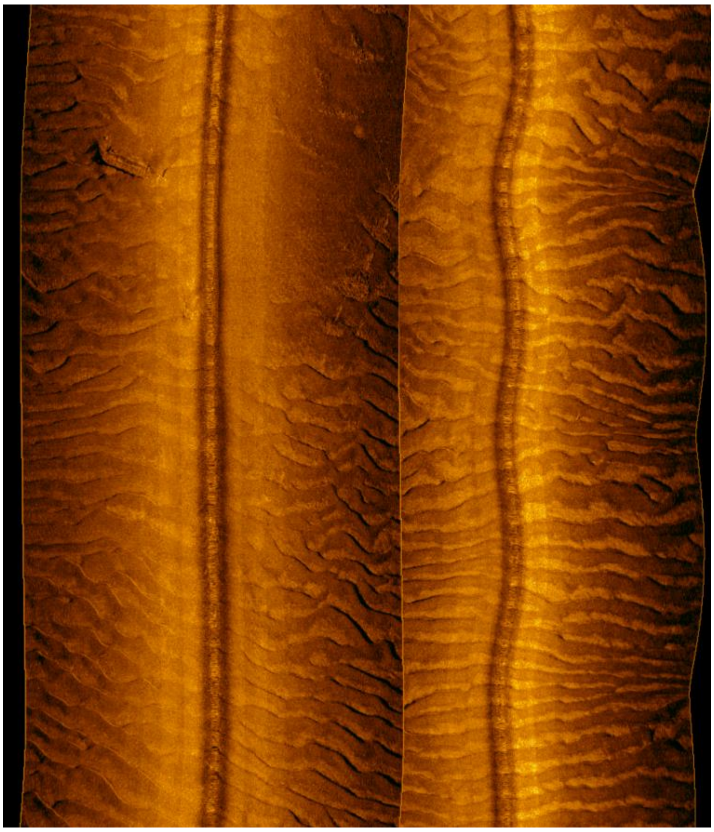

Figure 4.4: SSS images obtained from setting test showing *Sabellaria* findings around ship wreck. The track lines are orientated N-S and range of 75 m was used. The left track line has a flying height of 6.6 m and survey speed of 6.7 knots and the right track line a flying height of 6.6 m and a survey speed of 5.2 knots.

4.4 Results per sub-region

In this section a detailed overview of acquired sonar and ground-truth data is given per sub-region. The main preliminary findings are described, illustrated by examples of corresponding sonar and ground-truth data. An overview of the acquired data is given in Table 4.

Table 4: Data overview of sub-regions.

Area	Sonar coverage [km^2]	Sonar acquisition time	Sediment samples	Benthos samples	Video tracks (km distance)	CTD	SVP
A	4.8	5h 10min	3	-	6 (2.2)	2	1
B (Bsub)	15.1 (0.45)	27h 40min (2h)	15	6	10 (7.6)	1	3
E1+E2	5.8	8h 40min	3	-	6 (1.8)	-	1
F	10.1	11h 40min	10	3	2 (1.3)	-	2
G	9.3	10h 30min	3	-	2 (0.5)	1	2
Total	45.1	65h 40min	34	9	26 (13.4)	4	9

Areas C and D ended up not being surveyed during the two-week trial. The main reason was the limited survey time. To specifically discard area C and D had following reasons: Area C was selected in the desktop study to extent Area A and B but also to survey the crest of the sand bank. The two calibration lines sailed on the first day of the trial, crossing the entire sand bank, did not reveal any indicators for *Sabellaria* on the crests. This local field observation is no proof for the absence of *Sabellaria* on or near crests. However, in combination with the literature study indicating a generally low likelihood of *Sabellaria* on bathymetric highs, the decision was made to focus on the other areas. Area D was discarded because useful data had already been acquired from other parts of the same trough.

In this report the description of the sediment in the video footage is grouped into fine-grained (or fine) sediment and coarse sediment. The fine-grained sediment can contain mud to sand and the coarse sediment contains gravel and shells. The video footage does not allow a finer sediment classification and therefore it is kept more general before the grain size analysis of the sediment samples provides a more accurate classification.

4.4.1 Area A

The acquired MBES and SSS data in Area A covers a part of the eastern trough and slope of the main sand bank in the Brown Bank area (see Figure 2.13). MBES, SSS, boxcores and video recordings were taken during the first day of the first week (21-22/08/2023) (Figure 4.5). The ground truthing was focused on potentially interesting patterns observed in the SSS images. However, no extensive observations of *Sabellaria* were made during a preliminary analysis of the video recordings; only a few isolated locations were identified, as shown in Figure 4.6. The SSS patterns concerned were mistakenly seen as potential *Sabellaria* patches, either because of high backscatter caused by the slopes of megaripples and the presence of shells, or just because of noise artifacts (Figure 4.7). The MBES backscatter was sensitive to variations in the coverage of shell fragments and gravel on a fine-grained sediment, as shown in Figure 4.6 and Figure 4.8. In case The MBES bathymetry showed a morphology consisting mainly of megaripples, but also including larger bedforms (sand waves) in the western part of the trough between two sand banks.

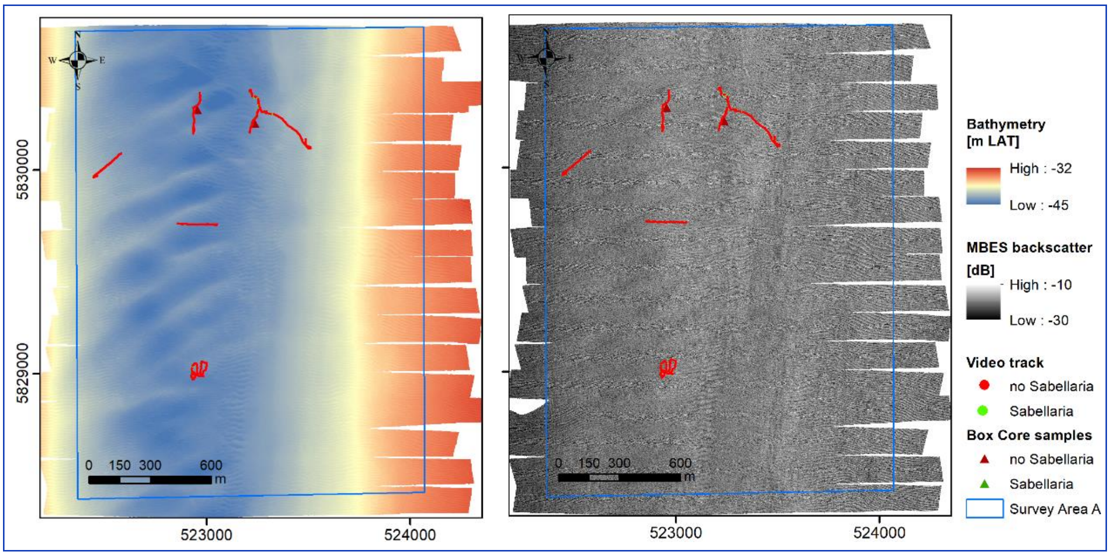

Figure 4.5: Mapped Area A with (left) MBES bathymetry and (right) MBES backscatter. In both maps, box-core locations as well as video tracks are classified to show the absence and presence of *Sabellaria*.

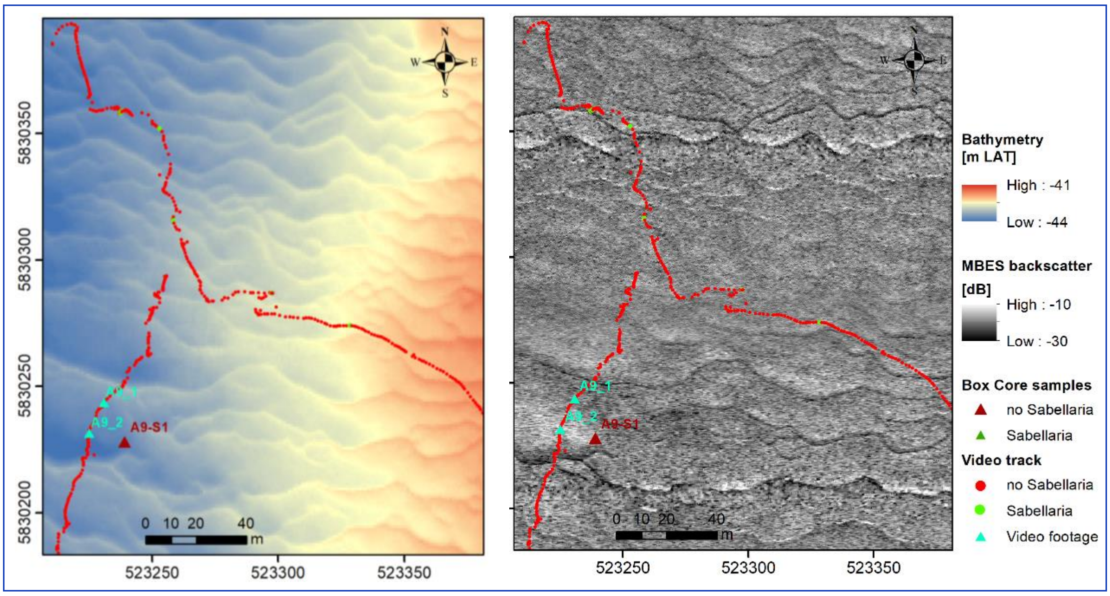

Figure 4.6: Subset of Area A showing (left) MBES bathymetry and (right) MBES backscatter. In both maps, boxcore locations as well as video tracks are classified to show the absence and presence of *Sabellaria*.

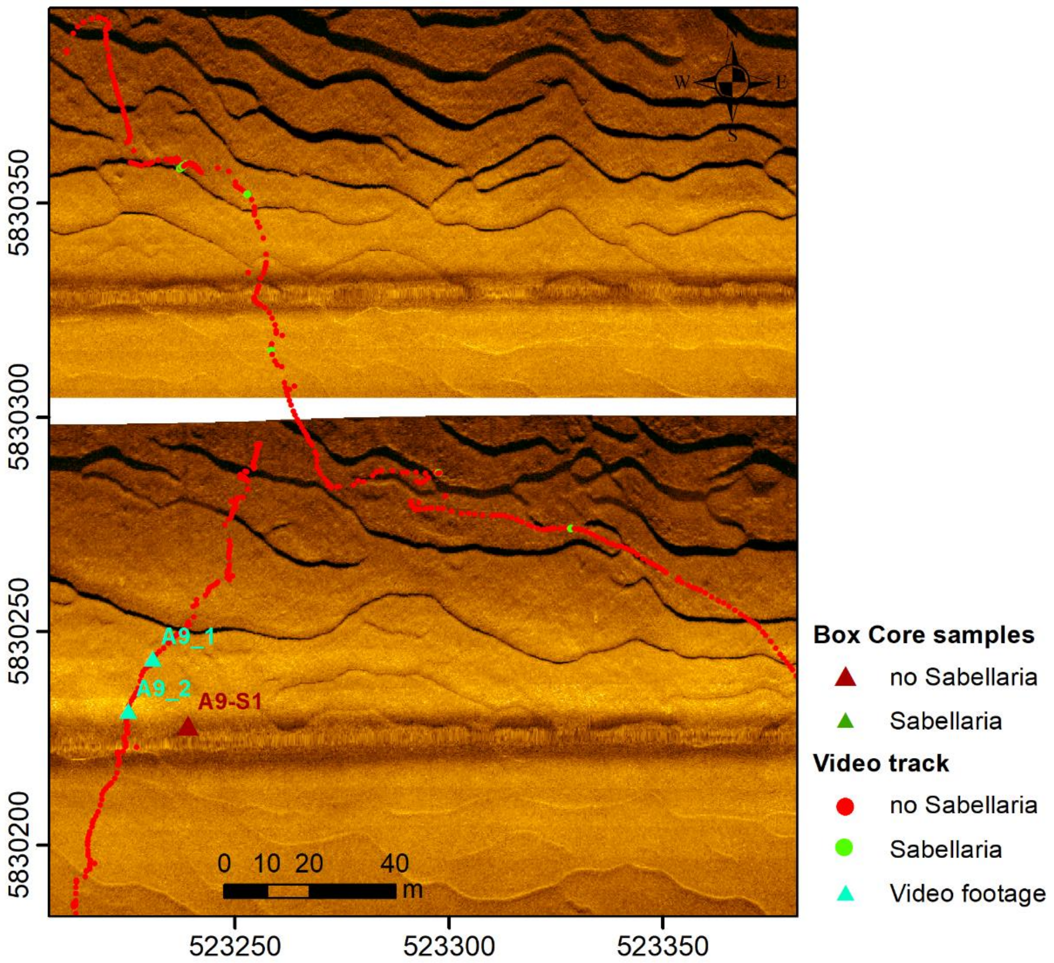

Figure 4.7: Subset of Area A showing SSS backscatter. Boxcore locations and video tracks are classified to show the absence and presence of *Sabellaria*.

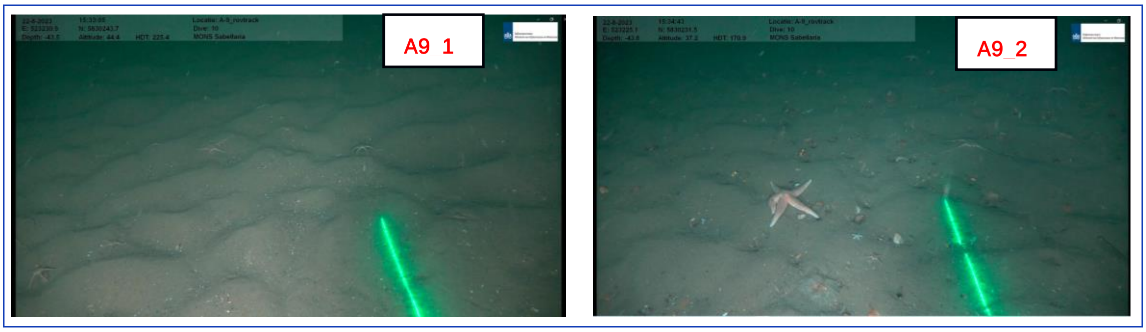

Figure 4.8: RVO video footage. (Left) A9_1 showing fine grained sediment and (right) A9_2 showing fine grained sediment with a medium amount of shells. Positions of the footage are indicated in Figure 4.6 and Figure 4.7.

4.4.2 Area B

The acquired MBES and SSS data in Area B covers a significant part of the western trough and slope of the main sand bank in the Brown Bank area. MBES, SSS, boxcores and video recordings were taken during the second day in the first week (22-23/08/2023). At the end of the first week the area was revisited to acquire more video recordings to ground truth promising SSS images. In the second week (30-31/08/2023) Area B was extended to cover the northern part of the trough as well. A small area, Bsub, was designated for a more detailed SSS survey with a narrower track-line spacing.

The aforementioned promising SSS images were collected in an area on the eastern slope of the sand bank (see pink polygon in Figure 4.1). They show a blotchy acoustic pattern, typical for *Sabellaria spinulosa* as reported in literature. This area was close to a wreck as shown in Figure 4.10. Video recordings revealed extensive distribution of elevated (~ 10 cm) *Sabellaria* patches, validating the blotchy SSS pattern as a key indicator of elevated *Sabellaria* reefs (Figure 4.12). This interpretation was further corroborated by the boxcores taken on top of the *Sabellaria* reef, allowing for a biodiversity analysis (Figure 4.13). To some extent, the *Sabellaria* patches are also visible in the MBES bathymetry (Figure 4.11), showing up as elevated features. The MBES backscatter seems not directly sensitive to the elevated *Sabellaria* patches but further investigation needs to be carried out.

Preliminary and manually driven mapping of this SSS pattern indicates a concentration of elevated *Sabellaria* reefs in area of around 1.7 x 0.7 km (Figure 4.9). In other parts of Area B this blotchy SSS pattern was not found, indicating that extensive distribution of elevated *Sabellaria* reefs are not to be expected elsewhere. A further detailed correlation analysis between SSS, MBES and video recordings needs to be carried out before final conclusion can be drawn.

Extensive concentrations of *Sabellaria* were found in the northern part of Area B as indicated by the green triangles in Figure 4.14. These *Sabellaria* patches were, however, not elevated but flat and buried. Since the *Sabellaria* patches were not elevated, they were not visible on the MBES bathymetry and, in the absence of an acoustic shadow, didn't cause the typical blotchy SSS pattern due to *Sabellaria* (Figure 4.14). The MBES backscatter shows in general slightly higher values in the northern area compared to the southern part of Area B. In the areas where the flat/buried *Sabellaria* was found a pattern of low and high backscatter stripes is present (Figure 4.14). The box coring in Area B was aimed at sampling the variation in backscatter (Figure 4.15). Here, in this area there is no clear tendency of the Sabellaria to the patches of higher or lower MBES backscatter. It is likely that this variation reflects differences in sediment composition since it's a major factor influencing the backscatter level. Pending the analysis of the sediment samples, which will be carried out post-trial, it is unclear to what extent a correlation between the presence of *Sabellaria* and the sediment composition exists.

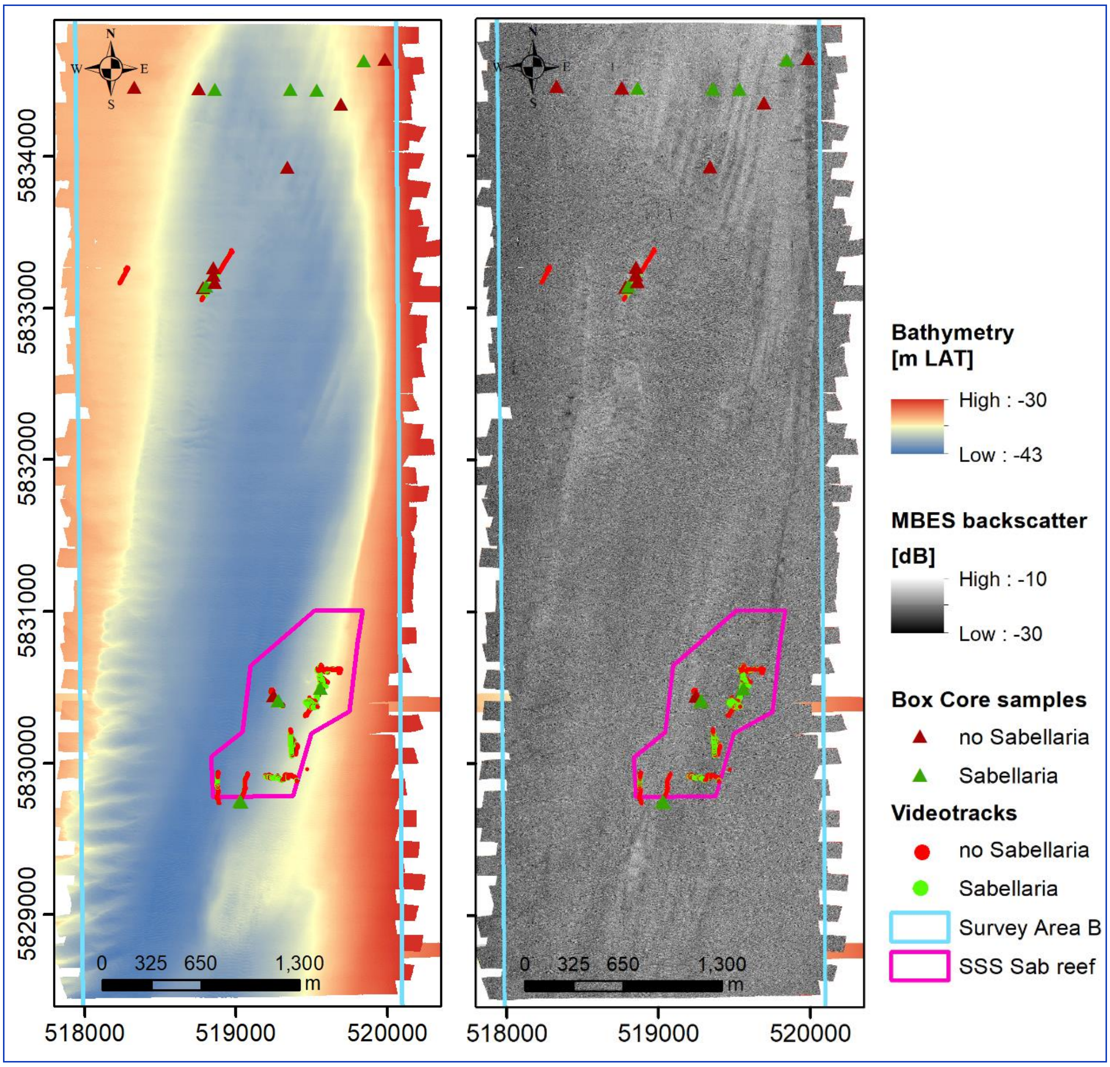

Figure 4.9: Mapped Area B with (left) MBES bathymetry and (right) MBES backscatter. In both maps, boxcore locations as well as video tracks are classified to show the absence and presence of *Sabellaria*. The pink polygon shows the area where a blotchy pattern in SSS imagery indicates the presence of elevated *Sabellaria* reefs.

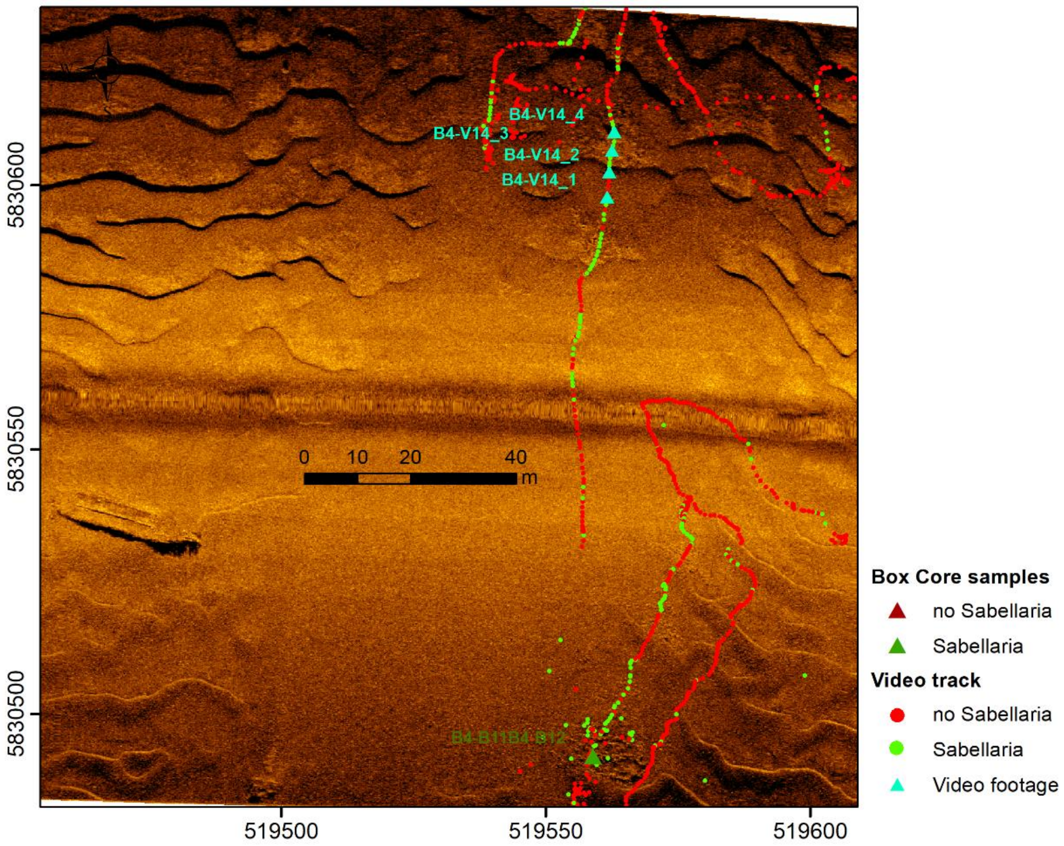

Figure 4.10: SSS image showing ship wreck and indicative patterns for elevated *Sabellaria spinulosa*. Light blue dots mark positions of video footage shown in Figure 4.12. Residue from boxcore B4-V11 (denoted in dark green) is shown in Figure 4.13. Boxcore B4-V12 was taken at the same position.

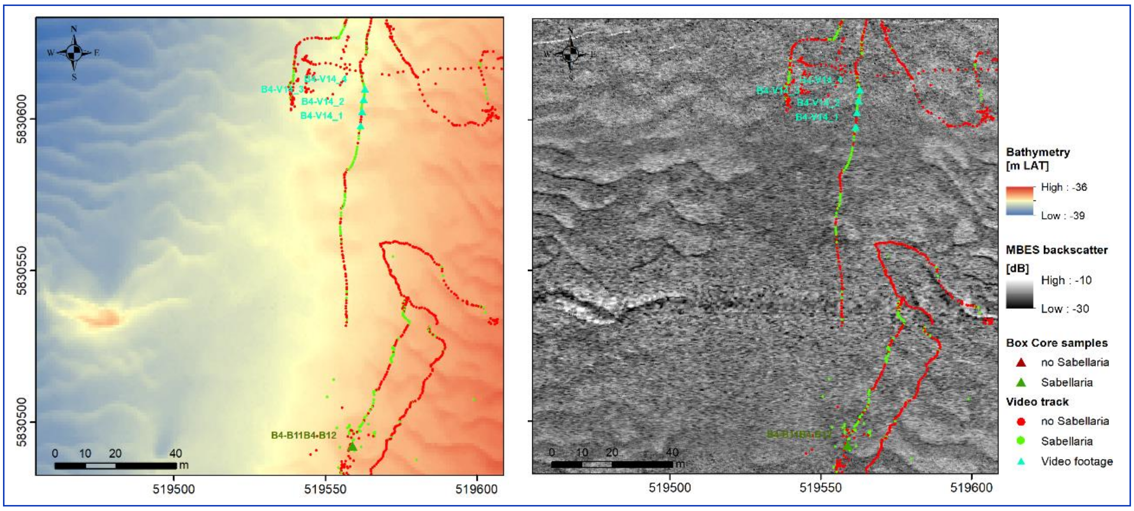

Figure 4.11: Same subset of Area B as in Figure 10, showing (left) MBES bathymetry and (right) MBES backscatter. In both maps, boxcore locations as well as video tracks are classified to show the presence and absence of *Sabellaria*.

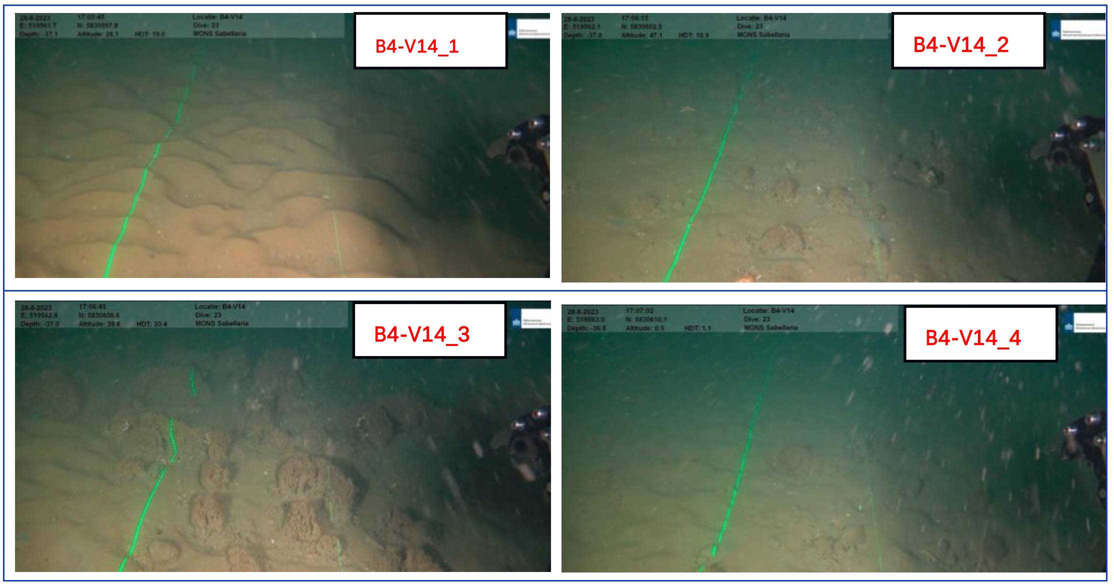

Figure 4.12: ROV video footage. Location of the snapshots are shown by light blue dots in Figure 4.10 and Figure 4.11. (Left top) B4-V14_1 showing fine-grained sediment, (right top) B4-V14_2 showing fine-grained sediment with elevated *Sabellaria*, (left bottom) B4-V14_3 showing fine-grained sediment with elevated *Sabellaria*, and (right bottom) B4-V14_4 showing fine-grained sediment with elevated *Sabellaria*.

Figure 4.13: Boxcore residue B4-V11 revealing *Sabellaria spinulosa*. This sample will be used for benthos analysis. Location is shown in Figure 4.10 and Figure 4.11.

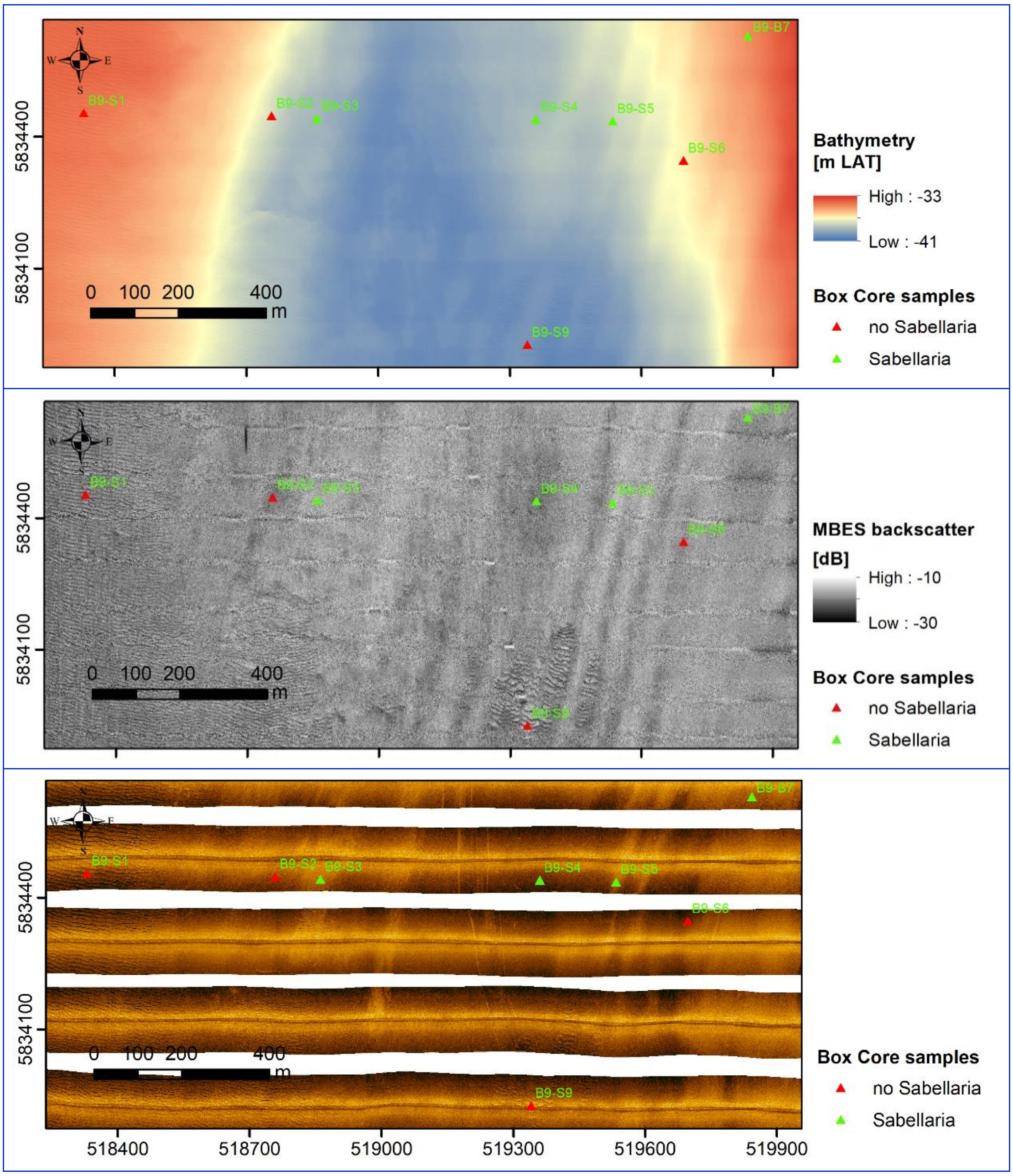

Figure 4.14: Northern part of Area B with distribution of flat/buried *Sabellaria* structures. (Top) MBES bathymetry, (middle) MBES backscatter and (bottom) SSS backscatter.

Figure 4.15: Boxcores: (left) B9-S2 without *Sabellaria*, (middle) B9-S4 with flat/buried *Sabellaria* and (right) B9-S5 with *Sabellaria*. These samples will be used for sediment analysis (including grain-size analysis). The locations where these boxcores were taken are displayed in Figure 4.14.

4.4.3 Area E

The MBES and SSS data acquired in Areas E1 and E2 covers the northernmost part of the eastern trough of the main sand bank, which extends into IJVER. MBES, SSS, boxcores and video recordings were taken during the third day of the first week (23-24/08/2023). This area was selected on the basis of SSS data of IJVER acquired in 2020. The blotchy pattern typical of Sabellaria in SSS imagery was observed in data from an extensive area on a flat seabed (see Section 2.3 and Figure 2.14). This easily recognizable pattern was absent in the SSS data acquired in our trial at exactly the same location. However, a similar pattern was found in the north of Area E2 (Figure 4.18). Its distribution matched with the presence of flat *Sabellaria* in fine-grained sediments observed in the video recordings (Figure 4.19). This was, however, the only Area E location with clear presence of *Sabellaria*. Contrary to the other areas where flat and buried *Sabellaria* was found, the SSS data is a key indicator here. Whether or not this is only a local exception to the general rule needs to be investigated.

Furthermore, the MBES bathymetry data shows large areas with a flat seabed. The flat seabed corresponds mostly to high MBES backscatter levels (Figure 4.16). As revealed by the video footage, the high backscatter level reflects the presence of shell and gravel beds (Figure 4.19 and Figure 4.21). The fine-grained seabed and the shell beds are clearly distinguishable on the MBES backscatter images (see link between MBES backscatter maps and video recordings in Figure 4.17 and Figure 4.19).

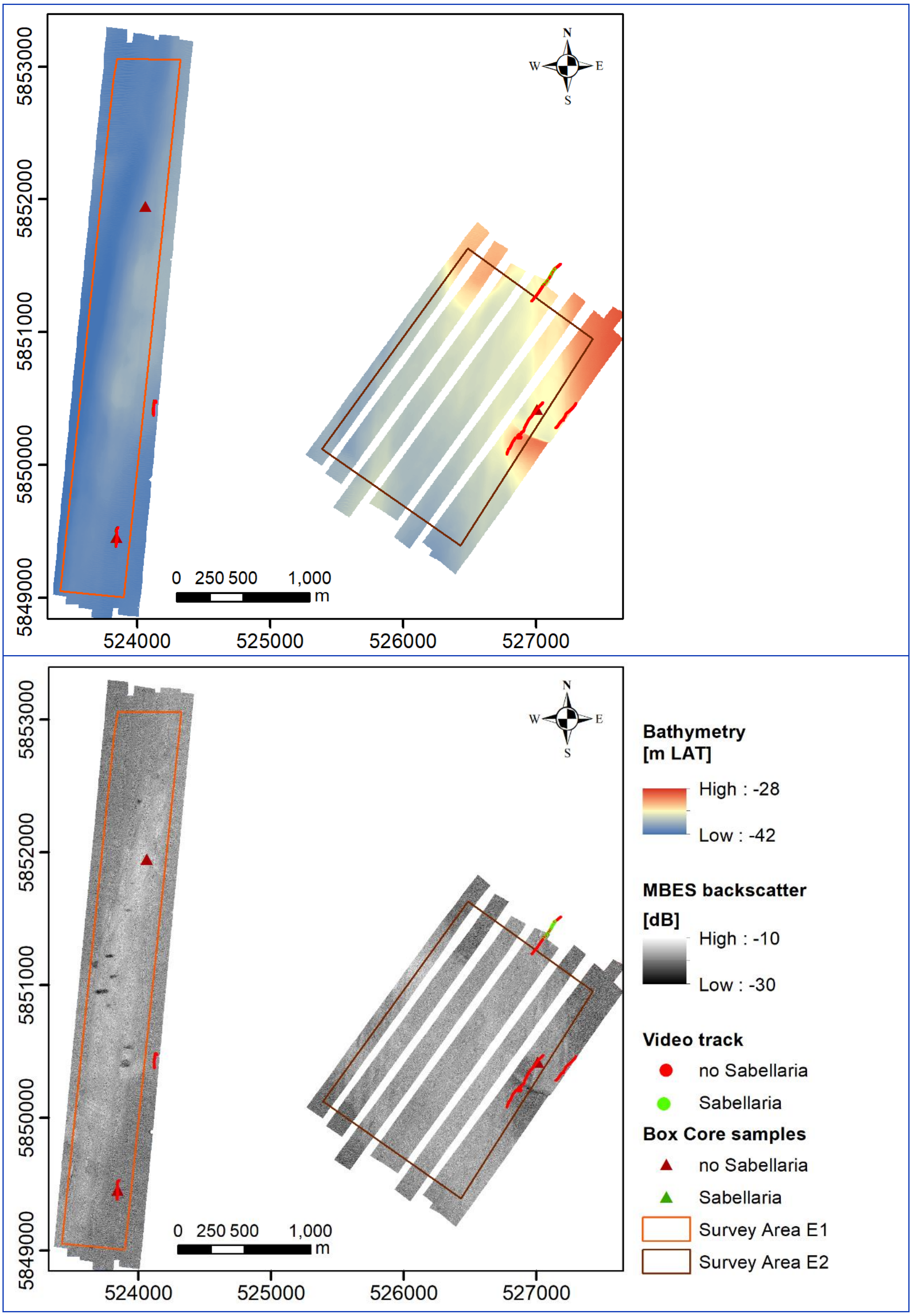

Figure 4.16: Mapped Area E1 (left) and E2 (right) with (top) MBES bathymetry and (bottom) MBES backscatter. In both maps, boxcore locations as well as video tracks are classified to show the presence and absence of *Sabellaria*.

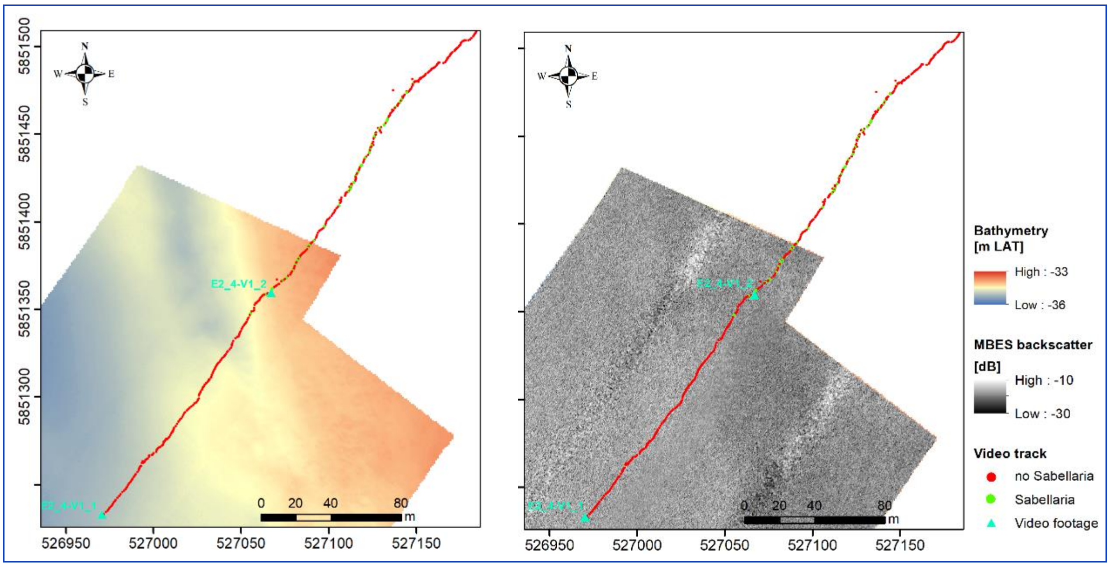

Figure 4.17: Subsection of Area E2 showing (left) MBES bathymetry and (right) MBES backscatter. In both maps, boxcore samples as well as video tracks are classified to show the presence and absence of *Sabellaria*. Sabellaria is present in the area with low MBES backscatter. Whether there is a correlation between the presence of Sabellaria and lower backscatter, indicating in general a finer sediment needs to be investigated and quantified.

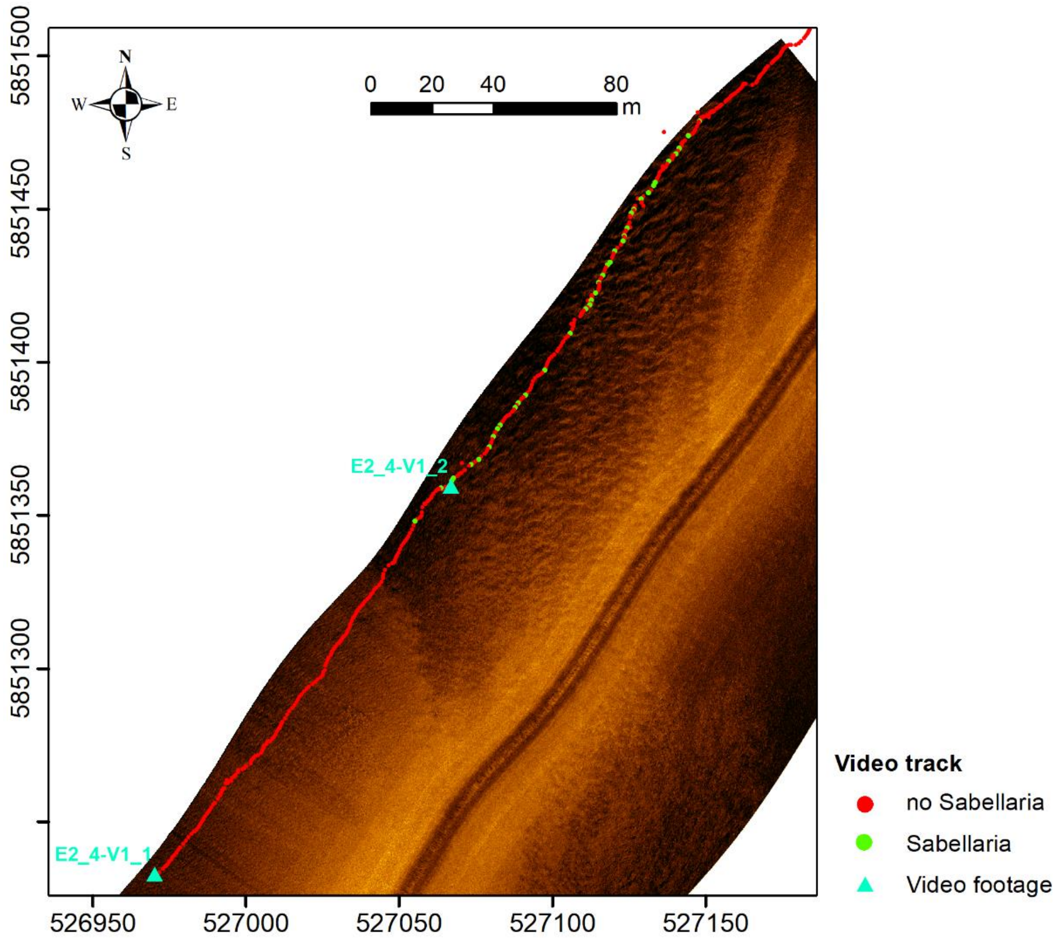

Figure 4.18: Subsection of Area E2 showing SSS backscatter. Boxcore locations and video tracks are classified to show the presence and absence of *Sabellaria*. In the SSS image, *Sabellaria* patches are represented by a blotchy pattern that is quite extensive.

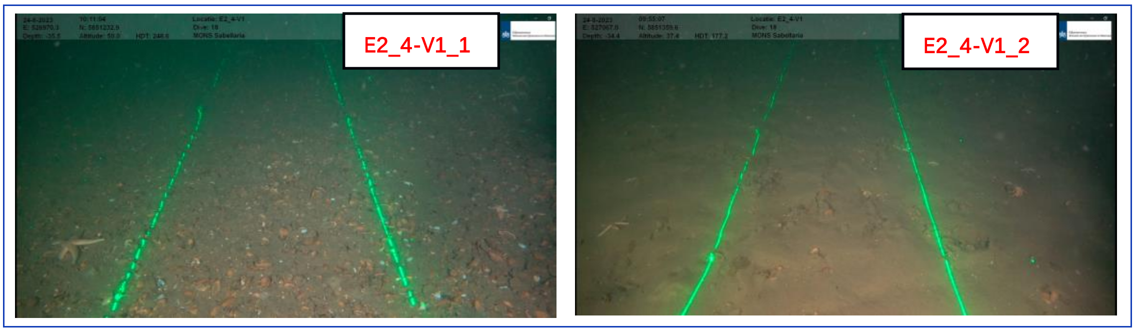

Figure 4.19: ROV video footage: (left) E2_4-V1_1 showing extensive shell and gravel bed and (right) E2_4-V1_2 showing finer-grained sediment with *Sabellaria spinulosa*. Corresponding locations are indicated in Figure 4.17 and Figure 4.18.

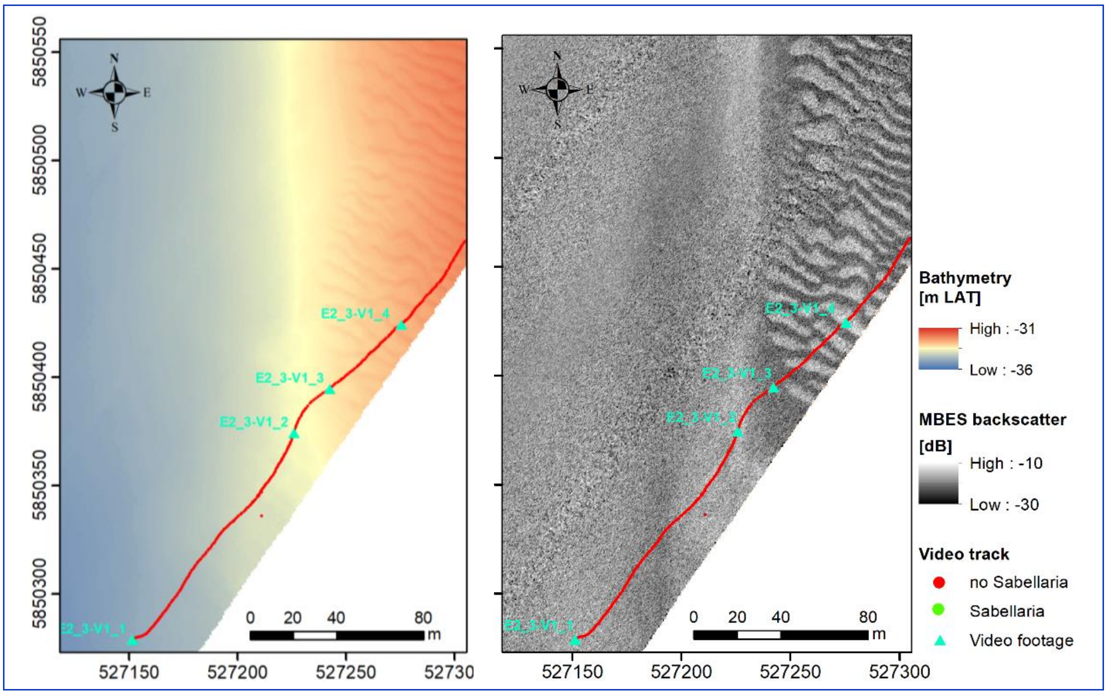

Figure 4.20: Subsection of Area E2 showing (left) MBES bathymetry and (right) MBES backscatter. In both maps, boxcore locations and video tracks are classified to show the presence and absence of *Sabellaria*.

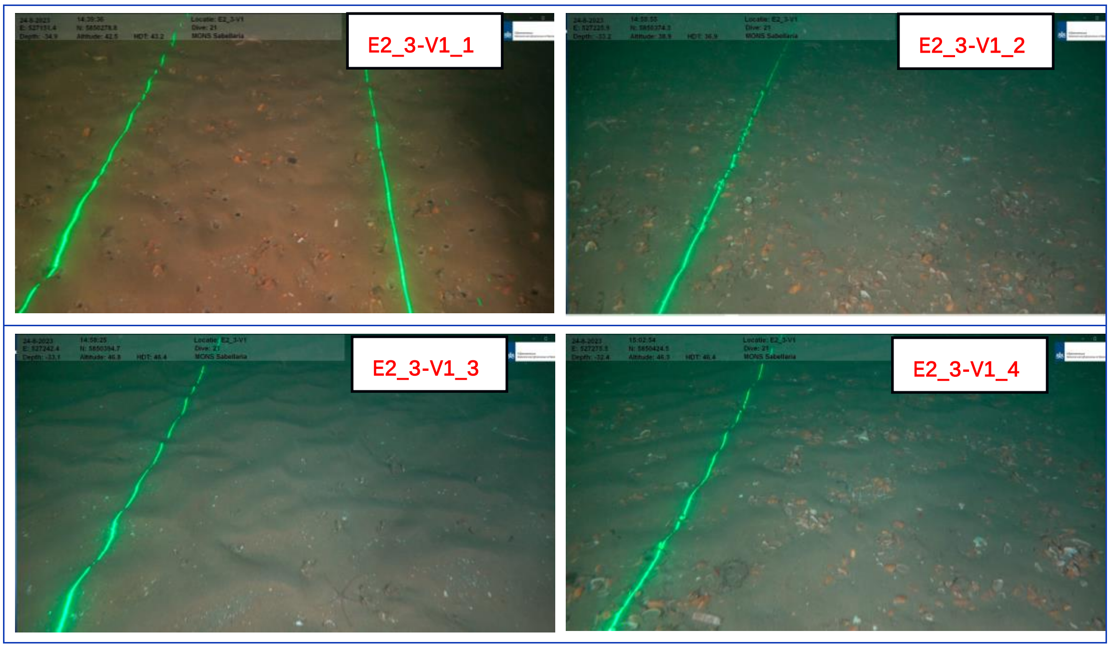

Figure 4.21: ROV video footage: (left top) E2_3-V1_1 showing a mixture of fine-grained sediment with shells and holes, (top right) E2_3-V1_2 showing shell bed, (bottom left) E2_3-V1_3 fine-grained sediment and (bottom right) E2_3-V1_4 fine-grained sediment with large amount of shells. Corresponding locations are indicated in Figure 4.20.

4.4.4 Area F

The acquired MBES and SSS data in Area F covers a part of the eastern trough and slope of the main sand bank in the north of the Brown Bank area (see Figure 2.13). In this area the trough is wider than in the south and therefore longer W-E sonar track lines could be sailed. MBES, SSS, boxcores and video recordings were taken during the second day of the second week (29-30/08/2023). Since the typical acoustic pattern for elevated *Sabellaria* was not observed in the SSS data, the ground truthing was primarily driven by the MBES backscatter and bathymetry data. The MBES bathymetry data showed large areas with a flat seabed, which were also present farther north in Area E but absent farther in south in Area A. The flat seabed corresponds mostly to high MBES backscatter levels, marking the remarkable N-S ribbon of high MBES backscatter (Figure 4.22). As revealed by the video footage, areas marked by a high backscatter level correspond to shell and gravel beds as identified in video footage (Figure 4.25). Flat and buried *Sabellaria* was mainly found on the flat seabed but within fine-grained sediment (silt and sand) and coarse substrate (gravel and shells). In the video recordings, *Sabellaria* is more clearly visible in fine-grained sediment than in coarse-grained substrate (Figure 4.25). The fine and coarse sediments are clearly distinguishable on the MBES backscatter (see link between Figure 4.23 and Figure 4.25). It indicates that the MBES backscatter may be less sensitive to the presence of *Sabellaria* than to the nature of the surrounding sediment. Low MBES backscatter values, indicating fine sediments, are usually observed as a transition zone between the flat gravel and shell beds and the margin of the megaripple field. This observation was already made in the dataset acquired in IJVER in 2020 (see description in Chapter 2.3). The SSS images do not show such sensitivity to the presence of flat/buried *Sabellaria* or their surrounding sediment (Figure 4.24).

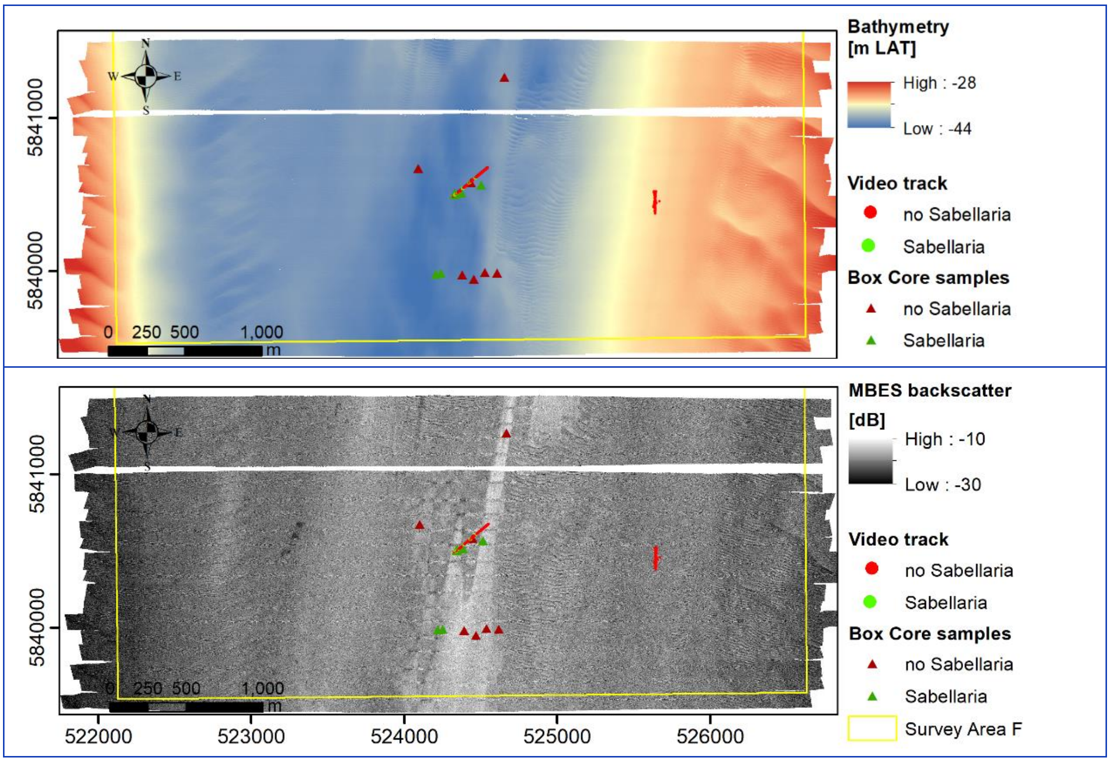

Figure 4.22: Mapped Area F with (top) MBES bathymetry and (bottom) MBES backscatter. In both maps, boxcore locations and video tracks are classified to show the presence and absence of *Sabellaria*.

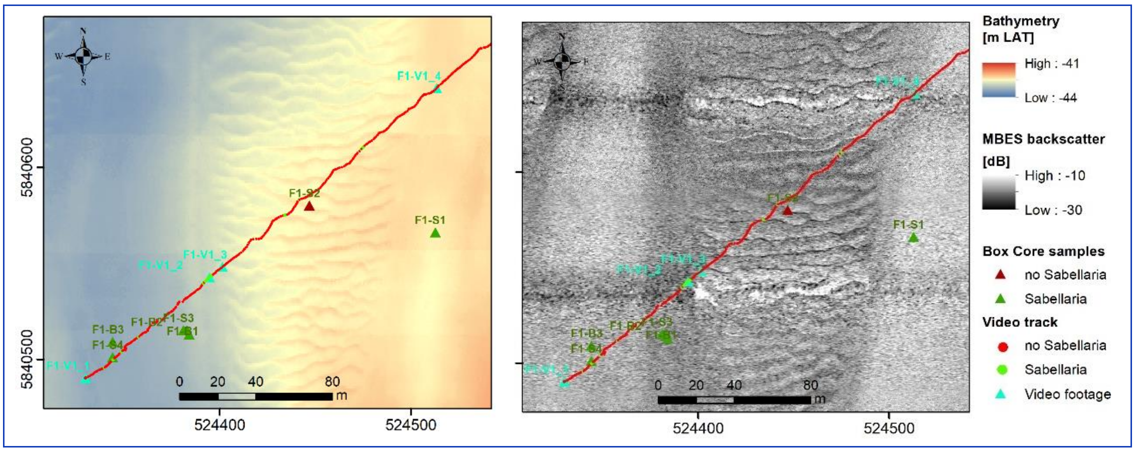

Figure 4.23: Subsection of Area F showing (left) MBES bathymetry and (right) MBES backscatter. In both maps, boxcore locations and video tracks are classified to show the presence and absence of *Sabellaria*.

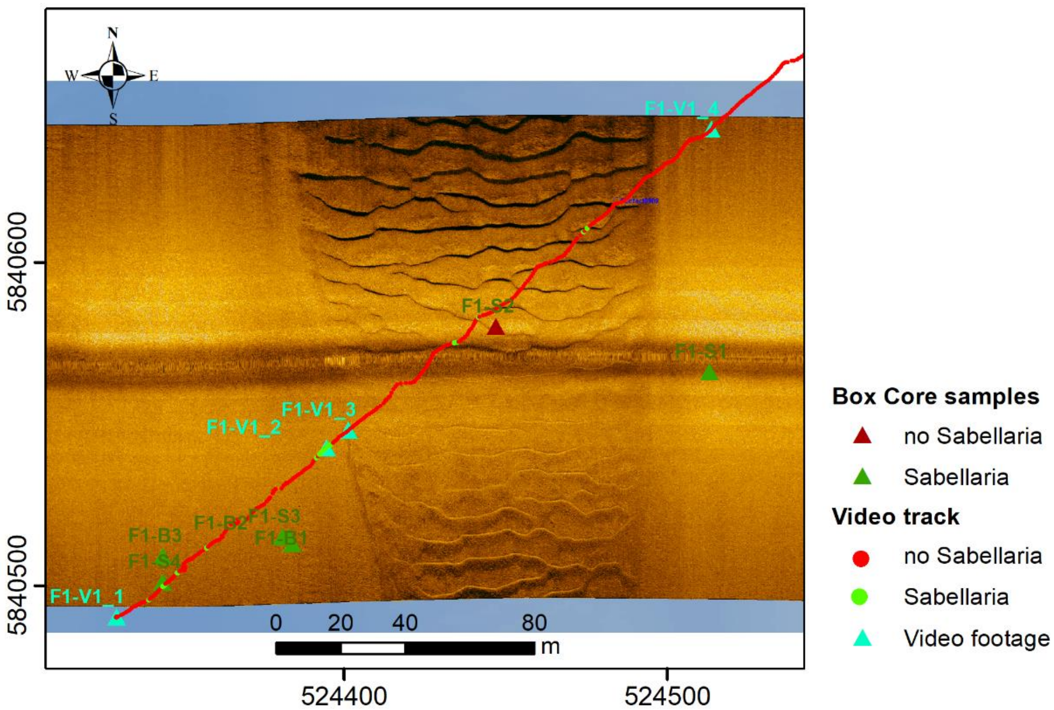

Figure 4.24: Subsection of Area F showing SSS backscatter, highlighting the extent of a megaripple field. Boxcore locations and video tracks are classified to show the presence and absence of *Sabellaria*.

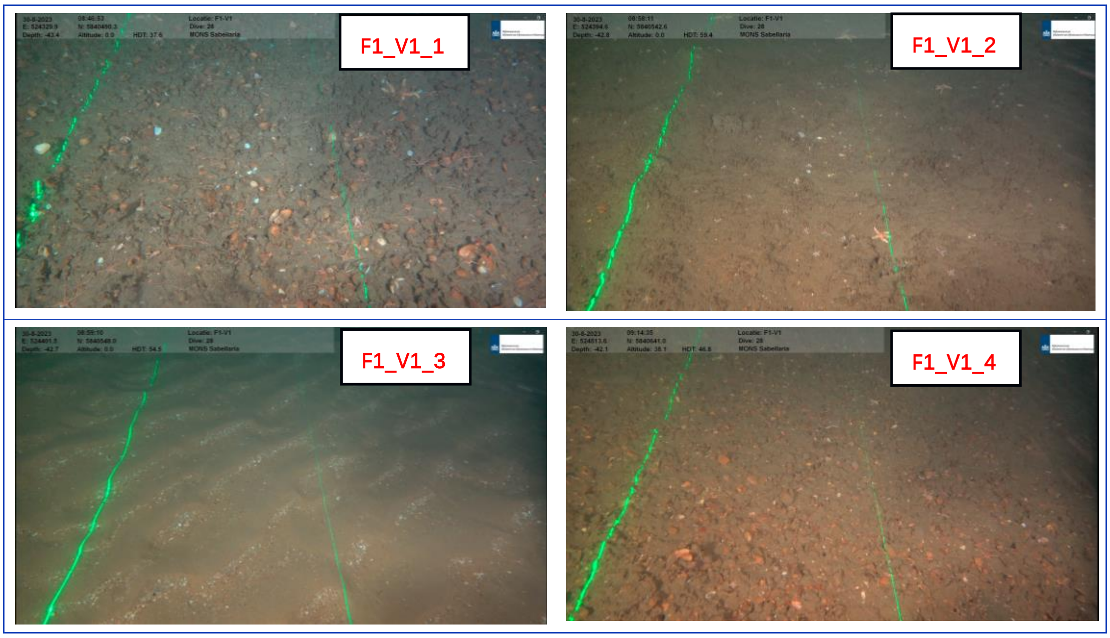

Figure 4.25: ROV video footage. Locations of this footage are shown by light blue dots in Figure 4.23 and Figure 4.24. (Left top) F1-V1_1 showing shell bed with *Sabellaria spinulosa*, (right top) F1-V1_2 showing fine-grained sediment with *Sabellaria spinulosa*, (left bottom) F1-V1_3 showing fined-grained sediment and (right bottom) F1-V1_4 showing shell and gravel bed.

4.4.5 Area G

The MBES and SSS data acquired in Area F covers a trough and the slope of another sand bank in the south of the Brown Bank area (see Figure 2.13). MBES, SSS, boxcores and video recordings were taken during the first day of the second week (28-29/08/2023).
In this area the sand bank trough is slightly deeper than the ones farther north. It has more morphological variation and is characterized by the absence of distinct flat areas marking parts of the troughs in the north (Figure 4.26). The MBES backscatter shows no larger areas with high levels being indicative for shell and gravel beds (Figure 4.26). Harder substrate appear to be limited to the troughs of the megaripples, where large amounts of shells are entrained within fine-grained sediment (Figure 4.27 and Figure 4.29). No indicative acoustic pattern for elevated *Sabellaria* is visible in the SSS images (Figure 4.28). In conclusion, the sonar data do not present clear indicators for the presence of *Sabellaria*. None of the chosen ROV tracks and boxcore locations yielded evidence of flat and buried *Sabellaria*.

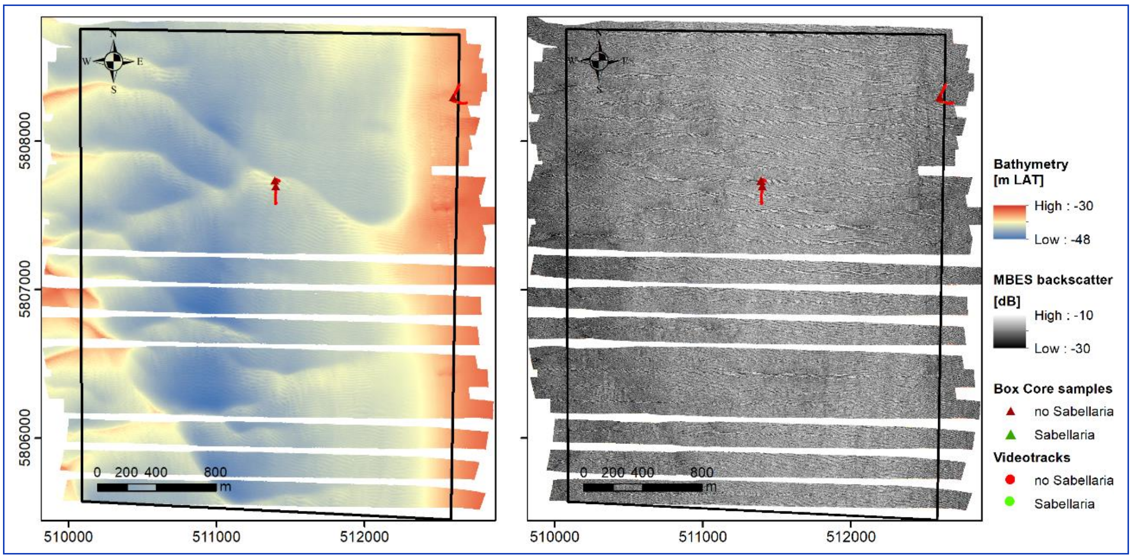

Figure 4.26: Mapped Area G with (left) MBES bathymetry and (right) MBES backscatter. In both maps, boxcore locations and video tracks are classified to show the presence and absence of *Sabellaria*.

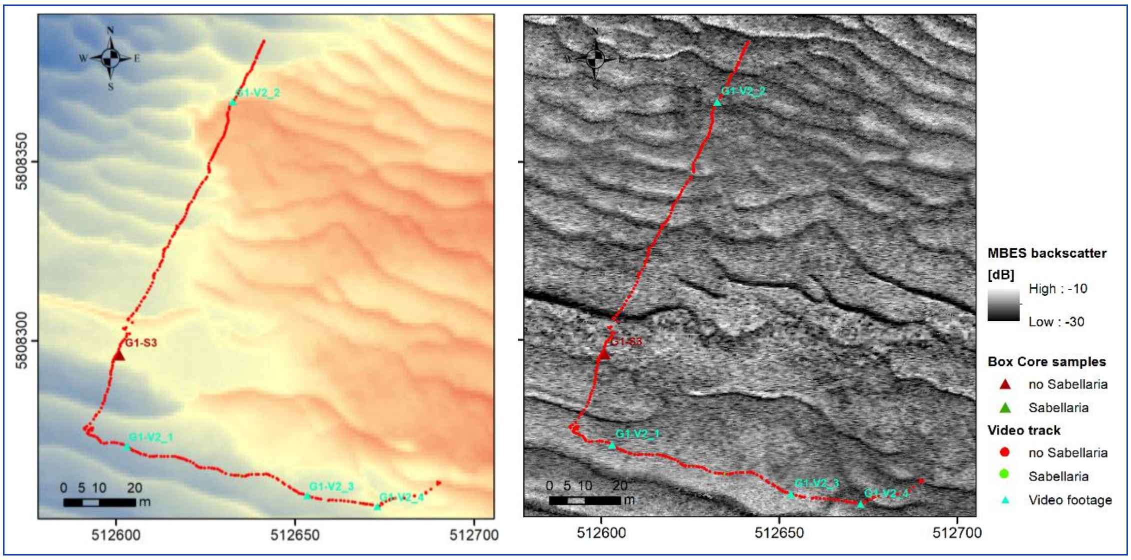

Figure 4.27: Subsection of Area G showing (left) MBES bathymetry and (right) MBES backscatter. In both maps, boxcore locations and video tracks are classified to show the presence and absence of *Sabellaria*.

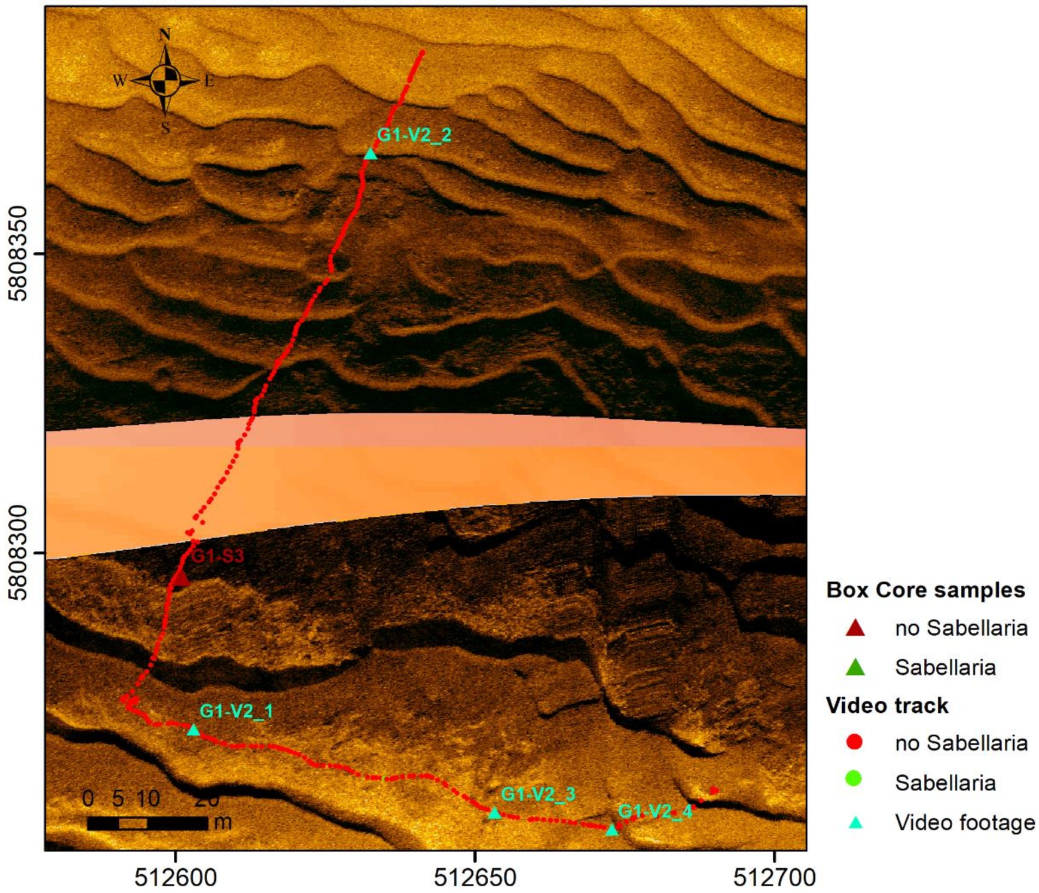

Figure 4.28: Subsection of Area G showing SSS backscatter. Boxcore locations and video tracks are classified to show the presence and absence of *Sabellaria*.

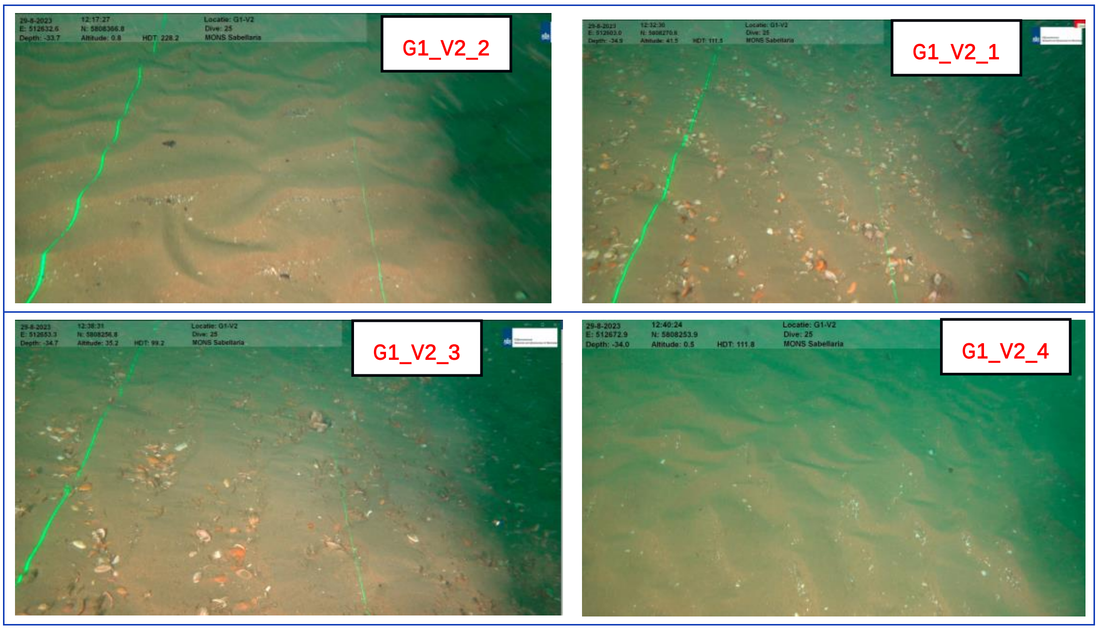

Figure 4.29: ROV video footage: (left top) G1-V2_2 showing fine-grained sediment, (top right) G1-V2_1 fine-grained sediment with large amount of shells, (bottom left) G1-V2_3 fine-grained sediment with large amount of shells, and (bottom right) G1-V2_4 fine-grained sediment with small amount of shells. Associated locations are indicated in Figure 4.27 and Figure 4.28.

4.5 Conclusions on *Sabellaria*

Sabellaria was found in the Brown Bank region:

- Extensive distribution of elevated *Sabellaria* structures (> 10 cm) characterizing a single location of around 1.7x 0.7km in Area B in the trough of the N-S sand banks. They were found on a flat seabed and in the troughs of megaripples with relatively fine grained sediment (Sand).
- Extensive distribution of relatively flat (< 10 cm) and buried patches in several locations within the Brown Bank area. The majority of the patches occupies a flat and fine grained seabed (silt, sand). At some locations the seabed surface contained various concentrations of hard substrate such as shells and gravel.
- *Sabellaria* was only found in the northern survey areas. Area G in the south did not reveal any evidence for the presence of *Sabellaria.*
- On a larger morphological scale, *Sabellaria* was exclusively detected on the east side of the trough towards the gentle slope of the sand bank and not on the west side close to the steep slope of the sand bank.
- Flat *Sabellaria* was observed also in the IJVER region.
- 9 Boxcore samples were taken directly from *Sabellaria* patches to allow a biodiversity assessments via a benthos analysis. Of these samples, one contained no Sabellaria and will be treated as reference sample. One sample contained low Sabellaria densities. The other seven samples contain (large) Sabellaria patches.
- The *Sabellaria* patches detected during the DISCLOSE project in 2017 and 2019 in the eastern trough of the sand bank (Area A) were not found. The area with the presence of elevated *Sabellaria* in the western trough (Area B), which was manually mapped using the SSS image (pink polygon in Figure 4.9), overlaps with most of the detected *Sabellaria* locations from the DISCLOSE trials. However, a detailed georeferenced comparison of the video tracks from 2017, 2019 and 2023 needs to be carried out before it is possible to develop a hypothesis on the potential longevity of *Sabellaria* reefs.

4.6 Evaluation of monitoring strategy

Our multi-sensor approach was critical to success of the trial. The SSS facilitated detection of elevated *Sabellaria*. MBES backscatter and bathymetry were used to describe the general seabed environment such as sediment composition and seabed morphology, providing useful proxy information to indirectly locate flat and buried *Sabellaria* patches. ROV video recordings proved indispensable for validating sonar observations. Boxcores will provide additional, detailed information about grain size and biodiversity.

Some specific conclusions are given below:

- A range of 75 m, flying height of 7.5 m above the seabed, a track-line orientation parallel to the megaripples (i.e. W-E in the Brow Bank area) and a track-line spacing of 100 m achieves the best result in terms of survey efficiency, data quality and *Sabellaria* mapping capability.
- Elevated *Sabellaria* is easier to detect in the sonar data than flat/buried *Sabellaria*. They have different acoustic signatures. In this light, both the manual interpretation and the subsequent automated classification have different requirements.
- While the SSS was suitable to detect elevated *Sabellaria* structures, the flat and buried *Sabellaria* structures were mostly invisible on the preliminarily processed SSS images. Only in a small area in the IJVER region, indicative patterns in the SSS images correlated with the presence of flat *Sabellaria*.
- Elevated *Sabellaria* structures were also visible to some extent on the MBES bathymetry.

- MBES backscatter does not appear sensitive to elevated *Sabellaria* structures.
- MBES backscatter shows variation in regions with flat and buried *Sabellaria* structures. To what extent a correlation between the presence of *Sabellaria* and MBES backscatter characteristics, and therefore possibly a preferred sediment composition, exists, may be clear following the still pending analysis of the sediment samples.

Furthermore, important lessons learned are:

- It is very difficult to keep a constant **survey speed** of around 5 knots in the dynamic North Sea. Tidal currents, wave direction and handling the flying height influence the survey speed. The vessel is faster when sailing with the current and waves and slower when sailing against them. Furthermore, the higher the speed the easier it is to sail straight lines.
- It is very difficult to maintain a constant flying height of the SSS tow fish. To keep the flying height of the tow fish stable, the cable needs to be pulled and pushed constantly. This manual process, carried out by the surveyor, is prone to human error. In areas with highly variable morphology, the flying height changes the most rapidly. To keep the flying height as constant as possible, tracks lines should be chosen where the least changes in water depth can be expected (if it aligns with other survey goals).
- In general, the navigation of the SSS tow fish was poor. In the first week the USBL was not operational and the positioning of the tow fish was done manually in Sonar Wiz adjusting the cable length. In the second week the USBL was operational and the positioning was improved: no manual cable-length adjustment was required anymore and the side drift of the tow fish was accounted for. Since the quality of the heading sensor of the tow fish was poor and the ship heading was used, a positioning error up to 10 m was still present. This error is not fixable in Sonar Wiz and in general difficult to solve, since the error changes with ping and range. Currently, the MBES bathymetry data, providing a cm-scale positioning accuracy, is used to locally georeference the SSS data. However, this is a time consuming solution and doesn't work for the entire track since the error changes with ping and range. Sailing the track lines with and against the current would keep the tow fish more stable (i.e., fewer heading changes), but might conflict with other parameters to optimize track-line orientation (i.e. constant flying height, sonification direction).
- Sailing the track-lines parallel to the megaripples (W-E) achieves better SSS image quality and allows better mapping of *Sabellaria* within the troughs of megaripples. However, longer tracks lines (i.e. fewer vessel turns) could be achieved in N-S direction since the extent of the trough is longer is that direction. In addition the main current direction is N-S and sailing against the current results in the most stabile fish position If the majority of the area is flat, the track-line orientation should be chosen on the basis of efficiency and fish stability.
- The highest frequency of the Kongsberg EM 2040 MBES, 400 kHz, does not allow use of the full sonar swath. The highest frequency allowing transmission of a swath of 130 degrees was 380 kHz; therefore, this frequency was chosen for the MBES.
- While the operation of the ROV went well during the majority of the trial, some optimizations are:
  - Move the camera and forward looking sonar to the bottom of the ROV frame.
  - Put the FLS fixed on the ROV frame at the ideal survey angle for the FLS used. It was now attached to the pan tilt unit of the camera which resulted in a poor, non-adjustable incident angle from an acoustic perspective. This was not an issue as the camera visibility was good enough for both navigation and detecting *Sabellaria* but in case camera visibility would have been worse the possibility to make a change would have been critical to effective operation of the ROV.

- the compass was primarily used for estimating the initial heading; afterwards, the heading was determined using the sailed ROV track provided by the USBL.
- The ROV thruster wash was giving some false positives at times but generally worked well. In the analysis of the data the reliability of the USBL locator needs to be examined.
- Only on Thursday 31st of August (morning) the currents where too strong for the ROV to operate and the planning needed to be altered.
- The ROV speed was generally between 0.15 and 0.2 knots which provided high-quality video. The tether-management system was deployed at ~13 m and gave good performance. Almost all track lines were longer than the max tether length, requiring the vessel to move in dynamic-positioning mode. This increased the time needed for the ROV surveys substantially.
- Given the strong currents the preferred direction of operation was facing the primary current direction in a straight line. Because of the patchiness of the *Sabellaria* and the presence of megaripples, the navigation was very challenging once deviating from a straight path against the currents. When needed, the ROV pilot managed to sail non straight tracks. The amount of data lost due to accidently sailing too far away from the seabed was observed to be acceptable.

5 Conclusion and way ahead

The goal of the expedition was to acquire the data needed to:
1. Evaluate the presence of *Sabellaria* reefs in the Brown Bank and IJVER areas.
2. Evaluate the biodiversity (content) of *Sabellaria* hotspots.
3. Study the environmental conditions of areas with a *Sabellaria* hotspot.

Regarding the first goal: the monitoring campaign was very successful. *Sabellaria* reefs were detected where they were discovered in the past and in new places in the Brown Bank region. However, the preliminary analysis also shows that in one area where Sabellaria was previously found, the reefs have disappeared.

Regarding the second goal: acoustic detection of potential *Sabellaria* hotspots made extensive ROV video collection and benthos sampling more focused and efficient. The volume and quality of this data are considered sufficient to realize this goal.

Regarding the third goal: detailed sonar surveys (MBES and SSS) conducted in the larger areas surrounding the *Sabellaria* hotspots, supplemented by ROV video tracks covering the environment surrounding the reefs as well, add to the understanding of the environmental conditions that support the settlement of *Sabellaria* and the subsequent formation of reefs. Once supplemented with sedimentological and grain-size analyses of boxcores, they will provide more clarity on relationships between the biotic and abiotic environment.

The main conclusions regarding the efficiency of the monitoring strategy are:
- *Sabellaria spinulosa* was successfully located in the Brown Bank using a multi-modal (Vessel and ROV) and multi-sensor (MBES, SSS, Camera, boxcorer) approach. Each platform and sensor was vital for the success of the trial.
- A clear link between the sonar images and the presence of elevated *Sabellaria* exist. It allows direct mapping of the distribution of elevated *Sabellaria*. Optimisation of the SSS surveying strategy for the local conditions was key to getting high quality data.
- Distinction between elevated and flat/buried *Sabellaria* from an acoustical point of view is required. The flat and buried *Sabellaria* was mostly invisible in the SSS sonar images and therefore hampers a direct mapping approach using only this type of sonar data. However, a preliminary analysis of the MBES backscatter and bathymetry data, being sensitive to sediment properties and revealing seabed morphology, indicates a potential link between the environmental conditions and the presence of *Sabellaria*.

The data obtained during the trial will be processed during a next project phase, using unsupervised or supervised classification methods to create maps of expected reef presence and if possible habitats with a high likelihood of supporting reefs. In Q4 of 2023, the ROV video recordings will be analysed following the more objective and structured procedure described in Section 3.8. Detailed grain-size and benthos analysis will also take place in Q4 of 2023. The outcome of these analyses will be addressed in the final project report. The final maps and results of this study will support RWS to draft more effective management policies to protect these reefs. As a contracting party of the OSPAR convention, RWS is committed to take measures and protect biodiversity. Finally, the results generated in this study will be used to validate and improve the quality of *Sabellaria* habitat-suitability maps for the southern North Sea, as produced by Deltares [3].

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Appendix A
Sonar settings

Side Scan Sonar navigation
A good navigational accuracy of the SSS is crucial. The horizontal positioning is important for the correlation with ground truthing and MBES data. In postprocessing the georeferencing of the SSS data can be further improved via a cross-correlation with morphological features detected in both SSS and MBES data. However, the accuracy of this correlation depends on the existence of clear features visible in images from both sensors. Since it is also time-consuming, it is only possible to a very limited extent during the trial. The vertical positioning of the SSS is important to reduce the influence of a varying flying height on the sonar-image quality consistency. This is of particular importance as the performance of the AI-driven clustering methods applied later in the project benefits from consistency in the data. During the DISCLOSE project the SSS was operated without a wing, which resulted in a varying flying height as well as a drift of the SSS up to 100 m to the side of the actual vessel track (personal communication with Leo Koop). Therefore, the SSS data collected at the time cannot be used during the trial as an location-specific indicator for *Sabellaria*, and the postprocessing was severely hampered.

Scanning the data quality on the vessel
A quick check of the MBES backscatter and bathymetry on the vessel for data quality is highly recommended. Appropriate software for checking the MBES data is, for example, *QPS FMGT* (MBES backscatter) and *QPS Qimera* (MBES bathymetry).

- MBES backscatter should be checked for cross-track and along-track stripes.
  - Low-intensity cross-track stripes are usually caused by bubbles in the water column, due to bad weather or high sailing speed. Reducing the sailing speed or waiting for calmer weather is recommended.
  - Along-track stripes can be caused by a change in sonar settings, change of water-column properties (wrong sound absorption), high sediment turbidity or change of seabed composition over time.
- MBES bathymetry should be checked for artifacts in regions with overlapping MBES data. Artifacts can be caused by:
  - Insufficient CTD sampling.
  - A wrong input of MBES and sensor-installation parameters.

Storage of MBES backscatter
Highly important is the storage of the MBES backscatter data during the acquisition. Without the MBES backscatter no sediment classification can be carried out. Usually, the surveyor has to enable the storage manually, otherwise (in default setting) the backscatter will not be stored in the MBES files.

Consistent MBES settings
In order to use acoustic backscatter for sediment and habitat classification, the MBES settings need to be consistent during the survey campaign. Only then, the data is representative of the current seabed state and allows a comparison between the acquired data.

SSS survey lines orthogonal to the orientations of the mega ripples
The orientation of the SSS track lines can alter the visualisation of the seabed. Therefore, it is recommended to define the orientation of the SSS lines on the basis of the project goal and the geological information available. It might even be necessary to adjust the track line on the vessel after the first check of the data quality. Still, it is recommend to do several lines orthogonal to each other to cover different perspectives.

Regular measurements of sound velocity and sound absorption in the water column
Insufficient water-column sampling leads to artifacts in the bathymetry and backscatter data. In particular, data quality of the measured bathymetry can suffer when the sound velocity required for the calculation of water depth from travel time of the acoustic signal is insufficiently known. With sophisticated software, the artifacts can be reduced to some extent.

Track-line spacing and SSS flying height
The MBES and SSS are aimed to be deployed simultaneously to increase efficiency. Possible complications due to acoustic interference between both systems need to be investigated during the first track lines. Judging from personal communication with RWS, no complications are expected. Track-line spacing is defined in order to obtain full coverage for both sensors. During the first day, a larger area is surveyed with an optimized line spacing for the MBES. The flying of the SSS is set to guarantee full coverage as calculated using the rule of thumb: flying height = 0.1*ground range. The acquired dataset is used to locate reef indicators. If reef indicators are identified, an associated site is selected as a test area. If not, the predefined test area (see Test area A1 in Figure 4.1) is chosen. The test area is surveyed with different SSS settings, i.e. SSS flying height, line spacing, survey speed and heading, to optimize the acquisition settings for the SSS. If significant improvements of the detection capabilities of *Sabellaria* reefs are obtained during the test, corresponding flying height and line spacing are chosen for the entire campaign.

Survey speed
The survey speed defines, among others, the coverage rate and is therefore crucial for surveying a large area. However, survey speed and ping rate combined define the along-track sounding density for the MBES and SSS. A lower speed or higher ping rate achieves higher along-track sounding coverage. A higher ping rate can be achieved for the MBES via a smaller swath coverage sector and for the SSS via a shorter fixed ground range or lower flying height. A suitable MBES survey speed is 5 knots, which yields a sounding density of 30 cm for a water depth of 40m and swath-coverage sector of 130 degrees. Considering the beam-footprint resolution of 70 cm below the vessel at 380 kHz, the sounding density is sufficient with 2.2 soundings per beam footprint in along-track direction.

The survey speed of 5 knots is assumed, for the start of the trial, to be reasonable for the SSS. In [10], *Sabellaria* was detected with a SSS using survey speeds of both 3 and 6 knots, for a short ground range of 50 m. Increasing this range to 150 m decreased the detectability for the higher survey speed (yielding lower along-track coverage). As described previously, the optimal SSS survey speed is investigated in the test area on the basis of the first dataset acquired.

Track-line orientation
The track-line orientation can be a critical factor for the detection of *Sabellaria* [10]. On the basis of previous experience and literature (personal communication with Leo Koop), track lines parallel to the megaripples (~10 m wavelength) in the survey area are recommend. However, the track-line orientation might be altered to be least impacted by currents

(relevant for towed SSS) and waves (relevant for MBES). Judging from personal communication with Govert Wesseling, the current speed (max 1.0 to 1.5 m/s, 30 – 210 degrees) is not expected to affect towing of SSS. Furthermore, in terms of time efficiency, the track lines should be parallel to the long-axis of the survey area to reduce the number of turns. The effect of the track-line orientation on the detection capability is further investigated as described previously in a separate test.

<u>MBES frequency, swath coverage sector (swath angle) and pulse type and length</u>
The aim is to use the highest frequency of 400 kHz (Kongsberg 2040C) to obtain the highest bathymetric resolution. Since it is important to use the same frequency over the entire trial for comparable backscatter data, the data quality acquired at the deepest location (-40 to -45 m LAT) at 400 kHz is evaluated. If data quality (due to low SNR) is too low, 300 kHz is chosen. The swath-coverage sector is set to 130 degrees, following general survey experience, in light of the trade-off between coverage and resolution, and to keep similar coverage between SSS and MBES. A CW (continuous wave) pulse is chosen over an FM (frequency modulated) pulse since better backscatter quality is expected. A pulse length of 100 µm is selected following previous survey experience and in light of the trade-off between backscatter resolution and a sufficient SNR. The pulse is an important parameter to keep consistent during the trial to obtain comparable backscatter data. Filters altering the pulse length should be switched off.

<u>MBES survey modes</u>
In general, the MBES data should be acquired in single-swath mode. Even though dual-swath mode would increase the along-track sounding density, it alters the frequency and consequently the backscatter. If insufficient along-track sounding density is noticed, it is best to either reduce survey speed or switch on dual-swath mode.

<u>MBES bathymetry filters</u>
The real-time bathymetry filters are chosen according to RWS standards but the requirement is that it should not significantly influence the consistency of the MBES backscatter. Figure A.1 provides an overview of the MBES settings and filters used during the actual survey. All settings are kept constant during the trial.

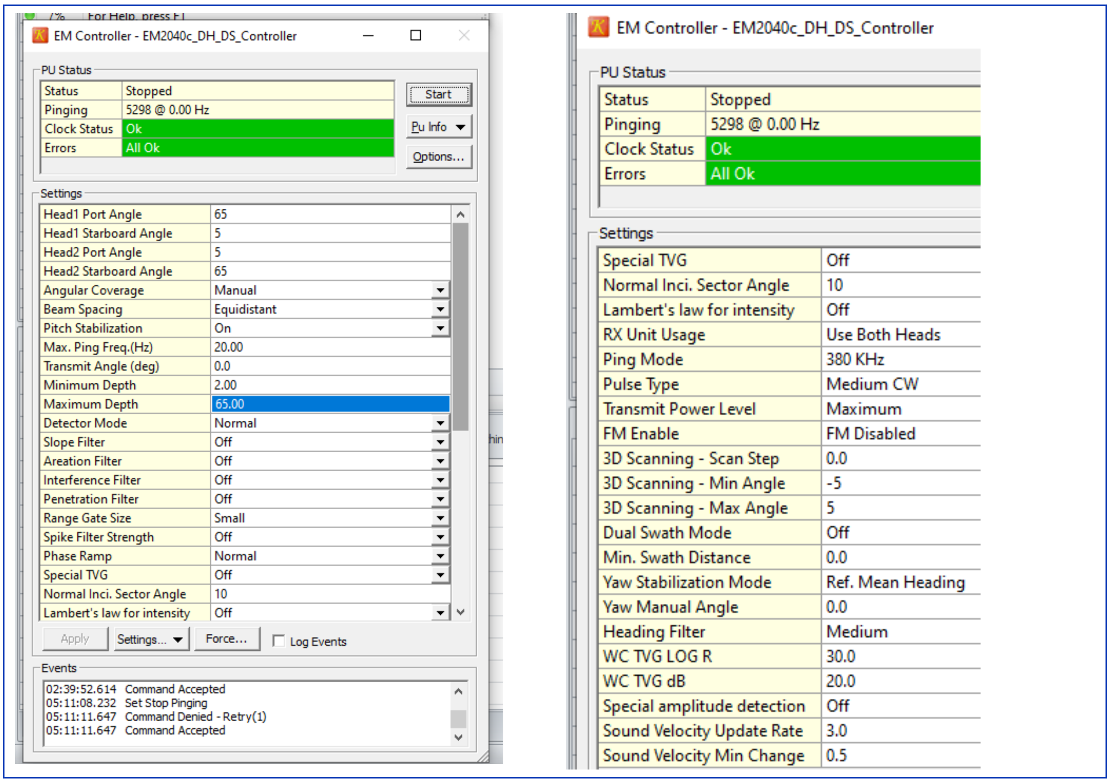

Figure A.1: The MBES settings and filters used during the trial.

Table 5: Default vessel and general settings.

Vessel and general Settings	
Survey speed	5 knots
Heading	W-E if environmental conditions allow
CTD	Beginning and end of night survey, following RWS experience
Coordinate system	Geographic: WGS84 or ETRS89 (0.5 to 1 m offset), Projected: ETRS 89 UTM31N

Table 6: Default MBES settings.

MBES Settings	
Frequency	380 kHz, keep constant
Swath-coverage sector	130 degrees
Pulse type	CW, keep constant
Pulse length	100 µm (medium), keep constant
Sounding pattern	Equidistant, keep constant
Swath mode	Single-swath
Filters	RWS standard, reduce negative effect on backscatter

Table 7: Default SSS settings.

SSS Settings	
Frequency	455 kHz
Range	~10% of flying height (further investigation)
Flying height	7.5 m (guarantee full-coverage MBES and SSS, high *Sabellaria*-detection capability)
Pulse type	Chirp
Pulse length	4, 8, 16 ms Chirp

Table 8: Default SBES settings.

SBES Settings	
Frequency	24 kHz (disable 210 kHz)

Example of surveying coverage and resolution

The default settings, as listed in Table 9 to Table 11 amd assuming a water depth of 38 m yield the following survey coverage and resolution:

- MBES ground range 81 m;
- MBES beam footprint at nadir of 0.7m and at 65 degree of 1.7m;
- MBES along-track sounding coverage of 0.3 m;
- SSS ground range 75 m;
- SSS along-track sounding coverage of 0.14 m.

Table 9: Default vessel and general settings.

Vessel and general Settings	
Survey speed	5 knots
Heading	West-East if environmental condition allow
CTD	Before and end of night survey, based on RWS experience
Coordinate system	Geographic: WGS84 or ETRS89 (0.5 to 1 m offset), Projected: ETRS 89 UTM31N

Table 10: Default MBES settings.

MBES Settings	
Frequency	400 (300) kHz, keep constant
Swath coverage sector	130deg
Pulse type	CW, keep constant
Pulse length	100 μm (medium), keep constant
Sounding pattern	Equidistant, keep constant
Swath mode	Single-swath
Filters	RWS standard, reduce negative effect on backscatter

Table 11: Default SSS settings.

SSS Settings	
Frequency	455 kHz
Range	~10% of flying height (further investigation)
Flying height	7.5 m (guarantee full-coverage MBES and SSS, high *Sabellaria* detection capability)
Pulse type	Chirp
Pulse length	4, 8, 16 ms Chirp

Appendix B
Ground-truth locations

Table 12: List of acquired box-core and video recordings stating if *Sabellaria* was detected. The coordinates are provided in ETRS89 UTM 31N. A detailed description is part of box-core and video analysis provided later by WE/WF.

Datum	Location	Type	Dive id	X [m]	Y [m]	Water Depth [m]	Sabellaria detected
8/22/2023	A1	Video	4	522865	5829735	-39.4	No
8/22/2023	A10	Video	11	522583	5830079	-43.0	No
8/22/2023	A2	Video	5	522954	5828995	-44.2	No
8/22/2023	A3-S1	Sediment		522956	5830294		No
8/22/2023	A3-S2	Sediment		522956	5830294		No
8/22/2023	A3/A5	Video	6	522937	5830177	-43.4	No
8/22/2023	A8	Video	7	523211	5830372	-44.1	Yes
8/22/2023	A9	Video	10	523255	5830293	-43.2	No
8/22/2023	A9-S1	Sediment		523239	5830228		No
8/23/2023	B1	Video	12	519234	5830474	-41.7	No
8/23/2023	B1-B1	Benthos		519279	5830411		Yes
8/23/2023	B1-B2	Benthos		519279	5830411		Yes
8/23/2023	B1-S1	Sediment		519248	5830443		No
8/23/2023	B2	Video	13	518892	5829738	-41.7	No
8/23/2023	B3	Video	14	519037	5829742	-40.9	Yes
8/23/2023	B3-B1	Benthos		519036	5829744		Yes
8/23/2023	B3-S1	Sediment		519026	5829748		Yes
8/23/2023	B4	Video	15	519474	5830322	-37.7	Yes
8/28/2023	B4-B11	Benthos		519559	5830492		Yes
8/28/2023	B4-B12	Benthos		519559	5830492		Yes
8/28/2023	B4-S10	Sediment		519559	5830492		Yes
8/28/2023	B4-V14	Video	23	519586	5830537	-36.4	Yes
8/24/2023	B4-V2	Video	22	519576	5830539	-36.8	Yes
8/29/2023	B6-V1	Video	27	519367	5830167	-37.8	Yes
8/29/2023	B7-V1	Video	26	519209	5829921	-38.0	no information
8/31/2023	B8-S1	Sediment		518784	5833136		No
8/31/2023	B8-S2	Sediment		518805	5833143		Yes
8/31/2023	B8-S3	Sediment		518862	5833170		No

Datum	Location	Type	Dive id	X [m]	Y [m]	Water Depth [m]	Sabellaria detected
8/31/2023	B8-S4	Sediment		518852	5833216		No
8/31/2023	B8-S5	Sediment		518882	5833263		No
8/31/2023	B8-V1	Video	31	518972	5833385	-39.3	Yes
8/31/2023	B8-V2	Video	30	518230	5833167	-33.8	No
8/31/2023	B9-B7	Benthos		519843	5834629		Yes
8/31/2023	B9-B7	Benthos		519843	5834629		Yes
8/31/2023	B9-S1	Sediment		518330	5834454		No
8/31/2023	B9-S2	Sediment		518758	5834447		No
8/31/2023	B9-S3	Sediment		518861	5834441		Yes
8/31/2023	B9-S4	Sediment		519360	5834439		Yes
8/31/2023	B9-S5	Sediment		519534	5834435		Yes
8/31/2023	B9-S6	Sediment		519696	5834346		No
8/31/2023	B9-S8	Sediment		519986	5834639		No
8/31/2023	B9-S9	Sediment		519340	5833926		No
8/24/2023	E1-1	Video	16	524133	5850483	-40.1	No
8/24/2023	E1-2	Video	17	523856	5849526	-41.3	Yes
8/24/2023	E1-2-S1	Sediment		523846	5849452		No
8/24/2023	E1-3-S1	Sediment		524065	5851947		No
8/24/2023	E2-3	Video	21	527150	5850278	-34.8	No
8/24/2023	E2-4	Video	18	527190	5851512	-32.9	Yes
8/24/2023	E2-5	Video	20	526782	5850077	-34.8	Yes
8/24/2023	E2-5-S1	Sediment		527014	5850420		No
8/30/2023	F1-B1	Benthos		524383	5840515		Yes
8/30/2023	F1-B2	Benthos		524384	5840513		Yes
8/30/2023	F1-B3	Benthos		524344	5840509		Yes
8/30/2023	F1-S1	Sediment		524513	5840566		Yes
8/30/2023	F1-S2	Sediment		524447	5840580		No
8/30/2023	F1-S3	Sediment		524381	5840515		Yes
8/30/2023	F1-S4	Sediment		524344	5840501		Yes
8/30/2023	F1-S5	Sediment		524102	5840672		Nee
8/30/2023	F1-V1	Video	28	524329	5840490	-43.4	Yes
8/30/2023	F2-S1	Sediment		524619	5839989		No
8/30/2023	F2-S2	Sediment		524537	5839993		No
8/30/2023	F2-S3	Sediment		524468	5839948		No
8/30/2023	F2-S4	Sediment		524391	5839979		No
8/30/2023	F2-S5	Sediment		524251	5839988		Yes

Datum	Location	Type	Dive id		X [m]	Y [m]	Water Depth [m]	Sabellaria detected
8/30/2023	F2-S6	Sediment			524218	5839982		Yes
8/30/2023	F3-S1	Sediment			524668	5841269		No
8/30/2023	F4-V1	Video		29	525650	5840518	-36	No
8/29/2023	G1-S1	Sediment			511403	5807696		No
8/29/2023	G1-S2	Sediment			511395	5807735		No
8/29/2023	G1-S3	Sediment			512601	5808296		No
8/29/2023	G1-V1	Video		24	511405	5807583	-40.2	Yes
8/29/2023	G1-V2	Video		25	512648	5808405	-34.7	Yes

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