Borkum Reef Grounds: inventory of habitats and biodiversity

Report C054/25

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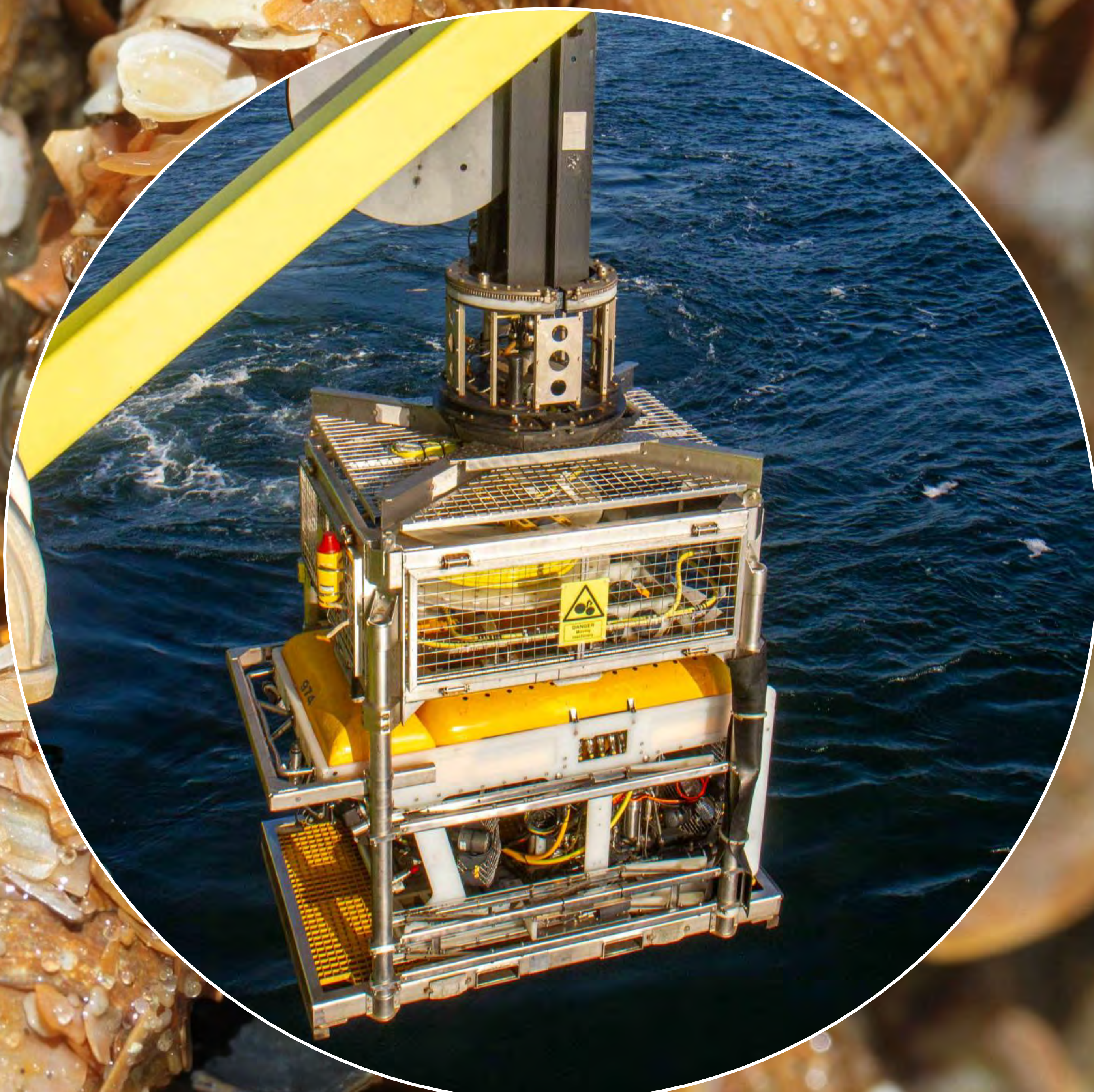

Borkum Reef Grounds: inventory of biodiversity and habitats

MONS ID49 Effectivity of Marine Protected Areas

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Wageningen Marine Research
Den Helder, April 2025

Wageningen Marine Research rapport C054/25

Wageningen Marine Research, Wageningen Marine Research report C054/25 7942; number of tables 10.; number of figures:23

Keywords: Borkumse Stenen, KRM, MSFD, MWTL, benthos, H1170, *Lanice*, *Loimia*.

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This research was carried out on behalf of the MONS programme. MONS forms the knowledge base for the North Sea Consultation (Noordzeeoverleg). This research is co-financed by the European Union.

NOORDZEEOVERLEG

Co-funded by the European Union

This report can be downloaded for free from https://doi.org/10.18174/697930
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Contents

Summary

As part of the nature transition, the Borkum Reef Grounds (BRG) (685 km^2), a marine protected area (MPA) established under the Marine Strategy Framework Directive (MSFD), will be protected against bottom fisheries under the EU Common Fisheries Policy (CFP) in the near future. The aim is to promote the recovery of benthos. To evaluate the effectivity of the fishery measure, monitoring will be needed before and after closure of the area. However, for the Borkum Reef Grounds area, it was not possible to set up a monitoring strategy yet, due to a lack of data on the distribution of habitats and biodiversity for a large part of the area.

The aims of this MONS project were hence to fill in knowledge gaps about the BRG biodiversity and distribution of abiotic (H1170), biogenic (*Lanice*) reef habitats and EU MSFD Broad Habitat Types, and to come up with a monitoring strategy in line with the national Natura 2000/MSFD monitoring program to evaluate the effectiveness of the fishery measures in the future. The project set-up consisted of (A) Analysis of available information, (B) Field research to collect additional data and analysis of the data in the lab and (C) Development of a monitoring strategy in line with the existing national Natura 2000/MSDF monitoring program.

<u>A.</u> <u>Analysis of available information</u>:
First existing biodiversity data (box corer, dredge and video transect samples) and information on the distribution of abiotic (H1170), biogenic (*Lanice*) reef habitats and EU MSFD Broad Habitat Types was collected. Also side scan sonar (SSS) maps of the Hydrographic Office were obtained for the same purpose, covering the whole BRG area. This allowed for setting up a sampling strategy for activity B including site selection and calculation of numbers of samples needed.

<u>B.</u> <u>Field research to collect additional data and lab analyis</u>:
Fieldwork was conducted from 26-30 Aug 2024 on board RWS ARCA (IMO 9167966; 83 m) equipped with a multibeam echosounder (MBES), side scan sonar (SSS), ROV and box corer, as well as two crews, allowing for 24h operations. The scope of the fieldwork was to fill in knowledge gaps to get better insight in the distribution and biodiversity of geogenic reefs H1170, biogenic reefs (*Lanice* reefs) and EU MSFD Broad Habitat Types (sand), in addition to the available information collected in part A. The sampling strategy for the abiotic (stone) and biogenic reefs (*Lanice*) consisted of collecting acoustic data (SSS and MBES) at night in 3 different subareas (2 areas with abiotic reefs (H1170) and 1 area with biogenic *Lanice* reefs), followed by ROV video transects to groundtruth the acoustic data in the morning, and box corer sampling in the afternoon. The sampling strategy for the sandy area consisted only of taking box corer samples. From these box corer and video samples, information on species densities was obtained per habitat type, as input for Part C (development of a monitoring strategy).

<u>*EU MSFD Broad Habitat Types (sand)*</u>: The box corer samples were partly analyzed on board following a dredge sampling protocol, to get an impression of the expected species assemblages and sediment characteristics, and partly in detail in the laboratory following a box corer protocol for more detailed species information as addition to the biodiversity data collected in part A. For the future monitoring strategy, it was concluded that dredge sampling was not needed and that box corer sampling would be sufficient to monitor soft sediment habitat development and effectiveness of measures (see part C).

<u>*Abiotic reefs (H1170)*</u>: In combination with new data (SSS, MBES, video and box cores), the historic SSS data (2008 and 2013) was used to map geogenic stone reefs (H1170) (manually) and biogenic *Lanice/Loimia* reefs in the whole BRG area (using AI classification). The rough boundaries of the stone fields identified using the new collected data overlapped very well with the stone fields that could be identified on the historic SSS data. Automated detection of stones using AI classification is possible but was not done within this project and could be developed in the future. Coarse substrate (mixture of shells, gravel, small stones with sand) in the abiotic reef areas (H1170) could be accurately detected using MBES backscatter data and its comparison to video/box corer data. Since there were no historic MBES data, this analysis could not be extrapolated to

the whole BRG area. For the future monitoring strategy, it was concluded that using historic data on positions of stones and boulders, video tracks could be defined to monitor geogenic reef community development. The use of MBES data to detect coarse substrate is promising, but will not be part of future monitoring (see part C).

Rocks (stones and boulders) were covered with anemones, predominantly the plumose anemone (*Metridium senile*), but also 'fluffy' hydroids and bryozoans and the soft coral dead man's finger (*Alcyonium digitatum*) and larger sponges such as fig sponge *Suberites ficus*. The area in between the rocks and stones consisted of sand, or gravelly substrate. Here sea stars (*Asterias rubens*), anemones (various species, a.o. *Cylista troglodytes*) were most abundant. At several locations, European lobsters (*Homarus gammarus*) and brown crabs (*Cancer pagurus*) were observed. In the sediment, in the box cores, many polychaete, bivalve and arthropod species were found, including an individual of the polychaete *Sabellaria spinulosa*.

Lanice/Loimia reefs: During the fieldwork, and later on in the lab, it was determined that *Loimia ramzega*, a tube building worm, similar to *Lanice conchilega* and only discovered as a new species in 2017 in France, is a common species on the Borkum Reef Grounds and occurs together with *Lanice conchilega*. In the *Lanice/Loimia* reef in the south, the two species show a ratio of 73%/27% in density (*Lanice/Loimia*) and 62%/38% in biomass (WW). It is not clear since when the species has been present in the area. This will be investigated by analyzing a few historic samples from previous projects. Within the 3 box cores in total 96 taxa (61 species) were determined, dominated by polychaetes, arthropods and bivalves.

Using the SSS data, this study has shown that high density *Lanice/Loimia* reefs are well detectable, both using the newly acquired SSS data (Area D), and using historic SSS data (whole BRG). Low densities of *Lanice/Loimia* were not accurately detectable. By combining historic and new SSS data, spatial changes over time of high density biogenic *Lanice/Loimia* reefs can be detected. Since the SSS data is also available for a large part of the Dutch North Sea, other areas can probably also be analysed for the presence of *Lanice/Loimia* reefs. For the future monitoring strategy, it was concluded that it would be useful to monitor the *Lanice/Loimia* reefs using SSS to detect changes in coverage over time, and to use video transect sampling to monitor biogenic reef community development (see part C.)

Biodiversity: The aim of the fieldwork was not to execute a well-balanced monitoring programme that allowed for comparison of biodiversity among habitats, but rather to collect additional samples on top of existing data, to determine a future monitoring strategy. The numbers of samples and the sampling techniques used in each habitat were only tailored to fill in data gaps. Therefore, the species richness found per habitat in the field study is just indicative and no efforts were made to create species accumulation curves to compare habitats. In terms of species richness, the *Lanice/Loimia* reefs contained the highest number of taxa (96) and species (61) (box cores sorted in the lab), followed by the broad EU MSDF habitats (sand: 81 taxa/54 species; box cores sorted on board and in the lab) and abiotic reefs (69 taxa/41 species: video + box cores sorted on board). However, for the abiotic reef areas (H1170) box cores were sorted on board, following a dredge protocol, and not in the laboratory, so the actual species numbers are probably an underestimation.

C. Development of a monitoring strategy:

The last step was to analyze and integrate the data and come forward with a monitoring strategy specifically tailored to the unique ecological characteristics of the area. The monitoring strategy is described in a parallel report by Wijnhoven et al. (2025). Technical details on acoustic monitoring are described in the TNO report in Annex A of this report. In short, the setup is:

EU MSFD Broad Habitat Types

- Box corer sampling at 38 fixed measurement locations in spring (19 within the MSDF area Borkum Reef Grounds (BRG) and 19 in the vicinity of the BRG) to monitor soft sediment habitat development and effectiveness of measures.

Abiotic reefs (H1170)

- Video transect sampling of 16 fixed 120 m stone-to-stone transects (lasers 50 cm apart) in summer (only in areas with >50 stones (often>100) per km^2) to monitor geogenic reef community development.

Lanice/Loimia reefs

- Video transect sampling of 16 fixed 120 m (standard straight line) transects (lasers 50 cm apart) in summer (8 within the MSFD area BRG and 8 in the vicinity of the BRG) to monitor *Lanice/Loimia* reef development and effectiveness of measures.
- Side scan sonar mapping of a fixed area within which the *Lanice/Loimia* reef is located. The mapping takes place both inside and outside the Borkum Reef Grounds MPA to monitor reef development in unfished and fished areas.

Annexes to this report:

Annex A	TNO report on the acoustic data .	'Analysis of sonar data for mapping geogenic and biogenic reefs in the Borkum Reef Grounds, Dutch Continental Shelf'
Annex B	Research plan missing data	'Onderzoeksplan ontbrekende gegevens'
Annex C	Field work plan	'Fieldwork plan Borkum Reef Grounds 2024'
Annex D	Field work logbook	'Logbook fieldwork Borkum Reef Grounds 26-30 August 2024'
Annex E	Benthos biodiversity data	
Annex F	Sampling locations	

1 Introduction

1.1 Background

1.1.1 MONS program

The research described in this report is part of the MONS program (Asjes et al., 2021) that aims to provide insight in the ecological consequences of the energy, food provisioning and nature transitions that take place in the North Sea. As part of the nature transition, a number of marine protected areas (MPAs) will be protected against different forms of bottom fisheries under the EU Common Fisheries Policy (CFP) (Figure 1). The Borkum Reef Grounds (BRG) (685 km2) is one of these MPAs and was established under the Marine Strategy Framework Directive (MSFD) in 2022 (Min I&W & Min LNV, 2022).

The fishery measure in the Borkum Reef Grounds will consist of a ban on bottom-disturbing fishing including beam trawls, trawls dredges and seines (see Joint Recommendation for details[1]) to promote the recovery of benthos. The main fisheries consists of shrimp fisheries. To evaluate the effectivity of the fishery measure in the future, monitoring is needed. This MONS project was set up to design such a monitoring strategy in line with the national Natura 2000/MSFD monitoring program (Min I&W & Min LNV, 2020). In this program, the biodiversity of benthic habitats in the Dutch North Sea is assessed using various methods, including video monitoring, Hamon sampling, box corer sampling, and dredge sampling. These data are used to populate the Benthic Indicator Species Index (BISI) (Wijnhoven and Bos, 2017; Wijnhoven, 2023). The BISI can be used to assess the quality status of EUNIS Level 3 habitats (e.g. A2.1 Littoral coarse sediment), of HD Annex I habitats (including H1110 Sandbanks and H1170 reefs), and to assess the effectiveness of fishery measures.

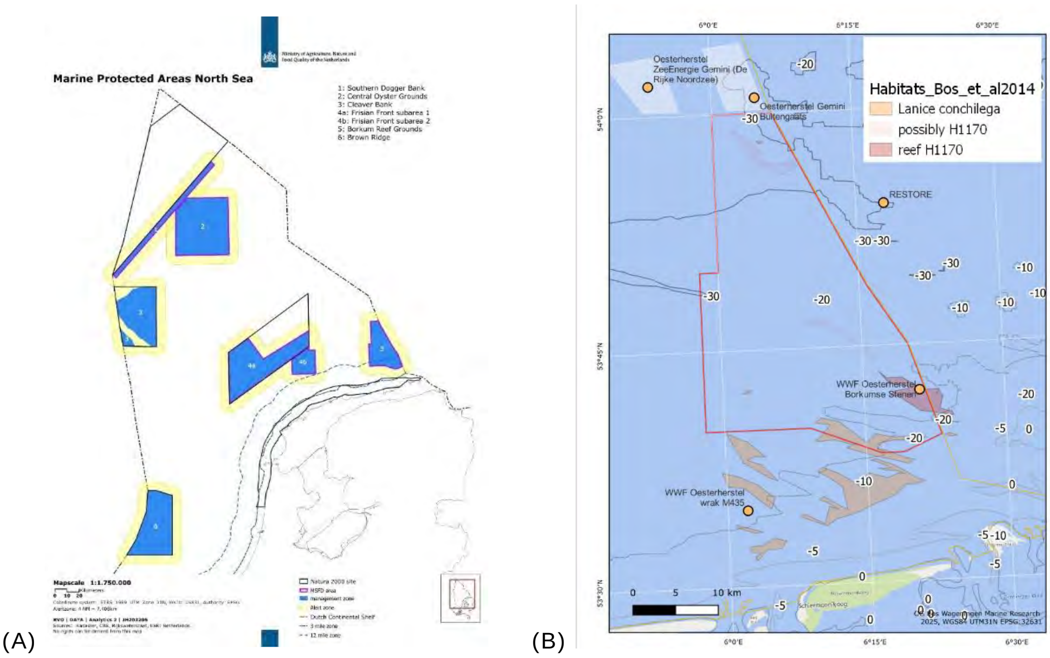


Figure 1 (A): Natura 2000 and MSFD Marine protected areas in the Dutch North Sea, with future fishery management zones under the CFP in blue. The MPA Borkum Reef Grounds is indicated by '5'. Source: Ministry of LVVN. (B): Bathymetry, oyster restoration projects and habitats described by Bos et al. (2014).

[1] See https://www.noordzeeloket.nl/en/@303190/joint-recommendation-north-sea-agreement/

1.1.2 The Borkum Reef Grounds: characteristics and previous research

1.1.2.1 Characteristics

The Borkum Reef Grounds (BRG) MPA is located 15 km north of the island of Schiermonnikoog in the northeastern part of the Dutch North Sea (Figure 1A). It stretches 40 km north up to Gemini Offshore Windfarm (Gemini OWF) and borders Germany along the east side. Depths are between -20 m in the south and -30 m in the north. Three distinct habitats are present: abiotic reefs (boulders, stones, gravel: H1170), biogenic *Lanice conchilega* reefs and sand (Bos et al. 2014, Coolen et al. 2015) (Figure 1B). In the 19th century, the BRG area formed part of the European flat oyster (*Ostrea edulis*) distribution (Thurstan et al., 2024; Olsen, 1883). Currently, at several locations in and near the area, European flat oyster (*Ostrea edulis*) restoration pilots take place (Bos et al., 2024) (Figure 1B).

1.1.2.2 Previous research

Historically, the Borkum Reef Grounds are known for the occurrence of stones and rocks and of oyster beds. A 1915 German fishery map (in Gercken & Schmidt, 2014) (Figure 2) shows the presence of stony reefs at that time. Also a map made by the Dutch Ministry of LNV (mid-20th century) for fishery research shows that Borkum Reef Grounds is classified as 'reef area' (Figure 3).

In the process of setting up the Natura 2000 network of MPAs, the Borkum Reef Grounds was identified as a potential area with special ecological values in 2005 (Lindeboom et al., 2005). A triangular boundary was proposed, bordering the proposed Natura 2000 site North Sea Coastal Zone in the south and the German border in the east (Lindeboom et al., 2005) (Figure 4. However, there was not enough evidence available on the distribution of reef habitats and on biodiversity to decide whether it should be an MPA or not.

To fill in the knowledge gap, the policy supporting project 'Additional MPAs' was commissioned by the ministry of LNV (Bos et al. 2014). Within that project, in 2009, a 1 week acoustic survey (side scan sonar (SSS) and Multibeam Echosounder (MBES) was carried out in the triangular shaped BRG area (Figure 4). The basis for this survey was formed by historical information (see below), including some data from NIOZ research from the 1990s (Bergman, 1992). The SSS data showed stones and hard substrate were very likely to be present in the eastern and central part of the area (Figure 4), and in the northern tip. However, the SSS tracks were mostly spaced 1.5 km apart and the SSS images were not compared to box cores or video recordings.

Ground truthing of the 2009 acoustic data was done during a second survey in 2013 (11-16 August 2013) with Scuba divers, box cores and a drop cam. An inventory was made of the biodiversity, the habitats and the sediment characteristics. This survey only covered the southern half of the triangular area (Figure 4) due to time restrictions. The site contained a rich benthic biodiversity in the abiotic reef area characterised by coarse sediments and stony reefs (together: H1170) and in the biogenic reefs, consisting of dense aggregations of the sand mason worm *Lanice conchilega* (Bos et al. 2014, Coolen et al., 2015). It was estimated that H1170 covered approximately 14.5 km^2 (Bos et al., 2014), about 2% of the proposed triangular MPA area.

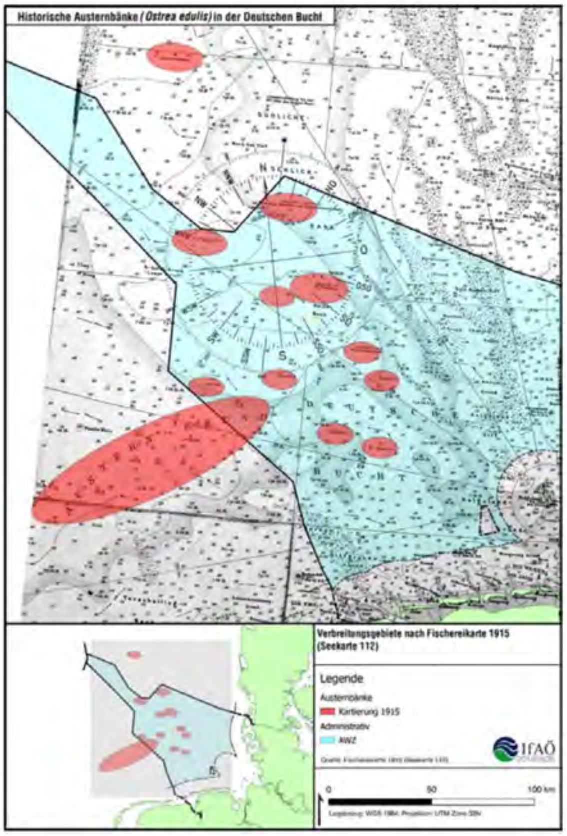


Figure 2. German 1915 Fishery map, showing stony reefs in the northern part of the Dutch Borkum Reef Grounds, and flat oyster beds (red), including the oyster grounds and the German section of the North Sea (from Gercken & Schmidt, 2014).

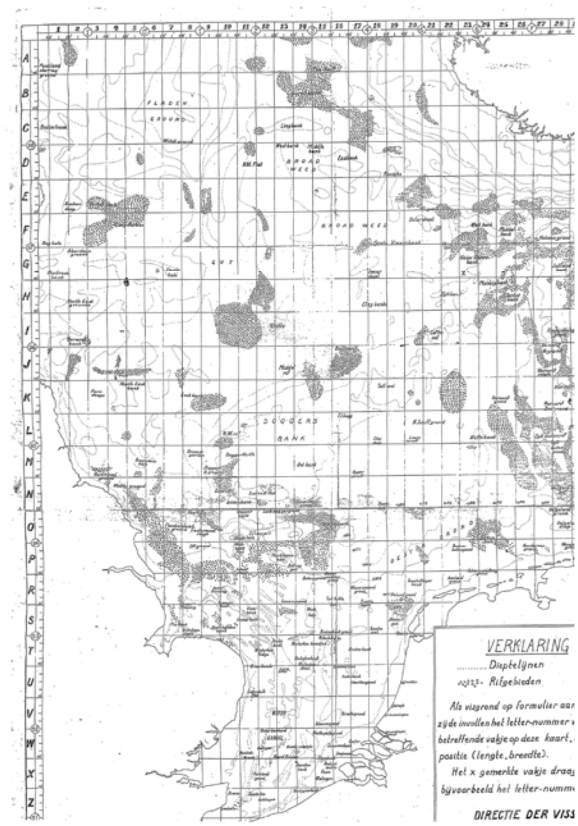


Figure 3. Dutch fishery map by the directorate of Fisheries, ministry of LNV. Date: unknown (probably mid-20th century) showing extensive stony reef areas.

After 2013, the area attracted attention of NGOs and researchers to investigate the abiotic reefs and to do European flat oyster (*Ostrea edulis*) restoration pilots. The abiotic reef area in the south was chosen in 2018 as a site for oyster restoration by WWF and ARK (video ARK/WWF oyster restoration project: https://vimeo.com/365305757). In the course of the years, also several scuba dive expeditions (Dive the North Sea Clean foundation) and research expeditions (OCEANA/DISCLOSE) visited the area (see e.g. OCEANA videos Borkum Reef Grounds: https://vimeo.com/228983030; https://vimeo.com/228230143). Observations by OCEANA confirmed the presence of the abiotic reef and *Lanice* habitat types (Álvarez et al., 2019). Also the oyster restoration work gave more insight in the reef habitat and its biodiversity (Didderen et al., 2020). A day of additional fieldwork using a small ROV in December 2021 confirmed the presence of some stony reefs in the northern part, close to Offshore Wind Park Gemini (O. Bos, pers. com). Several research projects were set-up to investigate the success of the oyster pilots (Figure 1B) (ECOFRIEND project; Bos et al., 2023a,b) and the functioning of the reef (REVIFES project; Coolen et al., 2021) (Figure 4). An analysis of oyster restoration projects is given in Bos et al. (2024) and shows that pilots were successful. Also, in the German Borkum Reef Grounds, an oyster restoration project takes place (RESTORE).

In 2020, in the North Sea Agreement (OFL, 2020), it was decided to close the BRG area under the MSFD. However, the triangular shaped boundaries proposed in 2005 included important shrimp fishing grounds. In negotiations between the ministry of LNV and the fisheries, the southern boundary of the area was moved up northward, to allow for the continuation of shrimp fisheries north of the N2000 site North Sea Coastal Zone. To compensate for this change, the proposed protected area was made much wider at the top, which also allowed for connecting the MPA with the oyster restoration sites in offshore wind park Gemini (Figure 4).

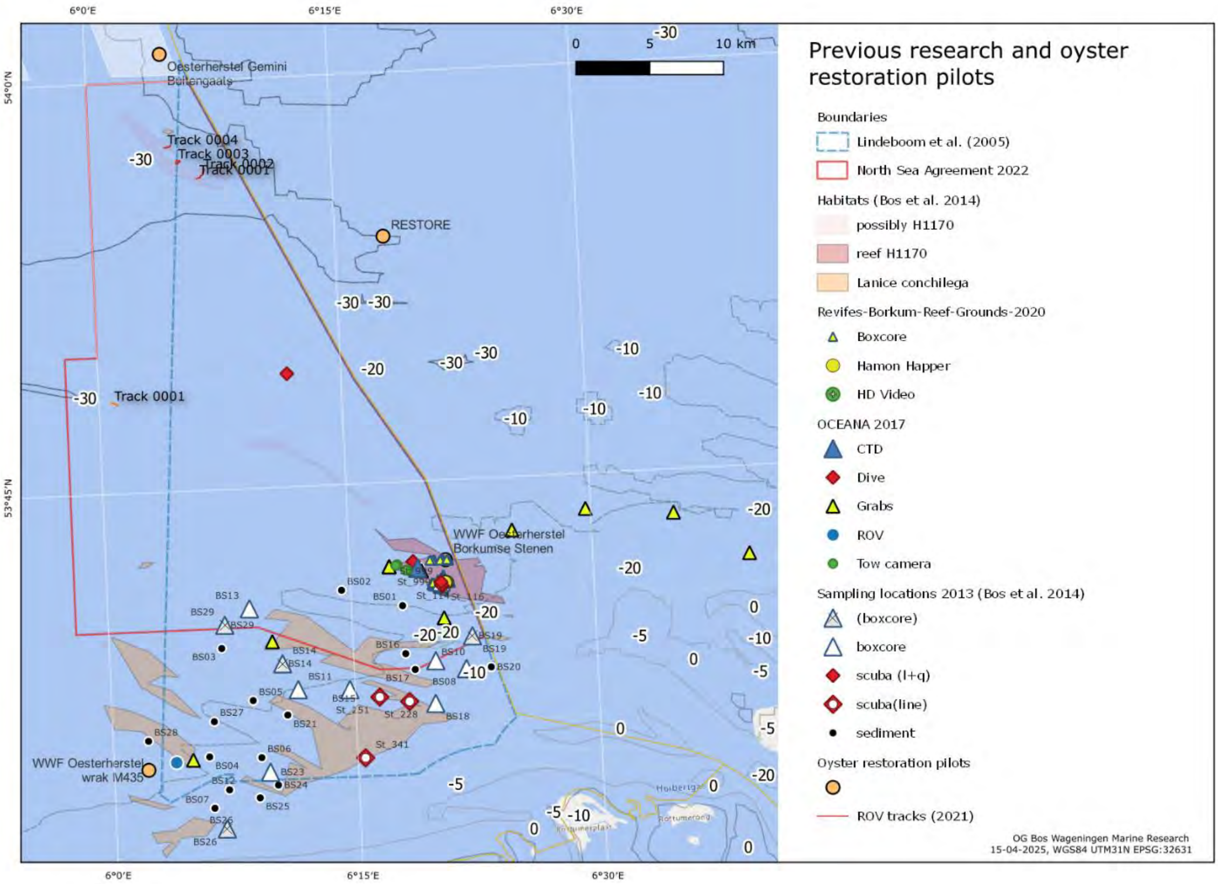


Figure 4. Overview of previous and current Borkum Reef Ground area boundaries, and previous research. Coloured polygons indicate the habitat types identified by Bos et al. (2014). Locations of previous sampling locations are also shown.

1.2 This research

1.2.1 Assignment

Rijkswaterstaat has asked Wageningen Marine Research and partners (Ecoauthor, Waardenburg Ecology and TNO) to come up with a monitoring strategy to determine the status of benthic habitats and benthos of the Dutch Borkum Reef Grounds (BRG). This research "MONS ID49 Effectiviteit gesloten gebieden (onderdeel Borkumse Stenen)" (RWS zaaknummer 31201219) is part of the MONS programme (Asjes et al., 2021). The roles were:

- Wageningen Marine Research (project coordination, laboratory video and benthos analysis, reporting)
- TNO: acoustic research (SSS, MBES, reporting)
- Waardenburg Ecology (fieldwork: boxcoring, on board ROV video annotations, data quality checks)
- Ecoauthor (statistical analysis, design of fieldwork and monitoring strategy, BISI indicator development, reporting)

1.2.2 Aims

This project was set up to design a future monitoring strategy of the Borkum Reef Grounds (BRG) in line with the national Natura 2000/MSFD monitoring program (Min I&W & Min LNV, 2020).

The aims of this research were to fill in knowledge gaps about the BRG biodiversity and distribution of abiotic (H1170), biogenic (*Lanice*) reef habitats and EU MSFD Broad Habitat Types, and to come up with a monitoring strategy to evaluate the effectiveness of the fishery measures in the future.

The project set-up consisted of (A) Analysis of available information, (B) Field research to collect additional data and analysis of the data in the lab and (C) Development of a monitoring strategy in line with the existing national Natura 2000/MSDF monitoring program.

1.2.3 Approach

The following approach was taken to come to a monitoring strategy:

A. Analysis of available information: The first step was to collect and analyze existing data on the distribution and diversity of habitats and benthos of the Borkum Reef Grounds. This was done to assess which additional data needed to be collected in the field for the development of a future monitoring strategy and BISI indicator.

B. Field research to collect additional data: The second step was to collect additional data of benthos and habitats in the field using box corer, ROV and acoustics (SSS, MBES). This was done from 26-30 Aug 2024.

C. Development of optimal monitoring strategy: The last step was to analyze and integrate the data collected under A and B to draw up the optimal monitoring strategy specifically tailored to the unique ecological characteristics of the area.

The results of this research are described in two reports:

- Data report: this report summarises the existing and new data collected for the habitats distribution and benthic biodiversity of the BRG (result of the activities A + B described above). The acoustic work to map habitats (SSS and MBES) is described in Annex A in the TNO report "Analysis of sonar data for mapping geogenic and biogenic reefs in the Borkum Reef Grounds, Dutch Continental Shelf". The other annexes describe the fieldwork monitoring plan that was organised to collect missing data for BESI calculations (Annexes B the theoretical background and C the practical workout of the different fieldwork activities), the fieldwork logbook (Annex D), the video and boxcore data (Annex E) and the list of locations (Annex F).
- Monitoring strategy: Wijnhoven et al. (2025) "*Meerjarig monitoringprogramma benthos Borkumse Stenen. Product MONS project ID49 Effectiviteit gesloten gebieden*", in which the future monitoring strategy is described.

2 Materials and Methods

2.1 Existing data

2.1.1 Acoustic data

Existing side scan sonar (SSS) data were obtained from the Hydrographic Office of the Netherlands which covers most of the BRG area. The dataset was recorded in 2008 and 2013 with varying data quality and not fully optimised for detecting biogenic or geogenic reefs (Figure 5). Details can be found in Annex A.

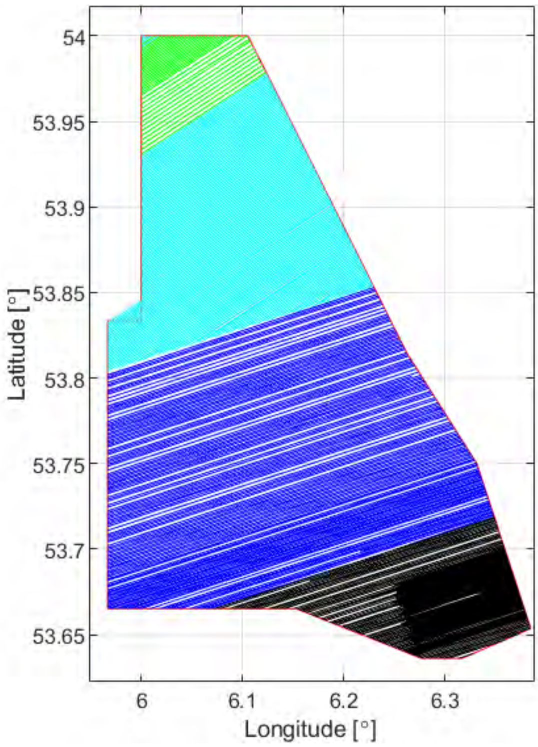


Figure 5. SSS line coverage of the Hydrographic Office data in the Borkum Reef Grounds area. Black and blue sonar lines were acquired in 2013 and green and cyan lines acquired in 2008. The coordinate system is ETRS 1989 (details in Annex A).

Figure 6. Side scan sonar (SSS) towfish used during the fieldwork.

2.1.2 Benthos data

To set-up a fieldwork sampling strategy and determine which new data were mostly needed, an inventory was made of existing biodiversity data from previous projects (see Annex B for details). Box corer and Hamon grab data from the southern stony reef area were obtained from the ReViFES project (2020) (box corer samples; C. Coral, NIOZ), from the German MSFD monitoring of the German Borkum Reef Grounds (dredge samples, video samples: L. Gutow and J. Beermann, AWI), and from previous research (Bos et al., 2014). Within the ReViFES project many box cores, Hamon grabs and video tracks were taken (Figure 4), but most were not yet analyzed. In Germany, the benthos samples are taken every 3 years and consist of video transects and dredge samples (see Annex B). Based on the available data, it was decided to collect new benthos data using both a dredge sampling protocol, in which samples are sorted on board, and a box corer sampling protocol in which samples are taken to the lab (see details in Wijnhoven et al. 2025). This way, later on it could be decided which monitoring technique (dredge and/or box corer) would be most suitable for future monitoring.

2.1.3 Habitat maps

Information on habitat distribution was obtained from our inventory of the area in 2009 and 2013 (Bos et al. 2014, Coolen et al. 2015) (see paragraph 1.1.2.2 and Figure 4).

2.2 Fieldwork sampling strategy

The fieldwork sampling strategy was designed to be in line with the national Natura 2000/MSFD monitoring program (Min I&W & Min LNV, 2020), in which sampling is done using a box corers, hamon grab, a dredge and video transect sampling. From these methods, box corers and video transects were assessed to be most suitable for the Borkum Reef fieldwork. The other methods (dredge, Hamon grab) were thought to be less suitable: the dredge would get damaged by stones and course sediment, and also damage the reef structure itself. The Hamon grab could be suitable, but is less accurate than a box corer. Since on the Borkum Reef Grounds, the sediment composition is suitable for a box corer, the Hamon grab was not used. In other ares, such as the Cleaver Bank, the sediment composition is too coarse to use a box corer, hence a Hamon grab is used instead. For the acoustic survey, MBES and SSS were chosen, being standard monitoring techniques. In previous MONS research on detection of *Sabellaria* reefs (Gaida et al., 2025), the combination of acoustic monitoring with ground truthing ROV video transect sampling and box coring led to the development of semi-automated classification models to map *Sabellaria spinulosa* reefs. The idea was that in the Borkum Reef Grounds, the combination of acoustic methods with ground truthing methods could lead to the development of classification models to detect *Lanice* reefs and possibly abiotic reefs.

For the fieldwork in 2024, the BRG area was divided into 4 survey areas of interest, covering the 3 major habitat types (Figure 7): Area A: the stony reef area in the southern part, bordering the German border. Area B: a possible stony reef in the northern part, towards Gemini offshore windfarm. Area C: all of the sandy habitat covering the majority of the BRG and D: the *Lanice* reefs in the south. For each area, one day of ship time was available.

In areas A, B and D the aim was to assess the extent of the geogenic and biogenic reef habitats and collect biodiversity data based on ROV and box cores. In area C the aim was to collect biodiversity data for the EU MSFD Broad Habitat Types (sand) using box cores. The monitoring strategy for areas A, B and D consisted of selecting the most promising part of the study area to find reefs using historic sidescan sonar (SSS), then mapping the selected study area (aim: ca 4 km^2/area) using sidescan sonar (SSS) and multibeam echosounder (MBES). Next, ROV tracks were done at 3 locations within the study area to groundtruth the observed SSS acoustic patterns, followed by boxcoring at a few locations that seemed most interesting on the ROV images. For Area D (*Lanice* area) the aim was to collect box corer samples at locations with relatively high *Lanice* densities. Locations with high *Lanice* densities were identified by ROV video monitoring. For Area C, the sampling strategy consisted of boxcoring at geographically widespread locations randomly determined prior to the fieldwork. Part of the samples were planned to be processed on board, following a dredge sampling protocol, and part of the samples in the lab, following a box corer sampling protocol (see Wijnhoven et al. 2025 for details). In general, the acoustic surveys were done during the night, the ROV monitoring in the morning and boxcoring in the afternoon and evening.

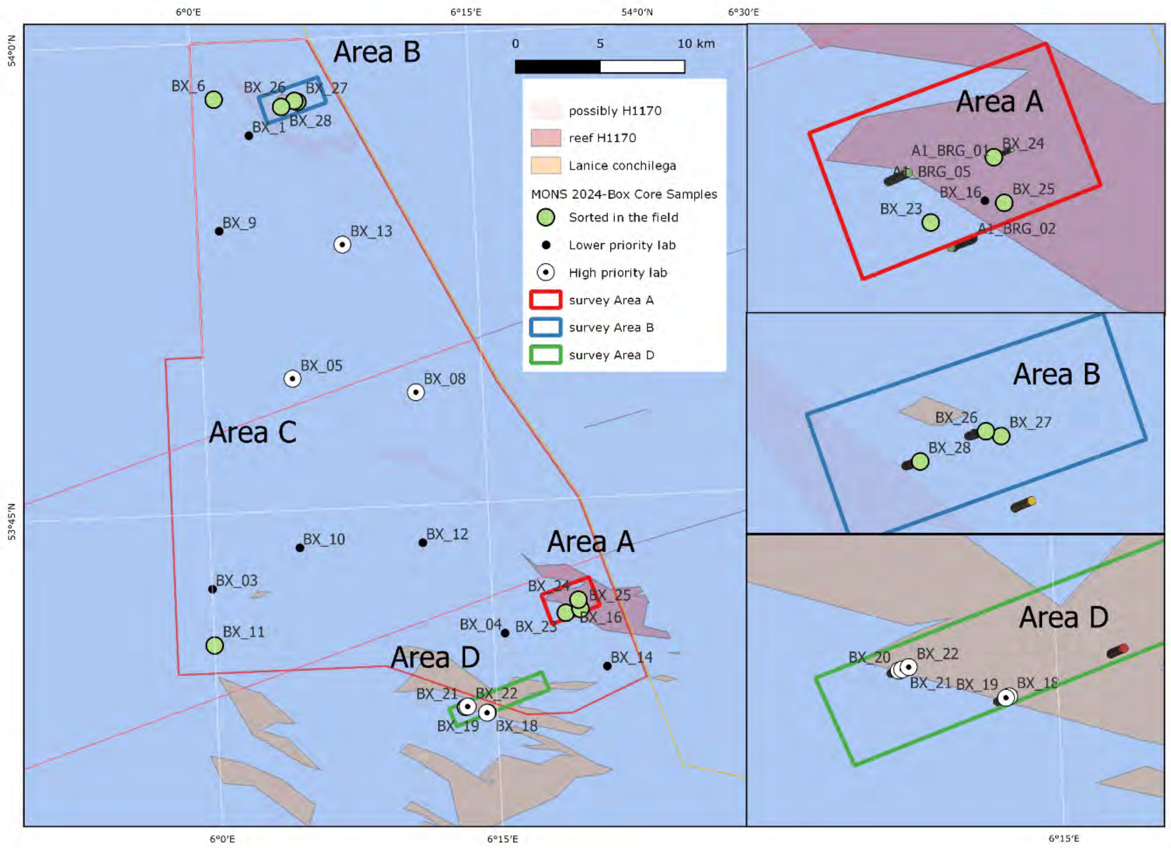


Figure 7. Borkum Reef Grounds. Overview of Box corer and ROV locations. Box cores were either sorted out in the field (green dot) or taken to the lab. For the lab, a distinction was made between samples to be sorted out with high priority (white dot) or lower priority (black dot). Coloured polygons indicate the habitat types identified by Bos et al. (2014).

2.2.1 Data analysis

The existing data (paragraph 2.1.1) were analysed to assess the number of box corer and video samples needed to be collected during the fieldwork campaign. This analysis resulted in a plan to take 15 geographically distributed box corer samples, of which 10 needed were to be sorted on board following a dredge sampling protocol and 5 in the laboratory following a box corer sampling protocol (for details, see Annex B and C).

The fieldwork data and laboratory data were analysed by S. Wijnhoven (Wijnhoven et al. 2025) for the set-up of the monitoring strategy and are described in Wijnhoven et al. (2025).

2.3 Field work and processing of samples in the lab

Fieldwork was conducted from 26-30 Aug 2024 on board the pollution control vessel RWS ARCA (IMO 9167966; 83 m length) equipped with a multibeam echosounder (MBES), side scan sonar (SSS), ROV and box corer, as well as two crews, allowing for 24h operations. Sailing time from Scheveningen Harbor to the BRG area was approximately 11 h.

The scope of this fieldwork was to:

- determine the location and boundaries of geogenic reef habitat H1170
- determine location and boundaries of biogenic reefs (*Lanice* reefs)
- develop/validate methodology to assess the quality of *Lanice* reefs;

- determine if different *Lanice* density classes (e.g. 0-500; 500-1500; >1500 ind/m^2) (following Rabaut et al. 2009) can be distinguished on the basis of SSS, ground truthed by ROV video and box core samples.

- take box corer samples from sandy habitat (EUNIS habitats), and analyze part of them on board following a dredge sampling protocol and part of them in the laboratory following a box corer sampling protocol.

2.3.1 Habitat mapping

The multibeam echosunder (MBES) and sidescan sonar (SSS) measurements took place every day between approximately 20.00h and 8.00h the next morning. Both systems were simultaneously operated. The USBL locator needed to be attached to the SSS for geographical positioning of the recorded data. The survey speed was between 5 to 6 knots. The ground range was fixed to 75 m and with an aimed tow fish flying height of around 7.5 m following the rule of thumb of 10% of the ground range. The flying was kept constant as operational conditions allowed (for technical details, see Annex A). In total, 22.5 km^2 of the seafloor was scanned in 32h 5 min (0.7 km^2/h) during the survey week (Table 1).

Table 1. Habitat mapping. Overview of scanned survey area and acquisition time. For area locations, see Figure 7. SSS=side scan sonar. MBES = multibeam echosounder. For details, see Annex A.

Sub area	Scanned area (SSS+MBES)	Acquisition time
A	5.7 km^2	8h 20 min
B	6.3 km^2	10h 45 min
D	7.3 + 3.2 km^2	10 h 26 min + 2h 34 min
Total	22.5 km^2	32h 5 min

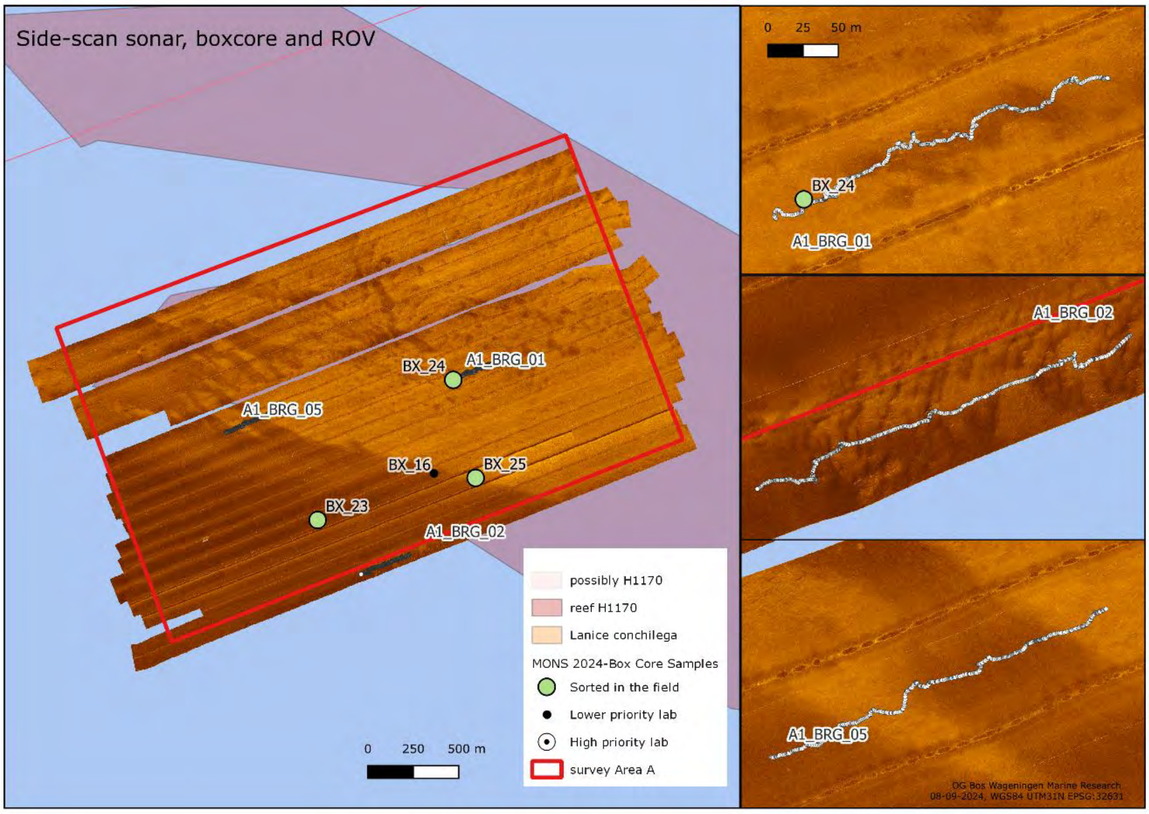


Figure 8. Borkum Reef Grounds, Area A (southern abiotic reef area). Side-scan sonar data and box corer and ROV-video locations.

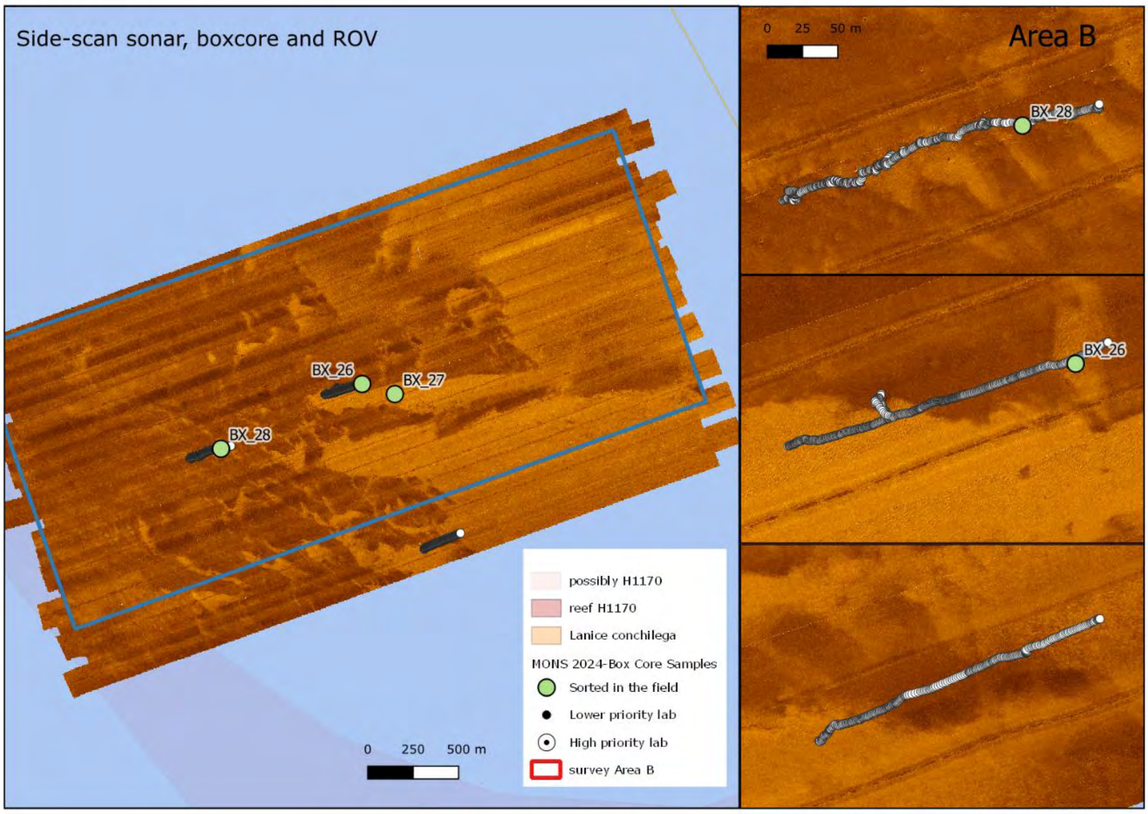


Figure 9. Borkum Reef Grounds, Area B (northern abiotic reef area). Side-scan sonar data and box corer and ROV-video locations.

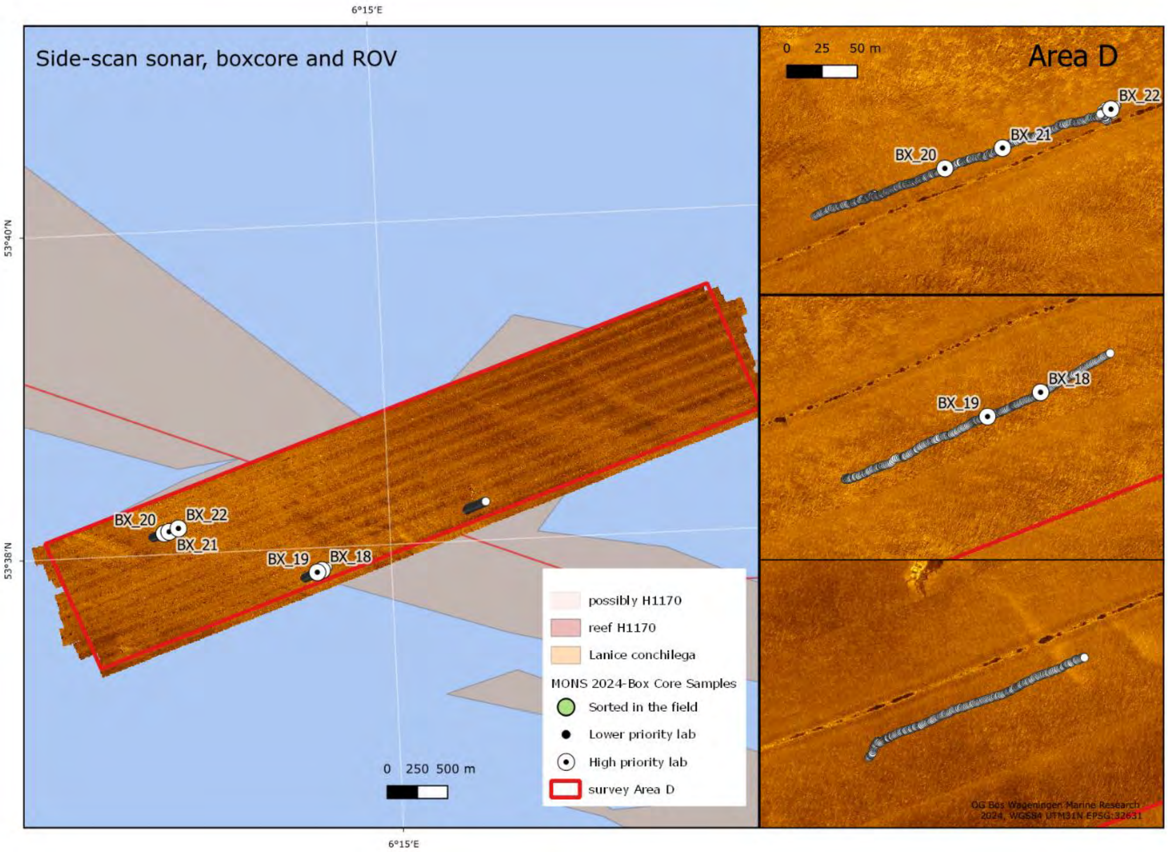


Figure 10. Borkum Reef Grounds, Area D (Lanice/Loimia area). Side-scan sonar results and overview of Box corer and ROV-video locations.

2.3.2 Benthos biodiversity

ROV video transects: The ROV transects were performed using a Saab Panter ROV operated by two Rijkswaterstaat operators in close cooperation with the captain to keep the ROV at the right distance to the vessel. Next to the operators, two biologists were present to decide on the trajectory and annotate video material. The typical flight speed over the ground was 10-15 cm/s. This allowed for obtaining a good image quality useful for subsequent species determination. Faster speeds result in blurry images. Video was recorded with a 4K camera pointed in a 45 degrees angle to the seafloor. Lasers lines (50 cm apart) helped determining size (e.g. of stones).

The locations of the ROV transects were based on the side-scan sonar and multibeam images acquired during the night before. ROV transects were chosen to cover acoustically interesting features that needed ground truthing. One ROV transect of 200-250 m took approximately 1 h. Between 3 and 5 ROV transects could be done per day, since also time was needed for boxcoring. In the stony reef areas (Areas A and B) (Figure 8, Figure 9) the focus was on filming as many stones and boulders as possible, rather than flying a straight line. In Area C, the focus was on *Lanice* reefs density (Figure 10).

ROV transects were flown against the current, to prevent bad visibility. During the transects, live annotation were made: *Lanice* reef types (*Lanice* 0-25%, *Lanice* 25-50%, *Lanice* 50-75% and *Lanice* >75%); Flat sand (0.625-2 mm); Sand ripples; Stone (6.4-25.6 cm); Boulder (>25.6 cm); shell fragments; special species.

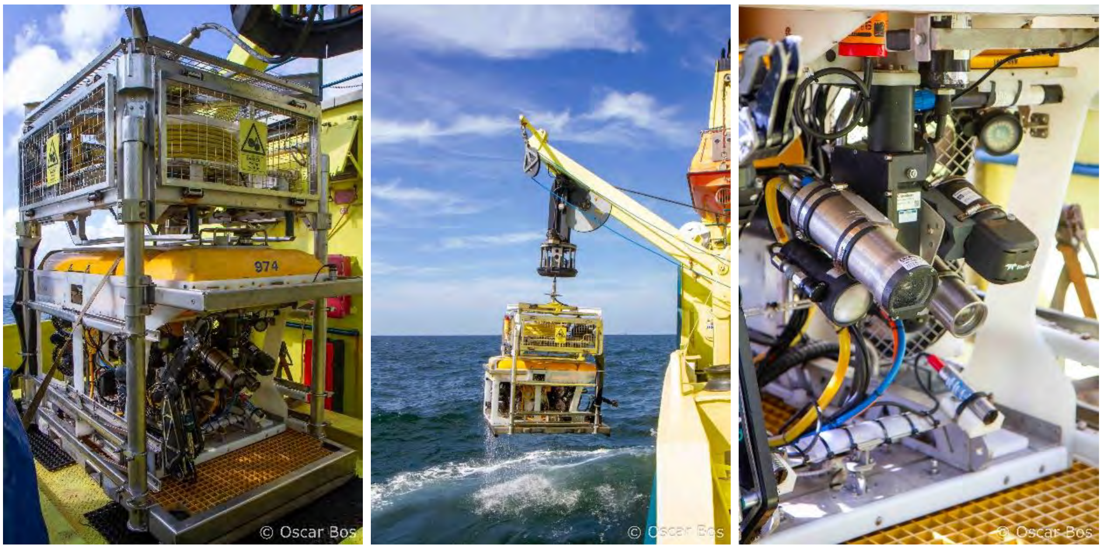


Figure 11. ROV of Rijkswaterstaat equipped with dimmable lights, 2 lasers and a 4K camera.

Boxcoring: Box corer samples were taken using an 31.5 cm diameter round box corer (surface 0.078m^2) (Figure 12). In total 24 box cores were taken, of which 10 were sorted out on board, following a dredge sampling protocol (RWSV voorschrift 913.00.B080 'bodemschaaf'[2]), and 14 were taken to the laboratory. In the laboratory 5 samples (3 *Lanice/Loimia* reef samples and 2 sand samples) were sorted following a box corer sampling protocol (RWSV voorschrift 913.00.B200 'boxcorer'[3]) (Table 3). On board, samples were sieved over a 1 mm round mesh sieve. Reef samples with lots of stones and shell fragments were sieved over a 4 mm square sieve with the 1 mm round mesh sieve underneath. Laboratory samples were put in plastic jars and conserved with formaldehyde, diluted with water. In the lab, Borax and Bengal Rose was added to buffer the formaldehyde and color the once living animals inside. From the 10 samples that were processed on board all larger species were identified. The aim was to get a rough indication of which species occur in larger quantities. The data obtained will therefore not be 1 on 1 comparable with the regular MSDF/N2000 MWTL monitoring.

[2] RWSV 913.00.B080 Bemonstering en analyse van macrozoöbenthos met behulp van de bodemschaaf (V2; 11-10-2018).

[3] RWSV 913.00.B200 Bemonstering van macrozoöbenthos en sediment in het litoraal en sublitoraal in mariene wateren. Methode: Reineck boxcorer, Van Veen happer, Hamon happer, Vacuüm steekbuis, Steekbuis. (v7; xx-11-2017).

Figure 12. The Rijkswaterstaat box corer (0.315 m diameter, surface 0.078 m²) (photo: Oscar Bos).

2.4 Laboratory work and data analysis

2.4.1 Habitat mapping: analysis of acoustic data

<u>Sediment mapping</u>: The MBES backscatter data was used to generate sediment maps from survey areas A, B and D. Generally, the MBES backscatter increases with increasing coarseness and hardness of the sediment. However, biogenic material or muddy sediments can contain gas inclusions that also increase the backscatter. Hence, there is not always a linear relationship between backscatter and sediment coarseness and hardness. Maps were validated with ROV video recordings and boxcore samples. Three sediment classes were visually discerned: (1) fine sand; (2) medium sand or fine sand with a few shells; (3) coarse substrate comprising mud or sand mixed with shells, gravel and stones (For details, see Annex A).

<u>Biogenic reefs mapping</u>: *Lanice/Loimia* reefs could be distinguished from other sediments (sand, shells) using AI classification of SSS images (Figure 13), similar to the detection of *Sabellaria spinulosa* reefs in the Brown Bank (Gaida et al., 2025). The SSS data were divided into 4 classes by relating the observed acoustic patterns to the densities of the tubeworms as observed on the video transects: (1) medium to high *Lanice/Loimia* coverage, (2) low *Lanice/Loimia* coverage, (3) potential *Lanice/Loimia* coverage and (4) sediment (everything not classified as class 1-3) (Figure 14). Both new and historical Hydrographic Office data were analysed. For more details, see Annex A.

<u>Stone density maps</u>: stones higher than ~15 cm above the seabed could be manually detected with high confidence in the processed SSS images of the historic BRG dataset. The manual detections were used to generate a stone density map. Expedition data were not used because of the overlap with the historic data. Three density classes were defined: (1) 1-3 stones per 240x240 m (57,600 m^2); (2): 4-10 stones and (3): >10 stones (sometimes > 50 stones) (Figure 16). For more details, see Annex A.

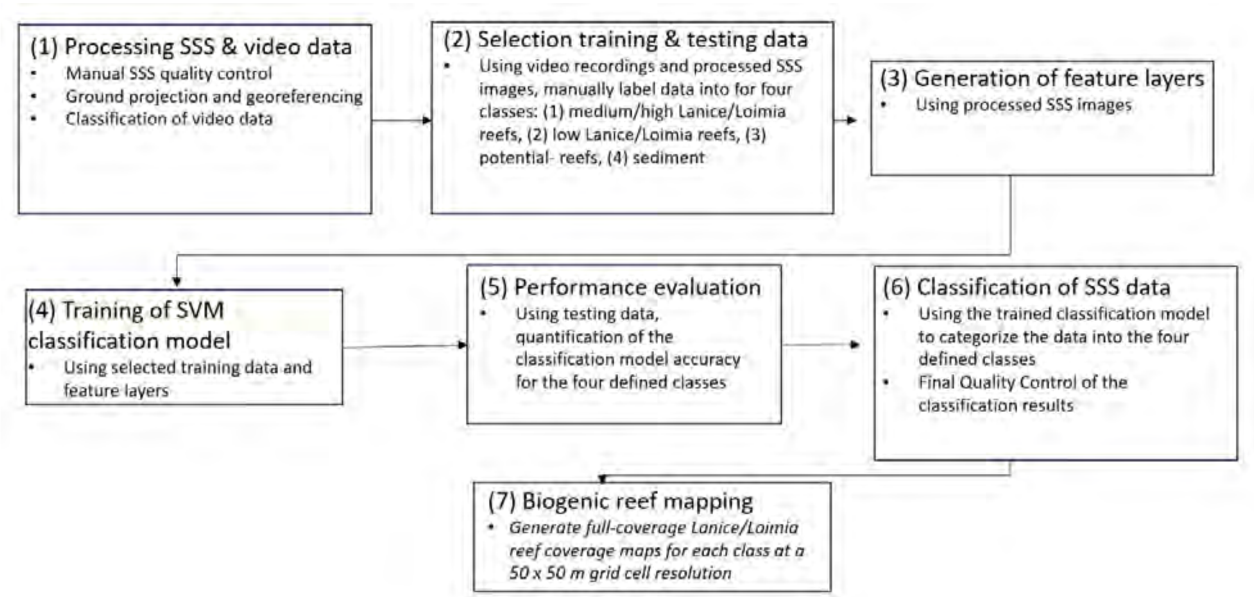


Figure 13. Machine-learning classification workflow used for the mapping of Lanice/Loimia reefs in the BRG, applied to both the expedition and HO data (for details per step, see Annex A).

Table 2. Habitat mapping. Overview of mapping techniques used per area and habitat type. For area locations, see Figure 7. SSS=side scan sonar. MBES = multibeam echosounder. BRG = Borkum Reef Grounds.

Habitats	Coverage	Mapping	MBES fieldwork 2024 data	SSS fieldwork 2024 data	SSS hydrographic office data (historic data)
Fine, medium and course sediments (in between reefs)	Areas A, B, D	MBES data validated with ROV video recordings and box core samples	Yes	Not used	No historic MBES data available
H1170: Stone density	BRG area	Manual SSS data analysis	Not used	Not used	Yes: historic SSS data are suitable. Next step: development of automatic AI classification
Sand	Area C	Not mapped	Not mapped	Not mapped	Mapped, not analysed.
Lanice/Loimia reefs	Area A,B, D and BRG area	AI classification model based on SSS data + ROV video ground truthing	Not used	Yes	Yes: historic SSS data are suitable

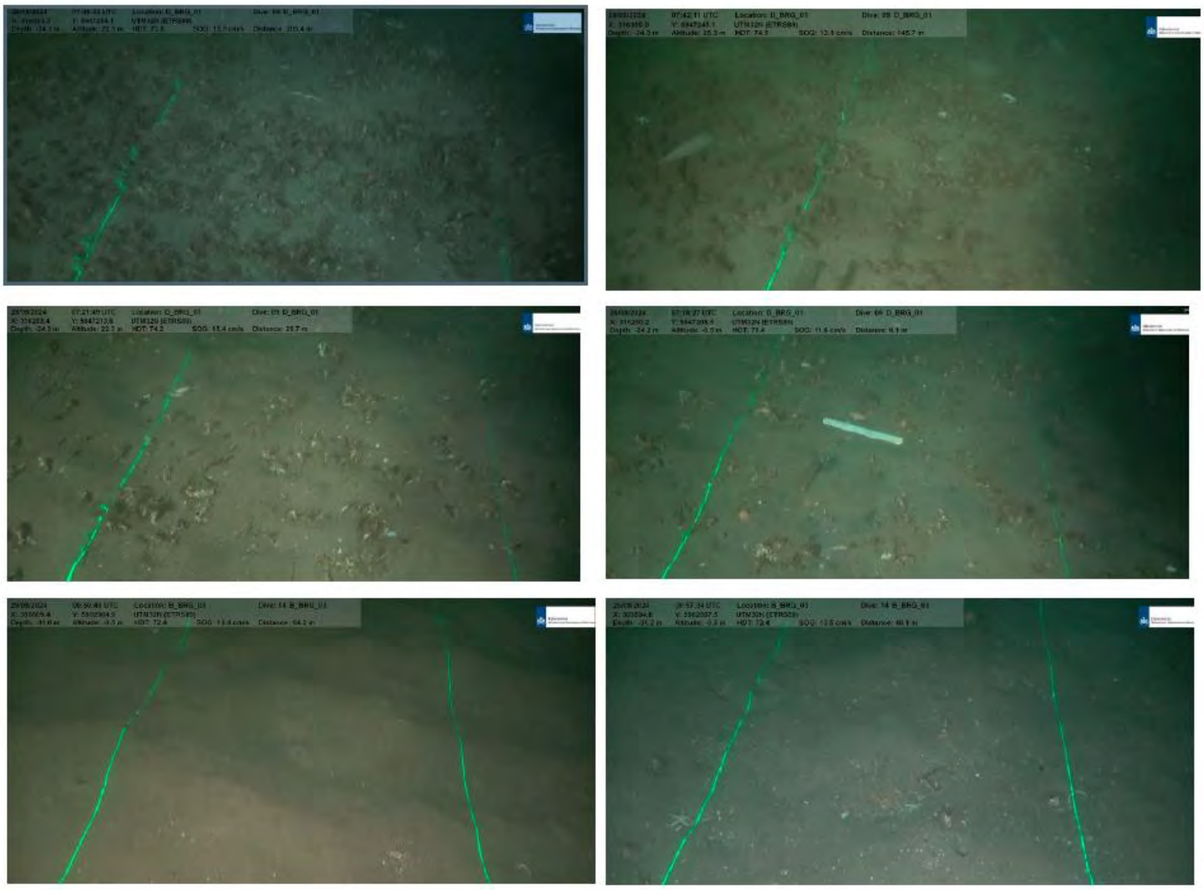


Figure 14. ROV video footage showing examples of (top row) medium to high Lanice/Loimia coverage, (middle row) low Lanice/Loimia coverage and (bottom row) sediment where the left footage shows a sandy sediment with small ripples and the right footage a muddy sand sediment. For more images, see Annex C.

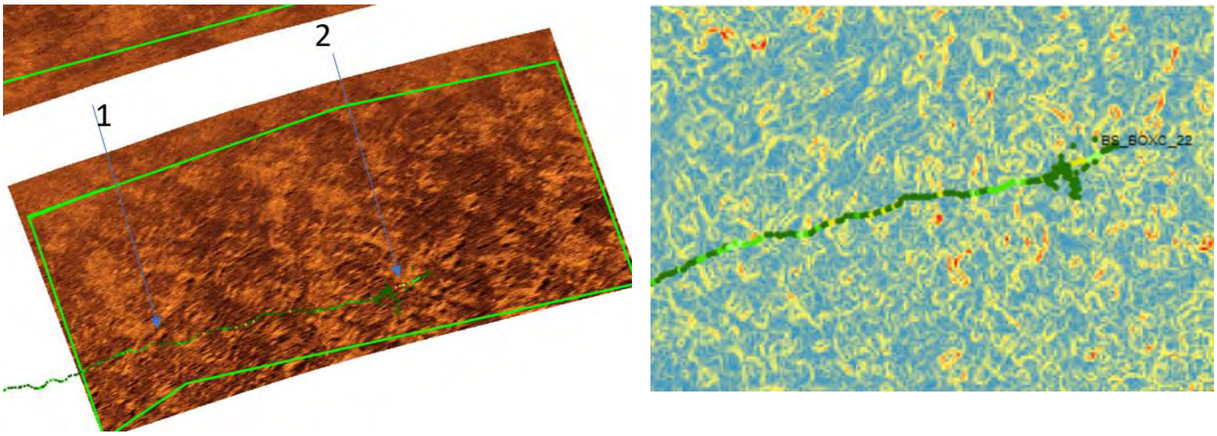
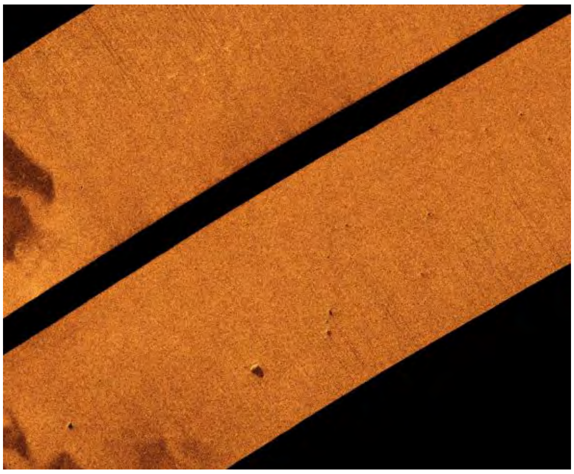


Figure 15. Example of acoustic data in an area with medium to high coverage of Lanice/Loimia (expedition data). (Left) Processed SSS image with indicative acoustic pattern for this class. Location of arrow 1 and 2 correspond to video footage in top row of Figure 14. The green polygon shows the area where training samples for the medium to high Lanice/Loimia coverage class were selected. (Right) Seabed slope computed from MBES bathymetry showing the morphological seabed elevation corresponding to the presence of medium to high Lanice/Loimia coverage. The dotted line, displayed in both figures, shows the video track where dark green indicates low Lanice/Loimia coverage and light green medium to high Lanice/Loimia coverage. For details, see Annex A.



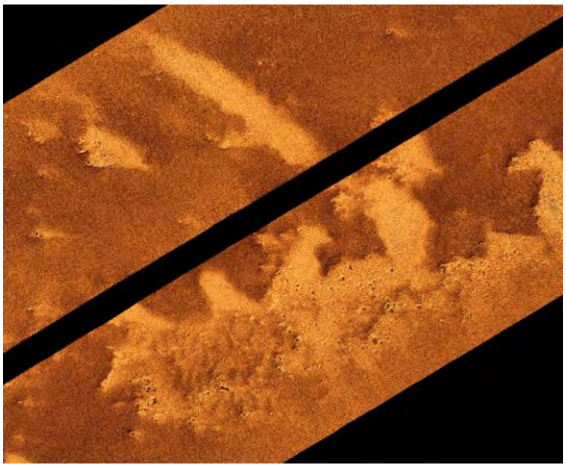


Figure 16. Examples of stone picking in the historic SSS dataset. Both images display an area of around 240 x 240 m and fall into the rock density class of >10 stones. (Left) Around 15 stones and (right) >50 stones are detected. For details, see Annex A.

2.4.2 Benthos biodiversity: laboratory analysis

Video transects: The 200-250m video transects took about maximum 1 h. The maximum size of a video file however, was 10:00 min (25 frames/second; size 3840x2160 px, 3 Gb/file), hence each transect was divided in multiple video files (see Table 3). For areas A and B, the aim was to determine species diversity of the stony reef. For this, from each 10 min file, the first 3 minutes were analysed. For the *Lanice/Loimia* reefs (area D), the aim was to annotate different density classes of *Lanice/Loimia*. For this, the whole video was analysed. Numbers per species were counted (results in Annex E). The video transects were analysed at Wageningen Marine Research using ImageJ software.

The boxcore samples were analysed at Wageningen Marine Research to the lowest taxa possible (3 *Lanice* reef samples, 2 sand samples) (see Table 3) according to protocol 'RWS A2.107 v8'. The remaining 7 samples were stored for possible further analysis. For all taxa, densities per sample were determined. For area D, also the wet weights (g WW) of *Lanice conchilega* and *Loimia ramzega* were measured.

Table 3. Overview of the number of box corer and video samples per method, sorted on board, or in the laboratory per habitat type and area.

Habitat	Method	Sample Code	on board	lab
H1170 (Areas A and B)				
	Box corer	BS_BOXC_23	1	
		BS_BOXC_24	1	
		BS_BOXC_25	1	
		BS_BOXC_26	1	
		BS_BOXC_27	1	
		BS_BOXC_28	1	
	ROV_video	A1_BRG_01		1
		A1_BRG_03		1
		A1_BRG_04		1
		B_BRG_01		1
		B_BRG_02		1
		B_BRG_03		1
Lanice/Loimia (Area D)				
	Box corer	BS_BOXC_18		1
		BS_BOXC_20		1

		BS_BOXC_22		1
Sand (Area C)				
	Box corer	BS_BOXC_01	1	
		BS_BOXC_03	1	
		BS_BOXC_06		1
		BS_BOXC_08		1
		BS_BOXC_11	1	
		BS_BOXC_12	1	

3 Results

3.1 Habitat mapping

3.1.1 Sediment mapping

The southern geogenic reef area A shows a clear spatial distinction between fine, medium and coarse sediments (Figure 17). Furthermore, in the northern abiotic reef area B, the fine, medium and coarse sediment types occur in a "flamed" pattern, while in the *Lanice/Loimia* reef area D in the south coarse substrate is almost absent, while fine and medium sand are present (for details see Annex A).

3.1.2 *Lanice/Loimia* biogenic reefs

The distribution of *Lanice/Loimia* reefs based on the newly collected SSS data compared reasonably well to the distribution of these reefs using the existing SSS data of the Hydrographic Office (Figure 18). This means that the comparison provides an indication of the temporal variability of the *Lanice/Loimia* fields (for details see Annex A).

3.1.3 Stone mapping using existing SSS data

Maps of stone density were made for the entire Borkum Reef Area showing areas with 0 stones counted per 240x204m, 1-3 stones (total: 3.4 km^2), 4-10 stones (5.76 km^2) and >10 stones (9.27 km^2), totalling 18.53 km^2 (Figure 19).

Table 4. Overview of stone density per 240x240 m^2 as shown on the map in Figure 19.

N stones per 240x240 m	N squares on the map	Area (m^2)	Area (ha)	Area (km^2)
1-3	59	3,398,400	339.84	3.40
4-10	100	5,760,000	576.00	5,76
>10	161	9,273,600	927.36	9.27
TOTAL	320	18,432,000	1843.20	18.43

Table 5. Summary table: estimated surfaces of stony reef habitat types in the Dutch Borkum Reef Grounds.

Area	Borkum Reef Grounds
Area total	684 km^2 (100%)
Areas with stones (categories 1-3, 4-10 and >10 stones per 240x240m2)	18.43 km^2 (2.7%)

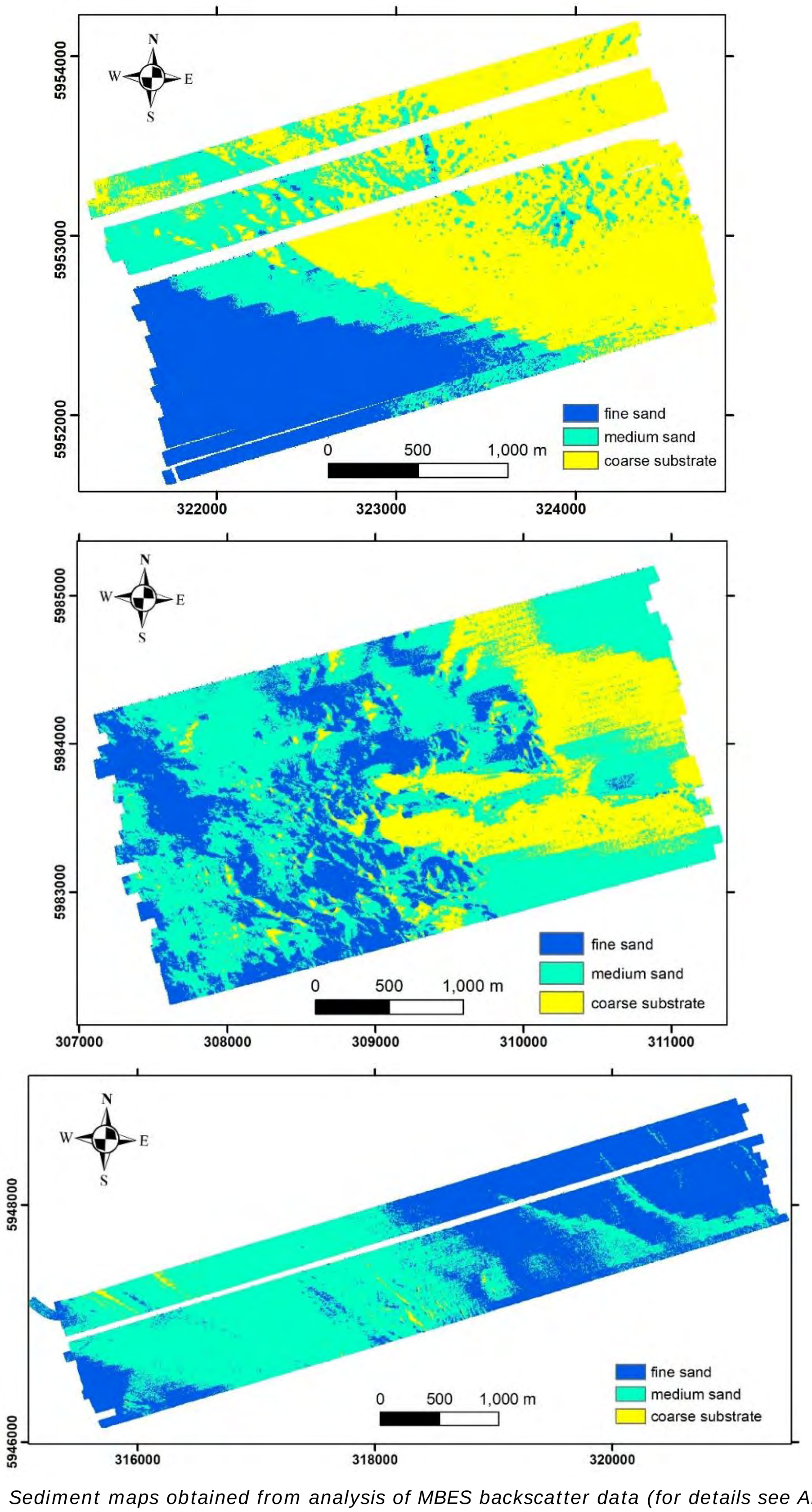


Figure 17. Sediment maps obtained from analysis of MBES backscatter data (for details see Annex A). (Top) Survey area A, (middle) survey area B and (bottom) survey area D. The coordinate system is ETRS 1989 UTM 32N (Map: Gaida & Binnerts 2025 in Annex A).

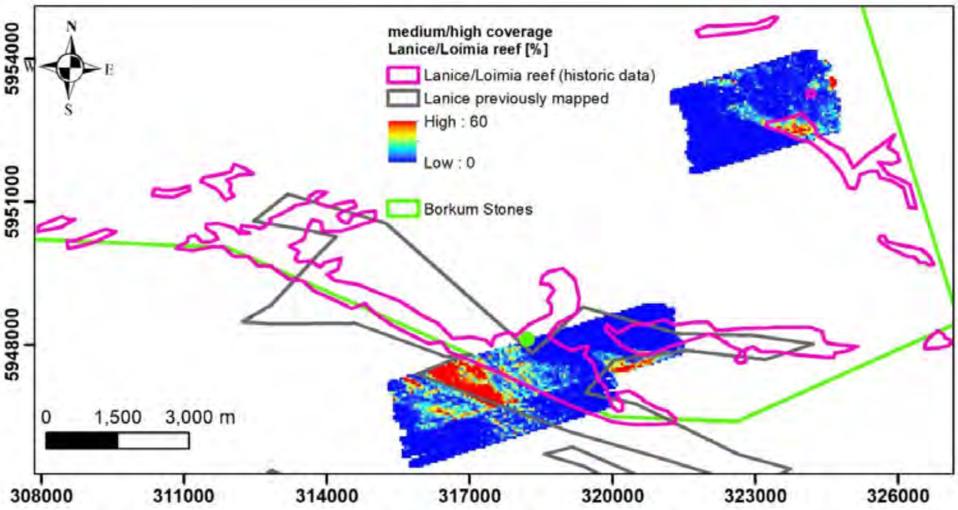


Figure 18. Lanice/Loimia reefs in the south of the Borkum Reef Grounds area. Coloured maps: expedition data for areas A and D. Grey polygons: Lanice reefs by Bos et al. (2014). Pink polygon: Lanice distribution based on analysis of the Hydrographic Office data. For details, see Annex A, figure 4.6.

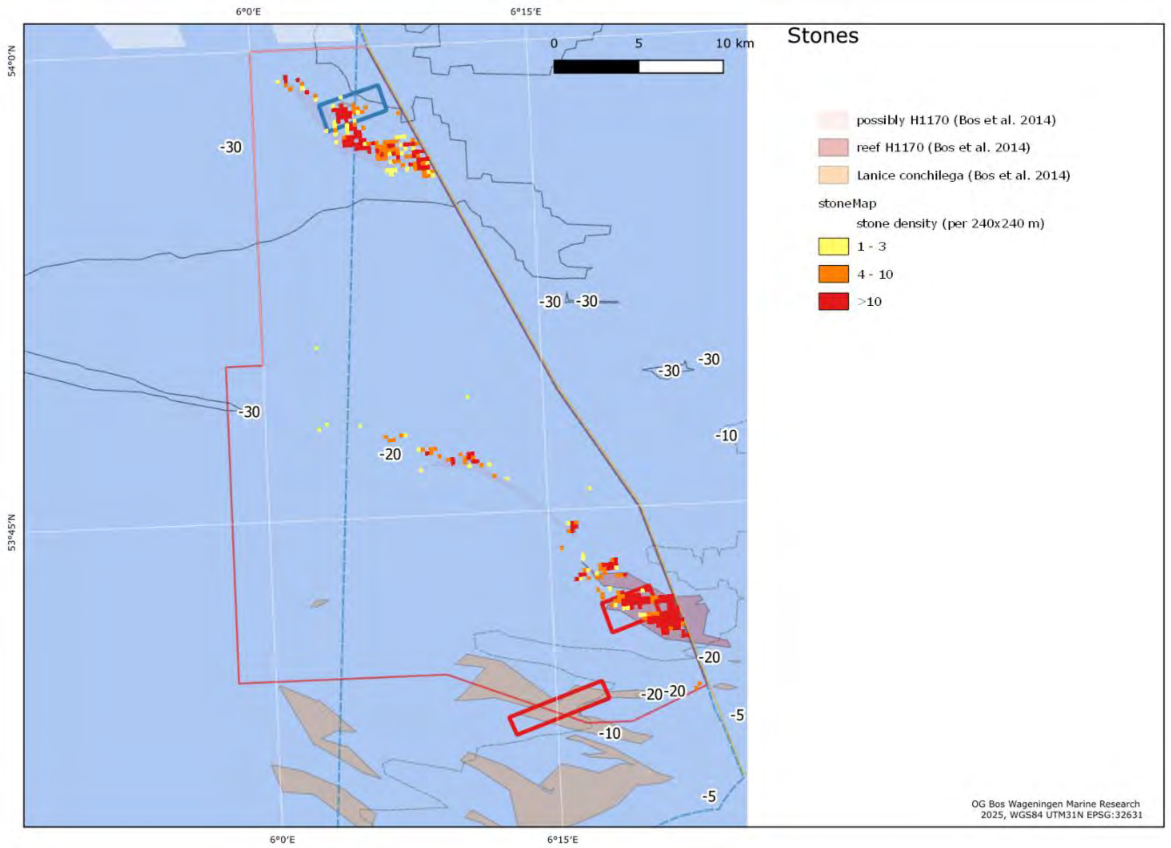


Figure 19. Stone coverage density map of the Borkum Reef Grounds. The classes indicate the number of stones (visible on SSS images, size ~ >15 cm elevation) within an area of 240 x 240 m. The map is produced via manual selection of stones using the processed and ground projected historic data. Coordinates system is WGS84 UTM31N. For details, see Annex A.

3.2 Benthos biodiversity

Box corer samples from the abiotic reef areas (A+B) were all sorted on board, while box corer samples from the *Lanice/Loimia* reef areas (area D) were sorted in the laboratory (Table 3). Box corer samples from the sandy area (area C) were partly sorted on board and partly in the lab.

In total, 164 different taxa (104 species) were determined. Most taxa and species were determined in the box corer samples (137 taxa, 88 species), compared to the video samples (36 taxa, 20 species) (Table 6, Table 8). The box corer samples sorted on board revealed 40 taxa (25 species), much less than those sorted in the laboratory (119 taxa, 77 species).

The box corer and video sampled different parts of the benthic community: only 4 species were identified both in the box cores and videos (*Asterias rubens, Electra pilosa, Ophiura albida* and *Sagartia undata*), while 84 species were exclusively determined in box corer samples (smaller species including >35 species of worms and >20 species of arthropods), and 16 species exclusively in the video (several fish species, anemones, soft coral (dead man’s finger), sponges and larger crustaceans).

Table 6. Number of taxa and species per method.

Method	N taxa (N species)	N taxa (N species) (%)
Box corer + video	164 (104)	100% (100%)
Box corer	137 (88)	84% (85%)
Box corer in laboratory (N=5)	119 (77)	73% (74%)
Box corer on board (N=10)	40 (25)	24% (24%)
Video in lab (N=6)	36 (20)	22% (19%)

3.2.1 Geogenic reefs (H1170) (Areas A and B)

Rocks (stones and boulders) were covered with anemones, predominantly the plumose anemone (*Metridium senile*), but also ‘fluffy’ hydroids and bryozoans. The latter taxa are hard to determine, even to the phylum level and are therefore grouped as hydrozoa/bryozoa. In total, 24 taxa (13 species) were identified from the video footage to be present at the stones and rocks (Table 8) including soft coral dead man’s finger (*Alcyonium digitatum*) and larger sponges such as fig sponge *Suberites ficus* (Figure 20). A species list can be found in Table E2, Annex E.

The area in between the rocks and stones consisted of sand, or gravelly substrate (see Figure 17, ‘coarse sediment’). Here 68 taxa (41 species) were identified by video analysis and box corer together (Table 8). Sea stars (*Asterias rubens*), anemones (various species, a.o. *Cylista troglodytes*) were most abundant. In the sediment, in the box cores, many polychaete, bivalve and arthropod species were found, including an individual of the polychaete *Sabellaria spinulosa*. At several locations, European lobsters (*Homarus gammarus*) and brown crabs (*Cancer pagurus*) were observed (see video screenshots, Figure 20). A full list of species and be found in Table E1, Annex E. The box cores were all sorted on board.

3.2.2 Biogenic *Lanice/Loimia* reefs (Area D)

During the MONS survey, the team’s benthos specialist (J. Cuperus) showed that the tubeworms in the box corer samples sorted on board not only contained *Lanice conchilega*, but also a similar looking tubeworm *Loimia ramzega*. This tubeworm was discovered as a new species in France in 2017 (Lavesque et al., 2017). In the laboratory, total densities of both species together (*Lanice + Loimia*) were determined to range from 282 to 2205 individuals/m^2 in Area D (box corer sample numbers 18, 20, 22: Figure 10), of which on average 73% consisted of *Lanice* and 27% of *Loimia* (Table 7). The total biomass (g WW) (*Lanice + Loimia*) ranged from 5 to 67 g/m^2 of which on average 62% consisted of *Lanice* and 23% of *Loimia* (Table E3, Annex

E). Hence, *Loimia ramzega* can be considered a very common species that occurs together with *Lanice conchilega,* mainly in the southern "*Lanice* reef" area D. *Loimia ramzega* was also present in the areas with hard substrate (A: box corer sample number 24 and B: 26, 27, 28) (Figure 20), but in lower numbers (Table E4, Annex E).

Within the 3 box corer samples taken in Area D, in total 96 taxa (61 species) were determined (Table 8), dominated by polychaetes, arthropods and bivalves (Table 9).

Table 7. Box corer data area D: Densities and wet weights (g WW) of Lanice conchilega and Loimia ramzega per m^2 based. For details, see Annex E, Table E3.

	N/m^2		Total N/m^2	gWW/m^2		Total gWW/m^2
	Lanice	*Loimia*	*Lan+Loi*	*Lanice*	*Loimia*	*Lan+Loi*
BS_BOXC_18	256 (91%)	26 (9%)	282	72 (95%)	4 (5%)	75
BS_BOXC_20	359 (50%)	359 (50%	718	74 (33%)	152 (67%)	226
BS_BOXC_22	1705 (77%)	500 (23%)	2205	351 (59%)	242 (41%)	593
Average	774 (73%)	295 (27%)	1068	165 (62%)	133 (38%)	298

3.2.3 Sandy area biodiversity (Area C)

The box corer samples from the sandy seafloor area C in total contained 81 taxa (54 species) (Table 8), dominated by polychaetes, arthropods and bivalves (Table 9).

*Table 8. Overview of taxa and species numbers determined per method, area and habitat type. Numbers of samples per method are listed in Table 8. *= box corer samples sorted on board; ** = box corers samples sorted in the lab. Note that the monitoring was not set-up to compare biodiversity of different habitats, but only to fill in knowledge gaps. Therefore, the numbers of taxa and species are only indicative. Note that the number of samples is also only indicative and refers to different kinds of samples that are not comparable (box corer samples sorted on board, sorted in the lab, and video transects). For details, see Annex E.*

Taxa and species TOTAL	Taxa	species	Taxa % of total	Species % of total	N samples
total (box corer + video)	164	104	100	100	21
Per method					
Box corer (sorted on board + sorted in the lab)	137	88	84	85	15
video (Areas A and B)	36	20	22	19	6
Per area					
Area A (video+box corer*)	54	32	33	31	3+3
Area B (video+box corer*)	41	22	25	21	3+3
Area C (box corer)	81	54	49	52	4
Area D (box corer**)	96	61	59	59	3
Per habitat					
Lanice/Loimia (box corer**) (Area D)	96	61	59	59	3
Sand (box corer) (Area C)	81	54	49	52	4
H1170 (all) (Areas A+B)	96	56	59	54	12
H1170 Rocks (video)	24	13	15	13	6
H1170 Sediment between rocks (video)	35	20	21	19	6
H1170 Sediment between rocks (box corer*)	37	23	23	22	6
H1170 Sediment between rocks (box corer*+video)	61	36	37	35	6+6

Table 9. Overview of taxa per taxonomic group determined per habitat type. For details, see Annex E.

	Habitat				TAXA	SPECIES
Phylum class or group	H1170_sand (taxa) Areas A+B	H1170-rocks (taxa) Areas A+B	Lanice/Loimia (taxa) Area D	Sand (taxa) Area C		
Annelida						
Clitellata			1	1	1	0
Polychaeta	13		44	35	56	37
Arthropoda						
Malacostraca	12	6	22	21	43	28
Thecostraca	1	1			2	
Bryozoa						
Gymnolaemata	1	1	2	1	2	2
Chordata						
Leptocardii	1				1	1
Teleostei	9	5			9	6
Cnidaria						
Hexacorallia	6	5	1		6	4
Hydrozoa	2	1	4	3	6	1
Octocorallia	1	1			1	1
Echinodermata						
Asteroidea	2	1	1		2	2
Echinoidea	2		2	2	2	1
Ophiuroidea	3		3	2	4	2
Hydrozoa/Bryozoa						
Hydrozoa/Bryozoa	1	1			1	
Mollusca						
Bivalvia	11		13	14	23	14
Gastropoda			1		1	1
Nemertea						
Nemertea	1		1	1	1	
Phoronida						
Phoronida			1	1	1	
Platyhelminthes						
Platyhelminthes				1	1	
Porifera						
Demospongiae	1	1			1	1
Porifera	1	1			1	
TOTAL	68	24	96	82	165	101

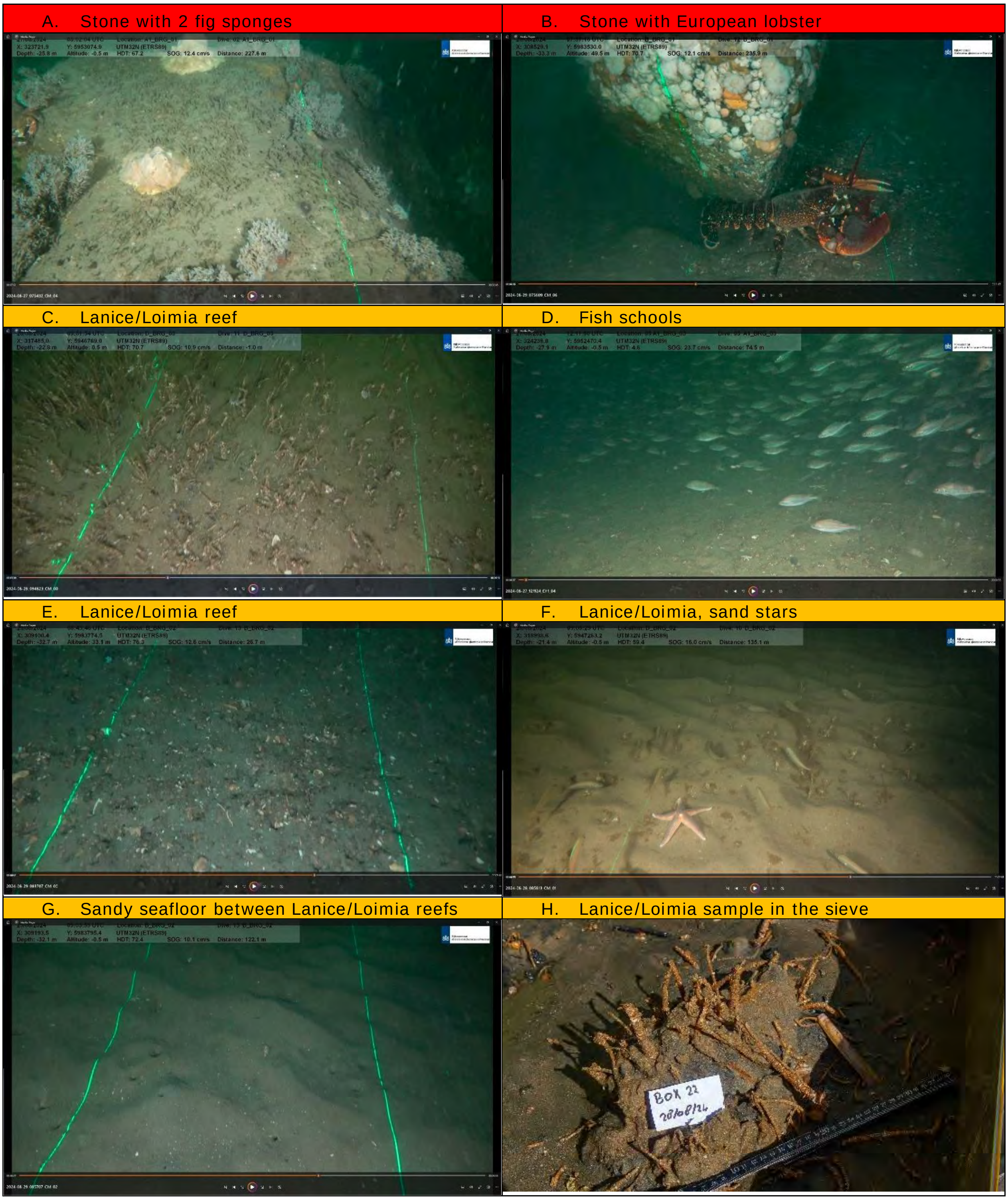


Figure 20. ROV images and photo of onboard box corer sieving showing several rocks (upper row), Lanice/Loimia habitat (middle rows), sandy habitat (lower left) and Lanice/Loimia sample (screenshots: ROV footage; photo bottom right: Oscar Bos).

Figure 21. Borkum Reef Grounds. (A) Lanice/Lomia in Area B; (B) Course sediment, with shells, Lanice/Loimia and smaller stones in Area D; (C) Fine sand, small shell fragments in area C. For more details, see Annex C.

4 Discussion

4.1 Habitat mapping

Historic data and expedition (new) data

The use of the historical (2008 and 2013) SSS data of the Hydrographical Office for ecological monitoring proved to be very useful, both for site selection and for mapping features such as stones and *Lanice/Loimia* reefs. The first challenge was to obtain the data from the Hydrographic Office, since data are physically stored on tape in a data warehouse. The second challenge was to open the files and extract the acoustic information from the data, since the data files are very large in size. Analysis of these data also required a long processing time due to the size. This could be solved by setting up an analysis pipeline and using a large calculation cluster or supercomputer, but this was not within the scope of the project. For practical reasons, it was therefore e.g. decided to leave out areas where no biogenic reefs were detected by manual inspection. Furthermore, data quality was not always sufficient: certain sonar lines were too noisy to allow for analysis.

SSS data are available for the whole of the Dutch North Sea and therefore probably have high added value for other ecological research. From the website of the Hydrographical Office it is not clear how often SSS data are updated, but given the size of the Dutch North Sea, this will probably only take place on a decadal scale. Note that because of national security issues (location of objects in relation to sabotage), data cannot simply be used by any party. Further technical issues regarding SSS are discussed in Annex A.

Abiotic reefs H1170 (stones and coarse substrate)

Geogenic reefs are probably stable in time, since stones and boulders will stay in their place. Therefore, the analysis of stone and boulder locations does not have to take place every monitoring cycle. While the manual picking of the stones was accurate, it was also time consuming. Automated detection of stones using AI classification of SSS data is possible using the Hydrographic Office data and could be worth developing, also for other areas in the North Sea. The rough boundaries of the stone fields overlapped well with the previously mapped stone fields (Bos et al. 2014).
Using the MBES backscatter data and its comparison to video/box corer data, coarse substrate (mixture of shells, gravel, small stones with sand) could be accurately detected using MBES data. Since there were no historic MBES data, this analysis could not be extrapolated to the whole BRG area. A more quantitative assessment and a finer distinction of the softer sediments classes (fine and medium sand) could have potentially been made in case a grain size analysis of the box core samples was done, but this was beyond the scope of this study. A technical challenge is to accurately geolocate SSS data (which is obtained by towing a fish behind the ship) and spatially relate the SSS to MBES data (sensor fixed under the ship) (for more technical issues, see Annex A).

Biogenic *Lanice/Loimia* reefs

Biogenic reefs are probably less stable than abiotic reefs. By combining historic and new SSS data, spatial changes over time of high density biogenic *Lanice/Loimia* reefs can be detected. Since this SSS data is also available for a large part of the Dutch North Sea, other areas can probably also be analysed for the presence of *Lanice/Loimia* reefs. Further technical issues related to the acoustic monitoring are described in Annex A.

In this study, the density classes used for AI training were obtained from comparing the SSS patterns with the video annotations made on board (Annex D). Later in the project, also actual *Lanice/Loimia* densities per box corer sample were determined in the lab, and video was analysed in detail. Due to time restrictions, these three sources have not been compared. Therefore, no exact densities can be assigned to the different classes. Despite that, this study has shown that high density *Lanice/Loimia* reefs are well detectable, both using the newly acquired SSS data (Area D), as using historic SSS data (whole BRG). Low densities of *Lanice/Loimia* were not accurately detectable.

Table 10. Scoring system for a variety of reef characteristics for Lanice conchilega (Rabaut et al. 2009)

	Characteristic score		
	Low 0	Medium 50	High 100
Elevation score			
Relative height of the patch	~5 cm	5–9 cm	>9 cm
Sediment consolidation score			
Shear vane stress	~1 kg cm^{-2}	~1.5 kg cm^{-2}	~2 kg cm^{-2}
Area score			
Extent of total area	1,000 m^2	50,000 m^2	>100,000 m^2
Average area of individual reefs	~1 m^2	~2 m^2	2–10 m^2
Patchiness score			
Percentage cover of patches within the total area	~5%	5–10%	>10%
Lanice conchilega *Density score*			
Average density of *L. conchilega* (/m^2)	~500 individuals	500–1,500 individuals	>1,500 individuals
Biodiversity score			
Species richness(S)	~18	~25	>30
Margalef's index (d)	~2	~2.5	>3
Longevity score	1 year	2 years	>2 years

To classify the reefiness of *Lanice* reefs, Rabaut et al. (2009) developed a classification scheme (see Table 10). According to their scheme, the 'medium/high reefs detected by SSS in this study (Figure 18) probably score 'medium' to 'high' in the classification scheme, given that a number of characteristics fall within the ranges proposed: the densities encountered in this study (combined *Lanice/Loimia* densities of 282-2205 ind/m^2), a large coverage (>100,000 m^2) (Figure 18), a high species richness (box corer average: 61 species: Table 8) and a reef longevity of > 2 years (Figure 18). Note that not all characteristics (e.g. Margalef's index, % coverage or average area of individual reefs) have yet been calculated, since that was beyond the scope of this study.

4.2 Benthos biodiversity

Loimia ramzega can be considered a very common species that occurs together with *Lanice conchilega* in the Borkum Reef Grounds area. The species has been discovered in a few other Dutch North Sea locations in the past 2 years (J. Cuperus, pers. com) and in the German Borkum Riff area as well (L. Gutow and J. Beermann, AWI, pers. com). To track down when the species was seen for the first time in this region, a few benthos samples from previous sampling campaigns are currently investigated in the WMR laboratory (B. van der Weide, pers. com).

The aim of the fieldwork was not to execute a well-balanced monitoring programme, but to collect additional samples on top of existing data, needed to determine a future monitoring strategy. Therefore, the species richness found per habitat in the field study is just indicative. To put the numbers in perspective however, in our study, less taxa and species (166 taxa and 104 species) were found in the Borkum Reef Grounds than in 2013 (193 taxa, 141 species) (Bos et al., 2014; Coolen et al. 2015).

During the fieldwork, box corer samples were partly sorted on board to obtain samples comparable to dredge samples (See Wijnhoven et al. 2025 for details). In this research, box corer samples sorted in the laboratory yielded far more species than box cores sorted on board. This effect is well visible in the comparison of box corer results between the *Lanice/Loimia* reefs (area D) with a high species richness and the abiotic reef areas A and B with an apparent low species richness, which is probably only due to the analysis method, since in earlier research the sediment in the abiotic reef area was determined to have a high species richness (Bos et al., 2014; Coolen et al. 2015).

4.3 Monitoring strategy

This research aimed at collecting existing and new data needed to develop a monitoring strategy (described in Wijnhoven et al., 2025). Upfront, it was expected that the future monitoring strategy would be similar to the existing strategy used in the existing N2000/MSFD monitoring of e.g. the Cleaver Bank. However, in the Borkum Reef Grounds area, the bigger stones are spaced apart quite far, so it was decided to develop a strategy in which the abiotic reef areas in the future would be monitored by hopping from one boulder to the other, as was done during our fieldwork, rather than flying in a straight line transect, where the change of encountering boulders is much smaller. Since boulders are not likely to move, it is expected that no new SSS data need to be collected to detect boulders, but that the locations found in this study are sufficient. ROV operators also use the ROV's forward looking sonar to detect objects, so that the boulders can be easily detected. Furthermore, in the BRG, biogenic reefs will be monitored, which is not done in the Cleaver Bank area.

5 Conclusions

5.1 Habitat mapping

Historic data and new data
This project has shown the value of using SSS data of 2008 and 2013 of the Hydrographical Office for ecological monitoring. The data was helpful for the preparation of the field study for site selection. And in combination with new data (SSS, MBES, video and box cores), the data could be used to map geogenic stone reefs (H1170) and biogenic *Lanice/Loimia* reefs in the whole BRG area.

Abiotic reefs H1170 (stones and coarse substrate)
Elevated stones could usually be detected (by visual inspection) using SSS data, except if they were masked by a complex heterogeneous seabed or if they were buried too deep. Automated detection of stones using AI classification is possible and remains to be developed.

The rough boundaries of the stone fields overlapped very well with the previously mapped stone fields (Bos et al. 2014). Coarse substrate (mixture of shells, gravel, small stones with sand) could be accurately detected using MBES backscatter data and its comparison to video/box corer data. Since there were no historic MBES data, this analysis could not be extended to the whole BRG area.

Biogenic *Lanice/Loimia* reefs
Using the SSS data, this study has shown that high density *Lanice/Loimia* reefs are well detectable, both using the newly acquired SSS data (Area D), as using historic SSS data (whole BRG). Low densities of *Lanice/Loimia* were not accurately detectable.
By combining historic and new SSS data, spatial changes over time of high density biogenic *Lanice/Loimia* reefs can be detected (Figure 18). See paragraph 4.1.3 in Annex A for examples. Since this SSS data is also available for a large part of the Dutch North Sea, other areas can probably also be analysed for the presence of *Lanice/Loimia* reefs.

For technical advice on future acoustic monitoring and data analysis, and more detailed discussions and conclusions see Annex A.

5.2 Benthos biodiversity

Loimia ramzega is a common species on the Borkum Reef Grounds and occurs together with *Lanice conchilega*. The two species show a ratio of, in numbers: 27% *Loimia* and 73% *Lanice* , and in biomass (WW) 38% *Loimia* and 62% *Lanice* (averages of 3 box corer samples in area D). It is not clear since when the species has been present in the area. This will be investigated by analyzing a few historic samples from previous projects.

The aim of the fieldwork was not to execute a well-balanced monitoring programme that allowed for comparison of biodiversity among habitats, but rather to collect additional samples on top of existing data, to determine a future monitoring strategy. Therefore, the species richness found per habitat in the field study is just indicative. The nature of the research was to fill in knowledge gaps, and not to execute a representative sampling program. Hence, species numbers are only indicative. Notably for the abiotic reef areas A and B, for which the box cores were sorted on board and not in the lab, the actual species numbers are an underestimation.

5.3 Monitoring strategy

The future monitoring strategy for the BRG area is described in detail in Wijnhoven et al. (2025). The fieldwork sampling strategy was designed to be in line with the national Natura 2000/MSFD monitoring program (Min I&W & Min LNV, 2020), in which sampling is done using a box corers, Hamon grab, a dredge and video transect sampling. The strategy for the Borkum Reef Grounds is designed in such a way that it collects enough samples to be able to assess the habitats quality in the future (using the BISI indicator), as well as assess the extent of the *Lanice/Loimia* reef. In short the setup is:

EU MSFD Broad Habitat Types

- Box corer sampling at 38 fixed measurement locations in spring (19 within the MSDF area Borkum Reef Grounds (BRG) and 19 in the vicinity of the BRG) to monitor soft sediment habitat development and effectiveness of measures.

Abiotic reefs (H1170)

- Video transect sampling of 16 fixed 120 m stone-to-stone transects (lasers 50 cm apart) in summer (only in areas with >50 stones (often>100) per km^2) to monitor geogenic reef community development (Figure 22).

Lanice/Loimia reefs

- Video transect sampling of 16 fixed 120 m (straight line) transects (lasers 50 cm apart) in summer (8 within the MSFD area BRG and 8 in the vicinity of the BRG) to monitor *Lanice/Loimia* reef development and effectiveness of measures.
- Side scan sonar mapping of a fixed area (Figure 23) within which the *Lanice/Loimia* reef is located. The mapping takes place both inside and outside the Borkum Reef Grounds MPA to monitor reef development in unfished and fished areas.

Figure 22 . Left: Overview map with box corer measurement locations for the Borkum Reef Grounds multi-year monitoring programme on and around the Borkum Reef Grounds. Right: video transect measurement locations for the 'from stone to stone' monitoring of geogenic reefs (for details, see Wijnhoven et al., 2025).

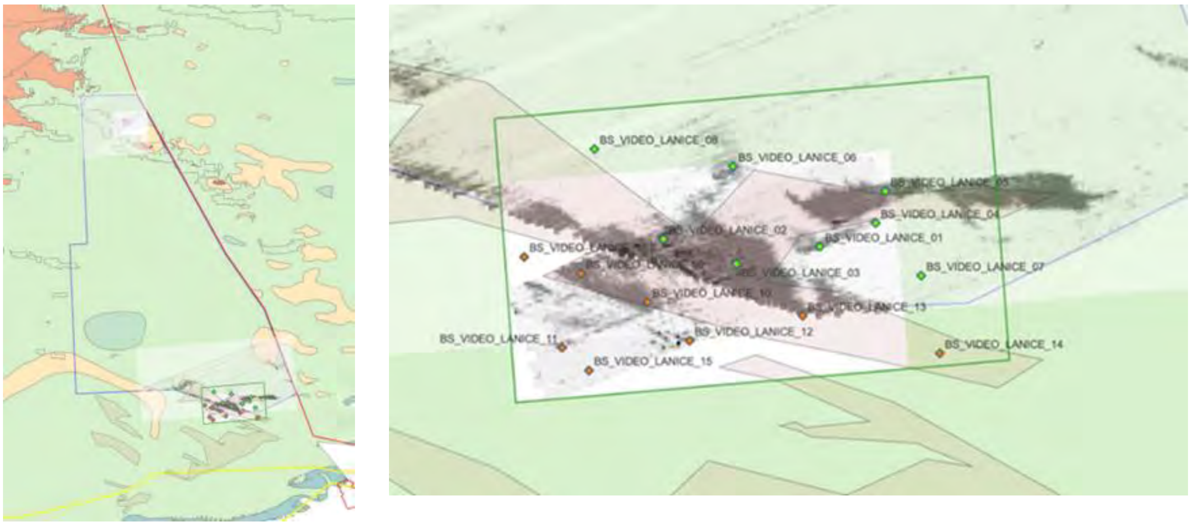


Figure 23. Left: Overview map of Borkum Reef Grounds with side scan sonar (SSS) plot to monitor Lanice/Loimia reef development measurement locations. Right: Detail of SSS plot with standard straight-line video transect measurement locations to monitor Lanice/Loimia reef development for the Borkum Reef Grounds multi-year monitoring programme on and around the Borkum Reef Grounds (for details, see Wijnhoven et al., 2025).

5.4 Recommendations

International cooperation

- During the preparation of the fieldwork for this project, the German colleagues from the Alfred Wegner Institute (AWI) indicated that they were very interested in studying the area together. Data sharing is a good start.

Use of historic Hydrographic Office (HO) side scan sonar (SSS) data

- The use of HO SSS data in this project proved to be very powerful for fieldwork preparation and for habitat mapping (stone reefs H1170 and biogenic reefs). We recommend further use of these data in other areas for site selection studies (e.g. for native oyster restoration, *Sabellaria* restoration, etc), and for habitat mapping.
- The discriminative ability and performance of SSS based *Lanice/Loimia* reef mapping can be augmented by improving the quality and quantity of SSS data as well as by inclusion of other data sources such as MBES and box corer data.
- For automatic detection of stones, it is recommended to develop an AI classification model as well.
- For more (technical) recommendations, see Annex A.

Biodiversity

- The discovery of *Loimia ramzega* has led to the reexamination of stored samples of previous research within the ReVifes programme (2020) and the 2013 Borkum Reef sampling campaign (results not yet available). We recommend to pay attention to this species in other projects and monitoring programs. We also recommend to determine its ecological role in comparison to *Lanice conchilega*.
- For analysis of the Borkum Reef biodiversity data, we recommend to not focus on the data in this report, but mainly use the video and box corer data that will be collected starting in 2025 (T0), because the nature of this research was to explore the Borkum Reef area and fill in knowledge gaps, and the nature of the future monitoring (see Wijnhoven et al., 2025) is to collect data in a standardized and statistically meaningful way.

6 Quality Assurance

Wageningen Marine Research utilises an ISO 9001:2015 certified quality management system. The organisation has been certified since 27 February 2001. The certification was issued by DNV.

The results of the data are reported with a decimal point (.) instead of a comma (,) (in derogation of the Dutch SI). The results stated in this report only apply to the samples as they have been received.

Benthic box corer samples on board have been processed according to the "Analysevoorschrift Rijkswaterstaat (A2.107)"

Benthic box corer samples in the lab have been processed according to the "Analysevoorschrift Rijkswaterstaat (A2.107)"

If desired, information regarding the performance characteristics of the analytical methods is available.

If the quality cannot be guaranteed, appropriate measures are taken.

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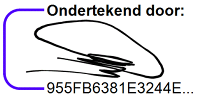
Justification

Report C054/25
Project Number: 4315100238

The scientific quality of this report has been peer reviewed by a colleague scientist and a member of the Management Team of Wageningen Marine Research

Approved: Sander Glorius
Researcher

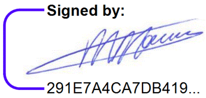
Signature:



Date: 24-07-2025

Approved: Dr. A.M. Mouissie
Business manager Projects

Signature:



Date: 24-07-2025

Annex A TNO report (acoustic surveys)

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TNO 2025 R10247 – April 2025

Analysis of sonar data for mapping geogenic and biogenic reefs in the Borkum Reef Grounds, Dutch Continental Shelf

Author(s)	T.C. (Timo) Gaida, B. (Bas) Binnerts
Classification report	ONGERUBRICEERD Releasable to the public
Title	ONGERUBRICEERD Releasable to the public
Report text	ONGERUBRICEERD Releasable to the public
	ONGERUBRICEERD Releasable to the public
Number of pages	44
Number of appendices	1
Sponsor	Rijkswaterstaat
Project name	MONS onderzoek KRM-gebied Borkumse Stenen
Project number	060.61672

The classification designation Ongerubriceerd is equivalent to Unclassified, Departementaal Vertrouwelijk is equivalent to NL Restricted, Stg. Confidentieel is equivalent to Confidential and Stg. Geheim is equivalent to Secret.

Medegefinancierd door de Europese Unie

Contents

1 Introduction

Acoustic systems, such as the Side Scan Sonar (SSS) and Multi-Beam Echo Sounder (MBES) are able to efficiently map and characterise large areas of the seabed [1] [2]. Post-processing of the raw sonar data can provide information about the seabed morphology, sediment distribution and biogenic/ geogenic reef coverage. Within the MONS - Sabellaria monitoring project, a research expedition to the NL part of the Brown Bank, demonstrated the successful application of using SSS and MBES, combined with ROV video ground truthing and sediment sampling to detect and map *Sabellaria spinulosa* reefs [3]. In this project, the same monitoring approach was used to map geogenic (stones and coarse substrate) and biogenic *(Lanice/Loimia)* reefs (also indicated as '*Lanice/Loimia* fields') at the Borkum Reef Grounds ('Borkumse Stenen') Marine Protected Area (MPA).

This report describes the outcome of the work conducted by TNO, which involved the (i) preparation and coordination of the acoustic measurements during the field trial and the (ii) analysis of previously acquired Hydrographic Office (HO) data and newly acquired data (referred to as expedition data) with the purpose of mapping the areas at the Borkum Reef Grounds with significant geogenic and biogenic reef presence.

This report is published as an appendix to the data report about the inventory of biodiversity and habitats for the Borkum Reef Ground [4]. The report is part of the project *'MONS ID49 effectiviteit gesloten gebieden (onderdeel Borkumse Stenen)'* (Rijkswaterstaat case number 31201900)

2 Data

2.1 Introduction

This section describes the data that was used in this project to map the areas in the Borkum Reef Grounds (BRG) with significant geogenic and biogenic reef presence. The data is separated into two categories:

- SSS data of the Netherlands Hydrographic Office (HO) with full coverage of the BRG - made available for this study under the condition that the raw data cannot be made available.
- Newly acquired SSS and MBES data, acquired during a one-week expedition with the vessel ARCA in August 2024 [4] - covering three preselected sub-areas of the BRG[1], as those are the areas where aggregations of geogenic reefs (sub areas A and B) and biogenic reefs (sub area D) are expected.

An overview of the data used in this project is shown in Table 2.1. More information on this data can be found in the subsequent sections of this chapter. Figure 2.1 shows a map of the BRG area indicating earlier identified possible presence of stone aggregations, areas with coarse sediment substrate and possible presence of *Lanice/Loimia* reefs based on SSS data and video-based validation on a limited number of sites [5], and indicating the current focal areas of the survey (Bos et al., 2025)

Table 2.1: Overview of sonar datasets and their application to generate maps.

Data type	Provider	Reef type that can be mapped using data	Area	Year
SSS	Expedition data - RWS	Lanice/Loimia fields, Stone density map	Sub areas	2024
MBES	Expedition data - RWS	Coarse substrate	Sub areas	2024
SSS	HO data - Hydrographic office	Stone density, Lanice/Loimia fields	Covering the BRG	2008 - 2013

2.2 Expedition Data

Full coverage MBES and SSS data, in addition to ROV (Remotely Operated Vehicle) video recording and box core samples were acquired in three selected survey areas. Survey areas A and D are located in the south and area B in the north of the BRG. The location of survey area D was chosen to be in an area where *Lanice/Loimia* was previously mapped [6], and the locations of area B and A were chosen to include previously detected and mapped stone aggregations potentially forming or considered geogenic reefs. The presence of stones in these areas was verified using the HO SSS data from the Hydrographic Office before the locations were finally selected.

[1] The sonar data was used at the time of the expedition to select suitable locations to ground truth the *Lanice/Loimia* fields, sediment properties and rock presence via ROV video inspection and box core sampling.

Sonar settings were optimised to balance the reef detection performance against coverage (see Table A.1 to Table A.3 in the appendix for the used acquisition settings). In total, an area of 19.3 km^2 was surveyed with both the MBES and SSS as these sensors can be used simultaneously (Table 2.2). The SSS in survey area D covered 3.2 km^2 more than the MBES due to malfunctioning of the MBES on the last day of the expedition.
The data acquired using the Klein sonar 5000 has the following characteristics:
- Target flying height: 7.5 m;
- Range (across-track) resolution: 3.75 cm;
- Along-track resolution: 10 cm (at 38 m range), 20 cm (at 75 m) and 36 cm (at 150 m);
- Along-track ping spacing: 35 to 45 cm (varies with speed);
- Track line spacing: Area A and B of 100m, Area D of 70 m;
- Sonar seabed coverage[2]: 150% (Area A and B), 207% (Area D).

Table 2.2: Overview of scanned survey area and acquisition time.

Area ID	Scanned area	Acquisition time
A	5.7 km^2	8h 20min
B	6.3 km^2	10h 45min
D	7.3 km^2 + 3.2 km^2	10h 26min + 2h 34min
Total	22.5 km^2	32h 5min

Figure 2.2 shows an example of the acquired and processed sonar data, such as the MBES bathymetry, MBES backscatter and SSS backscatter, for survey area B (see Figure A.1 and Figure A.2 in Appendix for area A and D). The MBES bathymetry was processed with *Qimera* 2.5.4 and the MBES backscatter with FMGT 7.10.3 (*QPS*, Zeist, The Netherlands). The displayed SSS images were processed on board of the ARCA with *SonarWiz* 8.2 (*Chesapeake Technology*, USA). The SSS data processing for generating the *Lanice/Loimia* reef presence maps and the stone density maps was carried out with software developed by TNO [3] [7].

[2] A sonar seabed coverage of 100% means that the seabed is fully scanned by the sonar, which would be the case for a line spacing of 150 m and a SSS range of 75 m. A sonar coverage of 150% means that 50% of the seabed is two times scanned from two adjacent track lines. A sonar coverage of 207% means that the seabed is two-times fully scanned from two adjacent track lines and 7% of the seabed is scanned even three-times from three adjacent track lines. Here, sonar coverage does not include removal of the nadir region, which was carried out in post processing.

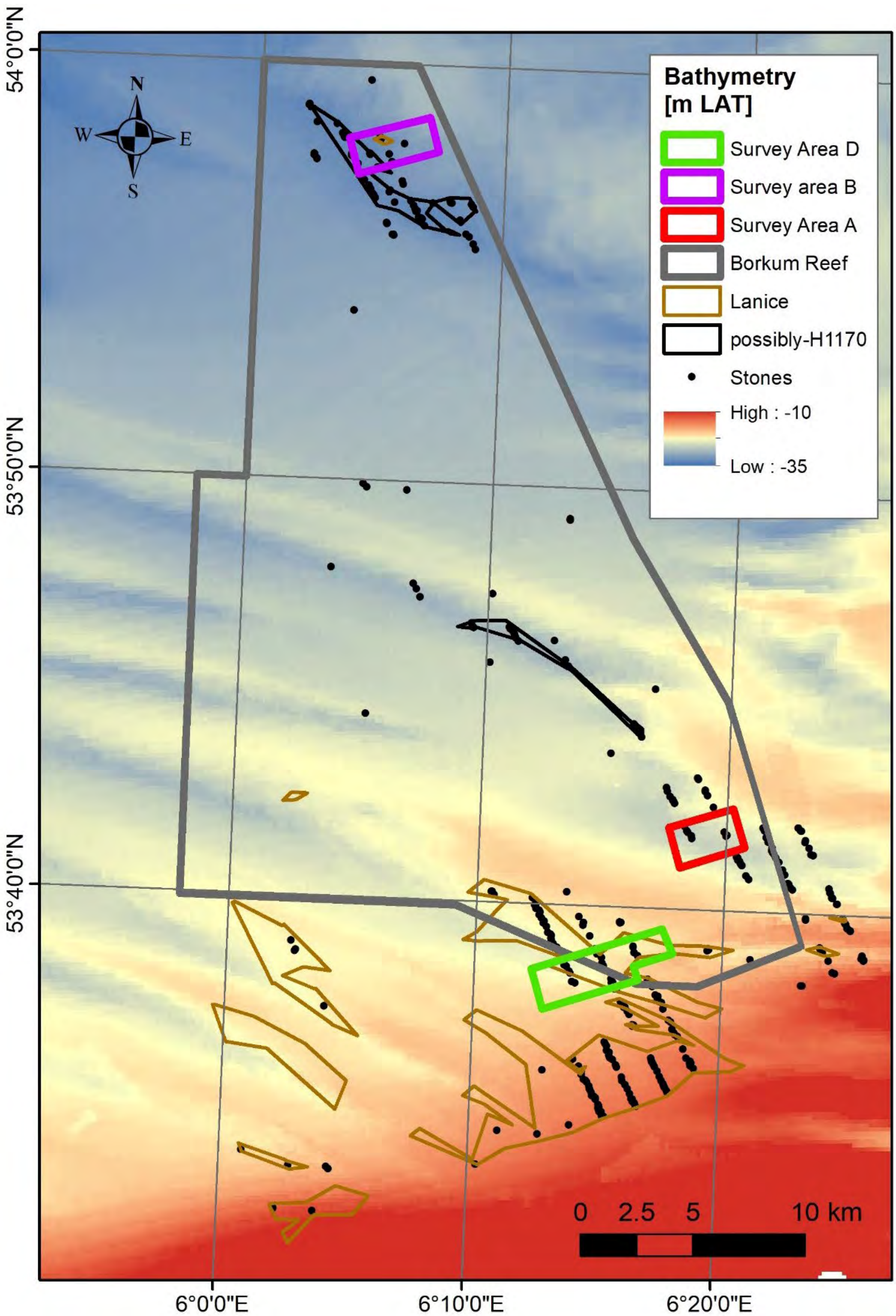

Figure 2.1: Overview map of BRG displaying previously mapped Lanice/Loimia reef presence and stone fields/ coarse substrate (that might classify as habitat type H1170) and regions surveyed during the expedition with the ARCA in August 2024.The coordinate system is ETRS 1989.

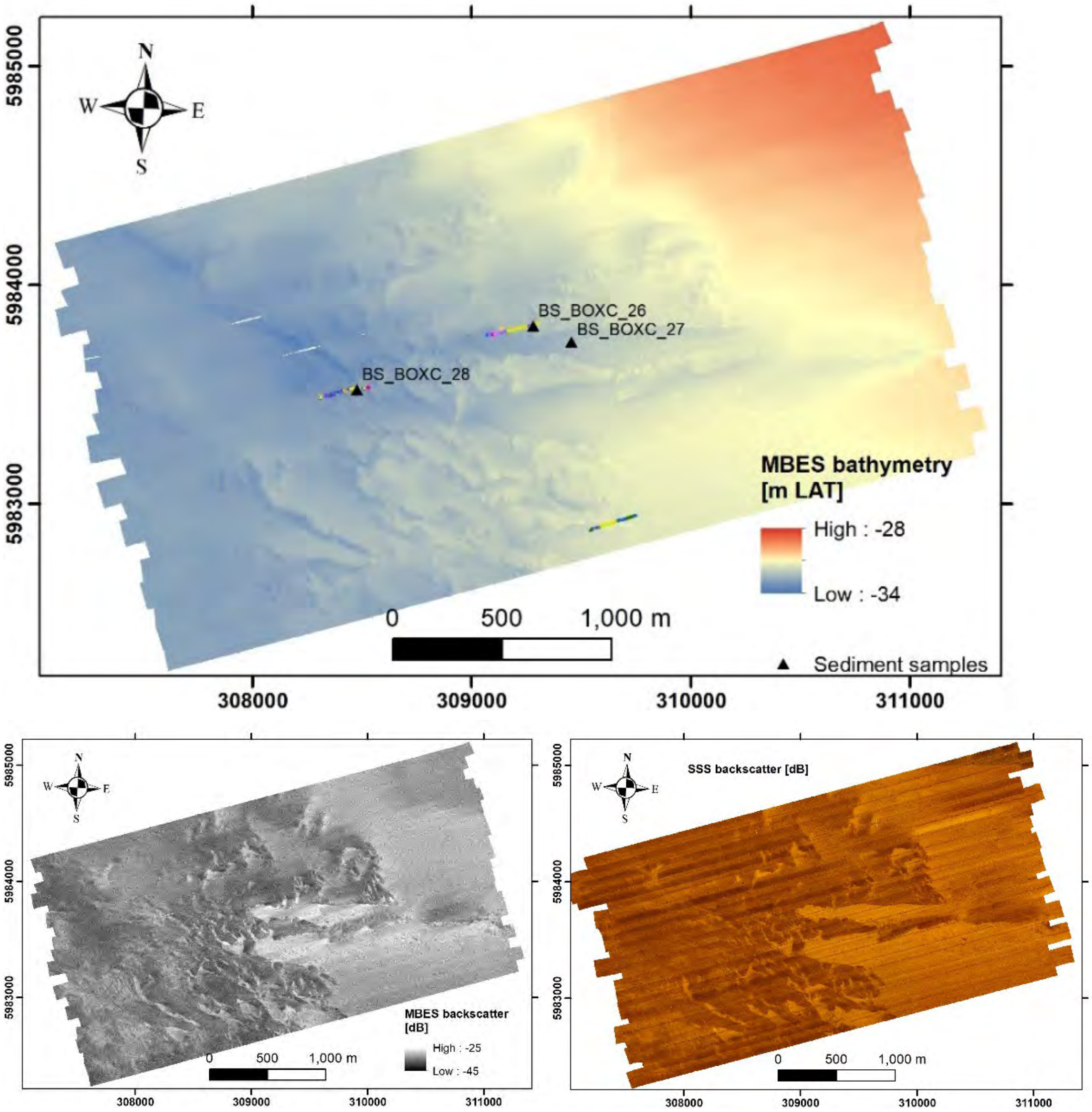

Figure 2.2: Sonar data acquired in area B. (Top) MBES based bathymetry mapping including positioning of collected video recordings and box core sediment samples, (bottom left) MBES backscatter and (bottom right) SSS backscatter. The legend for the classification of the video tracks is displayed in Figure A.2. The coordinate system is ETRS 1989 UTM 32N.

2.3 Hydrographic office SSS data

The Hydrographic Office[3] of the Netherlands regularly acquires SSS data in the Dutch North Sea. The dataset covers the majority of the BRG and was recorded between 2008 and 2013 (Figure 2.3). In agreement with the HO, The TNO-Geological survey of the Netherlands stores this data in the digital archives. This data is not open for the public. The quality of the data varies throughout the area due to fluctuating Meteocean and/or varying quality control. Additionally, the survey settings were not fully optimised for the detection of biogenic and geogenic reefs. For example, the sonar range was set to 150 m (compared to 75 m in this expedition), reducing the resolution of the system. A useful signal for the detection of *Lanice/Loimia* was only available until 100 to 120 m from the Sonar in both directions

[3] https://english.defensie.nl/organisation/navy/navy-units/hydrographic-service

(max 240 m Sonar swath width). Georeferenced SSS images were produced for each survey line in the BRG using the processing workflow developed by TNO (Figure 2.4). In total, around 5000 SSS images were computed, with each image covering an area of around 1200 m x 240 m. The total area of all SSS images is around 1500 km^2, however, as the SSS tracks were scanned with some overlap, the actual area covered on the seabed is smaller. The data acquired using the Klein 5000 sonar has the following characteristics:

- Target flying height: 15 m;
- Range (across-track) resolution: 3.75 cm;
- Along-track resolution: 10 cm (at 38 m range), 20 cm (at 75 m) and 36 cm (at 150 m);
- Along-track ping spacing: 15 to 25 cm (varies with speed);
- Track line spacing: between 10 and 400 m, with the majority around 120 m;
- Sonar seabed coverage (max useful range up to 120 m): around 200% (relates to track line spacing and sonar range).

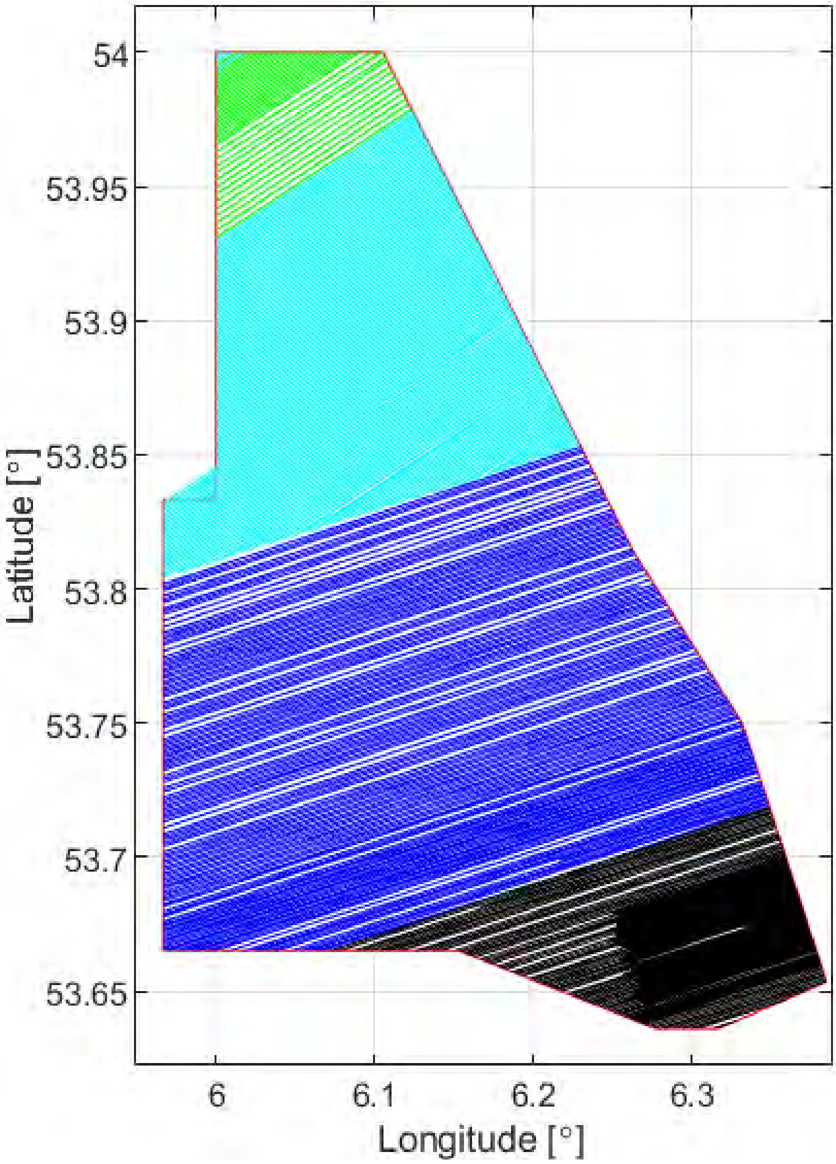

Figure 2.3: SSS line coverage of the Hydrographic Office data in the BRG. Black and blue sonar lines were acquired in 2013 and green and cyan lines acquired in 2008. The coordinate system is ETRS 1989. The colours represent different surveys.

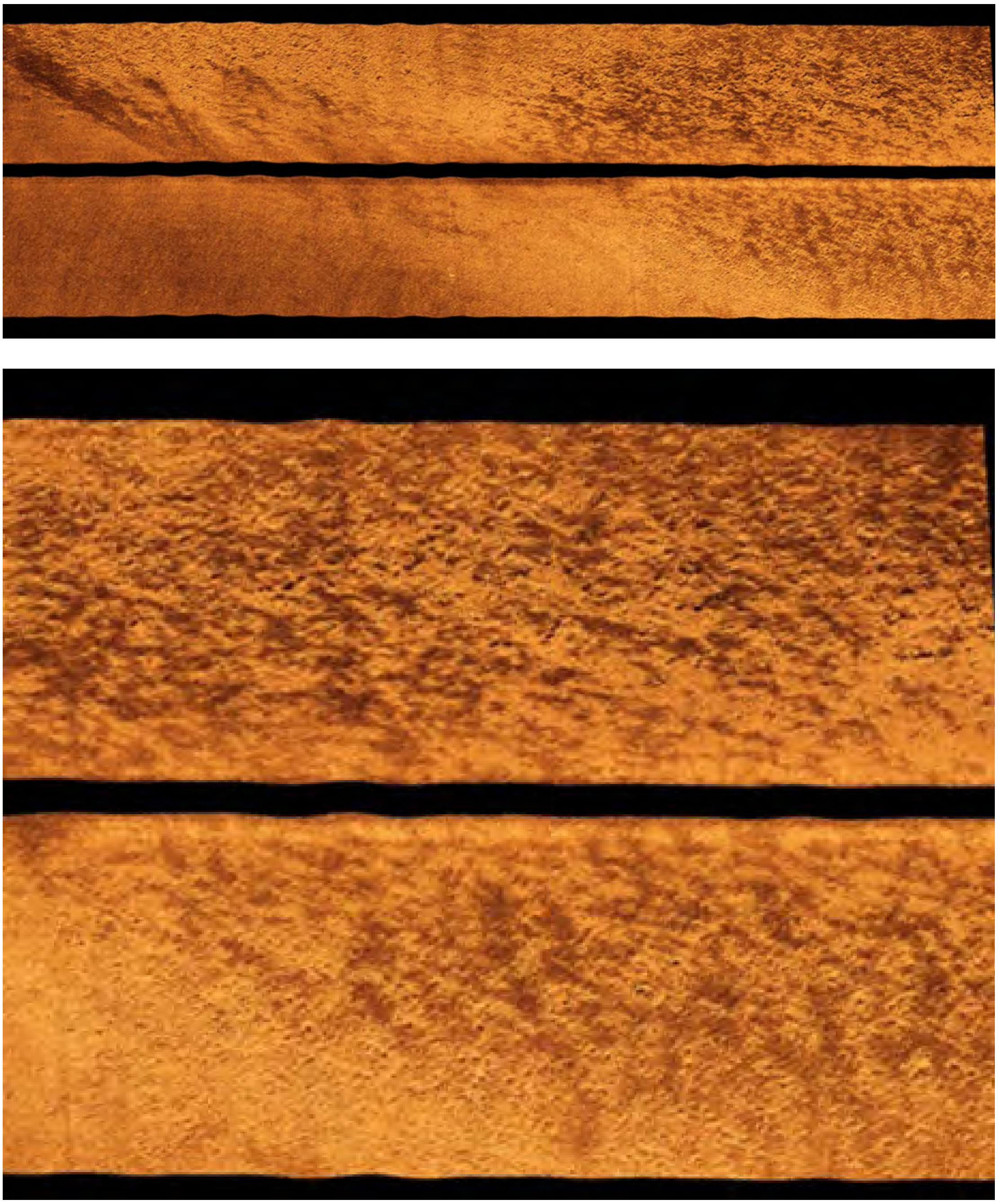

Figure 2.4: Georeferenced SSS image obtained from the application of the TNO processing code to the raw SSS data from the Hydrographic Office. A *Lanice/Loimia* field is indicated by the sonar data on the right side of the top image (bottom figure shows the same region zoomed-in. The size of the area depicted in the top figure is around 1200 m x 240 m.

3 Methodology

3.1 Biogenic reef mapping

Within this project, the semi-automated machine learning classification workflow developed for the mapping of *Sabellaria* in the area of the Brown Bank, Netherlands in 2023 [3] [8], was used to map *Lanice/Loimia* reefs for the entire BRG. As was discovered during this project, besides *Lanice conchilega*, the tubeworm species *Loimia ramzega* is present in the region. The recent observations during the expedition [4], but also recent observations from the German part of the BRG [9] show that the biogenic reefs can be reefs largely consisting of one of the two species or a mixture of both species, and that both species can be considered common in the area. Although it is likely that the presence of *Loimia ramzega* in this part of the North Sea is of relative recent date, it is also very likely that the species has been overlooked for years although it was already present in the region [9]. It is therefore uncertain whether tubeworm reefs as observed in the past consisted of solely *Lanice conchilega* or was a mixture of both indicated species as well. As both species construct tubes and form reefs, and in this study particularly the tertiary structure that is created (potentially providing habitat of added value for a variety of biodiversity), is most important, the origin of the observed reefs is not distinguished. Throughout this report, the biogenic reefs at and near the BRG will be indicated as *Lanice/Loimia* reefs, not distinguishing whether one or both species are locally present. Figure 3.1 illustrates the workflow, displaying the various manual and automated steps needed to obtain the final results being a percentage coverage map indicating *Lanice/Loimia reef* presence. To provide optimal results for the detection of *Lanice/Loimia* reefs, the workflow configuration was optimised separately for the application to the expedition and HO data. Details on the configuration used can be found in Section 3.1.1 and 3.1.2.

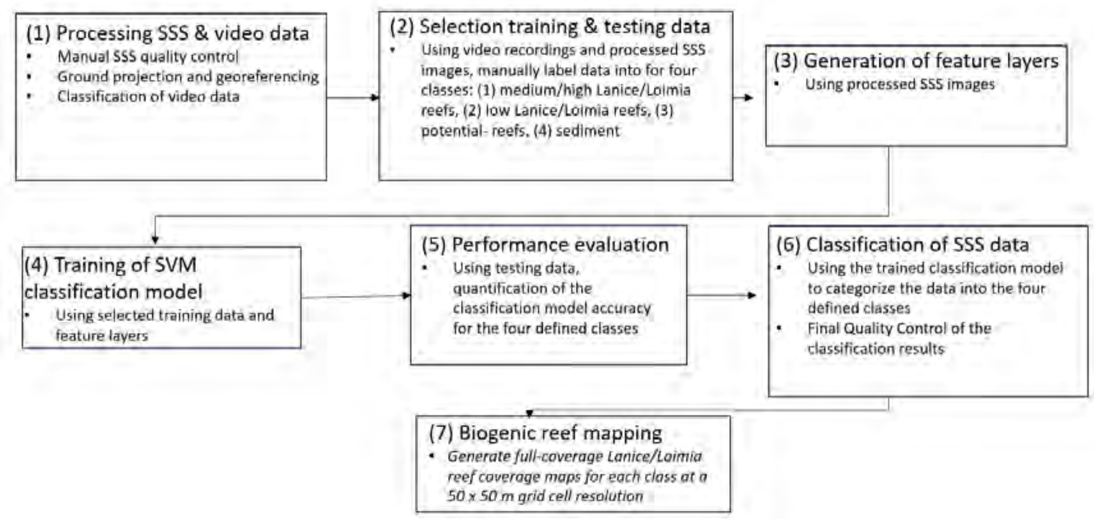

Figure 3.1: Machine-learning classification workflow used for the mapping of *Lanice/Loimia* reefs in the BRG, applied to both the expedition and HO data.

3.1.1 Expedition data

As part of the **first step** of the data processing workflow, the raw SSS data was processed and projected on a regular 10 cm x 10 cm georeferenced grid in ETRS89 UTM 32N coordinates. Quality control of the SSS data showed that the data quality at an incident angle < 50˚ (corresponding to a ground range of ~10 m at 8 m sonar-fish altitude (flying height)) was insufficient for the reliable detection of *Lanice/Loimia* fields, hence this part of the data was discarded.

As part of the **second step**, it was decided to define four labels for which training and testing data were created:

1. **Medium to high *Lanice/Loimia* coverage:** The medium to high *Lanice/Loimia* coverage class consists of mostly dense aggregations of *Lanice/Loimia*. Based on the video data, patches of lower density in between the medium to high density patches exist as well. The *Lanice/Loimia* individuals protrude a couple of centimetres out of the seabed. Most likely morphological seabed elevations generated by the *Lanice/Loimia* cause the indicative acoustic pattern. The morphological elevations are also visible on the MBES bathymetry map (see Figure 3.3).
2. **Low *Lanice/Loimia* coverage:** The low *Lanice/Loimia* coverage class consists of a lower density coverage, which means less individuals per square meter than indicated at label 1. The elevation of the individuals do not seem to differ from the medium to high coverage class based on the video recordings. The acoustic patterns of this class are different from the medium to high coverage class. The video footage has shown areas, where the low density of *Lanice/Loimia* was present but the acoustics were not indicative. Therefore, it is possible that patches of low density (maybe too little individuals to be detectable or they don't form morphological elevations) are missed by the trained classifier.
3. **Potential *Lanice/Loimia* coverage:** This third class is not based on the video recordings but on interesting acoustic patterns that could indicate the presence of *Lanice/Loimia,* but were "too dissimilar" (expert assessment) to label as category 1 or 2 (were considered to be different). Validation through video analysis in these regions is still needed to confirm the origin of the acoustic features.
4. **Sediment:** The fourth class is called sediment and includes everything what is not classified as class 1 to 3. As for example flat seabed with coarse (gravel, shells) sediment, sandy sediment with small ripples or a flat muddy sand sediment (Figure 3.2, bottom row).

Training and testing data were selected manually in areas where ROV video data was available but also in areas where similar acoustic patterns were present. This was needed to increase the training and testing datasets due to the limited availability of ROV video tracks indicating *Lanice/Loimia* reefs. An overview of the amounts of training/testing data used can be found in Table 3.1.

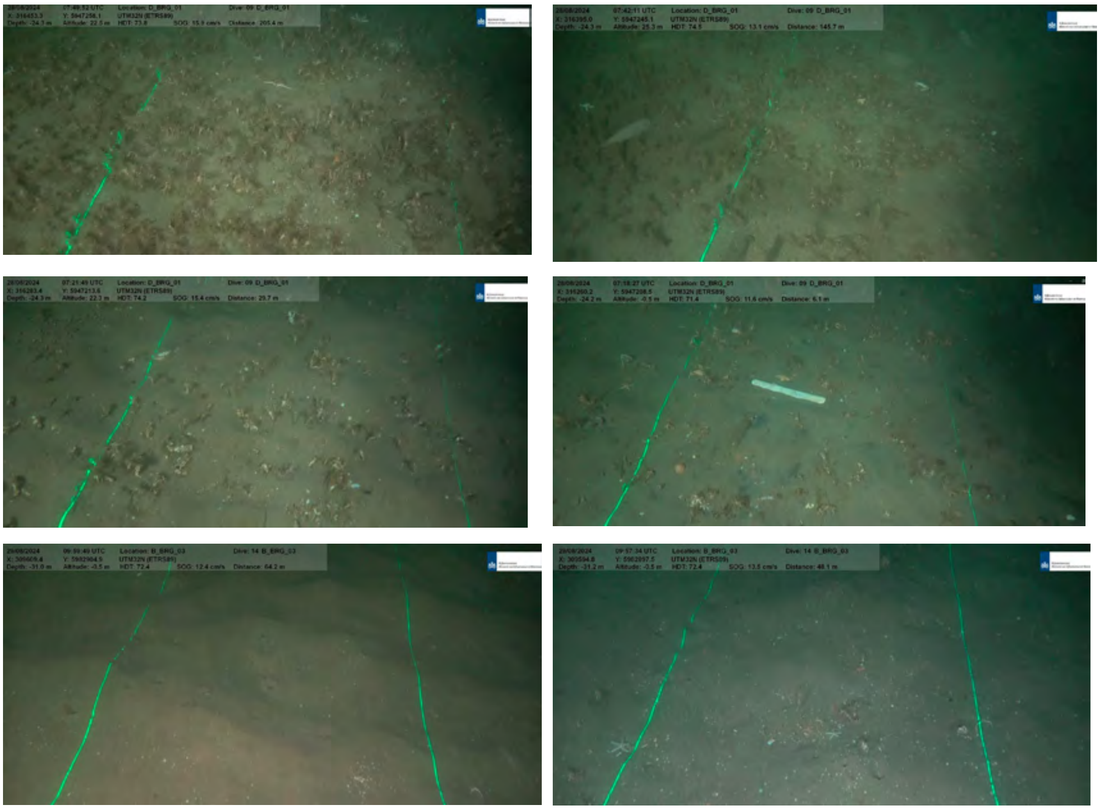

Figure 3.2: ROV video footage showing examples of (top row) medium to high *Lanice/Loimia* coverage, (middle row) low *Lanice/Loimia* coverage and (bottom row) sediment where the left footage shows a sandy sediment with small ripples and the right footage a muddy sand sediment.

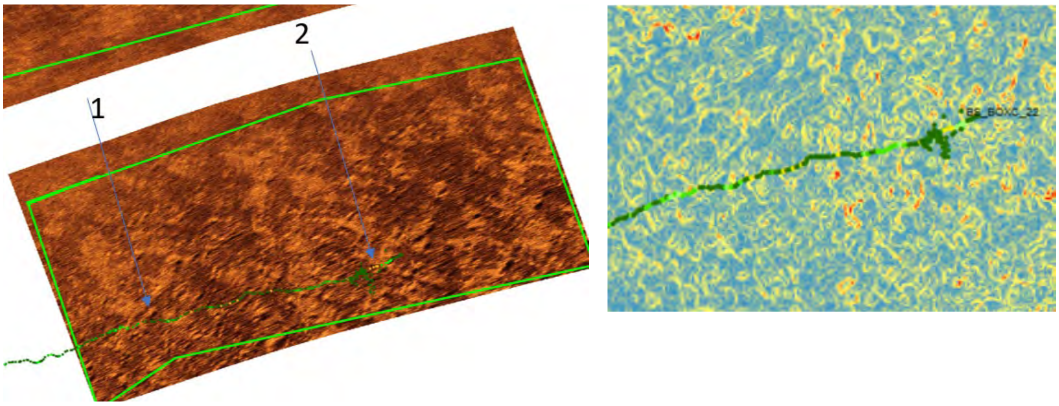

Figure 3.3: Example of acoustic data in an area with medium to high coverage of *Lanice/Loimia* (expedition data). (Left) Processed SSS image with indicative acoustic pattern for this class. Location of arrow 1 and 2 correspond to video footage in top row of Figure 3.2. The green polygon shows the area where training samples for the medium to high *Lanice/Loimia* coverage class were selected (Right) Seabed slope computed from MBES bathymetry showing the morphological seabed elevation corresponding to the presence of medium to high *Lanice/Loimia* coverage. The dotted line, displayed in both figures, shows the video track where dark green indicates low *Lanice/Loimia* coverage and light green medium to high *Lanice/Loimia* coverage.

Table 3.1: Amount of training and testing data samples used for SVM classification of expedition data.

Class	Training samples	Testing samples
Medium to high *Lanice/Loimia* density	2432	461
Low *Lanice/Loimia* density	733	187
Potential *Lanice/Loimia*	595	104
Sediment (*Lanice/Loimia*)	1500	227
Total	5260	980

Next, the feature layers are generated (step 3) and fed into the Support Vector Machine (SVM) machine learning algorithm (step 4). The GLCM metric, Gabor filter and basic statistics were used to create 78 feature layers.

- A Gabor filter[4] was applied to obtain directional spatial wavelength information. This filter investigates a specific spatial frequency (i.e. wavelength) content in the image in specific directions in a localised region around the point or region of analysis. Wavelength of 0.5, 0.8, 1.0, 2.0 m and 4.0 m towards the direction of 45 (SW-NE), 60 (WSW-ENE) 90 (W-E) and 135 (NW-SE) degrees were analysed.
- Gray level Co-occurrence Matrix (GLCM) metrics were computed (applied to the sonar amplitude image in dB). These metrics contain information about the texture in the image. Texture with different spatial information can be highlighted by computing the GLCM for different pixel distances (i.e. a pixel pair) in the image. The four features were created for pixel pairs of 1, 5 and 10 pixels (i.e. 0.1, 0.5 and 1.0 m distance between adjacent pixels). This way patterns with different spatial scales are highlighted.
- Basic feature layers were created being the ground range and mean and standard deviation (STDV) of the signal amplitude (in dB). The ground range is the distance between the tow-fish nadir and the ground projected sonar data.

Performance analysis of the results in step 5 showed that using 78 features layers resulted in the best classification accuracy. It should be noted however that the time spent on dimensionality reduction (reducing the amount of feature layers/ model input parameters) was limited in this project due to budget and time constraints.

The accuracy of the SVM classification was determined using the selected testing samples, displaying the outcome as a confusion matrix. This matrix provides (in addition to the overall accuracy that considers all class predictions) the individual class prediction performance via:

- The true positive rate (Sensitivity) and false negative rate which summarize how well the true class is predicted correctly of falsely;
- The true positive predictive rate (Precision) explains how well the prediction corresponds to the true class.

For a more detailed explanation on how to use the confusion matrix see [8].

After applying the classification model to all data in step 6, in step 7 the classified SSS lines are used to compute maps of the *Lanice/Loimia* reef percentage coverage for each sub-class. Further quality control of the classified data showed that the classification results at a ground range less than 25 m underpredicted the presence of *Lanice/Loimia* reefs. For this reason, this part of the data was discarded before creating the final reef coverage maps (see example shown in the Appendix in Figure A.4).

[4] https://nl.mathworks.com/help/images/ref/gabor.html

Because of the uncertainty of the sonar localisation data, the overlap of the lines and the data gaps at the nadir, the data of different sonar tracks at 10 cm x 10 cm resolution are aggregated onto a larger 50 m x 50 m grid, counting the 10 cm x 10 cm gridded data that were labelled as the specific sub-classes.

Finally, the obtained percentage values are multiplied with the precision of each class to incorporate the uncertainty of the prediction into the final map.

3.1.2 Hydrographic Office data

The machine learning classification workflow (Figure 3.1) was also applied to the Hydrographic office SSS dataset to map the *Lanice/Loimia* reefs for the full area. A few adjustment (with respect to the workflow used for the expedition data) of the workflow were needed:

- Because the HO SSS data was also used for the detection of stones (Section 3.2.1) and stones could be detected at a larger incident angle (<25 ° instead of <50 °), only data at incident angles <25° was discarded (corresponding to an approximate ground range of 7 m at 15 m fish altitude).
- In post-processing, the ground range beyond 120 m was removed because the SNR (Signal to Noise ratio) was too poor for the detection of stones and *Lanice/Loimia* reefs.
- The HO data has a usable range up to 100-120 m resulting in a lower along-track resolution. Because of this it was decided to project the HO data on a 20 cm x 20 cm georeferenced grid compared to the 10 cm x 10 cm grid for the trial data.

Additionally, the classification was only carried out for the medium to high *Lanice/Loimia* reef class and sediment (no reef) class. The classes low and potential *Lanice/Loimia* were excluded in the classification of the HO data due to following reason:

- The quality of the HO data varied throughout the BRG (high to low quality) compared to the expedition data, making it more difficult to distinguish between the subclasses for certain areas.
- The potential *Lanice/Loimia* class could not be confirmed by video data as no video data was available at the time of the HO surveys.

Since the HO data was acquired with a different sonar, acquisition settings and sonar settings (e.g., range, frequency) than the expedition data, the SVM classifier was trained and validated with training and testing samples from the sonar track lines of the HO data (Table 3.2).

Since more sonar data from *Lanice/Loimia* fields were available for the HO data, more training and testing samples could be selected compared to the expedition data. The same feature layers, as used for the expedition data, were used for the HO data. Since no ground truth data from the time period of the sonar data acquisition was available, the experience gained from selecting the training and testing samples for the expedition data set had to be used (expert assessment). The acoustic pattern, indicative for medium to high *Lanice/Loimia* coverage, visible and validated with the expedition data was also present in the HO data (see Figure 2.4 and Figure 3.4).

Mainly because of the long time needed for the processing of the data, it was decided to only apply the trained SVM classifier to the SSS images that showed any sign of features typical for the presence of *Lanice/Loimia* reefs (black and green lines in Figure 2.3)(manual Expert assessment, prior to step 6). The classifier was run on a number of SSS images to validate that the classifier indeed did not predict reefs at these locations, which was confirmed positively.

The reasons for excluding the other lines are:

- A manual inspection of the track lines has already indicated that the acoustic patterns, indicative for medium to high *Lanice/Loimia* coverage, were only present in the south of the BRG (green lines). The application of the classifier to the data in north (black lines) indicated the absence of *Lanice/Loimia* confirming the manual interpretation of the lines.
- Several sonar lines in the centre of the BRG (blue and cyan) were too noisy and were removed from the dataset (see Figure A.3 in the Appendix).

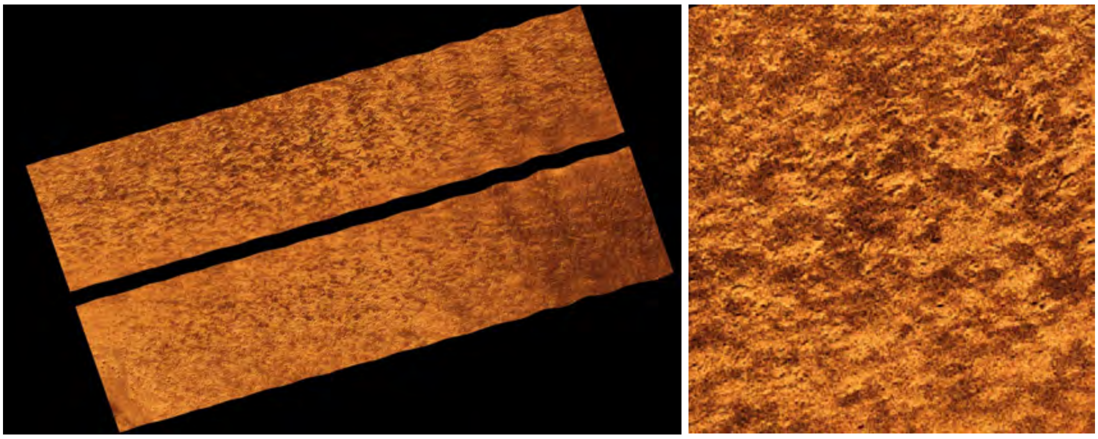

Figure 3.4: SSS image of HO dataset indicating a *Lanice/Loimia* field used to pick training samples for the medium to high *Lanice/Loimia* coverage class. (right) Zoom-in to *Lanice/Loimia* pattern visible in SSS images of HO data.

Table 3.2: Number of training and testing samples used for SVM classification of the HO data.

Class	Training samples	Testing samples
Medium to high *Lanice/Loimia reef* density	11213	5002
Sediment (no *Lanice/Loimia* reef)	18038	3764
Total	29251	8766

3.2 Geogenic reef mapping

3.2.1 Stone density mapping

The entire HO dataset was used to manually locate stones and to generate a stone density map for the BRG. The expedition data was not used for this purpose because of the overlap with the HO data (making the assumption that areas with stone aggregations (or positioning of individual stones) are stationary from 2008 to 2024). Visual inspection of a select number of stones partially confirmed the stationarity assumption.

Stones with an elevation higher than ~15 cm above the seabed could be manually detected in the processed SSS image. Three classes based on number of stones per 240 m x 240 m (57600 m^2) were defined (i) Class 1: 1 to 3 stones, (ii) Class 2: 3 to 10 stones and (ii) class 3 > 10 stones. As shown in Figure 3.5, the third class comprises a relatively wide spectrum including areas with > 50 stones within an area of 240 m x 240 m.

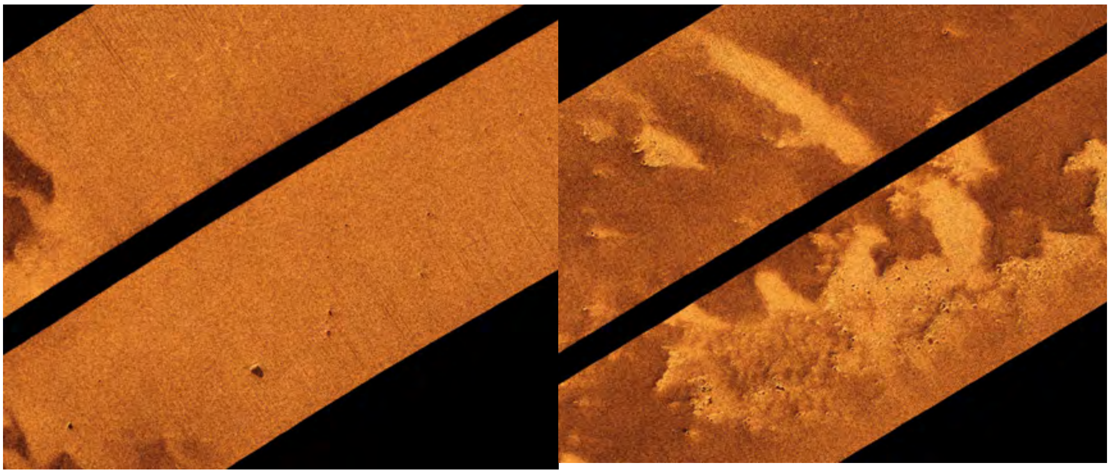

Figure 3.5: Examples of stone picking in HO dataset. Both images display an area of around 240 m x 240 m and fall into the rock density class of >10 stones. (Left) Around 15 stones and (right) >50 stones are detected.

3.2.2 Coarse substrate mapping

The MBES backscatter was employed to generate sediment maps from survey area A, B and D. The acoustic backscatter is dependent on the coarseness and hardness of the seabed [10]. Therefore, grain size, coarse particles such as shells or shell fragments, but also bioturbation, trapped gas inclusion, or biogenic material, effects the coarseness and hardness of the seabed. Generally, the backscatter increases with increasing coarseness and hardness for example from mud, fine sand, medium sand, coarse sand to gravel, shells and stones [11]. However, biogenic material or muddy sediments can contain gas inclusions increasing the backscatter. Therefore, it is not always a linear relationship between backscatter and sediment and the maps should ideally be validated with video tracks and grab samples.

An unsupervised k-means clustering was applied to the processed MBES backscatter maps [12], for clustering into three acoustic classes. The MBES backscatter values were averaged over a grid cell of 5 m x 5 m before being put into the k-means clustering. This grid cell size is considered sufficiently large to account for the positioning uncertainty of the box corer and video tracks and provides a robust backscatter value insensitive to intrinsic noise and small-scale seabed variation.

From the box core samples (and video recordings), three classes, corresponding to the number of acoustic classes from the k-means, were established:
Class 1: Fine sand;
Class 2: Medium sand or fine sand with a few shells;
Class 3: Coarse substrate comprising mud or sand mixed with shells, gravel and stones.

The classification of fine sand, medium sand and gravel corresponds to the Wentworth (1922) grain size classification. Note that the accuracy of the classification is limited because it was done based on visual interpretation (instead of the preferred grain size analysis using lab analysis). Figure 3.6 shows images corresponding to these classes.

Figure 3.6: Box core samples showing the sediment corresponding with the three classes of fine sand, medium sand and coarse substrate.

4 Results

4.1 *Lanice/Loimia* reef maps

In this section, the mapping results for *Lanice/Loimia* reefs are presented for the expedition and HO data. The quality of the predictions is discussed.

4.1.1 Expedition data

The trained SVM classifier achieved good performance on the expedition data with an overall accuracy of 80.4% (Figure 4.1). In particular, the sensitivity and precision of the medium to high *Lanice/Loimia* coverage class and the sediment class (no *Lanice/Loimia*) are very high. In 80.4% of the samples the prediction of the medium to high *Lanice/Loimia* class corresponds to the true class (precision), while for the low and potential *Lanice/Loimia* coverage class the values is lower with 61.7%.

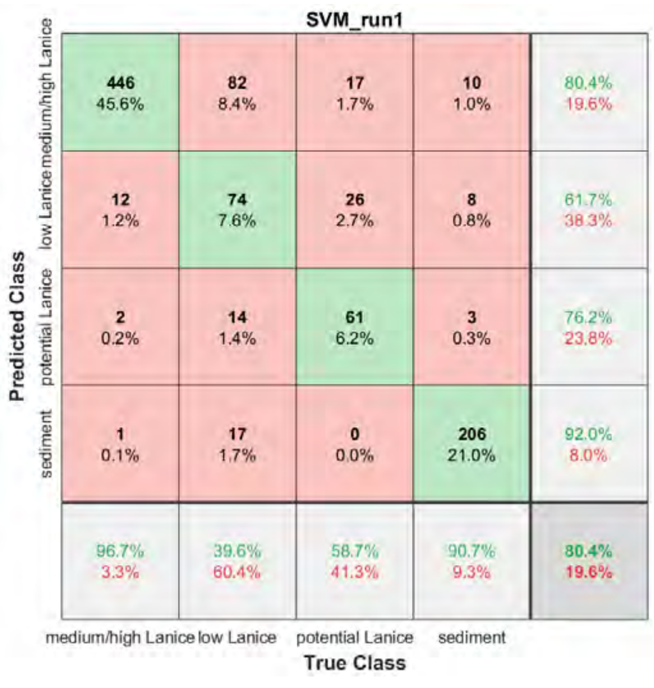

Figure 4.1: Confusion matrix obtained from the application of the trained SVM classifier to the testing dataset (expedition data). Green values in the right column show the precision per class and the green values in the bottom row show the sensitivity per class.

The trained SVM classifier was applied to each georeferenced SSS image of the dataset. Examples of the classification results are shown in the Appendix for three SSS images (Figure A.4 to Figure A.6). The classified SSS images were merged into a full-coverage map of the three *Lanice/Loimia* classes as described in Section 3.1.1.

The generated maps allow the identification of distinct patches of low and medium to high-density *Lanice/Loimia* reefs (Figure 4.2 and Figure 4.3). A large part of survey area D (12.5%)

is observed to be covered with a medium to high density of *Lanice/Loimia* (being the surveyed area with the most significant presence of this species). Survey area A has two distinct patches where significant amounts of medium to high densities of *Lanice/Loimia* occur with a total of 5.3% of the seabed covered with this class. In area B low to high densities are almost absent (Table 4.1). Both areas (A and D) with a significant amount of *Lanice/Loimia* are located in the south of the BRG. The maps indicate that the areas with medium to high densities are surrounded by areas with low densities of *Lanice/Loimia*, which could indicate a gradual decrease of the species from an area of highest density. The map of the potential presence of *Lanice/Loimia* is presented in the Appendix (Figure A.7) and could be used to direct future expeditions to validate the actual presence of *Lanice/Loimia* reefs. The combined classes mapping can be used to identify the core area for the monitoring of *Lanice/Loimia* reef quality, and to allow comparison of positioning and quality (in terms of share of observed density classes and fragmentation of reefs) with future inventories (including mapping of reefs).

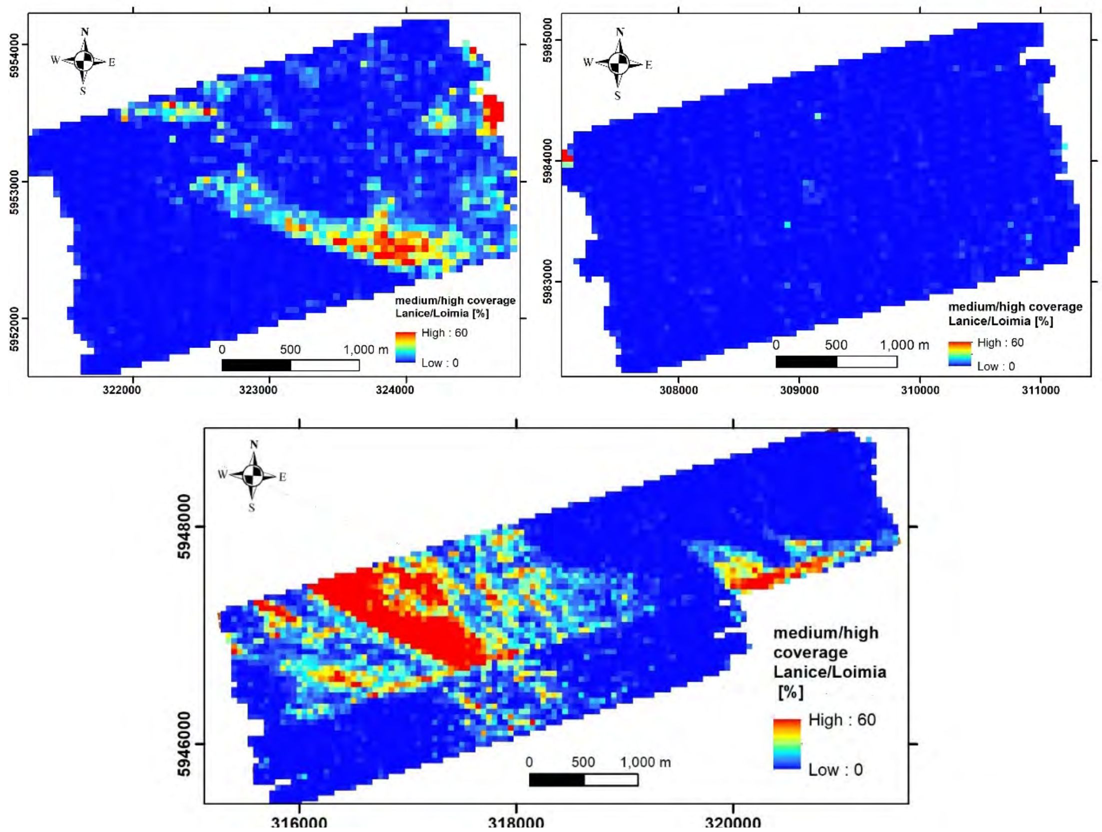

Figure 4.2: Medium to high *Lanice/Loimia* coverage map of (top left) survey area A, (top right) survey area B and (bottom) survey area D. Obtained from the application of the trained SVM classifier to expedition data (black sonar lines in Figure 2.3). The total coverage is 5.3%, 0.5% and 12.5% for area A, B and D, respectively. The coordinate system is ETRS 1989 UTM 32N.

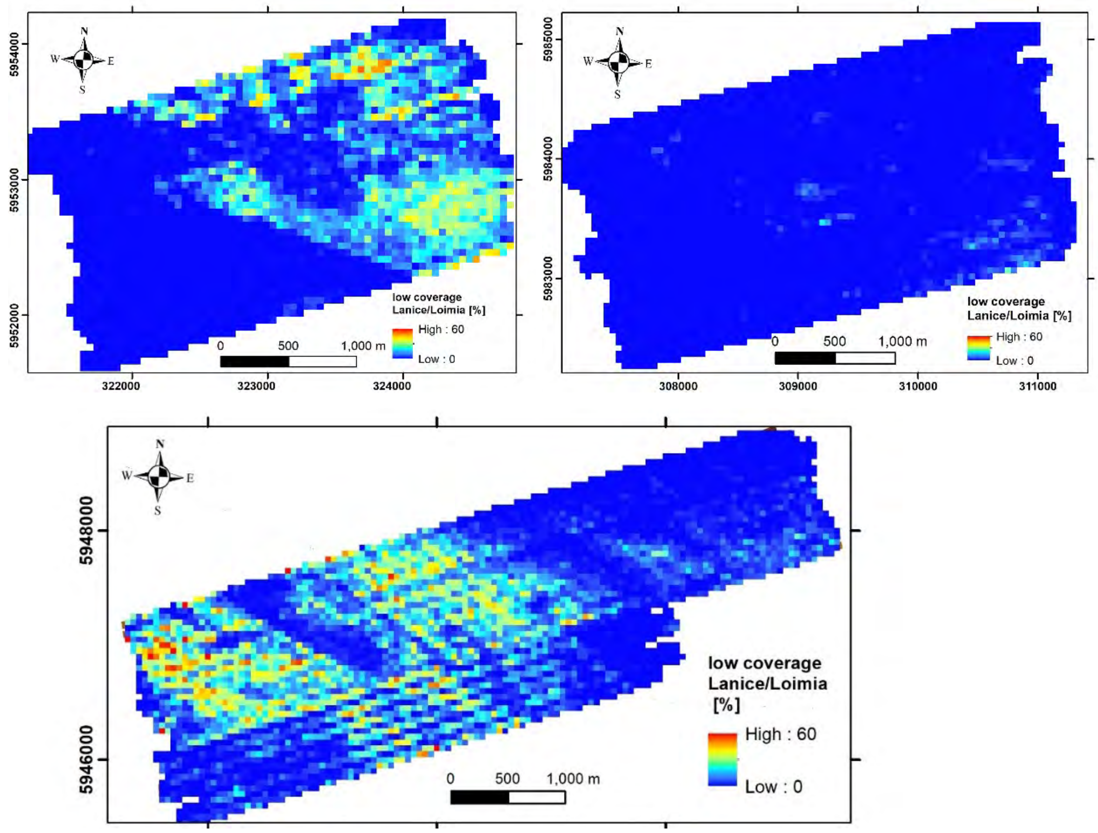

Figure 4.3: Low *Lanice/Loimia* coverage map of (top left) survey area A, (top right) survey area B and (bottom) survey area D. Obtained from the application of the trained SVM classifier to expedition data (black sonar lines in Figure 2.3). The total coverage is 7.2%, 0.3% and 7.4% for area A, B and D, respectively. The coordinate system is ETRS 1989 UTM 32N.

Table 4.1: Overview of predicted seabed coverage for each sub-class per survey area.

Area ID	Medium to high coverage *Lanice/Loimia*	Low coverage *Lanice/Loimia*	Potential coverage *Lanice/Loimia*
A	5.3%	7.2%	2.4%
B	0.5%	0.3%	0.1%
D	12.5%	7.4%	3.9%

4.1.2 Hydrographic Office data

The accuracy of the SVM classifier for the medium to high *Lanice/Loimia* reef class is very high with a precision and sensitivity of 96.6 and 89.2% (Figure 4.4). The reduction to two classes and the larger amount of training samples used could explain the higher accuracy compared to the results from the expedition data.

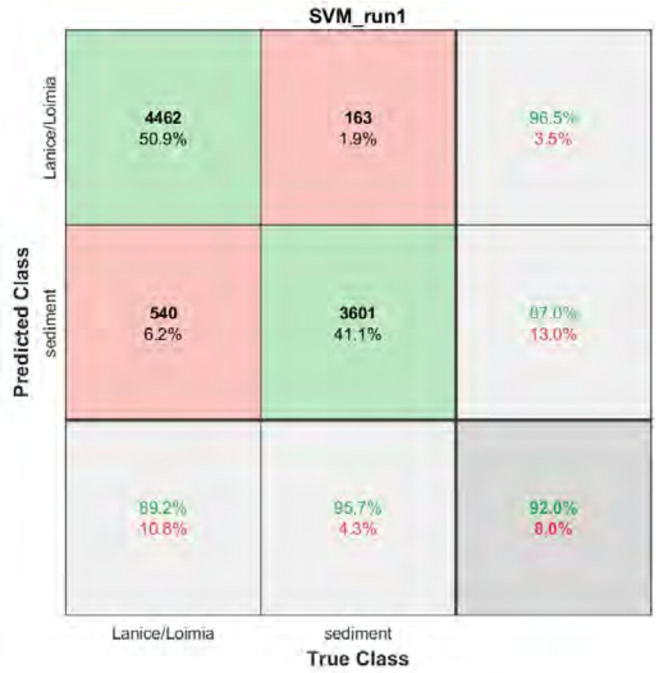

Figure 4.4: Confusion matrix obtained from the application of the trained SVM classifier to the testing dataset of the HO SSS data.

The medium to high *Lanice/Loimia* coverage maps for northern and southern BRG are shown in Figure 4.5. In the north of the BRG (except for a small patch) no *Lanice/Loimia* reefs were detected.

In the south of the BRG clear and distinct patches of the *Lanice/Loimia* reefs are predicted, indicating extensive distributions of *Lanice/Loimia* reefs in 2013. The largest patches are located in the west, and a few smaller patches occur in the east. The total seabed coverage with medium to high densities of *Lanice/Loimia* is 0.4% in the north and 8.7% in the southern region.

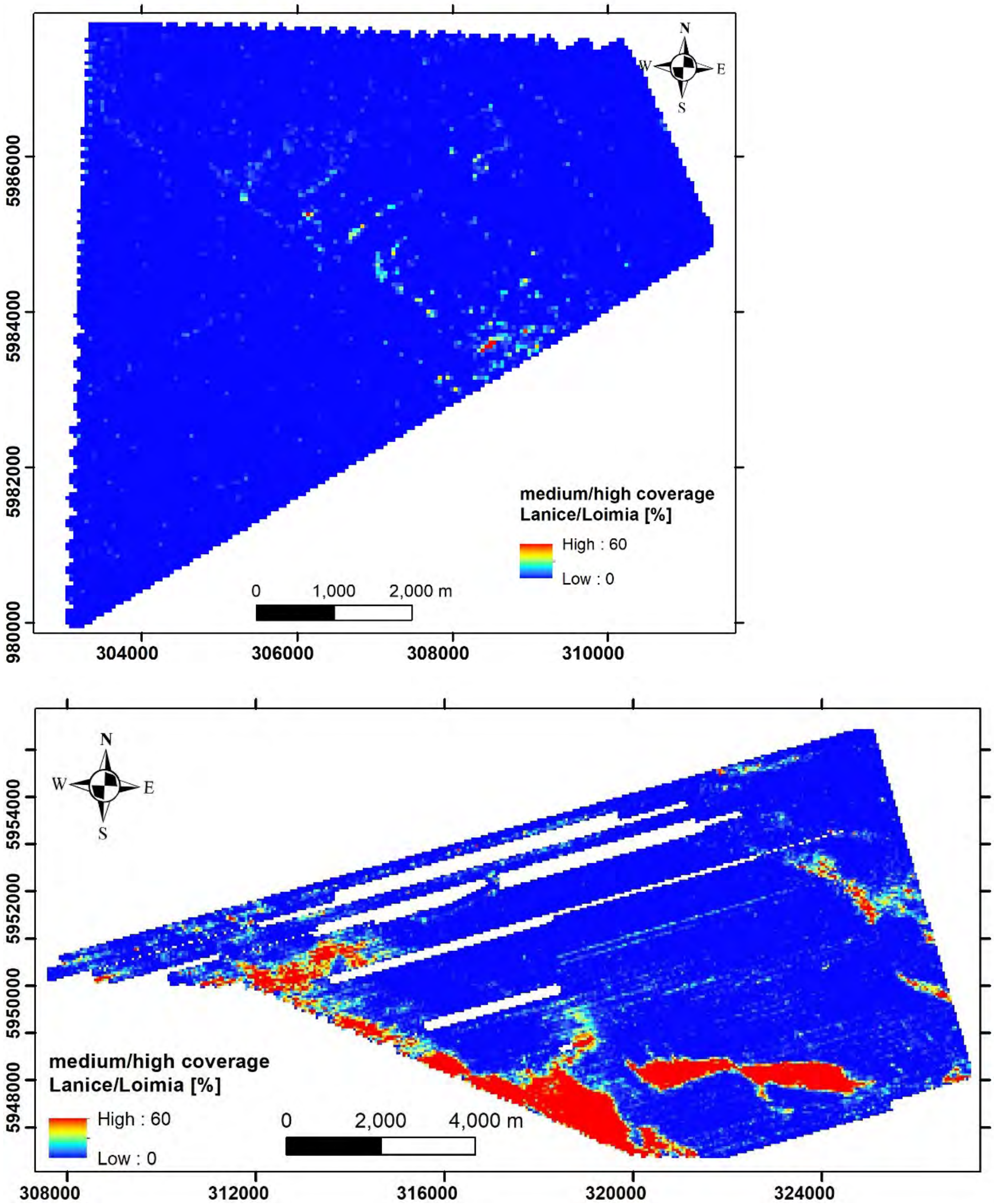

Figure 4.5: Medium to high *Lanice/Loimia* coverage map of the (top) northern and (bottom) southern BRG. Obtained from the application of the trained SVM classifier to the HO data (green and black sonar lines in Figure 2.3). The total coverage is 0.4% and 8.7%. The data gaps (white areas in the bottom figure) result from the manually rejected sonar images insufficient data quality. The coordinate system is ETRS 1989 UTM 32N.

4.1.3 Comparison of *Lanice/Loimia* maps

Lanice/Loimia maps were produced using both the HO and expedition data. A time difference of 11 and 16 years (2008/2013 to 2024) exists between the acquisition time of both datasets. Therefore, the comparison provides an indication of the temporal variability of the *Lanice/Loimia* fields. To allow for a qualitative visual comparison, a polygon was drawn manually around the mapped reefs for the HO data in Figure 4.6.

A comparison can be caried out where both datasets overlap, which is for a large part of the expedition areas A, B and D.

- Area A: both maps show good spatial agreement for the predicted *Lanice/Loimia* reef fields. For a small area, the 2024 map indicates that *Lanice/Loimia* reefs have slightly extended, even though this area is of lower percentage coverage. Another patch is slightly moved from west to east from 2013 to 2024.
- Area D: both maps indicate the presence of *Lanice/Loimia* reefs. First of all, the most significant patch of *Lanice/Loimia* (> 60% coverage and most extended) detected in 2024, is not overlapping with the analysed HO data. For the overlapping areas, in 2013 more *Lanice/Loimia* reefs were detected suggesting that part of the reef disappeared. A zoom-in comparison of such a location, where *Lanice/Loimia* reef disappeared from 2013 to 2024 is shown in Figure 4.7. The SSS image from 2013 shows an indicative acoustic pattern for *Lanice/Loimia* reef presence, while the SSS image from 2024 indicates rather homogeneous sediments with potential sand ripples. Only a small patch was detected in 2024, which was not present in 2013.
- Area B: both maps agree indicating to a large extent the absence of *Lanice/Loimia* reefs in 2008 and 2024. Since no *Lanice/Loimia* reefs were detected, a direct map comparison is not shown.

As an additional comparison, the *Lanice/Loimia* reefs mapped by [6] in 2015 are displayed in Figure 4.6. Since the method used to generate this map was not investigated as part of this project, only the rough area coverage overlap is compared. In general, a good overlap between these maps exists. For example, the significant reef patch mapped in 2024 matches approximately with the reef boundaries as described in [6]. Comparing the 2015 *Lanice/Loimia* map with the 2013 map, about half of the mapped reefs agree. Since the data for both maps roughly overlap in time, one of the maps seems to overpredict the distribution of *Lanice/Loimia* reefs over the other.

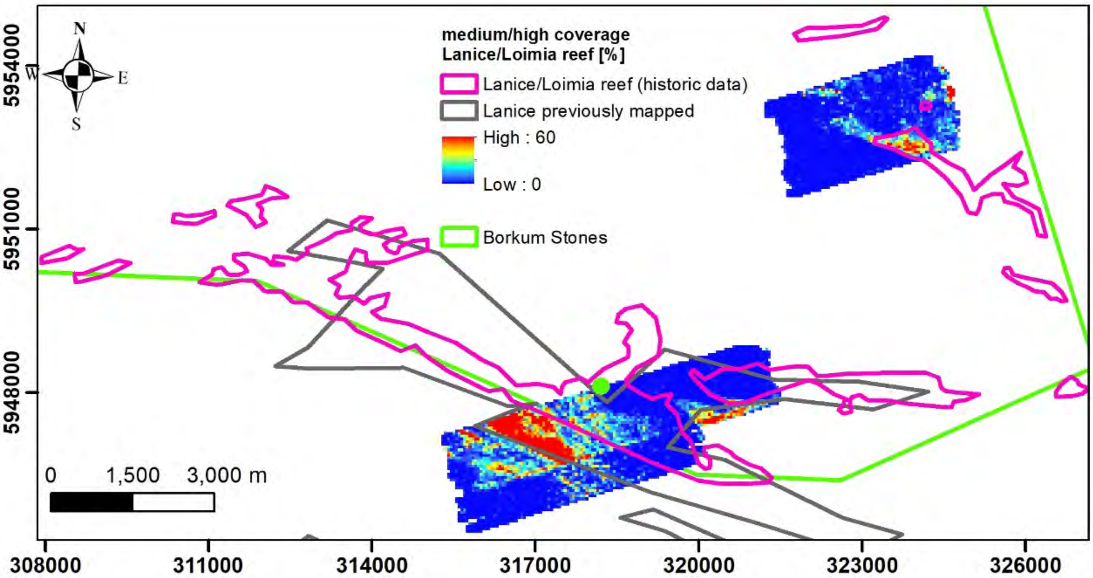

Figure 4.6: Comparison between *Lanice/Loimia* reefs mapped from three different data sources: (1) expedition data shown by coverage grid, (2) HO data shown by pink reef boundary polygon and (3) from [6] shown by brown reef boundary polygon. The map shows the south of the BRG. The green dot indicates the location of the SSS image shown in Figure 4.7. The coordinate system is ETRS 1989 UTM 32N.

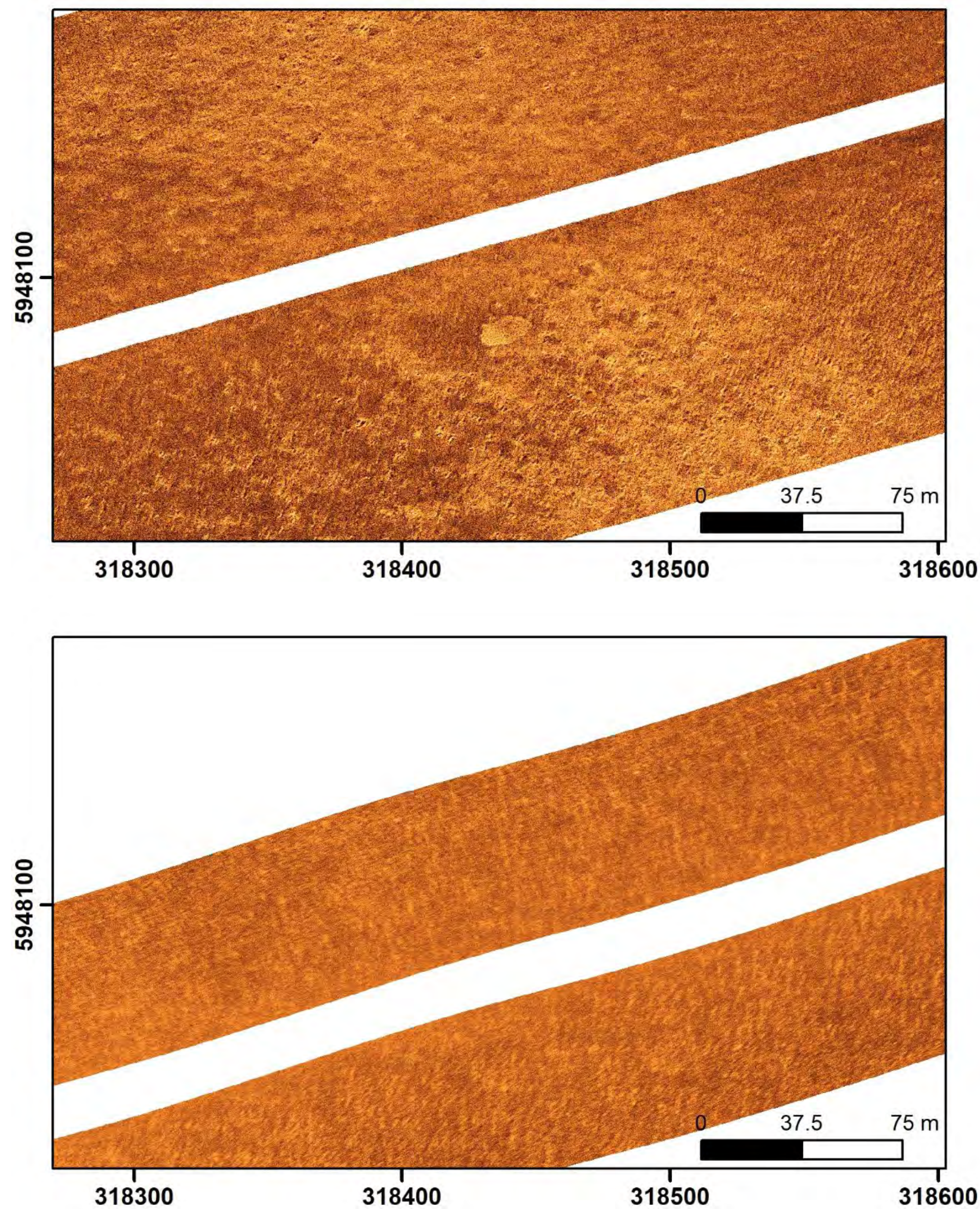

Figure 4.7: Zoom-in comparison of SSS image between expedition data (2024) and HO data (2013). The same location mapped in (top) 2013 and (bottom) in 2024 is shown. In 2013 this area was classified as medium to high density coverage of *Lanice/Loimia* (slightly decreasing coverage towards the west) and in 2024 as sediment (no reef). Acoustic pattern of Lanice are visible in the 2013 image whereas SSS image of 2024 indicates a more homogeneous seabed with potential sand ripples. The HO data has a longer range than the expedition data, therefore, the coverage is larger. Location of SSS images is indicated by green dot in Figure 4.6.

4.2 Rock density maps

The manual picking of the stones to estimate density classes (described in Section 3.2.1) resulted in a stone density map for the entire BRG (Figure 4.8). Figure A.8 in the appendix shows two SSS images in which stones are clearly visible.

Three main regions of aggregations of stones (stone fields) are visible in the north-east, south-east and centre. The one in north-east and south-east are the largest. A few individual stones are scattered over the entire area in very low densities. The map represents the time period from 2008 to 2013. The major stone fields overlap well with previously mapped stones and *Lanice/Loimia* Humps by [5], which are plotted in the same map.

Bos et al.,(2014) [5] indicated on the bases of SSS data analyses that (in the south-western part of the BRG and south of the BRG) tertiary structures are present for which it was concluded that this could include aggregations of stones. Later video analysis of these structures however showed that these structures where humps of *Lanice/Loimia*.
The manual picking of stones by TNO therefore seems to be correct.

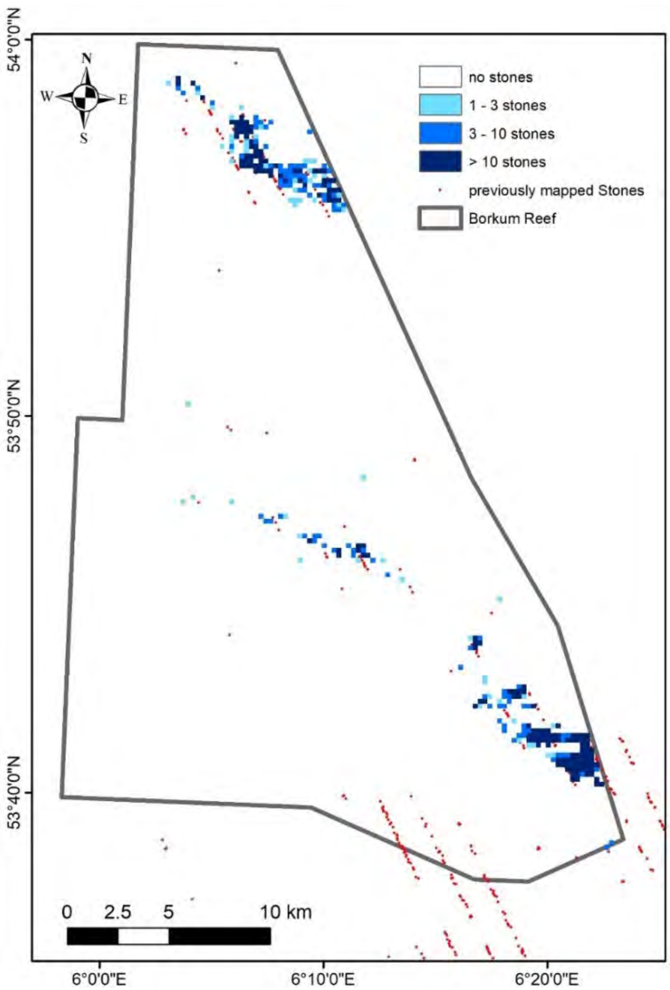

Figure 4.8: Stone coverage density map of the BRG. The classes indicate the number of stones within an area of 240 m x 240 m. The map is produced via manual selection of stones using the processed and ground projected HO data. All sonar lines displayed in Figure 2.3 were used. In addition, previously mapped possible presence of objects > 30 cm (Stones and *Lanice/Loimia* humps) are displayed as red dots. Coordinates system is ETRS 1989.

4.3 Coarse substrate maps

Comparing the MBES backscatter maps with the video recordings shows that the MBES backscatter could reliably reveal the sediment morphology and transitions from sandy sediments to coarse substrate.

Figure 4.9 demonstrates this for a sub area around a video track in survey area B where the coarse substrate (classified during the trial as mud/stone, shell/stone and gravel/stone), aligns with the high backscatter values (light colours), and the sandy sediment aligns with the low backscatter values (dark colours).

The visual inspection after the trial (see Figure 4.11) and its location plotted in Figure 4.9, confirm the capability to identify and map coarse substrate with MBES backscatter.
The k-means clustering results for the same sub area show that class 3, corresponding the highest acoustic class, corresponds very well with the coarse substrate.

The box core sample (green triangle in Figure 4.9), consisting of high amount of shells and gravel, is also located in a high value backscatter patch classified as class 3, confirming a good match.

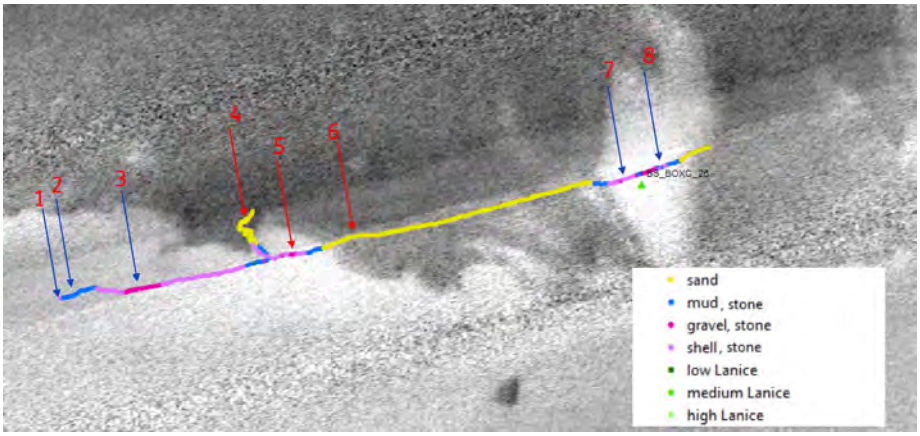

Figure 4.9: Comparison between MBES backscatter and classified video track. The light colour indicates a high backscatter and the dark colour a low backscatter. The variation in MBES backscatter matches very vell with the sediment transition from coarse substrate (shell, gravel, stone) to sand as observed in the video tracks. Examples of video footages are displayed in Figure 4.11 where the arrows indicate the location on the map (Figure 4.10). Additionally, the location of box core sample 26 is indicated by the green triangle. A picture of the sample, showing high amount of shells and gravel, is shown in Figure 3.6 (right column second picture).

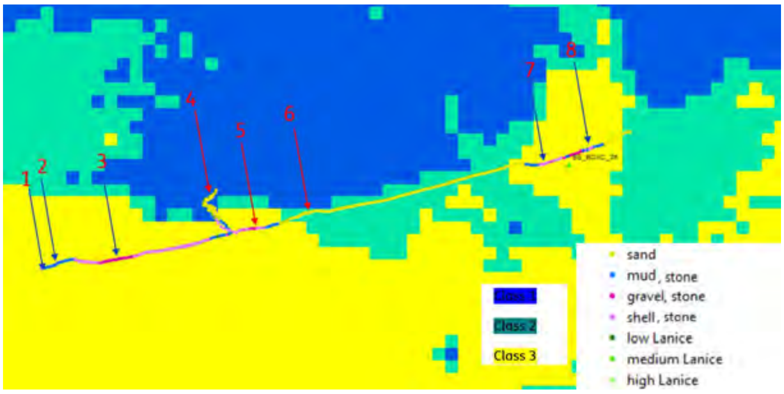

Figure 4.10: Comparison between k-means clustering results and classified video track.

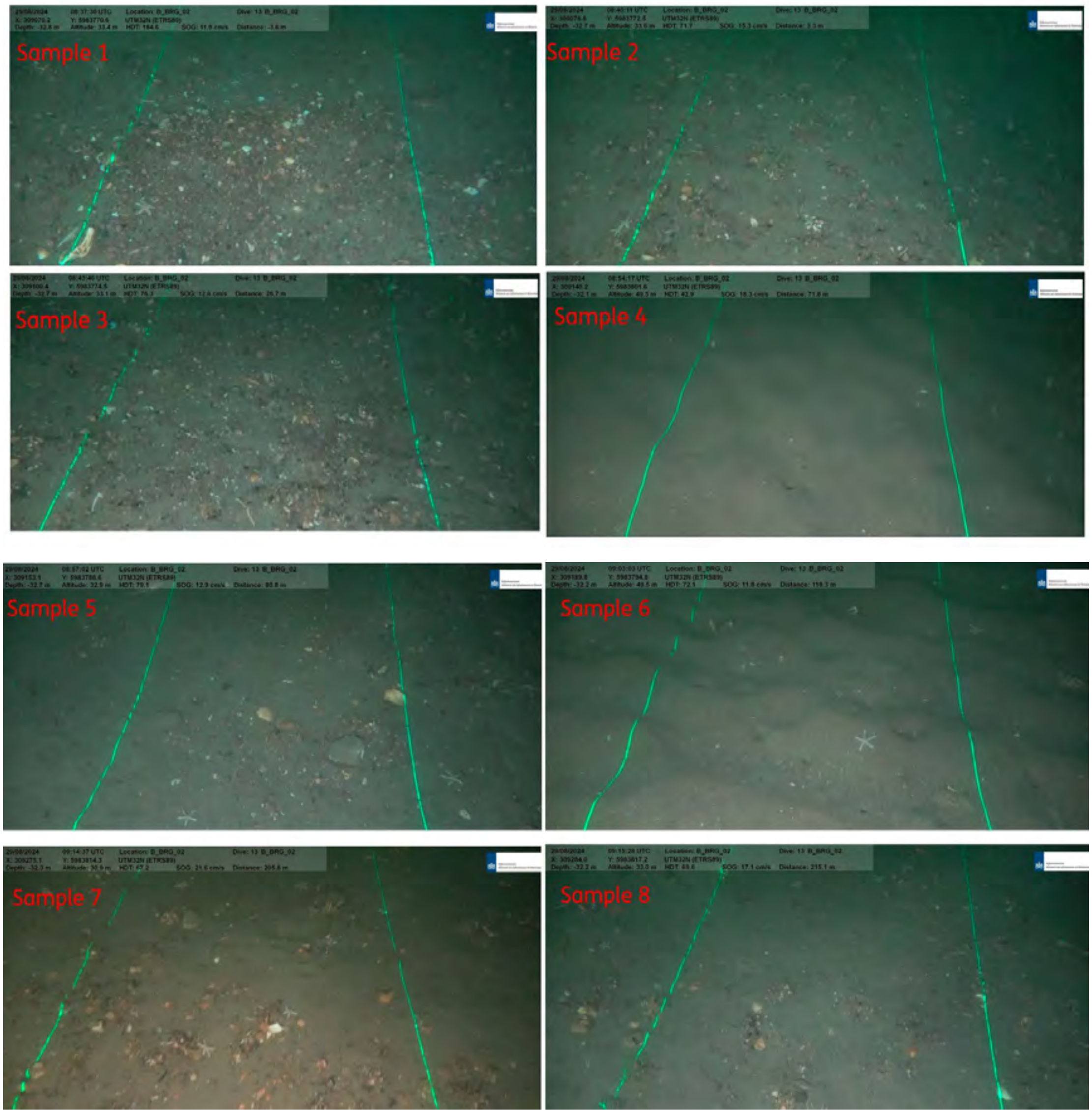

Figure 4.11: Video footages selected from video track in Area B. Sample 4 and 6 indicate a sandy seabed and the other samples a coarse substrate including gravel, shells and stones. The locations are displayed on the MBES backscatter in Figure 4.9.

A quantitative comparison between the MBES backscatter and classified video tracks shows that the MBES backscatter corresponding to the coarse substrate has a 1.5 dB higher median and around 4.5 dB higher 75th percentile than the sand class (Figure 4.12). This indicates a reasonable separation between coarse substrate and sand. The coarse substrate class comprises the mud/stone, gravel/stone and shell/stone classes.

The video classification used in this analysis was done during the trial where the main aim was not on the coarse substrate mapping. Visual inspection of the video data post-trial showed that the boundaries between sand and coarse substrate could have been drawn more accurately, which would likely have resulted in an even better quantitative separation in decibels. The final video analysis results generated by WMR where however not available on time to be included in this analysis.

For the final sediment map, acoustic class 3 was assigned to coarse substrate, class 2 to medium sand (fine sand + few shell fragments) and class 1 fine sand. A quantitative correlation of acoustic class 1 and 2 with fine and medium sand could not be established because no grain size analysis was carried out and the video footage don't clearly reveal a difference between fine and medium sand. However, visual inspection of the sediment sample indicates that the MBES backscatter shows a difference between fine and medium sand (or fine sand + shells). In addition, simulations and other field campaigns showed that fine and medium sand results in different backscatter values [11]. A corresponding spread in backscatter values is present in the MBES backscatter maps (Figure 2.2, Figure A.1, Figure A.2).

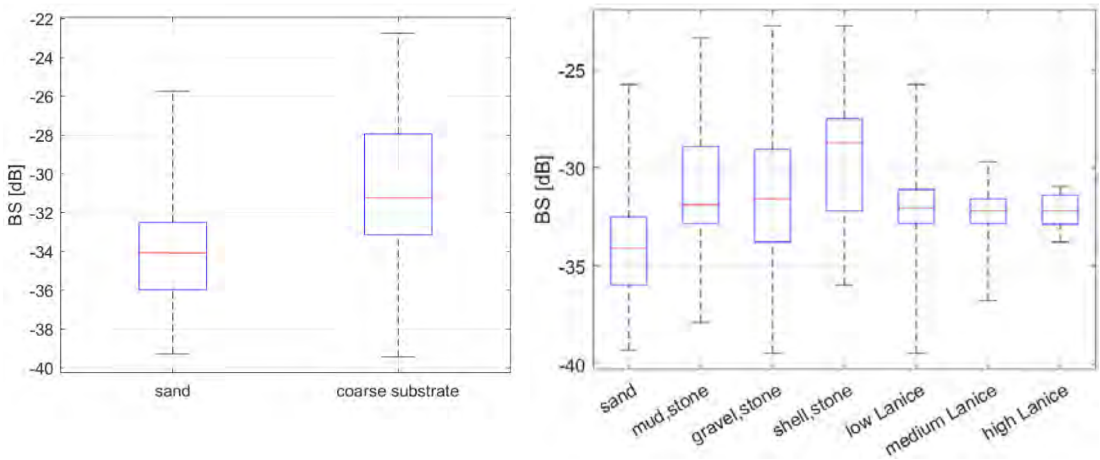

Figure 4.12: Correlation between MBES backscatter and classified video track samples. (left) Coarse substrate class comprises mud/stone, gravel/stone and shell/stone class. (right) Original classes are shown. Lanice classes are removed. Low, medium and high refers to the coverage of *Lanice/Loimia* on the seabed. The box indicates the 25th and 75th percentiles, the horizontal line within a box the median and the whiskers the maximum and minimum values.

The sediment maps, showing the distribution of coarse substrate in survey area A, B and D, are shown in Figure 4.13. The presence of coarse substrate varies significantly between the survey areas (see Table 4.2). While 50% of the seabed in survey area A is covered with coarse substrate, in Area B it is 23% and area D almost no coarse substrate is present according to the classification results. If shells, gravel or stones are the main content of the coarse substrate cannot be assessed.

Table 4.2: Percentage of presence of sediment classes in the surveyed areas.

Area ID	Fine sand	Medium sand	Coarse substrate
A	25.92%	23.82%	50.26%
B	25.27%	52.17%	22.56%
D	45.68%	53.58%	0.01%

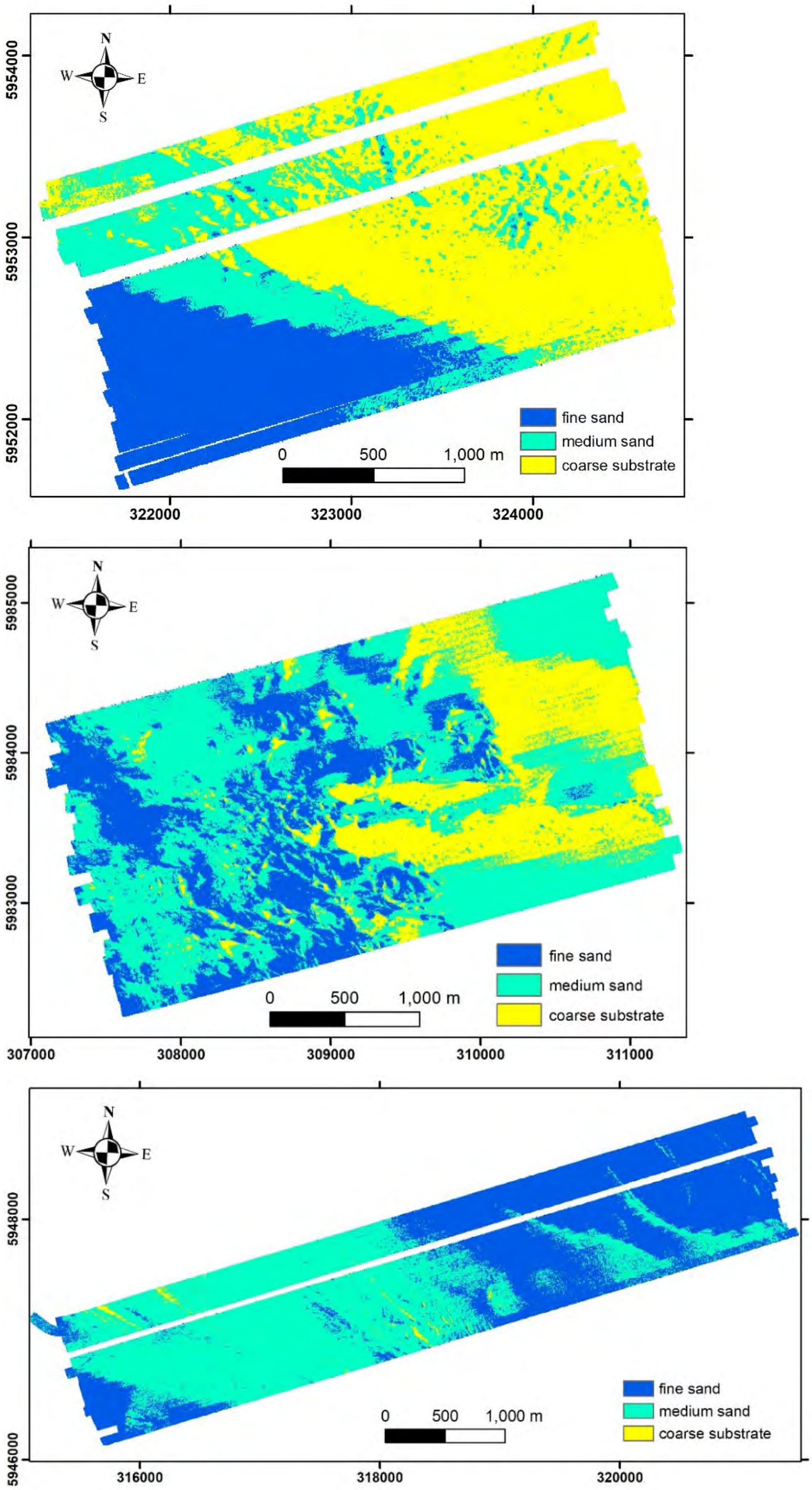

Figure 4.13: Sediment maps obtained from k-means clustering applied to the MBES backscatter. (Top) Survey area A, (middle) survey area B and (bottom) survey area D. The coordinate system is ETRS 1989 UTM 32N.

5 Conclusions

The analysis of the HO SSS and newly acquired SSS and MBES data enabled the mapping of *Lanice/Loimia* reefs (biogenic reefs), stones and coarse substrate (geogenic reefs) in the area of the BRG. A supervised machine learning classifier (SVM) was used to map the biogenic reefs, an unsupervised clustering method (k-means) was used to map the coarse substrate and stone fields were mapped manually.

The results presented in this report provide insight on:
- The past and current distribution of biogenic (*Lanice/Loimia*) and geogenic reefs (Coarse substrate and stone fields).
- The type and quality of the information that can be obtained using SSS and MBES sonars for habitat mapping, including initial insights on the possibility to monitoring changes in biogenic reef presence.
- Advice on how to best design acoustic monitoring surveys in combination with ROV video validation and box core sampling.

These results are used as input for the recommendations for the future monitoring of the BRG. A more detailed summary of the findings and recommendations that followed from this project is described in the remainder of this section, sorted per reef category.

<u>Biogenic reefs (*Lanice* and *Loimia*)</u>
The study has shown that medium to high densities of *Lanice/Loimia* reefs are detectable using SSS. A precision and sensitivity of 80.4% and 96.7% for the expedition data and 96.5% and 89.2% for the HO data was obtained, respectively. It was however also observed that detection accuracy of *Lanice/Loimia* fields decreases with the species density. It is therefore expected that using a SSS is mainly suitable for the detection of larger reefs conglomerates. The performance analysis for lower reef densities resulted in a precision of 61.7% and sensitivity of 39.6% within the expedition data. For the HO data this class was fully excluded since the acoustic pattern corresponding to low densities could not clearly be identified in the SSS images. Furthermore, investigation of the MBES data overlapping with the *Lanice/Loimia* reefs suggests that it may be secondary effects of the reef presence (mainly morphological elevations) that cause the acoustic patterns visible in the SSS data.
This further complicates the possibility to do reliable estimations of e.g. species density using SSS data. The SSS data and its classification results can be used to investigate spatial changes of *Lanice/Loimia* fields over time, as it was shown by the application of the classifier to the expedition data and the HO data.

<u>Geogenic reefs - Stone fields</u>
Elevated stones can usually be detected using SSS data except if they are masked by a complex heterogeneous seabed or if they are buried to deep (not protruding from the seabed to show up in the SSS data). The rough boundaries of the stone fields overlapped very well with previously mapped stone fields where it should be noted that Lanice humps in the southwest of the BRG that were previously incorrectly labelled as stones were now correctly discarded.

Geogenic reefs – coarse substrate
The study has shown the potential of the MBES backscatter data for the mapping of coarse substrate. A sediment map showing the distribution of coarse substrate, i.e., shells, gravel and small stones, could be generated from the MBES backscatter and its comparison with video footage and box core samples. The coarse substrate is clearly visible in the MBES backscatter and can therefore be mapped with a high confidence. A more quantitative assessment and a finer distinction of the softer sediments classes (fine and medium sand) could have potentially been made in case a grain size analysis of the box core samples was done.

Value of Hydrographic Office dataset
This project has demonstrated the potential of using SSS from the Hydrographic Office for the purpose of ecological monitoring. First of all, the data was used for the trial preparation such as the selection of suitable/prioritized survey areas. Furthermore, the data was used to map both the stone fields and *Lanice/Loimia* fields in the area. It could also show changes in biogenic reef size that took place over time.

Sonar surveying recommendations
The sonar scanning rate depends on the survey speed, maximum set range (SSS) or swath width (MBES), desired data overlap and number of turns (longer tracks result in less turn). During the project expedition, the sonar scanning rate was on average 1.4 km^2/hour.
The length of sonar tracks varied per survey area and the track spacing was optimised to have full coverage (SSS seabed coverage of 150% (Area A & B) and 207% (Area D)) for both the MBES and SSS data. More survey details can be found in Appendix A appendix.

The analysis of the HO SSS data showed that both *Lanice/Loimia* reef mapping and stone detection could be done up to a range of 100 to 125 m. This means that the max SSS range of 75 m can potentially be increased (maintaining a flying height of 10 % of the max range). In addition, the analysis of both the RWS and HO SSS data showed that the first 25 m of the SSS ground range was not usable for *Lanice/Loimia* detection. This limitation needs to be considered when planning the track line spacing.
A maximum range of 75 m and a track line spacing of 75 m would result in full coverage SSS data (covering the poor data quality gap of the first 25 m range). This choice would result in 200 % Sonar Seabed coverage (under the assumption that navigational drift of the tow fish can be neglected).

Recommendations

- To further improve the discriminative ability and performance of SSS based reef mapping, it is expected that both the sonar data quality as well as the amount of data used to train the classifier need to be improved. Another way to possibly improve the classifier performance is the inclusion of features based on other data sources such as the MBES. A challenge to overcome is the difference in geolocating accuracy of the MBES and SSS data (where the SSS location accuracy is much less than the MBES).
- To enable more accurate mapping of the coarse substrate, it is recommended to increase the amount of video and box core data used for the segmentation of the MBES backscatter data.
- While the manual picking of the stones was accurate, it was also time consuming. In case this will be a recurring activity, it may be worth to extend the classification workflow to allow for the automated detection and localisation of stones.
- Comparison of the HO and expedition data showed that for the majority of the data the quality of the images is higher for the HO data. This is not expected as (i) the HO sonar was older, the HO flying height was larger (~15 m vs. ~8 m) and the range was longer (150 vs. 75 m), it is therefore recommended to investigate the possibilities to improve the quality of SSS data acquired by RWS in the future.

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Appendix A

A.1 Survey settings project expedition

Table A.1: Vessel and general settings.

Vessel and general Settings	
Survey speed	4 to 7 knots
Heading	WSW-ENE with and against current direction
CTD	Beginning and end of night survey, following RWS experience
Coordinate system	Geographic: ETRS84, Projected: ETRS 89 UTM32N
Line spacing	100 m (Area A and B) and 70 m (Area D)

Table A.2: MBES settings.

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

Table A.3: SSS settings.

SSS Settings	
Frequency	455 kHz
Range	75 m
Flying height	Target: 7.5 (~10% of range). In practice the height varied between 7 and 12 m
Pulse type	Chirp
SSS seabed coverage	150% (Area A and B), 207% (Area D)

A.2 Expedition data

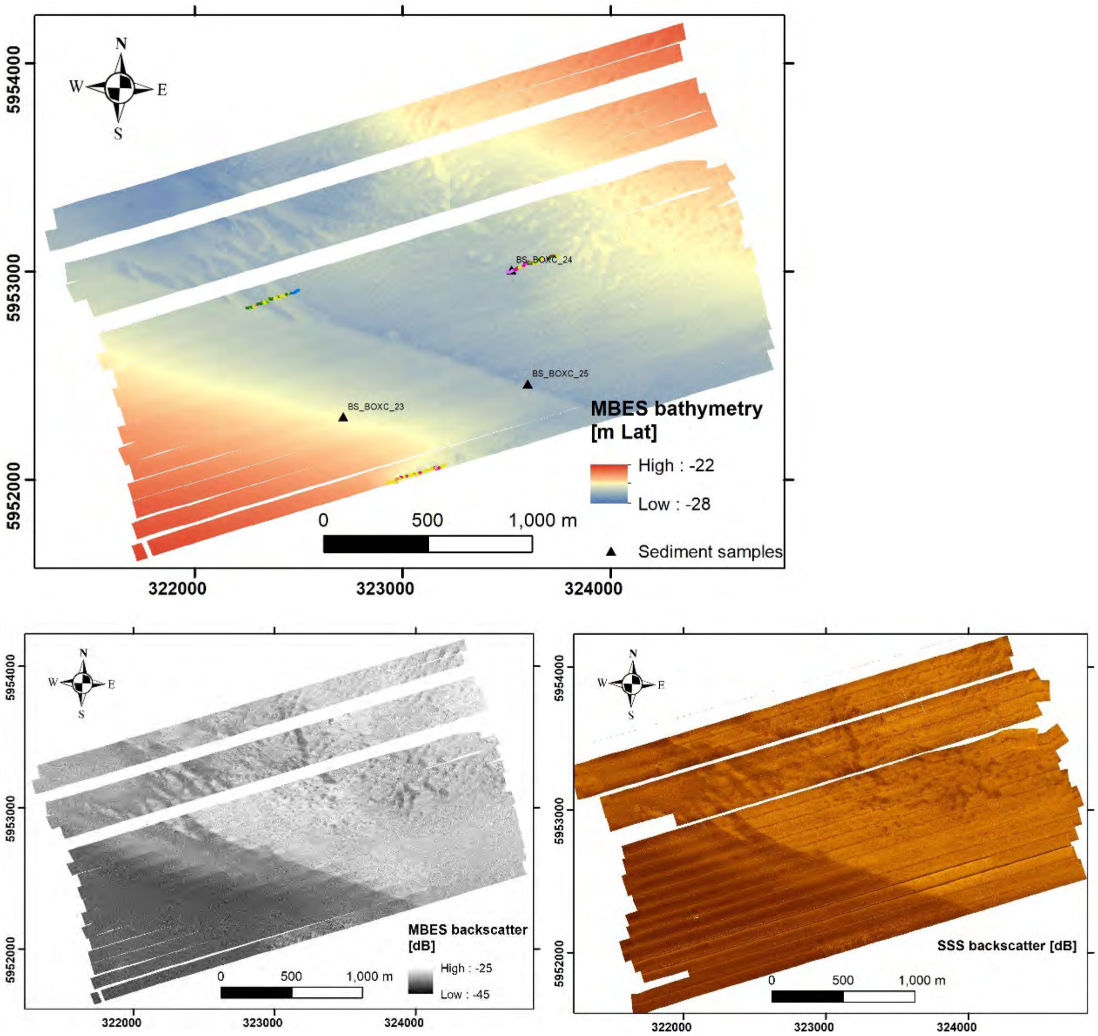

Figure A.1: Sonar data acquired in area A. (Top) MBES bathymetry including the collected video recordings and box core sediment samples, (middle-left) MBES backscatter and (middle-right) SSS backscatter. The coordinate system is ETRS 1989 UTM 32N.

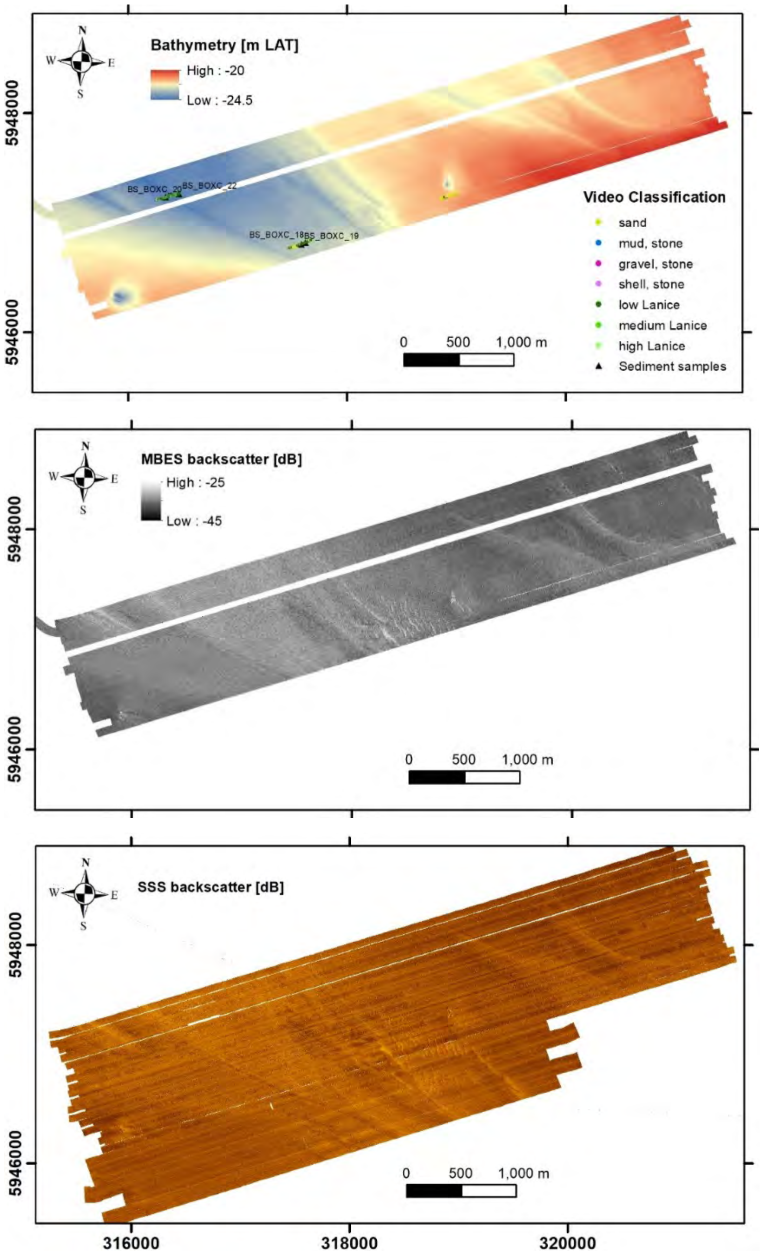

Figure A.2: Sonar data acquired in area D. (Top) MBES bathymetry including collected video recordings and box core sediment samples, (middle) MBES backscatter and (right) SSS backscatter. The coordinate system is ETRS 1989 UTM 32N.

A.3 Example poor quality SSS data

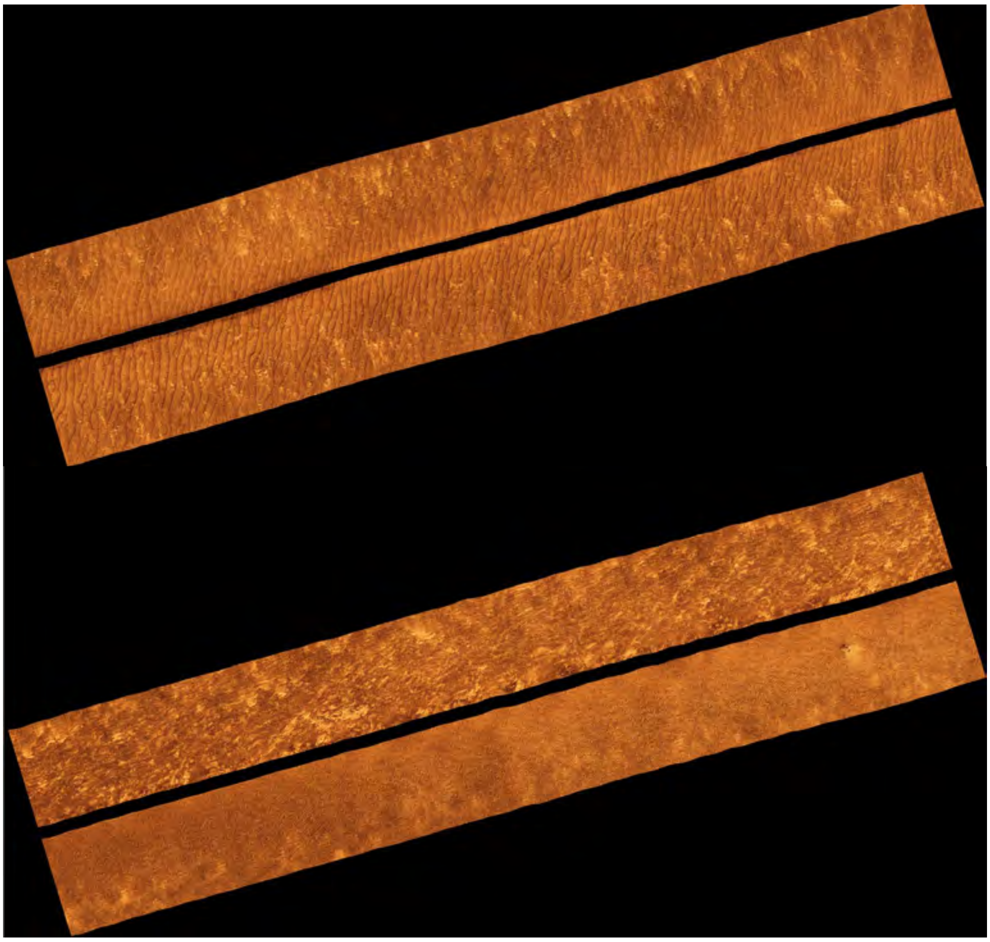

Figure A.3: Processed and georeferenced SSS images obtained from the HO dataset. The two SSS images provide an example of noisy data, which was removed from the SVM classification. (Top) Starboard and portside show artifacts for instance caused by water bubbles or strong movement of the sonar. (Bottom) Only one side is affected by very strong artifacts. Motion data analysis (not shown here) shows a strong tilt of the Sonar.

A.4 Classification for *Lanice/Loimia* reefs

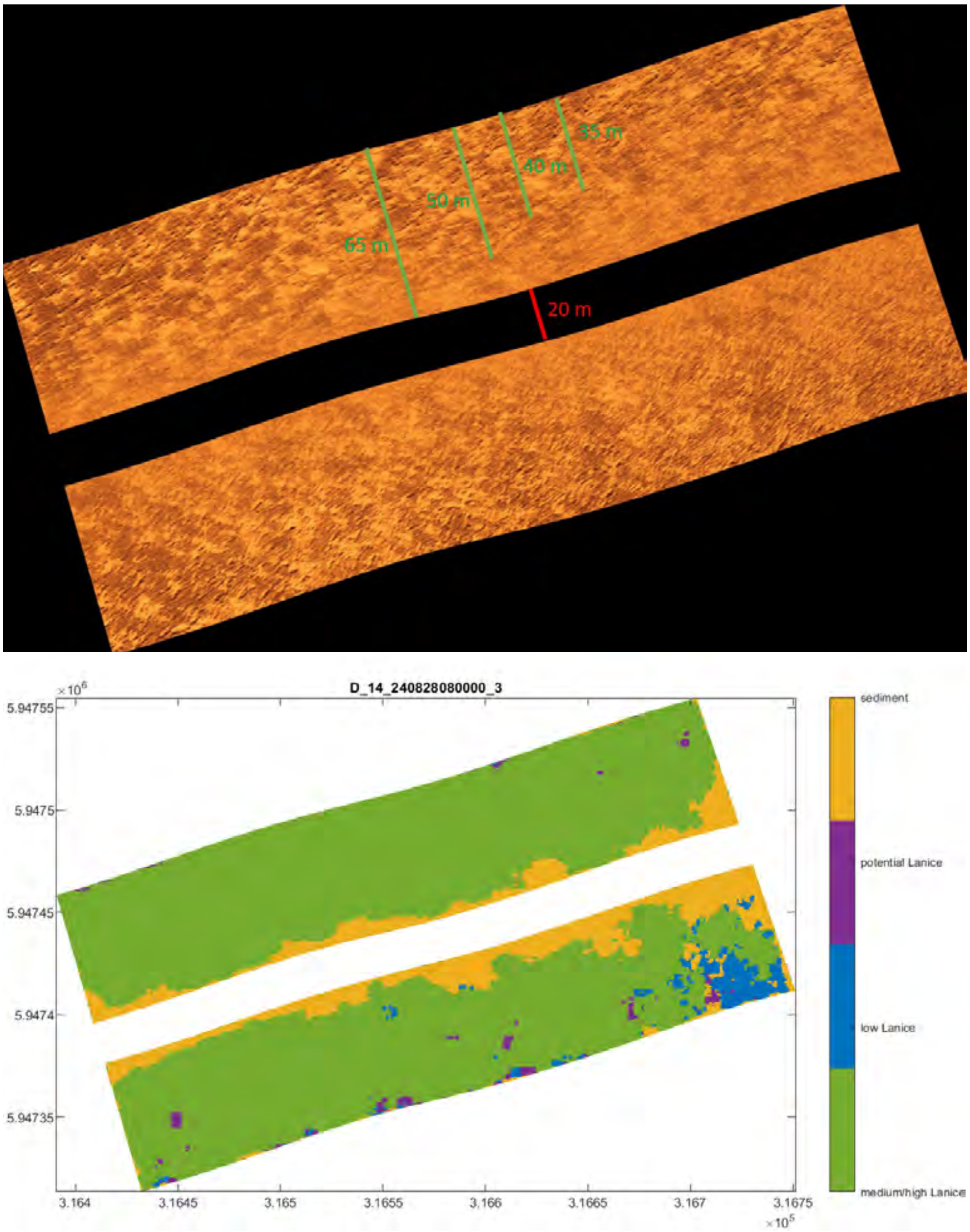

Figure A.4: SVM classification of expedition data. (Top) Processed, ground projected and georeferenced SSS image. Red line of 20 m (covering black region between sonar data on both sides) shows the removed nadir region. The 65 m green line shows the remaining data per side after nadir removal (total ground range 75 m per side). (Bottom) Classified image showing mainly medium to high coverage of *Lanice/Loimia reefs*. Area classified as sediment (yellow pixels) at short ground range was removed in post processing (< 25 m ground range removal, see 50 m green line for remaining data used to produce the Lanice/Loimia reef maps). The coordinate system is ETRS 1989 UTM 32N.

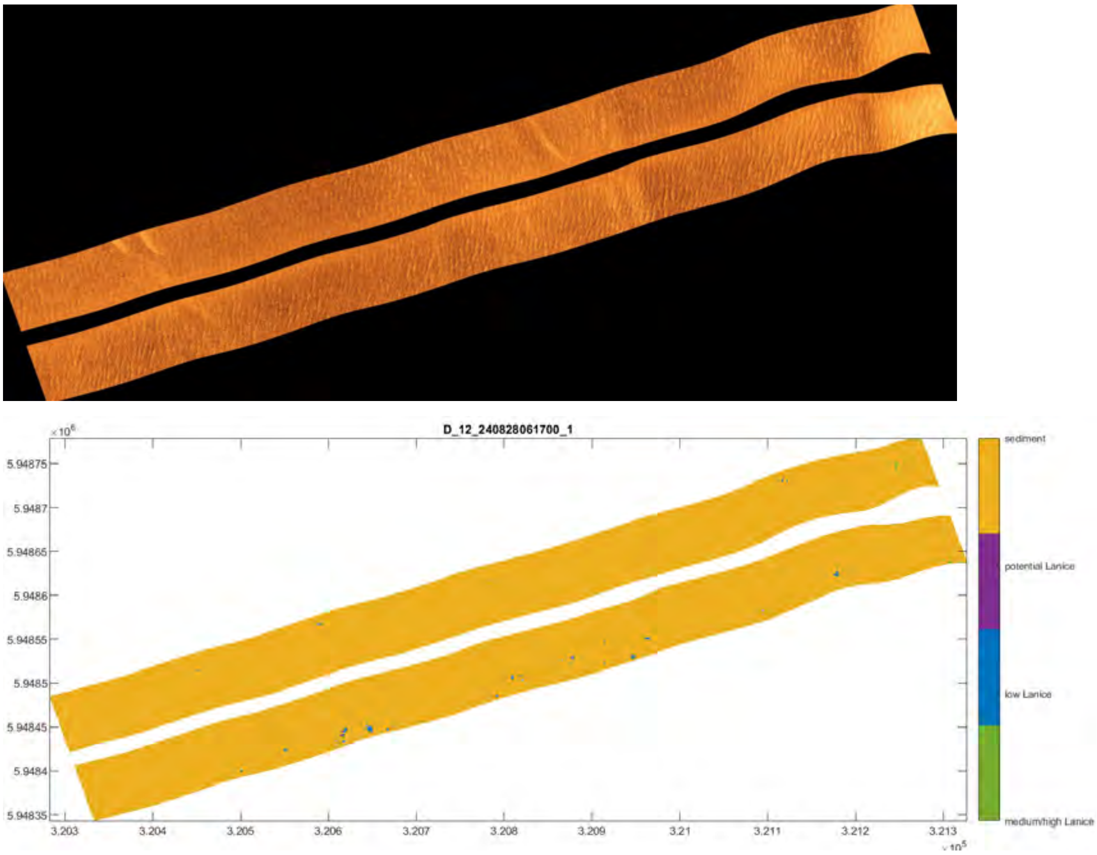

Figure A.5: SVM classification of expedition data. (Top) Processed, ground projected and georeferenced SSS image indicating an area of megaripples (Bottom) Classified image showing only sediment and no presence of Lanice (yellow pixels). The coordinate system is ETRS89 UTM 32N.

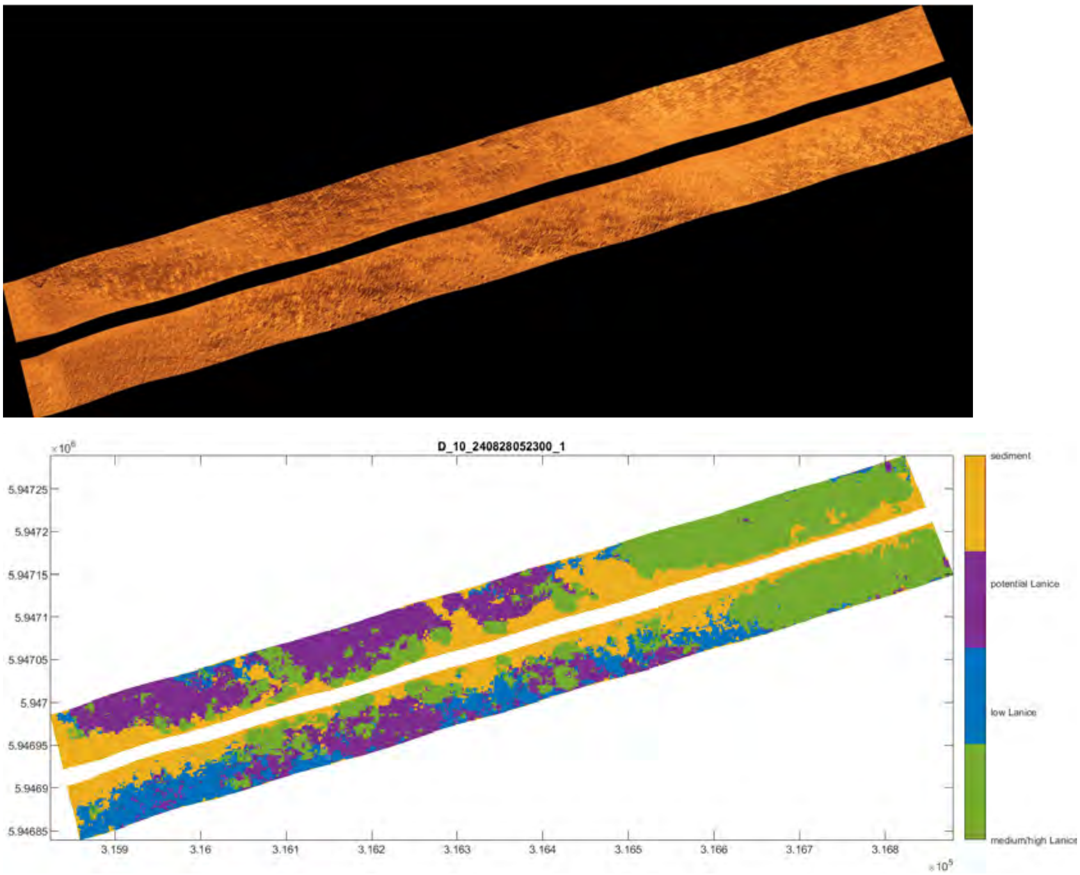

Figure A.6: SVM classification of expedition data. (left) Processed, ground projected and georeferenced SSS image indicating a heterogeneous seabed with diverse acoustic patten (right) Classified image showing in the east medium to high coverage of *Lanice/Loimia*, towards the west patterns of low *Lanice/Loimia* coverage mixed with potential presence of *Lanice/Loimia.* The coordinate system is ETRS 1989 UTM 32N.

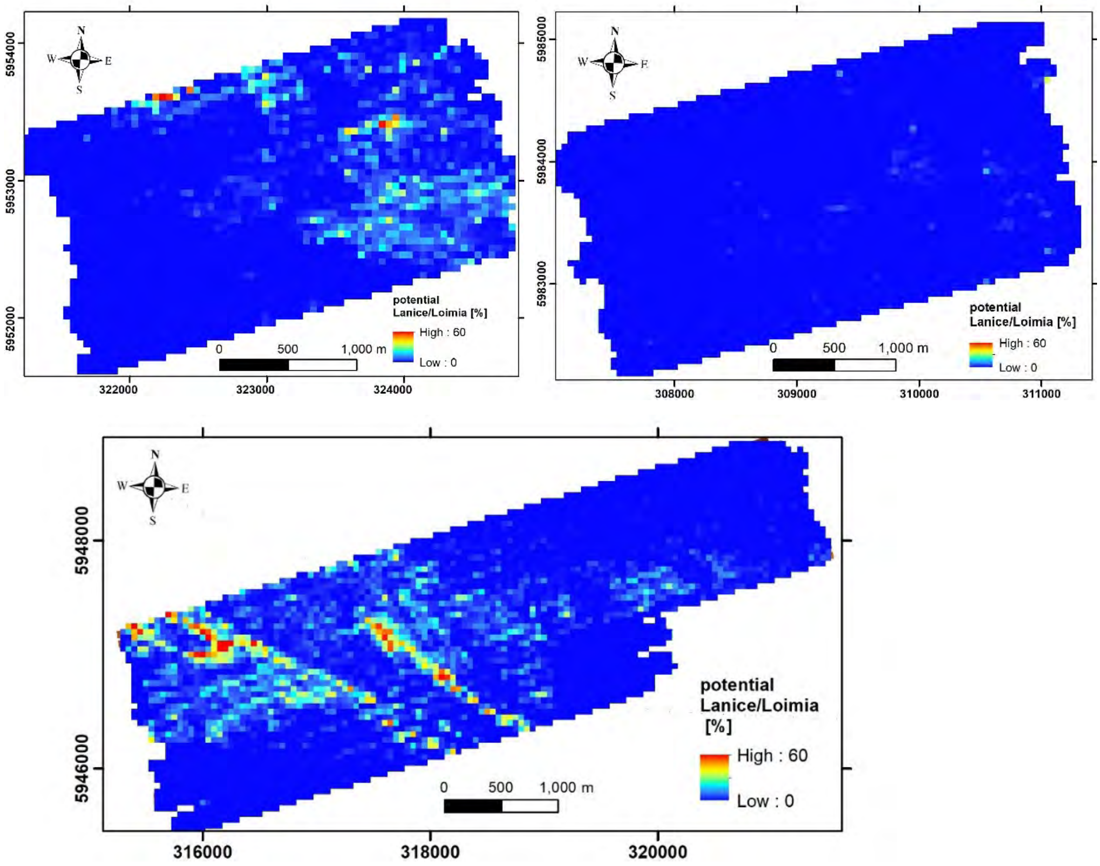

Figure A.7: Potential *Lanice/Loimia* coverage map of (top left) survey area A, (top right) survey area B and (bottom) survey area D. Obtained from application of trained SVM classifier to expedition data. The total coverage is 2.4%, 0.1% and 3.9% for area A, B and D, respectively. The coordinate system is ETRS 1989 UTM 32N.

A.5 Stone density map example

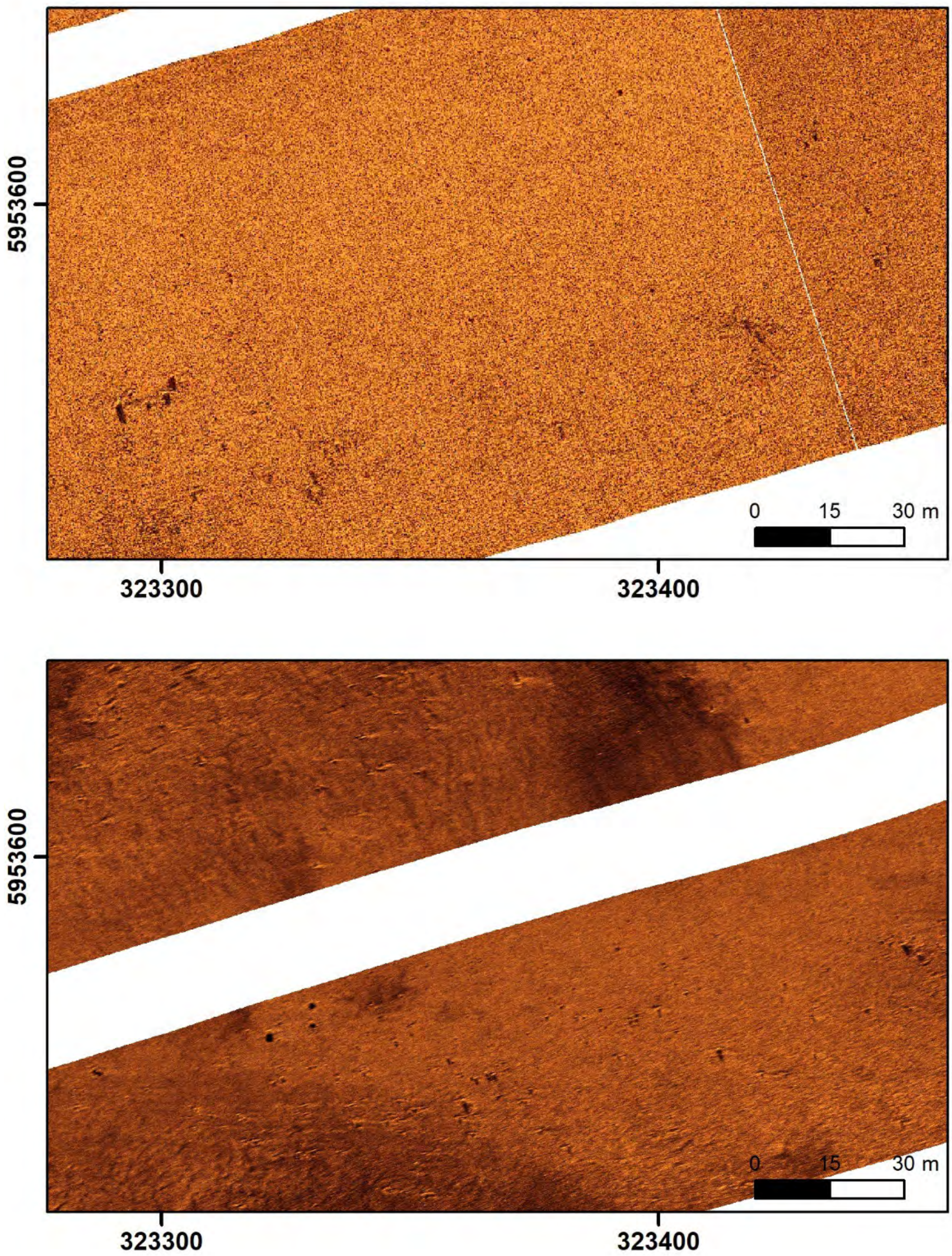

Figure A.8: Stone field in the south-east of the BRG. (bottom) HO data from 2013 and (top) expedition data from 2014.

Annex B Onderzoeksplan ontbrekende gegevens

Onderzoeksplan Borkumse Stenen gericht op inwinning van ontbrekende gegevens

Ten behoeve van uitwerking meerjarig monitoringprogramma Borkumse Stenen als onderdeel van MONS project ID49 Effectiviteit gesloten gebieden

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Achtergrond

In het Nederlandse deel van de Noordzee liggen bodembeschermingsgebieden die zijn aangewezen onder de Habitatrichtlijn of de Kaderrichtlijn Mariene Strategie (KRM). In deze gebieden wordt in het kader van het MONS-programma[4] onderzoek gedaan naar de effectiviteit van het sluiten van gebieden voor bodemberoerende visserij ten behoeve van het verbeteren en uiteindelijk bereiken van een goede kwaliteitstoestand van de benthische habitats. Eén van de gebieden die sinds 2022 onder de KRM is beschermd (Mariene Strategie deel 3[5]) en die naar verwachting begin 2025 wordt gesloten voor bodemberoerende visserij conform het Noordzeeakkoord NZA[6], is het gebied van de Borkumse Stenen. Om de effectiviteit van de maatregel over een langere periode te kunnen evalueren, is het essentieel dat (1) een specifieke monitoringstrategie wordt ontwikkeld en (2) een initiële nulmeting wordt uitgevoerd, die zodoende nog begin 2025 dient te worden uitgevoerd. Op dit moment is er echter onvoldoende informatie beschikbaar over de bodemgemeenschap van de Borkumse Stenen om een onderbouwde keuze te kunnen maken voor een langlopend monitoringprogramma en de inhoud van de nulmeting. Zodoende is geïnventariseerd wat er aan informatie met betrekking tot de benthische habitats en hun ligging en de samenstelling van de bodemgemeenschappen in het bijzonder voor de Borkumse Stenen en vergelijkbaar habitat in de directe omgeving (waaronder het Duitse deel van de Borkumse Stenen) beschikbaar is; zie overzicht beschikbare informatie 'Bos et al., 2024'. In het huidige onderzoeksplan wordt uiteengezet welke informatie ontbreekt en nog dient te worden ingewonnen tijdens een campagne (vaartocht) eind Augustus 2024 (week 35) zodat een onderbouwd langjarig monitoringplan inclusief plan voor de initiële nulmeting kan worden uitgewerkt.

[4] Monitoring en Onderzoek Natuurversterking en Soortenbescherming; MONS-programma.
[5] Mariene Strategie deel 3, 2022-2027; De Mariene Strategie deel 3 -tweede termijn.
[6] Het Akkoord voor de Noordzee (2020); Noordzeeakkoord.

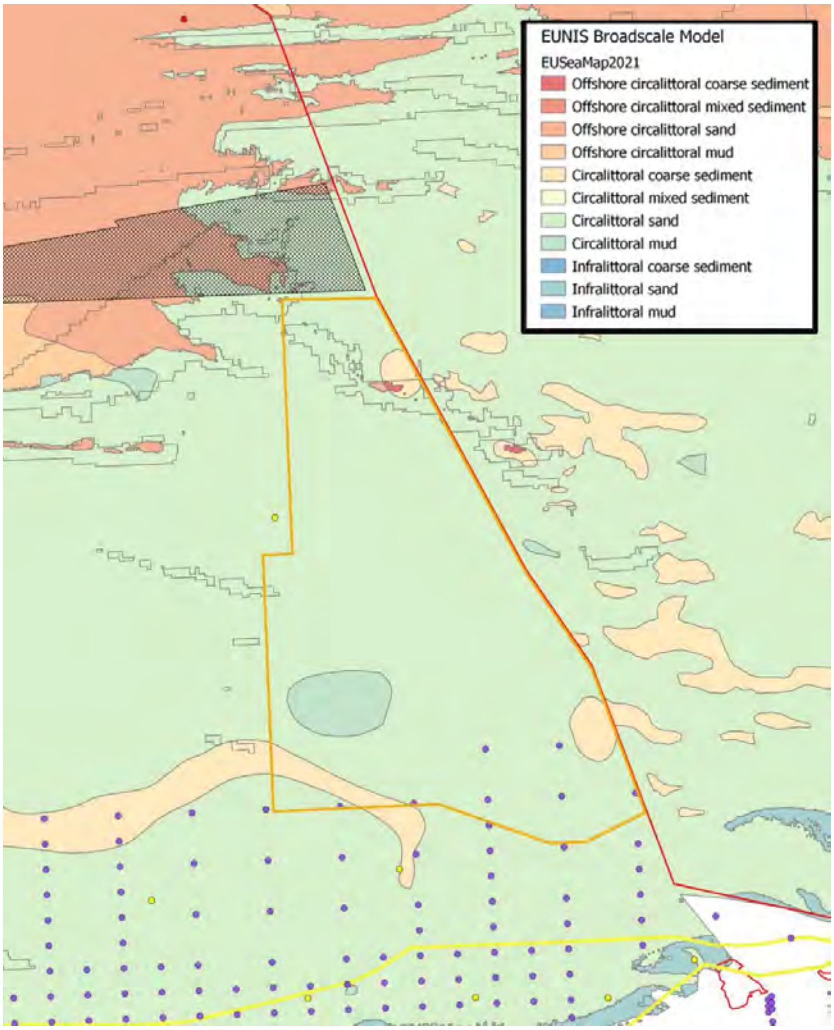
Beschikbare en benodigde informatie

Het uiteindelijke doel van het meerjarige monitoringplan "Borkumse Stenen' is het verschaffen van de benodigde data om de kwaliteitstoestand en -ontwikkeling van de benthische habitats en specifiek de effectiviteit van maatregelen (van gebiedssluiting voor bodemberoerende visserij) te kunnen beoordelen. Indirect dient de informatie daarmee potentieel bij te dragen aan KRM beoordelingen (EU KRM Artikel 8 rapportage) en daarmee de actualisatie van de Mariene Strategie deel 1, en daar waar relevant bruikbaar te zijn voor Habitatrichtlijn beoordelingen (Habitatrichtlijn Artikel 17 rapportage) en beoordelingen in het kader van OSPAR ('Quality Status Reviews' en 'Intermediate Assessments').
Specifiek betekent dit dat inzicht dient te worden verkregen in:

- samenstelling en ontwikkeling (oppervlak en ruimtelijke constitutie),
- en kwaliteit (op basis van kwaliteitskenmerken en samenstelling benthische gemeenschappen),

van aanwezige habitattypes. Meer bepaald betreft het de:

- aanwezige brede habitattypes (EU MSFD Broad Habitat Types),
- en specifieke habitattypes (van belang als kwaliteitskenmerken onder de KRM, kwalificerend als habitattype onder de Habitatrichtlijn en/of aangemerkt als bedreigd of beschermd habitattype (Threatened & Declining Habitats) onder OSPAR, zodoende ook weer terugkomend als 'Other Habitat Type' onder de KRM en daarmee de focus van de Natuurherstelwet (EU Nature Restoration Law).



Figuur B1. Borkumse Stenen met onderverdeling in Brede Habitattypes (EUSeaMap 2021) en indicatie benthos meetlocaties situatie 2023 met WOT bodemschaaf meetlocaties (in paars) en KRM boxcorer meetlocaties (in geel). Het gearceerde gebied betreft het zoekgebied 'Ten Noorden van de Wadden' waarbinnen de Gemini windmolenparken liggen, de rode lijn betreft de begrenzing van het Nederlandse deel van de Noordzee en de gele lijn de begrenzing van het HR-gebied Noordzeekustzone.

KRM brede habitattypes:

Voor wat betreft de brede habitattypes wordt ervan uitgegaan dat de modellering van EMODnet in de vorm van de 'EU MSFD Broad Habitat Type' kaart (EUSeaMap 2021) een redelijk betrouwbaar beeld geeft. Het betreft een modellering, dus net als voor andere delen van het Nederlandse deel van de Noordzee (en de Europese mariene wateren in het algemeen) is validatie van de kartering waardevol en de kartering onderhevig aan updates op basis van nieuwe inzichten. Gedetailleerde validatie van brede habitattypes binnen het gebied van de Borkumse Stenen is niet direct onderwerp van het huidige onderzoek (maar verkregen informatie met betrekking tot sediment samenstelling/classificatie is waardevol voor validatie en kan worden gedeeld met EMODnet). Er worden (nu en in de toekomst) geen substantiële veranderingen in de habitatsamenstelling van de Borkumse Stenen op het niveau van brede habitattypes verwacht, tenzij er duidelijke aanwijzingen zijn voor activiteiten of aanleg structuren die leiden tot een overgang van de de ene brede habitatklasse in de andere; gedefinieerd als habitatverlies[7]. Te denken valt aan aanleg van kabels of plaatsing platforms en windmolens, waarvoor nu gestandaardiseerde impactgebieden in beoordelingen worden aangehouden. Op het moment dat dit speelt zou dit onderwerp moeten zijn van effectstudie, maar op dit moment geen reden voor aanpassing van de huidige brede habitatkartering of nader onderzoek in deze fase.

De kwaliteitstoestand van ieder van de brede habitattypes dient op landelijk niveau te worden beoordeeld. Specifiek voor een gebied als de Borkumse Stenen is het dan niet noodzakelijk om ieder van de afzonderlijke brede habitattypen op gebiedsniveau te kunnen beoordelen, maar volstaat een representatieve monitoring die voorziet in de kwaliteitsbeoordeling van het gebied als geheel en daarmee de dominante brede habitattypen in het bijzonder. Figuur 1 laat zien dat de Borkumse Stenen voornamelijk bestaan uit 'Circalitoraal zandig habitat' (93%) en in mindere mate de aanwezigheid van 'Circalitoraal slibrijk habitat' (4%) en 'Circalitoraal grof sediment habitat' (3%). Andere habitattypen (offshore varianten van zandig en grof sediment habitat) betreffen ieder slechts 0,2% van het oppervlak en zullen nauwelijks dieper gelegen zijn dan het circalitorale habitat in de nabijheid. Er is een beperkt aantal bodemschaafmeetlocaties gelegen in het gebied van de Borkumse Stenen aan de zuidkant, die de afgelopen 10 jaar (en vaak al langer en wellicht ook de komende jaren) vrijwel allemaal jaarlijks zijn bemonsterd. Er zijn enkele boxcorer meetlocaties gelegen in de nabijheid van de Borkumse Stenen die sinds 2012 om de 3 jaar worden bemonsterd (voor die tijd jaarlijks tussen 1995-2010).

Voor de analyse/beoordeling van de kwaliteitstoestand van het gebied van de Borkumse Stenen (samengesteld op basis van brede habitattypes) wordt (zoals gevraagd) aangesloten bij de systematiek van het kunnen beoordelen op basis van het voorkomen van ten minste enkele gebieds- en/of (circalitoraal zandig) habitat-specifieke indicatorsoorten en de gecombineerde indicatorsoortengemeenschap op basis van de Benthische Indicator Soorten Index (BISI) (o.a. Wijnhoven, 2022). De verwachting is dat de samenstelling (qua habitats en indicatorgemeenschappen) redelijk vergelijkbaar is met de situatie rond de zandige delen van de (ook in 2025) te sluiten delen ten zuiden van het Friese Front (waarvan een deel sinds 2023 al gesloten is). De habitatvariatie is daar net iets groter en omvat ook dieper gelegen delen, terwijl 'Circalitoraal zand', met een voorkomen van 66%, iets minder dominant aanwezig is. De verwachting is dan ook dat het voor dat gebied begrootte aantal van 14 boxcorer en/of 21 bodemschaafmonsters, eerder de bovengrens aangeeft van wat op de Borkumse Stenen nodig zou kunnen zijn voor kwaliteitsbeoordeling van het gehele gebied. Er wordt voorgesteld om met behulp van een multivariate analyse te bepalen in hoeverre overwegend circalitoraal zandige monsters (eventueel aangevuld met iets slibrijkere en iets grovere monsters) uit de omgeving van de Borkumse Stenen (en enkele boxcores van de survey uit 2013 gelegen net binnen en ten zuiden van de Borkumse Stenen; Bos et al., 2014), van rond het zandige deel van het Friese Front en van het Duitse deel van de Borkumse Stenen, zich tot elkaar verhouden. Een selectie aan monsters met iets meer variatie dan voor een beperkt aantal monsters uit de directe nabijheid van de Borkumse Stenen, kan een goede indicatie zijn van de te verwachten gemeenschappen en dienstdoen voor een gedetailleerdere afleiding van het benodigde aantal monsters door middel van een 'power analyse' voor het langjarige meetprogramma. Te zijner tijd kan dan een besluit worden genomen over de inzet van enkel de boxcorer (of ook in combinatie met de bodemschaaf) en/of ook een Before-After-Control-Impact (BACI)

[7] Onder de KRM is habitatverlies (op het niveau van 'EU MSFD Broad Habitat Type') gedefinieerd als verandering van breed habitattype (onder invloed van menselijke activiteiten en/of aanleg structuren op de zeebodem); European Commission, 2022. MSFD CIS Guidance Document No. 19, Article 8 MSFD, May 2022.

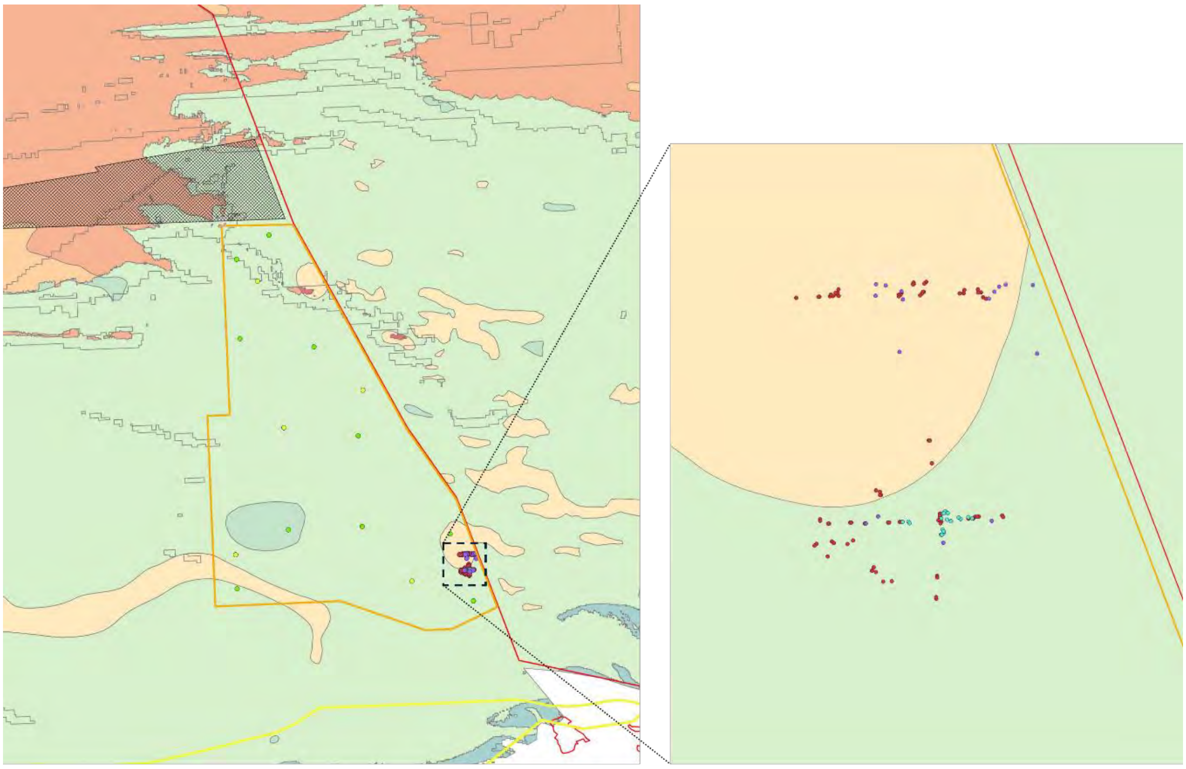
opzet wordt aangehouden. Een BACI opzet zal vragen om eenzelfde aantal extra monsters in de (niet gesloten) omgeving van de Borkumse Stenen (bij goede vergelijkbaarheid op basis van de multivariate analyse kunnen daar mogelijk ook nog enkele bestaande meetlocaties uit de omgeving of nabij het Friese Front voor worden ingezet). Om een goede analyse (multivariate en power berekening) mogelijk te maken is het nodig enkele (representatieve) boxcorer monsters van de Borkumse Stenen te nemen en deels volledig uit te werken op het lab. Door omzetting van de resultaten van in detail uitgewerkte monsters naar grof uitgewerkte monsters, kan een inschatting worden gemaakt van de aanwezige variatie in het gebied van de Borkumse Stenen. Deze variatie kan vervolgens worden meegewogen in de bepaling van de representativiteit (en selectie) van monsters van elders op basis waarvan de benodigde monitoringinspanningen van het langjarige monitoringvoorstel wordt bepaald. Op basis van de representativiteitsbepaling van boxcorer monsters, kan de representativiteit van bodemschaafmonsters uit dezelfde gebieden worden afgeleid (indien inzet van bodemschaaf voor langdurige monitoring wordt overwogen).

- ☐ 15 'random' boxcorer monsters van zacht substraat habitat waarvan
  - o 10 grof uitgewerkt aan boord (registratie voorkomen op zicht te onderscheiden taxa volgens RWSV voorschrift 913.00.B080 'bodemschaaf'[8])
  - o en 5 gedetailleerd uitgezocht op het laboratory (volgens RWSV voorschrift 913.00.B200 'boxcorer'[9]).

Tabel B1. Overzicht voorgestelde meetlocaties voor bemonstering met boxcorer ten behoeve van afleiding bemonsteringsinspanning beoordeling zacht substraat habitats.

Monstercode	Bemonsterings-techniek	Uitwerking	EPSG:4258-x	EPSG:4258-y
BS_BOXC_01	boxcorer	Lab-analyse	6,05000	53,95000
BS_BOXC_02	boxcorer	Lab-analyse	6,20000	53,85000
BS_BOXC_03	boxcorer	Lab-analyse	6,00000	53,71000
BS_BOXC_04	boxcorer	Lab-analyse	6,26000	53,68000
BS_BOXC_05	boxcorer	Lab-analyse	6,08000	53,82000
BS_BOXC_06	boxcorer	Aan boord uitzoeken	6,02000	53,97000
BS_BOXC_07	boxcorer	Aan boord uitzoeken	6,32000	53,72000
BS_BOXC_08	boxcorer	Aan boord uitzoeken	6,19000	53,81000
BS_BOXC_09	boxcorer	Aan boord uitzoeken	6,02000	53,90000
BS_BOXC_10	boxcorer	Aan boord uitzoeken	6,08000	53,73000
BS_BOXC_11	boxcorer	Aan boord uitzoeken	6,00000	53,68000
BS_BOXC_12	boxcorer	Aan boord uitzoeken	6,19000	53,73000
BS_BOXC_13	boxcorer	Aan boord uitzoeken	6,13000	53,89000
BS_BOXC_14	boxcorer	Aan boord uitzoeken	6,35000	53,66000
BS_BOXC_15	boxcorer	Aan boord uitzoeken	6,07000	53,99000

[8] RWSV 913.00.B080 Bemonstering en analyse van macrozoöbenthos met behulp van de bodemschaaf (V2; 11-10-2018).
[9] RWSV 913.00.B200 Bemonstering van macrozoöbenthos en sediment in het litoraal en sublitoraal in mariene wateren. Methode: Reineck boxcorer, Van Veen happer, Hamon happer, Vacuüm steekbuis, Steekbuis. (v7; xx-11-2017).



Figuur B2. Positionering van de geplande boxcorer meetlocaties (zacht substraat) op de Borkumse Stenen met onderscheid uit te zoeken op het lab (geel) en aan boord (lichtgroen). Tevens zijn de locaties weergegeven die in het kader van Revifes project zijn bemonsterd met boxcorer (donkerrood), Hamon happer (lichtblauw) en video (donkerblauw); zie tevens detail.

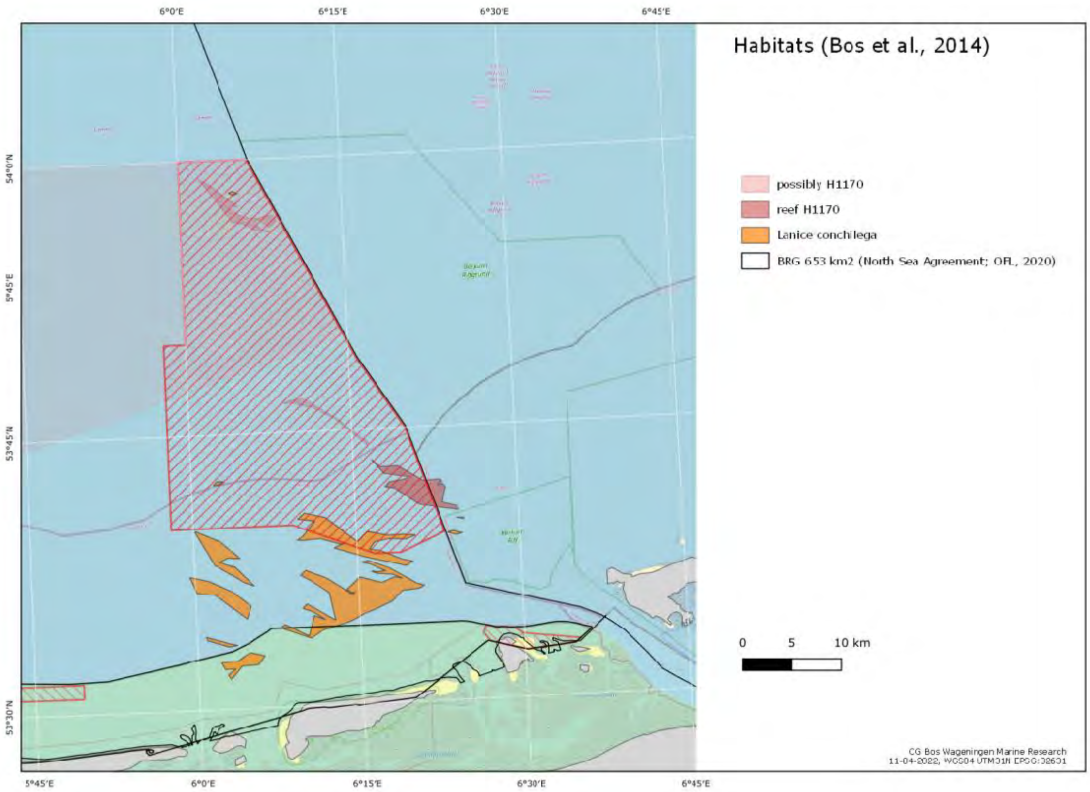
Biogene riffen (*Lanice*-velden):

Ondanks dat er discussie is over mogelijke tijdelijkheid dan wel in potentie permanente aanwezigheid (op vaste locaties) van *Lanice conchilega* velden onder goede kwaliteitsomstandigheden, is het duidelijk dat de kokerworm-aggregaties zorgen voor een toename in sedimentatie en verhoging en tertiaire verrijking van de zeebodem (Rabaut et al., 2009). Daarnaast leidt de aanwezigheid van de kokerworm-aggregaties (ten minste tot bepaalde hoge dichtheden) tot een duidelijke toename in soortenrijkdom, diversiteit en totale dichtheden van de geassocieerde benthische fauna (Van Hoey et al., 2008). Daarmee kunnen de gemeenschappen als biogene riffen worden beschouwd. Los ervan of *Lanice*-riffen uiteindelijk om een aparte kwaliteitsbeoordeling onder de KRM of OSPAR vragen, is het duidelijk dat het belangrijke kwaliteitselementen zijn van zacht substraat habitats, die in potentie te lijden kunnen hebben onder verstorende activiteiten als bodemberoerende visserij. De duidelijke/gekende aanwezigheid van *Lanice*-riffen in het gebied van de Borkumse Stenen, de huidige maatregelen van sluiting van het gebied voor bodemberoerende visserij, en de onzekerheid over effecten van dergelijke maatregelen op de ontwikkeling in oppervlak en kwaliteit van de riffen, maakt dat de Borkumse Stenen een goede 'test case' is om de ontwikkelingen te monitoren en te analyseren. Daar komt bij dat het op dit moment nog onduidelijk is in welke mate de ontwikkeling, zowel kwantitatief als kwalitatief, van *Lanice*-riffen (grootschalig) te monitoren is, en er nog geen vastgestelde methodiek ligt hoe de kwaliteit van *Lanice*-riffen te beoordelen. De Borkumse Stenen is door de relatief grote maar nog te 'behappen' omvang een goede onderzoekslocatie om te onderzoeken of en hoe de kwaliteitsontwikkeling van *Lanice*-riffen direct of indirect kan worden meegewogen in grootschalige kwaliteitsbeoordelingen.

Het huidige onderzoek dient inzicht te geven in welke mate de voorgestelde monitoringtechnieken inzicht kunnen geven in ruimtelijke en kwaliteitsontwikkeling van *Lanice*-velden. Het is in deze fase niet noodzakelijk om tot een oppervlakte bepaling te komen, maar wel dient duidelijk te worden in welke delen de riffen aanwezig zijn of kunnen zijn, wat de oppervlaktes zijn die kunnen worden gescand op de aanwezigheid van *Lanice*-riffen en in welke mate de verkregen informatie inzicht in de ruimtelijke patronen en/of kwaliteitskenmerken van *Lanice*-riffen oplevert.

Bos et al. (2024) presenteren een kaart waarin de op basis van Side Scan Sonar (SSS) inventarisaties in 2009 en met observaties (boxcores, video en/of duiker) gevalideerde gebieden met veronderstelde aanwezigheid van *Lanice*-riffen zijn aangegeven (met het voorbehoud dat het Noordelijke deel vrijwel niet is onderzocht) (Figuur 3). Daarnaast blijkt dat *Lanice*-riffen ook veelvuldig voorkomen in de in het verleden als H1170 aangeduide gebieden en een belangrijk habitat(sub)type zijn tussen de stenen kemerkend voor H1170. In de praktijk bleek een deel van de op basis van Side Scan Sonar gedetecteerde 'verhogingen' op de zeebodem geen stenen te betreffen, maar juist kokerworm-aggregaties.

Voorafgaand aan en bij aanvang van de vaartocht (op de heenweg) worden de historische Side Scan Sonar data, die opnieuw zijn geanalyseerd, bekeken, om na te gaan of er mogelijk indicaties zijn van de aanwezigheid van *Lanice*-riffen (of stenen of grind), zodat tijdens de vaartocht, de meest belovende gebieden kunnen worden opgezocht.



Figuur B3. Borkumse Stenen met indicatie van verwachte aanwezigheid Lanice-riffen en verwachte aanwezigheid van potentieel H1170 habitat (biogeen rif) op basis van inventarisaties in 2013 zoals beschreven in Bos et al. (2014).

In eerste instantie zal de focus van het onderzoek liggen op het gebied aan de zuidoost kant van de Borkumse Stenen, tegen de grens met Duitsland. Dit omdat daar de kans het grootste is dat zowel *Lanice*-riffen als biogene riffen zullen worden aangetroffen, zodat voorgestelde monitoringstechnieken kunnen worden toegepast, er kan worden bepaald of verschillende typen en kwaliteitstoestand kunnen worden onderscheiden en zodoende de toepassing van Side Scan Sonar (eventueel in combinatie met Multi-beam) kan worden gevalideerd. Specifiek voor *Lanice*-riffen kan indien nodig ook de zuidrand van het gebied van de Borkumse Stenen worden bezocht, om riffen met verschillende kokerworm dichtheden te treffen. In eerste instantie wordt gezocht naar een gebied met uitgebreide aanwezigheid van riffen (wellicht van verschillende kwaliteit of in verschillende stadia van ontwikkeling) voor 'training'. Er worden enkele proefbanen ingevlogen waarbij wordt meegekeken met de video voor verifiëring. De resultaten van de Side Scan Sonar worden aan boord opgewerkt en vergeleken met de visuele (video) waarnemingen. Ten eerste wordt onderzocht of *Lanice*-riffen kunnen worden onderscheiden van de zandige omgeving, waarbij ook de fragmentatie (afwisseling van rif en zacht substraat zonder rif) van belang is. Onderzocht wordt wat de resolutie is die wordt gehaald. Daarnaast wordt door eerdere studies (Van Hoey et al., 2008; Rabaut et al., 2009) indicatief de grens van wel/geen rif gelegd bij 500 kokerwormen per vierkante meter. Het is dus de verwachting dat dit overeenkomt met wat men op beeld (video) wel of geen rif zou noemen. Er zal tevens onderzocht worden of er op basis van de Side Scan Sonar verdere classificatie van verschillende rif kwaliteit mogelijk is. Er valt te denken aan onderscheid in 'lage kokerwormdichtheid' riffen en 'hoge dichtheid' riffen, waarbij hetgeen te onderscheiden valt afhankelijk is van SSS-resultaten maar wellicht bij meer dan enkele duizenden kokerwormen per m^2 de structuur substantieel verschilt van 500+ individuen per m^2. Anderzijds is wellicht ook het begin van rif-vorming (aggregaties van kokerwormen <500 individuen/m^2) nog te onderscheiden van werkelijke riffen. In principe zullen de ecologen aan boord moeten aangeven wat zij op zicht als te onderscheiden zouden classificeren, waarbij de SSS-experts zullen moeten aangeven of dat ook op basis van SSS-data het geval is (en andersom). Wanneer er voldoende overeenstemming is met betrekking tot te detecteren en te onderscheiden overgangen kunnen er klassen worden gedefinieerd. Er zal worden gezocht naar minimaal 2 klassen (geen of wel rif) en idealiter 4 of zelfs 5 klassen bestaande uit beginnend rif en lage en hoge dichtheid rif of zelfs een medium dichtheid rif tussen-klasse. Rabaut et al. (2019) maakt onderscheid in riffen met rond de 500 individuen per m^2, tot 1500 ind/m^2, en >1500 ind/m^2, wat over het algemeen blijkt te correleren met rif-hoogte (respectievelijk rond de 5 cm, 5-9 cm en >9 cm). Wanneer er op zicht en op basis van SSS enige overeenstemming lijkt te zijn, worden proef boxcores genomen, die in principe enkel dienen om de kokerwormdichtheid te bepalen. Het is de verwachting dat dit door middel van sub-sampling vrij snel kan worden bepaald. Er worden enkele boxcores per klasse genomen, zodat er enig zicht komt op de dichtheid waarbij de klasse-overgang om-en-nabij plaatsvindt.

In het tweede deel van de vaartocht zullen gebieden waar tot op heden de informatie gebrekkig is, maar waar wel *Lanice*-riffen zouden kunnen worden verwacht (met name Noordelijke deel van de Borkumse Stenen) worden opgezocht. Het betreft dan inventarisatie ten behoeve van de nadere invulling/verbetering van de kaart, waarbij gestructureerd (afhankelijk van het nader te onderzoeken oppervlak) parallelle banen worden gescand op basis waarvan de kaart nader kan worden ingevuld. Afhankelijk van de benodigde inspanningen en het te scannen oppervlak kan worden bepaald hoe ver banen uit elkaar liggen (vlak-dekkende inventarisatie zal te ver gaan, zodat interpolatie tussen banen noodzakelijk zal blijven). De data zullen de nul-situatie qua rif-oppervlak en wellicht (tot op zekere hoogte) ook kwaliteit vastleggen en vormen uiteindelijk ook de basis voor analyse om te komen tot een monitoring design. Zo'n monitoring (van oppervlak en kwaliteit) dient uiteindelijk deels te bestaan uit periodiek enkele 'random' SSS-banen door geïdentificeerd gebied om te komen tot een schatting van oppervlak en kwaliteit, waarbij de vraag is welk oppervlak en hoeveel banen daarvoor volstaan? Indien voldoende voor invulling/verbetering kaart met betrekking tot ligging *Lanice*-riffen is de verwachting dat hieruit de benodigde inspanning voor monitoring ontwikkeling oppervlak en (indien mogelijk) classificatie kwaliteit kan worden afgeleid. Analyse van betrouwbaarheid indicatie ligging, oppervlak en kwaliteit bij reductie aantal banen (gescand oppervlak) waarbij aandacht voor aspecten als fragmentatie (oppervlak afzonderlijke patches en/of percentage gebied bedekt door rif) en dus kokerwormdichtheid en/of rif hoogte, ten behoeve van het langjarig monitoringplan kan worden afgeleid. Het vastleggen van de nul-situatie zoals hierboven genoemd, betreft in deze fase enkel de positionering van de riffen (vaststelling welke gebieden onderdeel dienen te zijn van de *Lanice*-rif monitoring). Tijdens de T0 (en daaropvolgende monitoringmomenten) dient volgens uit te werken methodiek een indicatie van kwaliteit (en kwaliteitsontwikkeling) te worden verkregen en kan wellicht met een lage scanningsintensiteit ook overig gebied worden bezocht om enig zicht te hebben op de eventuele vorming van nieuwe riffen.

- ☐ Voldoende SSS-banen om ten minste de positionering van *Lanice*-riffen vast te leggen (voldoende om kaart te actualiseren waarin gebieden met riffen worden aangegeven).

Zoals aangegeven wordt SSS-toepassing gecombineerd met video om direct de link te kunnen leggen tussen veranderingen in scanning resultaten en betekenis met betrekking tot rif aanwezigheid en indien rif aanwezig, de kwaliteits-aspecten. Er wordt ten minste 5 km aan video-transect (=1500 m^2; hetgeen gelijk staat aan 5 reguliere video-transecten zoals ingezet voor KRM/MWTL monitoring) door *Lanice*-gebied (geïdentificeerd als gebied met riffen) geregistreerd en opgeslagen. Bij voorkeur wordt de video en SSS opname gelijktijdig uitgevoerd. Analyse betreft in eerste instantie enkel de registratie van (tijdens trainingsfase) gedefinieerde aan- en afwezigheid van riffen en kwaliteitsklassen riffen. Daarbij wordt de treklengte met een bepaalde kwaliteit geregistreerd (start en einde rif en indien mogelijk indicatie beginnend rif en lage, medium en hoge dichtheid rif; eventueel ook te onderscheiden op basis van hoogte). Indien op basis van video wel 5 kwaliteitsklassen kunnen worden onderscheiden (maar niet op basis van SSS), dan worden toch die 5 klassen geregistreerd. Wellicht kan analyse direct aan boord worden uitgevoerd. Opslag van transecten is wel nodig zodat later eventueel hieruit nog bevroren beelden kunnen worden betrokken ten behoeve van de uiteindelijke keuze voor de in te zetten techniek voor kwaliteitsbeoordeling *Lanice*-riffen.

☐ Ten minste 5 km aan video-transect door *Lanice*-gebied analyseren op aanwezigheid en kwaliteit rif (registratie kwaliteitsklassen) en opslaan (bij voorkeur opname tegelijkertijd uitgevoerd met SSS opname; te traceren op basis van tijdregistratie).

Voor kwaliteitsbeoordeling *Lanice*-riffen wordt dus onderzocht in hoeverre dit kan worden ingevuld door SSS en/of video-transecten. Daarnaast zal de combinatie met de inzet van boxcorer bemonstering worden onderzocht. Wellicht is een gecombineerde (boxcorer en rif-scanning techniek) beoordeling in eerste instantie het meest voor de hand liggend, maar in geval van goede resultaten met rif-scanning technieken en goede correlatie met soortensamenstelling kan worden overwogen (op termijn) boxcorer bemonstering achterwege te laten. In deze fase is het zaak over voldoende boxcorer monsters van *Lanice*-riffen in verschillende ontwikkelingsfases/kwaliteitstoestand te beschikken, zodat kan worden bepaald hoeveel boxcorer-monsters benodigd zijn om kwaliteitsverschillen te detecteren. Voor beoordeling wordt gedacht aan een vergelijkbare beoordeling als voor brede habitattypes; dus op basis van gecombineerd voorkomen indicatorsoorten (*Lanice*-rif specifieke BISI) en het ten minste kunnen detecteren van verschillen voor enkele individuele indicatorsoorten. Van Hoey et al. (2018) geeft een overzicht van de meest onderscheidende soorten tussen zacht substraat habitats met en zonder *Lanice*-riffen, hetgeen kan dienen als basis voor de selectie van indicatorsoorten en de afleiding van referentiewaarden. Ten behoeve van power berekeningen (om het benodigde aantal monsters om een representatief beeld te krijgen van de kwaliteitstoestand van de *Lanice*-riffen binnen het gebied van de Borkumse Stenen) kunnen we gebruik maken van boxcorer-monsters uit de KRM/MWTL monitoring die op basis van aanwezige *Lanice* dichtheden kunnen worden gekenmerkt als rif-monsters van riffen met verschillende kwaliteit. Zo beschikken we over 13 monsters met rond de 500 ind/m^2, 2 monsters met tot de 1500 ind/m^2 en 7 monsters met >1500 ind/m^2, waaraan vanuit de survey in 2013 (Bos et al., 2014), 4 Borkumse Stenen specifieke monsters voor de laatste categorie kunnen worden toegevoegd. Mogelijk zijn er ook nog *Lanice*-rif specifieke data beschikbaar voor het Duitse deel van de Borkumse Stenen (dient duidelijk te worden na opvraag van de data bij de Duitse collega's van AWI). Daarnaast is het mogelijk dat ook het Revifes project heeft bemonsterd in *Lanice*-velden; monsters zijn echter grotendeels nog niet geanalyseerd en het is onduidelijk of en wanneer eventueel bruikbare data beschikbaar kunnen komen. Dit maakt dat naar verwachting voldoende data aanwezig zijn voor power analyses, maar dat met name aanvullende data met betrekking tot de medium dichtheid categorie (rif-hoogte 5-9 cm) waardevol zou zijn. Op basis van de SSS en video resultaten worden boxcorer-monsters genomen op *Lanice*-rif locaties met naar verwachting 500-1500 ind/m^2. Voor snelle verificatie van de *Lanice* dichtheden worden al boxcorer monsters genomen. Het valt te overwegen om enkele van dezen te conserveren en mee te nemen voor lab-analyse.

☐ 5 boxcorer monsters van *Lanice*-rif locaties met naar verwachting 500-1500 ind/m^2 uitzoeken op het lab (volgens RWSV voorschrift 913.00.B200 'boxcorer'[5]).

Geogene riffen:

Kenmerkend voor het gebied van de Borkumse Stenen, is de aanwezigheid van hard substraat in de vorm van stenen. De stenen komen weliswaar voor in lagere dichtheden dan bijvoorbeeld op de Klaverbank, en de verspreiding is wellicht beperkt tot enkele delen (Figuur 3), hetgeen ook onderwerp is van het huidige onderzoek. Zodoende is het gebied van de Borkumse Stenen niet aangewezen onder de Habitatrichtlijn (met betrekking tot H1170 Riffen van de open zee), maar beschermd onder de KRM. Echter wel van bijzondere waarde bevonden, juist vanwege de aanwezigheid van met H1170 overeenkomende geogene rif-structuren. Het huidige profieldocument voor H1170[10] geeft aanwijzingen van hetgeen onder habitattype H1170 valt, maar is niet heel precies in waar dan de begrenzing zou moeten liggen. Om die reden wordt er ook een update van het profieldocument voorzien. Een memo uit 2018 (Van den Oever et al., 2018) probeert wel een uitwerking te geven van hetgeen aangeduid wordt in het profieldocument, vertaald naar hetgeen in het veld kan worden gemeten, om zodoende op basis van veldwaarnemingen (combinatie SSS, video en in dit geval bodemhappen) tot een kartering van H1170 habitat te komen. De belangrijke elementen daarin zijn:

- De aanwezigheid van concentraties aan stenen groter dan 30 cm, omdat dat een maat is die afzonderlijk kan worden gedetecteerd met de SSS. Er wordt gesproken over een concentratie aan stenen wanneer er minimaal 50 stenen in een gebied van 1 km^2 aanwezig zijn. De aanwezigheid van sessiele organismen bepaalt dan of het waarschijnlijk H1170 habitat is of mogelijk H1170. In het geval van meer dan 100 stenen is er bij aanwezigheid van sessiele organismen sprake van H1170 en

10 Habitatrichtlijn Profiel document H1170 Riffen (versie 2014): Riffen (H1170) – Natura 2000.

in afwezigheid waarschijnlijk sprake van H1170 (wellicht is ontbreken van sessiele organismen vooral een teken van H1170 in slechte toestand).
- Ook (zandig) grind (fractie >2 mm) zal waarschijnlijk H1170 zijn wanneer sessiele organismen aanwezig zijn (anders mogelijk H1170).
- Bij aanwezigheid ander (fijner) sediment gaat het nog mogelijk om H1170 wanneer sessiele organismen worden aangetroffen.

Daarbij spreekt het profieldocument[6] over tussenliggend zacht substraat dat tot H1170 kan worden gerekend wanneer het 100 m^2 rond stenen (van overigens >64 mm) betreft. Uitgaande van een cirkel met oppervlak 100 m^2 rond een steen, betekent dit dat er gesproken kan worden over doorlopend H1170 habitat wanneer de onderlinge afstand tussen de afzonderlijke delen maximaal 11,3 meter (2x de straal) betreft.

Deze systematiek volgend kan worden gesteld dat er H1170 habitat aanwezig is in het gebied van de Borkumse Stenen. Met betrekking tot de Habitatrichtlijn is dit van belang van de beoordeling van het oppervlak en de kwaliteit van het habitattype buiten Habitatrichtlijngebieden. Voor een KRM-gebied als de Borkumse Stenen is het duidelijk dat de kwaliteit van de habitats, met aanbod van natuurlijke hard substraat elementen die enerzijds voor structuurverrijking (driedimensionale gemeenschappen) zorgen en anderzijds hun eigen unieke soortengemeenschappen herbergen, voor een grotere diversiteit op het gebiedsniveau zorgt en daarmee een grote bijdrage levert aan de totale biodiversiteit van het gebied.

Voor wat betreft de uitwerking van een monitoringprogramma, is het zaak dat een nulmeting inzicht geeft in de ligging en het oppervlak aan potentieel H1170 habitat. Het gaat dan om het substraat en de harde elementen die potentieel als H1170 habitat kunnen classificeren. Dit is ook wat naar verwachting op basis van SSS opnamen in kaart kan worden gebracht, en wat in feite al in deze fase dient te worden vastgesteld tijdens het onderzoek met betrekking tot de invulling van ontbrekende gegevens. De aanwezigheid van sessiele organismen (hetgeen onderwerp zal zijn van de langlopende monitoring inclusief de nulmeting) geeft dan uitsluitsel of het (op dat moment) ook als H1170 habitat wordt geclassificeerd, en uiteraard wat de kwaliteit van het habitattype is. Zo kan in principe worden gesteld dat het oppervlak aan potentieel H1170 habitat, niet erg veranderlijk is, wanneer er niet direct sprake is van activiteiten die leiden tot afdekking ('sealed loss') of onttrekking van substraat. Enig voorbehoud hierin is eventueel het verlies van potentieel H1170 habitat onder invloed van activiteiten op afstand of grootschalige veranderingen die leiden tot toenemende sedimentatie en daarmee bedekking van potentieel H1170 habitat wat in eerste instantie zal leiden toch achteruitgang in kwaliteit en uiteindelijk mogelijk tot verlies. Zo ook zou in potentie hard substraat of een grovere sediment fractie aanwezig onder het oppervlak, bloot kunnen komen te liggen door toenemende erosie, wat dan tot uitbreiding van (potentieel) H1170 habitat kan leiden. Zodoende wordt ook na vaststelling van de T0 enige (wellicht minder intensieve) monitoring van oppervlak potentieel H1170 habitat gevraagd.

Tijdens het huidige onderzoek dient op basis van SSS een goed beeld te worden verkregen van de ligging van potentieel H1170 habitat (dus op basis van aanwezig substraat). De kartering van H1170 en mogelijk H1170 habitat zoals weergegeven in Bos et al. (2024) en waar mogelijk verfijnd met behulp van hernieuwde analyse van de data van de Hydrografisch dienst (in het veld gevalideerd tijdens de vaartocht), geeft wellicht een goede indicatie van de zoekgebieden.

☐ Voldoende SSS-banen om de positionering van potentieel H1170 habitat vast te leggen (voldoende om kaart te actualiseren waarin gebieden met potentieel habitat worden aangegeven).

Wat het werkelijke oppervlak aan H1170 habitat is, wordt vervolgens bepaald door monitoring van de aanwezigheid van sessiele organismen. Dezen, en geassocieerde benthische organismen, bepalen uiteindelijk ook de kwaliteit. Het is niet haalbaar om voor het gehele oppervlak aan potentieel H1170 habitat een vlak-dekkend beeld te krijgen, of het ook werkelijk H1170 habitat betreft. Het langjarige monitoringprogramma zal uiteindelijk dienen te bestaan uit een vastgesteld aantal video-transecten, eventueel in combinatie met boxcore monsters (of Hamon monsters wanneer blijkt dat dit vanwege de substraatsamenstelling nodig is). Daarbij betekent het ontbreken van sessiele organismen in feite een zeer lage kwaliteitstoestand wat gelijk staat aan afwezigheid H1170. Daarmee is het ten behoeve van de beoordeling van de toestand en ontwikkeling van het H1170 habitat in principe voldoende om op basis van een representatieve monitoring van de benthische gemeenschappen voor het gehele oppervlak aan potentieel H1170 habitat de kwaliteitstoestand te beoordelen.

Op de Klaverbank wordt gewerkt met een combinatie van video-transecten en Hamon happen en is er een specifieke BISI voor H1170[11] uitgewerkt (Wijnhoven, 2023). In principe lijkt de BISI voor H1170 ook een goede basis voor de beoordeling van geogene riffen in het gebied van de Borkumse Stenen, maar valt het te overwegen enkele gebied-specifieke soorten toe te voegen of een enkele soort specifiek kenmerkend voor de Klaverbank, te laten afvallen. Het is ook de vraag of het gehanteerde referentievoorkomen op de Klaverbank één op één kan worden overgenomen voor de Borkumse Stenen, waar de potentie van het habitat (hard substraat aanbod) van mindere kwaliteit is dan op de Klaverbank. Op het kunnen detecteren van kwaliteitsverschillen en/of het benodigde aantal monsters, heeft de hoogte van de gehanteerde referentie echter geen effect (is iets om later nader te bepalen).

De insteek zal zijn om de beoordeling volledig te baseren op de inzet van video-transecten. De toepassing van schaafbemonstering wordt gezien de kwetsbaarheid van de steenstructuren en de focus op de geogene rif-structuren niet overwogen. Boxcorer monsters zouden met name iets kunnen zeggen over de gemeenschappen in de gebieden tussen de stenen of het grovere sediment. Met de focus op H1170, zijn echter juist de sessiele organismen (die daar voorkomen) van belang. De verwachting is dat een substantieel deel van die organismen (met uitzondering van kleine exemplaren) op basis van video kunnen worden gemonitord. Het missen van kleine exemplaren kan betekenen dat beginnende kwaliteitsverbetering minder goed detecteerbaar zal zijn, maar voor het uiteindelijke doel van geogene riffen in goede kwaliteitstoestand zullen ook de goed zichtbare organismen die hard substraat gemeenschappen gaan uitmaken, zichtbaar moeten worden. De verwachting is dat initiële kwaliteitsverbeteringen (niet direct grootschalig zichtbaar met video) wel op basis van de boxcorer monitoring van de Borkumse Stenen (in het algemeen) zullen worden opgepikt. En daarmee kan dan ook worden verwacht dat er positieve ontwikkelingen zijn binnen het potentiële H1170 habitat, ook al wordt dat nog niet noodzakelijkerwijs bevestigd door (op basis van video) zichtbare hard substraat gemeenschappen. Uiteraard dient voor uitwerking van het langjarig monitoringplan voldoende informatie (op basis van video) aanwezig te zijn voor afleiding van het benodigde aantal transecten. Enerzijds is de variatie in aan te treffen gemeenschappen in de qua oppervlak beperkte gebieden van de Borkumse Stenen naar verwachting niet zo groot als op de Klaverbank (wat om minder benodigde transecten zou vragen). Wel wordt er ingezet op het gebruik van enkel de video, wat juist om iets meer metingen kan vragen, omdat het aantal potentiële indicatorsoorten daarmee afneemt. De huidige monitoring op de Klaverbank maakt gebruik van 16 video-transect meetlocaties, specifiek gericht op beoordeling H1170 habitat (Wijnhoven, 2020).

We gaan er van uit dat data van videotransecten beschikbaar zijn vanuit de monitoring door AWI op het Duitse deel van de Borkumse Stenen (11 locaties sinds 2012) en wellicht de OCEANA expeditie (2 locaties in 2017). Eventueel komen ook nog video (en boxcorer en grab) data beschikbaar vanuit het Revifes project, maar op dit moment zijn monsters grotendeels niet geanalyseerd, en het is onduidelijk wanneer eventueel bruikbare data wel beschikbaar kunnen zijn. Tot op zekere hoogte kan ook een vergelijking worden gemaakt met resultaten van de Klaverbank (in totaal 32 locaties die ten minste 2x zijn bemonsterd; Wijnhoven, 2020). Zodoende is er behoefte aan ten minste 10 geanalyseerde video-transecten/meetpunten (verdeeld over de 2 a 3 kerngebieden zoals geïdentificeerd) waarbij volgens RWSV voorschrift 913.00.B090[12] (dus 2x 500m is 300 m^2 per meetlocatie) wordt gewerkt. (In Figuur 3 is sprake van 2 kerngebieden; een zuidelijke op de grens met Duitsland waarvoor al wat data beschikbaar zijn, en een noordelijk gebied waar in ieder geval al eens stenen zijn waargenomen; mogelijk is er in het tussenliggende deel ook nog sprake van een derde gebied). Daarmee kan via multivariate analyse zicht worden verkregen op de vergelijkbaarheid van gebieden (Nederlands en Duits deel Borkumse Stenen en Klaverbank) waaruit de resultaten worden betrokken. Vervolgens kan via power analyse op basis van de vergelijkbare meetlocaties en waargenomen variatie van de gemeenschappen meewegende, worden bepaald hoeveel meetlocatie voor een langjarig meetprogramma benodigd zijn. Tijdens het onderzoek om de ontbrekende gegevens in te vullen (de vaartocht) kunnen meetlocaties naar inzicht worden geselecteerd zodat inderdaad zo veel mogelijk het potentiële H1170 habitat wordt geïnventariseerd. Zoals in het voorschrift aangegeven is het van belang dat habitattype (sedimenttype en aanwezigheid stenen) per transect-segment wordt genoteerd (dient ook inzicht te geven in mate van fragmentatie).

[11] Assessment tool 'Benthic Indicator Species Index (BISI)'; Application of BISI v3 in the Dutch North Sea with consolidation of earlier identified references. V021023. (http://ecoauthor.net/wp-content/uploads/2023/11/BISI-v3-Assessment-Tool-for-the-Dutch-North-Sea-v021023.xlsx).

[12] RWSV 913.00.B090. Analyse macrozoöbenthos, EUNIS habitat en antropogene materialen met behulp van een onderwatervideosysteem. (v1: 17-08-2020).

- ☐ Ten minste 10 video-transecten door (potentieel) H1170 habitat verspreid over de geïdentificeerde gebieden, analyseren conform RWSV voorschrift 913.00.B090[7].

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Annex C Field work plan

Fieldwork plan Borkum Reef Grounds 2024

MONS ID49 Effectiviteit gesloten gebieden (PR003)

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4. TNO

This plan is a shortened version of the fieldwork plan and only shows the planned sampling strategy and locations

Research Area and sampling sites

The focus areas for reef H1170 detection are A and B (yellow).
The focus area for EUNIS habitat sampling is C (green). For Lanice reefs area A and D (Figure C1).

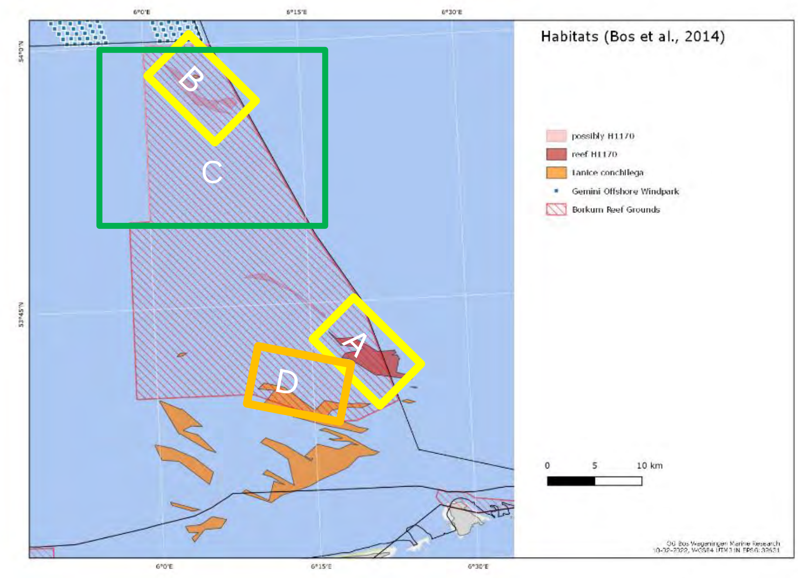


Figure C1. Focus areas for this research.

Global planning

The plan for Monday is set. The schedule for the other days will be as follows:
In the morning, the first results of the SSS and MBES will be discussed. Based on these discussions, it will be determined what will be done during the day. Because more and more results become available during the day, we may change the schedule slightly.

<u>Monday 26 August 2024</u>

08:30:	boarding Scheveningen Harbour
11:00	leaving Scheveningen Harbour
Morning	processing old SSS data, make a new map
Afternoon:	arrival at first sampling location. If there is time, a first ROV track
Night:	SSS/ MBES survey, Area A, full coverage

<u>Tuesday 27 August 2024</u>

Morning/ afternoon	ROV survey Area A - H1170 ground truthing (indicative at least 6 video transects to be analyzed with focus on geogenic reef and additionally 2 transects with focus on Lanice, which equals 8 km in total)
	Benthic sampling Area A *Lanice* 500-1500 ind/m2 (at least two box cores to be
taken	to laboratory)
Night:	SSS/ MBES survey, Area D, Likely number of individual tracks scattered throughout Area D

<u>Wednesday 28 August 2024</u>

Morning/ afternoon	ROV survey Area D, *Lanice* 500-1500 ind/m2 (indicative at least 2 video transects to be analyzed with focus on Lanice, which equals 2 km in total)
	Benthic sampling Area D *Lanice* 500-1500 ind/m2 (at least two box cores to be
taken	to laboratory) and box corer sites in southern part Borkumse Stenen (sand habitat – EUNIS)
Night:	SSS/ MBES survey, Area B, full coverage

Thursday 29 August 2024

Morning/ afternoon	ROV survey Area B - H1170 ground truthing (indicative at least 4 video transects to be analyzed with focus on geogenic reef and additionally 1 transect with focus on Lanice, which equals 5 km in total) Benthic sampling northern part Borkumse Stenen (sand habitat - EUNIS) Benthic sampling Area B *Lanice* 500-1500 ind/m2 (at least one box core to be taken to laboratory)
Night:	SSS/ MBES survey, Area B, full coverage

Friday 30 August 2024 DEPARTURE when??

Morning	ROV survey + benthic sampling EUNIS (residual box cores)
Return to harbour 13:00	

Acoustic survey plan

MBES and SSS settings

The multibeam echosunder (MBES) and sidescan sonar (SSS) measurements take place approximately between 20.00 to 8.00 during the night. Both systems are simultaneously operated. The USBL locator needs to be attached to the SSS. At the first and second day, a CTD should be taken at the beginning of the survey. The survey speed should be between 4 to 5 knts with a preference to 4 knts if the vessel can be kept on a straight path. A relatively constant tow fish flying height of 10% of the fixed ground range is important. With a fixed ground range of 75 m, it should be aimed for a flying height of around 7.5 m. If observations during the trial, plead for an adjustment of the survey settings it should be carefully discussed in terms of the project goal. The optimal shape and location of the survey areas should be chosen with respect to following criteria: (1) less vessel turns as possible, therefore a rectangular area with a long axis in order to sail long straight tracks, (2) heading direction with and against the current to obtain a stable fish position, (3) little bathymetric variation to keep the flying height as constant as possible and (4) in case of presence of megaripples, long axis should be perpendicular to the crest. It will be difficult to satisfy all criteria and therefore it is likely that the location and shape of the survey area will be a comprise. The preliminary survey areas for day 1, day 2 and day 3 of the trial are shown in Figure C. This selection was based on the assumption that the major current direction is WSW-ENE and ENE-WSW. The suggested survey areas can be modified on board in collaboration with the surveyors and the measured currents at the study site. Each day the data will be analyzed and based on the findings, the survey areas or settings might be adapted. Therefore, only the survey areas for the first three nights are given.

The MBES and SSS data will be copied from the acquisition computer in the morning (around 5 am) to the processing computer and the processing and interpretation of the first batch of sonar data will be caried out. As soon as results are obtained, a discussion with the ecologist and eventually with the RWS survey team will lead to the selection of suitable ground truthing location. If the processing of the acoustic data requires more time, the ground truthing can start with predefined locations. In particular for day 1, it is of advantage to be able to start with predefined locations.

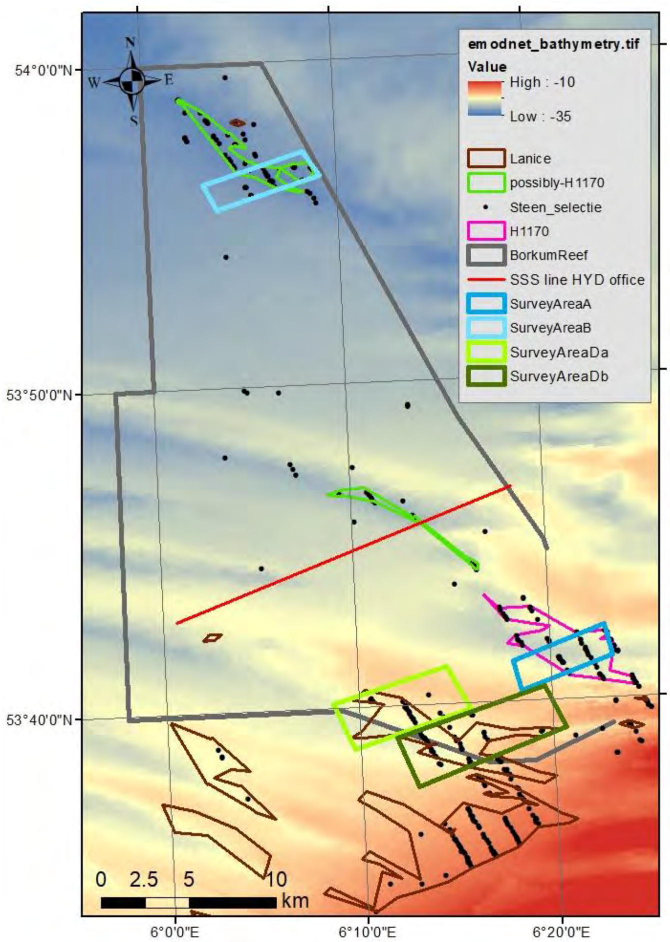


Figure C1 Overview of planned (preliminary) acoustic survey area and historic data (Bos et al. 2014) Coordinates system is ETRS89.

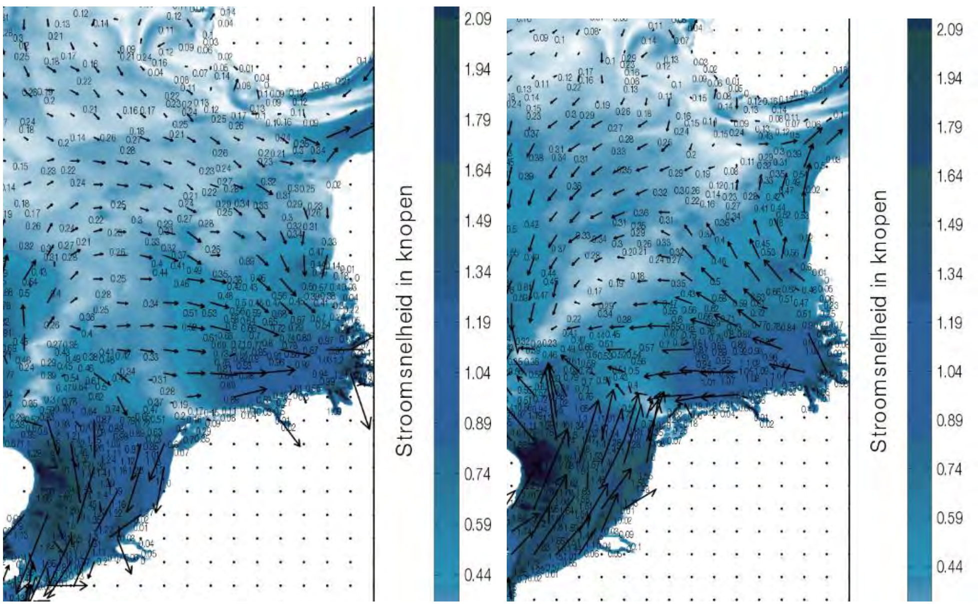


Figure C2 Main current directions

Table C1. Default vessel and general settings.

Vessel and general Settings	
Survey speed	4-5 knts (slowest possible while still sailing straight tracks)
Heading	With current/against direction: 250 and70 degrees
CTD	Before survey (only first two days)
Coordinate system	Geographic: ETRS89; Projected: ETRS 89 UTM 32N
Track line spacing	65 m (Survey area A); 75 m (Survey area B)

Table C2. Default MBES settings.

MBES Settings	
Frequency	300 kHz, keep constant
Swath coverage sector	140 deg
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
Data Storage	Bathymetry + backscatter, DB files

Table C3. Default SSS settings

SSS Settings	
Frequency	455 kHz
Range	75m
Flying height	7.5 m (guarantee full-coverage MBES and SSS)
Data storage	XTF and SDF files

Area A

The survey of Area A is planned for the first night (26 to 27th of August). It is located in an area where stones and reefs are expected and therefore it will provide a good reference measurement for the following days. The size of the area is 5.6 x 1.8 km, which is assumed to take around 12 h for a full-coverage survey with the settings provided in the tables. A line spacing of 65 m and a heading of 250/70deg are optimal.

Area D

Area D is a potential area for the second night (27 to 28th of August) to stay in the south avoid a large transit to the north. The area is divided into two sub areas D1 and D2. In area D we aim to cover a large area to scan Lanice and therefore the survey area is larger than area A and B. Therefore, a large line spacing is required. The size of area D1 is 9.0 x 2.8 km and with a line spacing of 500 m the survey time is around 7 h. The size of area D2 is 6.9 x 2.8 km and with a line spacing of 500 m the survey time is around 6 hours. A heading of 250/70deg is optimal. However, the findings from the first acoustic survey and the following ground truthing might provide valuable insights leading to an adjustment of the area or survey strategy.

Area B

Area B is a potential area for the third night (28 to 29th of August). The size is 6.2 x 1.7 km, which is assumed to take around 10 h to survey with the settings provided in the tables. A line spacing of 75 m and a heading of 250/70deg heading are optimal. However, the findings from the first acoustic survey and the following ground truthing might provide valuable insights leading to an adjustment of the area or survey strategy.

Benthic survey

The acoustic survey will guide the ground truthing. During the night SSS and MBES will be acquired and during the morning processed. Based on the bathymetric and backscatter features areas of interest will be selected and discussed with Timo, Oscar and Joël.

The video will be used to ground truth the acoustic data. The acoustic data will also be checked with the help of the box corer. For both purposes, different protocols will be used. Based on the findings and the success of the methods a change of order or prioritisation can occur.

Additionally, a number of video transects is recorded (and directly analyzed or to be to be analyzed later), that cover H1170 habitat (geofenic reef), or cover *Lanice* fields (needed to develop quality assessment methodologies for these habitat types and/or calculate number of samples needed as part of the long-term monitoring).
Also 15 box corer samples from soft sediment habitat are taken preferably approximately at indicated locations (in case inaccessible, an alternative location in the vicinity can be sampled), of which 5 samples are taken to the laboratory (for analyses) and 10 samples are sorted directly on board. An additional 5 box corer samples with indicative 500-1500 Lanice ind/m2, are taken for analyses in the laboratory.
For more details and background see Annex B (‘Onderzoeksplan ontbrekende gegevens’).

During the Sabellaria monitoring project, an important observation was that we would like to have more video transect data in the difference diverse areas. Therefore, during this survey we will try to fly in relatively more video transects and take less box corer samples for ground truthing.

ROV survey

A similar methodology as the 2024 MONS *Sabellaria* survey will be used for the video survey. The camera on the ROV will be moved to the front, so that you can view as large an area as possible. If the water is very turbid, it will be examined whether the camera can be placed under the ROV. The advantage of this is that you have less "sea snow" in the picture, but the total field of view is smaller.

Timo, Oscar and Joël will determine where an ROV track should be flown. This should be flown against the current. It is permitted to deviate during the track and fly towards a stone, for example. 1 track will be flown at each location. RWS will fly the track at the chosen location. Joël and Oscar will watch live and provide additional instructions if necessary.

During the tracks, an Excel sheet will be filled in. Important observations and stamps where a habitat occur will be noted. If possible, an indication of the amount of stones, gravel and *Lanice* is given. In addition, the following will also be noted:

- Analyst
- Pilot and co pilot
- Date
- Time

- Location (Area_number)
- Transect name (Area_number_letter)
- Direction of the current
- Observations
- EUNIS/ habitat
- Video quality

Locations will be registered by the meetleider van RWS (Mobiel meten). On the video image an overlay will be added with:

- Location name (Area_number)
- Transect number (Counts up)
- Position (EPSG:4258)
- Date (dd/mm/YYYY)
- Time in UTC:0 (hh:mm:ss)
- Heading (degrees)
- Depth (m)
- Transect length (m)

Benthic sampling Box corer / Hamon grab

A total of 20 benthic box corer samples will be taken during the expedition. Additionally, box corer samples are taken for ground truthing. The required amount for ground truthing will be determined during the campaign.

Five samples are taken from the EUNIS habitat sand and 5 samples from a medium (500-1500m^2) *Lanice* bank. These box corer samples are taken according to the standard Rijkswaterstaat protocol: RWSV 913.00.B200 Bemonstering van macrozoöbenthos en sediment in de mariene wateren. Methode: Reineck box corer, Van Veen happer, Hamon happer, Vacuümsteekbuis, Steekbuis, 01-09-2021. The analysis will be performed according to: A2,107 Waterbodem marien – Uitzoeken en determineren van Macrozoöbenthos, 08-09-2021 and A2.120 Bepaling van het AFDW als maat voor de biomassa van macrozoöbenthos, 08-09-2021. Hard substrate species, such as Hydrozoa, Anthozoa and Nudibranchia should be sampled and analysed. These are indicated with an asterisk in the various protocols.

The other 10 samples are processed on board. The sample is sieved and then roughly sorted. All larger species that are also analyzed in the Triple D dredge will be named. The aim is to get a rough indication of which species occur in larger quantities. The data obtained will therefore not be 1 on 1 comparable with a MWTL dataset.

Overview planned survey locations

SSS locations (possibly to be adjusted)

Table C4. Coordinates of survey area for MBES and SSS measurements. Coordinates represent points of survey polygon. Coordiantes in EPSG:25832-E ETRS89, UTM32 and in EPSG:4258-lon ETRS89

Area ID	Survey technique	EPSG:25832-E ETRS89, UTM32	EPSG:25832-N ETRS89, UTM32	EPSG:4258-lon ETRS89	EPSG:4258-lat ETRS89
Survey area A	SSS and MBES	322115.64 321766.52 327143.53 327486.67	5950436.89 5952164.60 5953832.24 5952034.37	6.3070657 6.3007945 6.3812003 6.3873934	53.6723483 53.6877415 53.7045217 53.6884920
Survey area B	SSS and MBES	312194.18 313058.52 307059.84 306406.22	5982194.00 5980705.36 5979233.03 5980703.90	6.1376937 6.1517604 6.0614245 6.0505524	53.9539647 53.9409138 53.9254973 53.9384562
Survey area Da	SSS and MBES	311315.02 317916.03 319140.55 312346.40	5950476.60 5952131.63 5949635.18 5947816.80	6.1437514 6.2425747 6.2625497 6.1609490	53.6689189 53.6861180 53.6641297 53.6454126
Survey area Db	SSS and MBES	314837.03 323468.13 324514.44 315853.37	5948264.31 5950585.14 5948103.90 5945426.51	6.1983141 6.3274316 6.3446549 6.2153517	53.6503167 53.6741377 53.6522116 53.6251980

ROV locations

To be decided on bases of SSS results and the expected presence of H1170 (geogenic reef) habitat or Lanice fields.

Benthic sampling locations

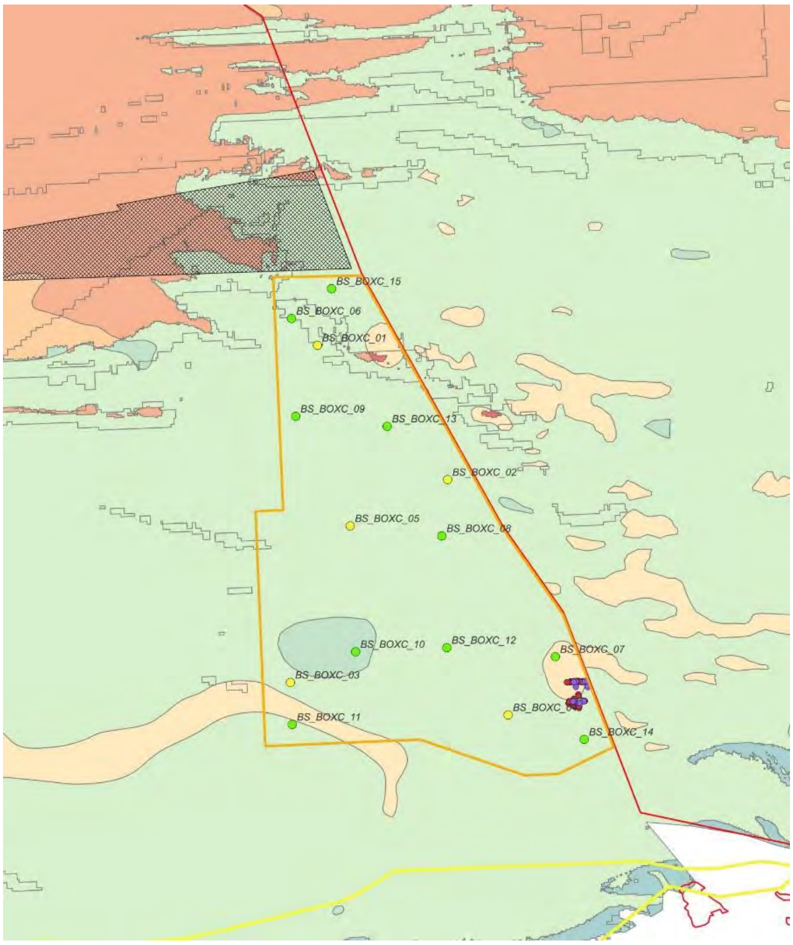


Figure C3. Box corer locations with samples to be analyzed in the laboratory (according to RWSV 913.00.B200) in yellow and samples to be sorted on board (according to RWSV 913.00.B080) in light green (additionally the sites sampled in a restricted area within the frame of the ReVifes project are shown, which include box cores, grabs and video footage).

Table C5. Overzicht voorgestelde meetlocaties voor bemonstering met boxcorer ten behoeve van afleiding bemonsteringsinspanning beoordeling zacht substraat habitats.

Monstercode	Bemonsterings-techniek	Uitwerking	EPSG:25832-E ETRS89, UTM32	EPSG:25832-N ETRS89, UTM32	**EPSG:4258-x** **ETRS 89**	**EPSG:4258-y** **ETRS 89**
BS_BOXC_01	boxcorer	Lab	306423.455	5981989.237	6,05000	53,95000
BS_BOXC_02	boxcorer	Lab	315824.353	5970467.880	6,20000	53,85000
BS_BOXC_03	boxcorer	Lab	302014.202	5955436.404	6,00000	53,71000
BS_BOXC_04	boxcorer	Lab	319040.187	5951406.700	6,26000	53,68000
BS_BOXC_05	boxcorer	Lab	307795.754	5967449.803	6,08000	53,82000
BS_BOXC_06	boxcorer	On board	304549.052	5984295.921	6,02000	53,97000
BS_BOXC_07	boxcorer	On board	323169.767	5955704.348	6,32000	53,72000
BS_BOXC_08	boxcorer	On board	314990.472	5966045.227	6,19000	53,81000

BS_BOXC_09	boxcorer	On board	304221.456	5976511.003	6,02000	53,90000
BS_BOXC_10	boxcorer	On board	307383.895	5957440.656	6,08000	53,73000
BS_BOXC_11	boxcorer	On board	301873.297	5952100.127	6,00000	53,68000
BS_BOXC_12	boxcorer	On board	314638.202	5957147.955	6,19000	53,73000
BS_BOXC_13	boxcorer	On board	311401.250	5975100.570	6,13000	53,89000
BS_BOXC_14	boxcorer	On board	324899.896	5948956.939	6,35000	53,66000
BS_BOXC_15	boxcorer	On board	307919.623	5986383.363	6,07000	53,99000
BS_BOXC_16 t/m BS_BOXC_20	boxcorer	+ 5 Lanice monsters 500-1500 m2 Lab				

Annex D. Logbook fieldwork Borkum Reef Grounds 26-30 August 2024

Auteur(s) Bos, O.G. (1), Cuperus, J. (2), Gaida, T. (3)

1. Wageningen Marine Research
2. Waardenburg Ecology
3. TNO

Content

1 Introduction

This fieldwork report describes the work conducted at the Borkum Reef Grounds from 26-30 August 2024 within the MONS program, to fill in knowledge gaps with respect to location of abiotic reefs and biotic reefs and the biodiversity of the benthic community.

1.1 Scope of work

The Borkum Reef Grounds (Borkumse Stenen) will be closed for seafloor disturbing fisheries under the European Fisheries Policy in the near future. The focus of this fieldwork was to fill in knowledge gaps on the presence and distribution of abiotic reefs (H1170) as well as biotic reefs (*Lanice conchilega*), and fill in knowledge gaps on the biodiversity of broad scale EUNIS habitats. This information is needed to design a statistically sound 3-yearly monitoring programme (KRM/MWTL/MONS) for future assessments of the quality status and development of the different benthic habitats, using the BISI indicator.

The scope of this fieldwork was to

- determine the location and (about) boundaries of reef habitat H1170
- determine location and (about) boundaries of *Lanice* fields
- develop/validate methodology to assess quality of *Lanice* reefs; can density classes be distinguished on bases of SSS (additional sampling of preferably the 500-1500 ind/m^2 density class for quality assessment)
- take 15 boxcorer samples from sandy habitat (EUNIS habitats) of which 5 are taken to the laboratory and 10 are sorted on board

1.2 Approach

In general, we worked from large scale to fine scale:

1) H 1170 Reef identification (areas A and B: Figure 13)
   a. Determine reef areas based on historic acoustic data and earlier research (TNO+WMR+WE)
   b. In the field: perform SSS and MBES surveys of interesting areas (RWS+TNO) (per night: ca 2x2 km)
   c. Validate with ROV tracks (optionally grab samples) (WE+WMR)
2) *Lanice* field identification (areas A, B and D: Figure 13)
   a. locate potential reefs based on historic acoustic data and benthic sampling (TNO)
   b. In the field: perform SSS and MBES surveys of interesting areas (RWS+TNO) (per night: ca 2x2 km)
   c. Validate with ROV tracks; try to define *Lanice* field quality classes (indicative: no *Lanice* – few *Lanice* <500m^2; medium density *Lanice* field 500-1500m^2 – high density *Lanice* field >1500m^2 (WE+WMR)
   d. 5 grab samples of preferably 500-1500 ind/m^2 to be sorted in laboratory (optionally additional grab samples to validate density classes on board) (WE+WMR)
3) EUNIS habitats sampling (entire area):
   a. Grab samples at predetermines places widespread over the area (WE+WMR)
   RWS protocols will be followed (to be checked by WE + WMR).

The focus area was the Dutch part of the Borkum Reef Grounds, extending from 15 km offshore Schiermonnikoog to south of the Gemini Windfarm. This border has been chosen based on the idea that shrimp fisheries in the area above Schiermonnikoog are minimally affected by an area closure. In the North, the area is connected to the Gemini offshore windfarm area. At several locations in the area, flat oyster restoration pilots are performed. Depths are between -20 (southern part) and -30 m (near Gemini).

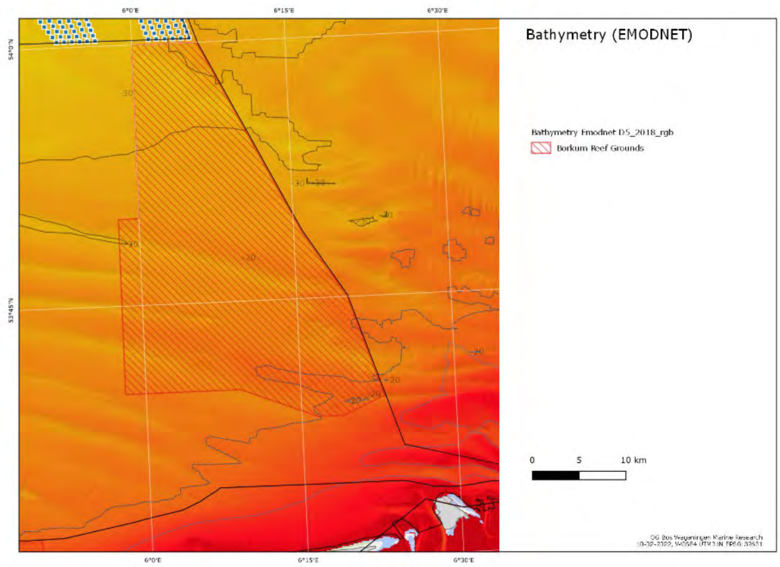


Figure 1. Bathymetry of the Borkum Reef Ground. Source: EMODNET (https://portal.emodnet-bathymetry.eu/).

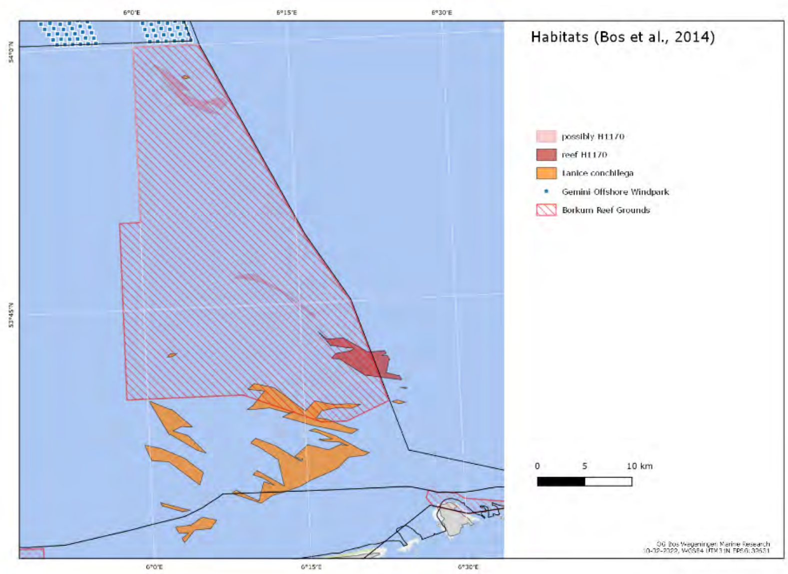


Figure 2. Habitats of the Borkum Reef Ground. Source: Bos et al. 2014.

2 Materials and methods

2.1 Study area

The study area was divided in subareas A, B, C and D (Figure 3). The areas surveyed by side scan sonar (SSS) and multibeam echosounder (MBES) are A (assumed to be H1170), B (possibly H1170) and D (assumed to be *Lanice* reefs). The ROV-tracks are indicated with lines within these areas. Area C represents the rest of the areas for sampling the wider EUNIS habitats.

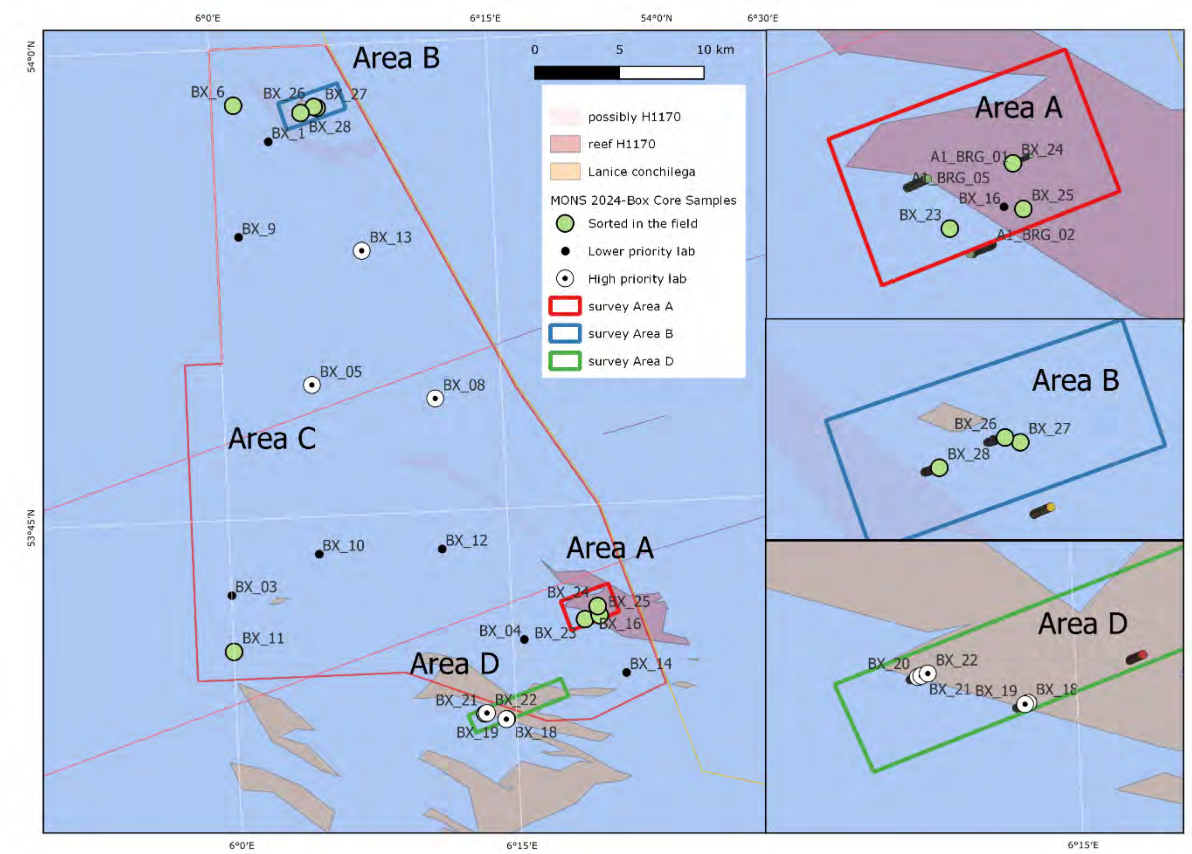


Figure 3. Borkum Reef Grounds. Overview of Boxcore and ROV locations. Boxcores were either sorted out in the field (green dot) or taken to the lab. For the lab, a distinction was made between samples to be sorted out with high priority (white dot) or lower priority (black dot). For detailed maps, see main report.

2.2 Dates

Port of departure and port of arrival was Rijkswaterstaat, Houtrustweg 600, 2583 GA The Hague/Scheveningen. Sailing dates: departure Monday 26 Aug 11:00 AM, return Friday 30 August 11:30 AM. Dates were chosen on basis of availability of the ship.

2.3 Vessel and crew

The survey was performed on board the vessel ARCA, built in 1998, 83.2 m long, 13.10 m wide. The scientists on board were Timo Constantin Gaida (TNO, acoustic specialist), Joël Cuperus (Waardenburg Ecology, benthic species specialist) and Oscar Bos (Wageningen Marine Research: marine ecologist, project lead). The crew consisted of 4 technicians from Rijkswaterstaat Mobiel Meten, responsible for the ROV, boxcore and side-scan sonar and multibeam operations, and the ship's crew.

Figure 4. ARCA (source: https://kustwacht.nl/eenheden/arca/)

2.4 Weather and sea conditions

The weather was very good during the whole week: wind 1-3 Bft, low waves 0.1-0.5 m, sunny and sometimes cloudy. The water temperature was around 19 degrees C.

2.5 Acoustic surveys

Figure 5. Side scan sonar towed fish with the USBL, which was deployed during each night.

The multibeam echosunder (MBES) and sidescan sonar (SSS) measurements took place every day between approximately 20.00h and 8.00h the next morning. Both systems were simultaneously operated. The USBL locator needed to be attached to the SSS. The survey speed was between 5 to 6 knts. The ground range was fixed to 75 m and with an aimed tow fish flying height of around 7.5 m following the rule of thumb of 10% of the ground range. The flying was kept constant as operational conditions allowed.

The optimal shape and location of the survey areas was chosen with respect to following criteria: (1) a rectangular area with a long axes in order to sail long straight tracks, (2) heading direction with and against the current to obtain a stable fish position, (3) little bathymetric variation to keep the flying height as constant as possible and (4) in case of presence of mega ripples, the long axis should be perpendicular to the crest. The major current direction is WSW-ENE and ENE-WSW. A compromise was needed to satisfy all criteria as good as possible. Before the trial, historic data acoustic data were obtained from the Dutch

Hydrographic Office. For each area, the historic data were processed. Based on the findings in the historic data and the data acquired during the trial, the originally planned survey areas were continuously adapted. The Multibeam Echosounder (MBES) and sidescan sonar (SSS) data were copied from the acquisition computer in the morning (around 5:30 am) to the processing computer and the processing and interpretation of the first batch of sonar data was carried out. As soon as results were obtained, they were discussed with the ecologists to choose relevant ROV and boxcore ground truthing locations.

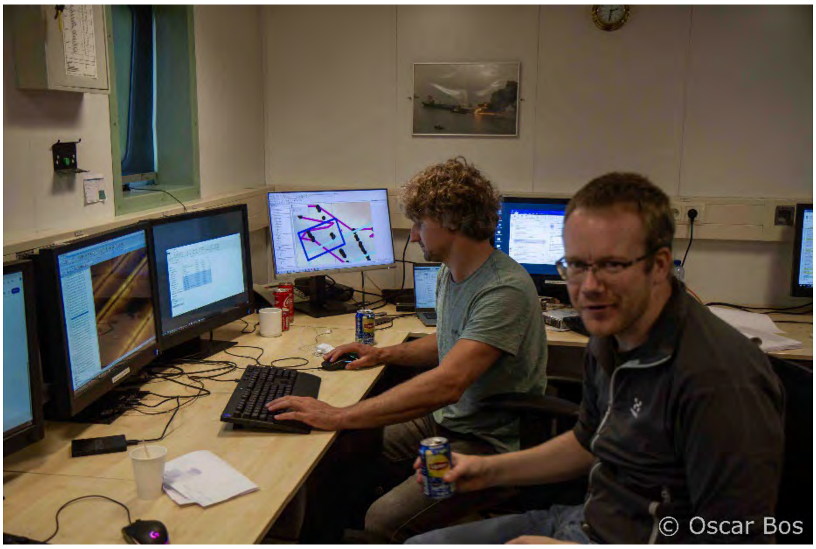


Figure 6. Data processing room.

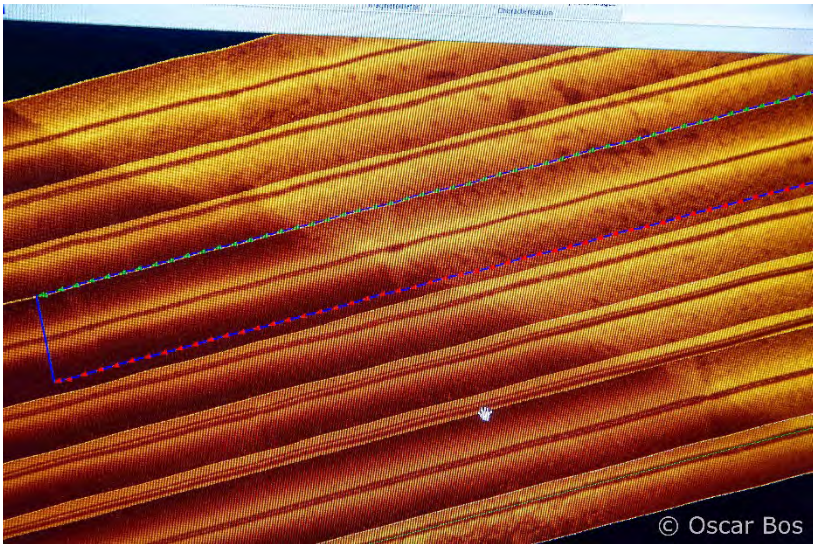


Figure 7. Side-scan sonar data visualized in SonarWiz.

2.6 ROV transects

The ROV transects were performed using a Saab Panter ROV operated by two Rijkswaterstaat operators in close cooperation with the captain to keep the ROV at the right distance to the vessel. The typical flight speed over the ground was 10-15 cm/s. This allowed for obtaining a good image quality useful for subsequent species determination. Faster speeds result in blurry images.

The locations of the ROV transects were based on the side-scan sonar and multibeam images acquired during the night before. ROV transects were chosen to cover acoustically interesting features that needed ground truthing. In the stony reef areas (Areas A and B) the focus was on filming as many stones and boulders as possible, rather than flying a straight line. One ROV transect of 200-250 m takes about 1 hour of work. Between 3 and 5 ROV transects could be done per day, since also time was needed for boxcoring.

In the ROV control room (Figure 10) the marine ecologists (Joël and Oscar) watched the ROV video footage live and provide additional instructions to the ROV operators. This is similar to the methodology using in the 2023 MONS *Sabellaria* survey. The camera was mounted on the front of the ROV at a 45 degrees angle, to view as large an area as possible. Lasers were set 50 cm apart.

ROV transects were done against the current to prevent bad visibility. During the transects, live annotation was made from a custom-made list:

- *Lanice* reef types (*Lanice* 0-25%, *Lanice* 25-50%, *Lanice* 50-75% and *Lanice* >75%)
- Flat sand (Zand, 0.625-2 mm)
- Sand ripples
- Stone (steen, 6.4-25.6 cm)
- Boulder (kei, >25.6 cm)
- Shell fragments (schelpen gruis)
- Special species (Bijzondere soort)

The videos were stored in *.mp4 format. In the video itself, the following information is displayed:

- Date and time (UTC)
- Location (x, y, ETRS89 UTM32N)
- Location and transect name (Area A, B or D; Location Borkum Reef Grounds (BRG))
- Depth (m), speed over ground (SOG; cm/s), Flight distance from starting point (m)

Figure 8. Side-scan sonar data. Screenshot of ROV video footage in the Lanice area (area D). Metadata are visible in the upper left corner.

Annotations were stored in a Video Log file (.xls file; see tables in Annex2).
ROV GPS tracks were recorded in the QINSy logfile (.csv file). Transect were named according to the subarea (A, B, D) in the Borkum Reef Grounds (BRG).

- Analyst
- Pilot and co pilot
- Date
- Time
- Location (Area_number)
- Transect name (Area_number_letter)
- Direction of the current
- Observations
- EUNIS/ habitat
- Video quality

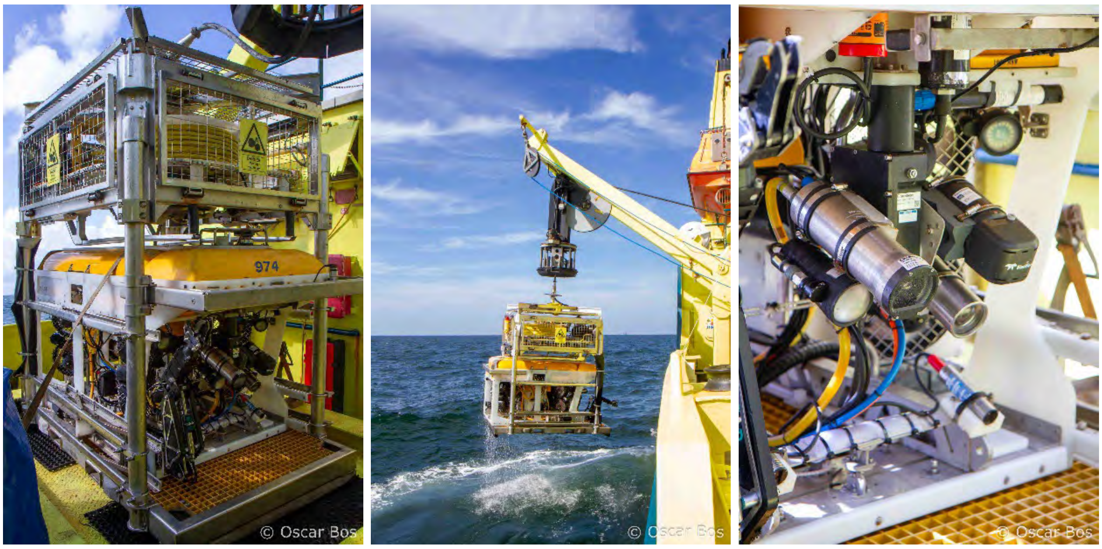


Figure 9. ROV of Rijkswaterstaat equipped with dimmable lights, 2 lasers and a 4K camera.

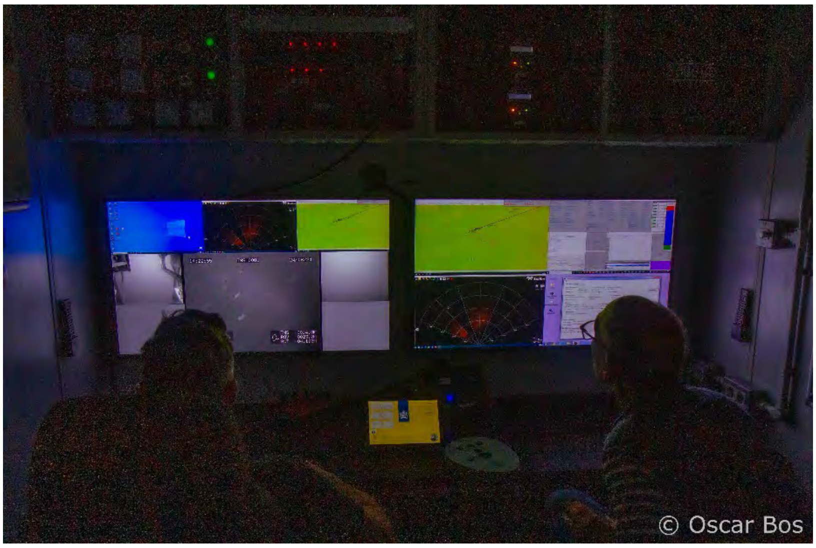


Figure 10. ROV control room.

2.7 Boxcore sampling

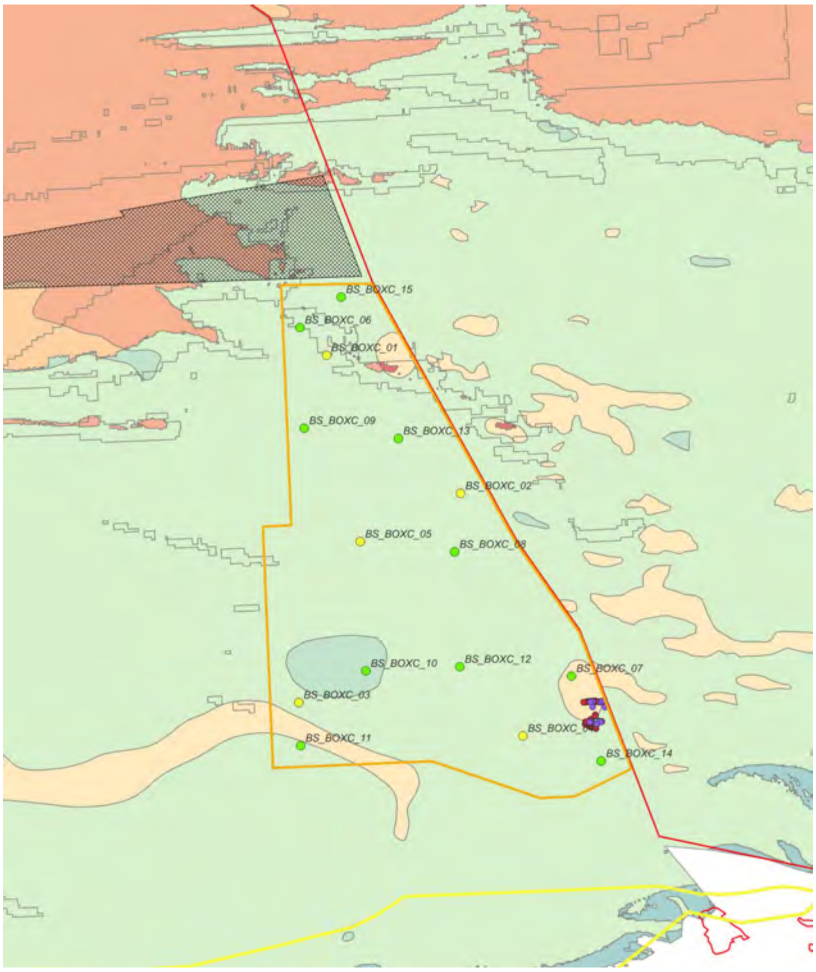


Figure 11. Planned boxcorer locations with samples to be analyzed in the laboratory (according to RWSV 913.00.B200) in yellow and samples to be sorted on board (according to RWSV 913.00.B080) in light green (additionally the sites sampled in a restricted area within the frame of the Revifes project are shown, which include boxcores, grabs and video footage).

Figure 12. The Rijkswaterstaat boxcore (0.078 m^2).

Figure 13. Sieve (1 mm round holes) and boxcore.

Boxcoring samples were taken using a 31.5 cm diameter boxcore (surface 0.078 m^2) (Figure 12). In total 24 boxcores were taken, of which 10 were sorted out on board and 14 were taken to the laboratory. Samples were sieved over a 1 mm round mesh sieve (Figure 13). The required sieve was not available, so an old, rejected sieve was used during the trip. It is possible that some organisms were lost during the sieving for the lab samples. We expect that no organisms were lost from the samples that were processed on board. Reef samples with lots of stones and shell fragments were sieved over a 4 mm square sieve with the 1 mm round mesh sieve underneath. Lab samples were put in plastic jar and conserved with formaldehyde, diluted with water. In the lab, Borax and Bengal Rose was added to buffer the formaldehyde and color the once living animals inside. Sediment samples were not taken, as the aim of the research is not to carry out a full sampling program, but to fill in knowledge gaps. In the south part of the Borkum Reef Grounds, sediments samples were taken in the past (Bos & Paijmans, 2013).

The other samples were processed on board. The sample was sieved and then roughly sorted. All larger species that are usually also analysed in the Triple D dredge will be named. The aim is to get a rough indication of which species occur in larger quantities. The data obtained will therefore not be 1 on 1 comparable with a MWTL dataset.

Boxcorer samples were, where possible, taken according to the standard Rijkswaterstaat protocol: RWSV 913.00.B200 *Bemonstering van macrozoöbenthos en sediment in de mariene wateren. Methode: Reineck boxcorer, Van Veen happer, Hamon happer, Vacuümsteekbuis, Steekbuis, 01-09-2021.* The analysis will be performed according to: *A2,107 Waterbodem marien – Uitzoeken en determineren van Macrozoöbenthos, 08-09-2021* and *A2.120 Bepaling van het AFDW als maat voor de biomassa van macrozoöbenthos, 08-09-2021*. Hard substrate species, such as Hydrozoa, Anthozoa and Nudibranchia are sampled and analysed. These are indicated with an asterisk in the various protocols.

3 Log of events (in Dutch)

3.1 Maandag 26 augustus 2024

Figure 14. ARCA

08:30 Aankomst, spullen laden, veiligheidsrondje rond het schip. Scheveningen.
11:00 Briefing door projectleider (Oscar) voor gehele bemanning over het doel van deze week. Afwijking: er is een bed te weinig. Oplossing: Oscar slaapt op de grond op een extra matras. Kapitein meldt dat kantoor dit goed vindt.
11:15 Voorbereiding van de boxcore bemonstering. De zeef zit vast aan de boxcore tafel. Wordt door de bemanning losgemaakt. Constatering: er is niet veel reservemateriaal voor de boxcore aan boord. Afwijking: de geleverde boxcore zeeftafel is OK, oud en niet gekeurd. De ketels zijn niet allemaal rond.
11:15 TNO (Timo) start analyse oude akoestische data.
12:30-13:00 eten
13:00 ROV-annotaties categorieën aangemaakt, zodat deze kunnen worden gebruikt om de beelden te annoteren.
14:00 SSS+MBES: op het schip zelf zijn beelden aanwezig van het gebied in het zuiden (ankerplaats) van het Borkumse Stenen gebied. Deze kunnen wellicht gebruikt worden als tijdserie voor de monitoring in gebied D (het *Lanice* gebied).
Middag: technische discussies met RWS en TNO over SSS/multibeam
15:00 Verdere analyse multibeam. Op beelden van RWS in het ankergebied onder in het Borkumse Stenen gebied ziet Timo rare gaten. In de literatuur over bruinvissen in Duitsland zijn dergelijke gaten geïdentificeerd als feeding pits van bruinvissen. Vraag: zijn dit dezelfde soort gaten? Voorleggen aan een bruinvis collega.
18:00 Eten: brood en hamburger
18:30 We bekijken oude akoestische data van gebied A. Er is ca 7 uur scantijd beschikbaar.
19:30 Verder met oude data in gebied A bekijken. We besluiten het gebied ten westen van het WWF/ARK gebied te gaan scannen, omdat hier op de oude data van de hydrografische dienst stenen en interessante akoestische patronen te zien zijn. In verband met aanvaringsgevaar met de boeien van het WWF/ARK gebied blijven we buiten dat gebied.
’s nachts: side scan sonar + multibeam scannen gebied A

3.2 Dinsdag 27 augustus 2024 (gebied A: steenrif noord)

Figure 15. Transit to next boxcore location in area A. The One Dyas jackup and German offshore windfarm are visible.

05:30 Timo heeft alle nieuwe multibeam en side-scan sonar tracks van gebied A gedownload en geanalyseerd.

08:30 Op basis van de nieuwe beelden hebben we 3 ROV transecten op de kaart gezet: eentje over de *Lanice*/stenen, eentje over zand/stenen, eentje over het grensgebied zand/stenen.

3.2.1 ROV transecten

Figure 16. Boulder with 2 fig sponges, hydroids.

ROV transect A1_BRG_01

09:00 ROV transect A1_BRG_01.

Uit de multibeam data blijkt dat het hoogteverschil max 30 cm is tussen pieken en dalen. Het gebied is naar verwachting een *Lanice* gebied, afgewisseld met stenen. Eerst wordt de ROV 'kooi' naar beneden gelaten, daarna zwemt de ROV uit de kooi.

Bodem: dode schelpen waaronder *Ensis*, schelpengruis, zeedahlia, heel veel *Ensis*. Nog meer schelpengruis. Stenen (<26 cm) met hydroidpoliepen. Zeedahlia's. Kei (>26 cm). Aantal grote keien van 1 m met hydroiedpoliepen en mosdiertjes, dodemansduim, fluwelen zwemkrab, zeedonderpad, botervisjes.

Bodem: niet veel *Lanice*. Pitvis. Fijnzandig. Zeedahlia. Af en toe dode *Ensis*, veel kleine zeesterren, zand met ribbels. Viltkokeranemoon.

09:34 Zandribbels. Zeesterren. Kei met fluwelen zwemkrab. Zand met 1% *Lanice*
Pitvis. Grote kei (1.5m) met kreeft, steenbolk, *Tubularia*, dodemansduim, fluwelen zwemkrab, Noordzeekrab, *Metridium*, 3 Noordzeekrabben, aantal stenen, *Metridium*, slibanemoon,

09:42 Grote steen, spons, spinkrab, sepia-eieren, vijgspons, penneschaft, zeesterren.

09:44 Zandbodem, zeedahlia, veel zandribbels. Patronen zijn zandribbels met beetje schelpgruis. Af en toe *Lanice*.

09:50 Pitvis mannetje. Slibanemonen. Meer structuur.

09:53 Scharretje. Zandribbels, beetje schelpgruis. Platvis. Heremietkreeft. Slibanemoon. Dwergtong. Zeedahlia. *Lanice* 2%. Zwemkrab. Grondels.

08:00 Bodem weer glad.

10:01 Kei 70 cm. Twee keien. Begroeid met hydroiedpoliepen, 2 grote vijgsponzen, gele bedekkende spons.

10:06 Einde. ROV gaat weer in de kooi.

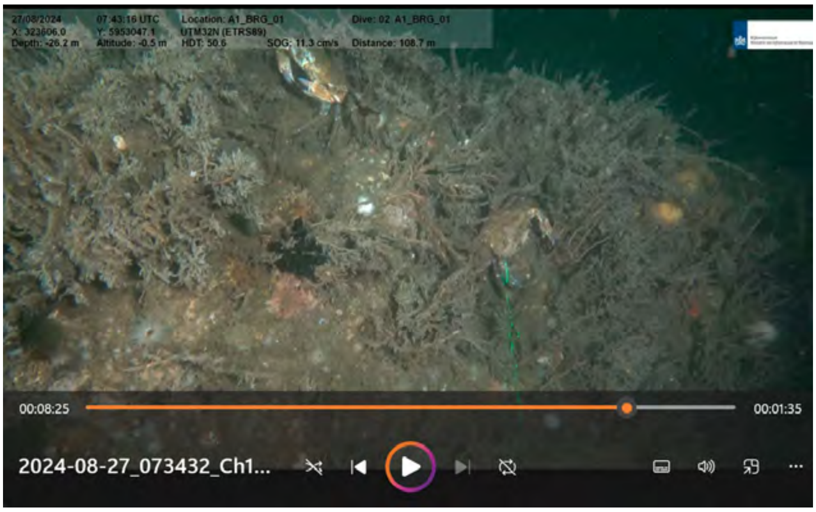


Figure 17. Sepia eggs (black).

Conclusie: bodem bestaat voor maximaal 1-3% uit *Lanice/Loimia*. De ribbels zijn allemaal zandribbels. Er zijn stukken vlakke bodem en geribbelde bodem. Tussen de ribbels ligt wat schelpengruis. Af en toe is er een steen of een kei te zien. De keien zijn begroeid met sponzen bovenop (vijgspons een aantal keer). Er zit soms dodemansduim op. Een beetje *Metridium*. Af en toe een botervisjes. Fluwelen zwemkrab. De posities van de stenen kloppen exact met de akoestische data.

ROV transect A1_BRG_02

10:56 ROV down. Transect naam: A1_BRG_02. Dit tweede transect is over een zandgebied met veel stenen.

11:02 Zand, slangster, *Loimia* (reuzenworm), slangster, zandribbels, af en toe *Lanice*, ruwere zandribbels, pitvissen, *Obelia* (Hydroiedpoliep), aantal keien en stenen, beetje kale steen met slibanemonen, hydo/mosdier, *Ensis*, pitvis.

11:10 Keien/stenen met slibanemonen, verder niet erg begroeid. Bodem met stenen, harde ribbels, platvis.

11:11 We gaan weer verder. Stenen, schelpengruis, dikke ribbels, af en toe een *Lanice*, hydroiedpoliepen, zeedonderpad, platvis, zand.

10:14 Stenenveld. Pitvis.

11:15 Kei met anemonen, fluwelen zwemkrab. Grotere zandribbels op megaribbels.

11:17 Megaribbels. Kleine zandribbels. Af en toe *Lanice*. Grondeltjes. Pitvis vrouwtje. Slangster. Pitvis. Af en toe *Lanice*, 1 m^2.

11:19 Kaal zand. Slangster. Zandribbels van begin tot eind.

11:23 Mul.

11:24 Vlakke bodem met zandribbels. Zwemkrab. Vrij kaal.

11:30 Kei met anemonen, blauwpootzwemkrab, slibanemoon.

11:34 Witte massa, lijkt op pijlinktviseieren, slibanemoon, slangster, *Ensis siliqua* schelpstukje.
11:39 Grote ronde steen 1 meter, steenbolkjes, fluwelen zwemkrab.
11:43 Kleinere steen 50 cm met kreeft. Stenenveldjes.
11:44 Fluwelen zwemkrab op kleinere stenen. Grote zeenaald. Zandbodem, zandribbels, slangster. Megaribbels aan de oostzijde liggen de stenen.
11:47 Zandribbels, *Lanice*, 2x slangster, slangster, grondeltjes, zeester.
11:48 Grote kei 50x60. Slibanemonen, fluwelen zwemkrab. Kleine zeesterren.
Opvallend: stenen minder begroeid aan deze kant. Vaker begroeid met slibanemonen.
Viltkokeranemoon. Slibanemoon, 5x mul.
11:55 kamster, slangster, slangsterren, zandribbels, 1x mul, slangsterren, slangster. Ribkwallen in het water. *Obelia (longissma*), Kamster.
12:01 Eind ROV track.

Totale indruk: er liggen stenen in kuilen in het zand. Veel zandribbels, met heel af en toe een *Lanice*/ *Loimia*. Op de zandbodem af en toe slangsterren, een beetje dood schelpmateriaal, 1x mul. Redelijk veel stenen en keien. Fluwelen zwemkrabben op de stenen. 1x een grote kreeft. Een schooltje steenbolkjes(?). Slibanemonen.

ROV transect A1-BRG-03
13:25 Duik 3. A1-BRG-03 Gebied met mogelijk *Lanice*
13:30 ROV down. *Lanice*, pitvis. Zandige bodem.
13:33 Kei en steen. Kamster. Mogelijk *Loimia* (reuzenworm). Zeesterren. *Lanice* 5%. Zeedahlia. Slibanemoon. Zwemkrab sp.
13:39 Witte vilkokeranemoon.
13:40 Steen, 20 cm. Platvis (schar). Noordzeekrab. Kei. Pitvis. Zeester. Perkamentkokerworm? Kamster. Sepiaschild.
13:49 Boxcore punt x324310.8 y 5952
13:50 'Bijzondere soort'= potentieel boxcore punt: opvallend sediment
11:52 Bodem met *Lanice*. Platvis. Schar. Pitvis mannetje en vrouwtje
11:58 Slibanemoon, schelpmateriaal, vlakke bodem. Zwemkrab. Blauwpoot zwemkrab.
14:00 Grote steen 1 m met kreeft, zeeanjelieren *Metridium*, veel dood schelpmateriaal eromheen. Steen was vrij kaal verder. Steenbolk.
Zandbodem: heel onregelmatig. Veel schelpmateriaal. Slibamonen in verschillende kleuren. Zeesterretjes. Grovere zandbodem dan de andere transecten.
14:03 Grote steen. 2-3-4m x 1.5 meter. Begroeiend met zeeanjelieren, steenbolkjes (?), fluwelen zwemkrab. 1.5 m hoog. Paar honderd steenbolken eromheen.
14:14 Grote wolk steenbolk(?): paar honderd.
14:20 Kamster, zand met paar procent *Lanice*. Schelpenmateriaal. Zeesterren. Af ten toe *Lanice*. Lege *Ensis*.
14:24 ROV transect gestopt.

Algemene indruk: bodemscan liet onregelmatige patronen zien. Er is een lage dichtheid *Lanice/Loimia* aanwezig van circa 5%. De bodem is vrij onregelmatig. Veel dood schelpmateriaal. We hebben een grote steen gezien van ca 3-4 m grootte met paar honderd vissen eromheen. Af en toe zijn er patches met 25% *Lanice/Loimia* bedekking. Sommige ribbels zijn vrij groot en lijken veel leven te bevatten. Niet duidelijk waar die uit bestaan.

ROV transect A1_BRG_04.
15:11 ROV-duik 4. We duiken van oost naar west. We verwachten *Lanice* op de bodem.
15:13 Vrij vlakke bodem met kleine stukjes. Driearmige gewone zeester. Goudkammetje. Pitvis. Redelijk veel slibanemonen. Platvisjes. Zeesterren. Af en toe *Lanice*. Krabben in het zand.
Platte structuur met schelpresten. Blauwpoot zwemkrab. Mul. Slibanemonen. Kleine zeesterren. *Electra pilosa* (exoot).
15:24 ROV-motor doet het niet meer.
15:32 ROV uit het water voor reparatie.

3.2.2 Boxcore sampling

Overgestapt op Boxcore terwijl ROV-probleem opgelost wordt.
We hebben 2 extra punten gedefinieerd: BX16 op de plek waar we met de ROV geëindigd waren, omdat het sediment er zo gek uit zag. En BX17 op de track 3 van de ROV.
Eerste sample van BX16: *Owenia*, de nieuwe reuzenworm (*Loimia)*, kwam hier veel voor. Foto's gemaakt van molkreeftje, een paar reuzenwormen, zandzager. Monster gefotografeerd en weggegooid.

Boxcore 16 naar lab
17:00 Tweede monster BX16 genomen. In twee potten. Verzoek van Joel om deze wormen te weten. Voor zover hij weet eerste keer dat deze reuzenworm wordt aangetroffen in dit gebied.
17:30-18:00 eten. We liggen dicht bij het gasplatform. Daar voert Greenpeace nu actie.

Boxcore 14 naar lab
18:10 Boxcore BX14, zandig gebied ten zuiden van de stenen. Meegenomen in een potje.

Boxcore 4 naar lab
19:00 Boxcore BX04, zandig gebied ten westen van de stenen

3.2.3 ROV transecten

19:30 ROV doet het weer. Nu naar ROV transect 5.
19:47 ROV down

ROV transect A1_BRG_05
Zandbodem. Speed 0.15. Bodem met om de 20 cm een dikke worm. *Lancie* of reuzenworm, *Loimia*?
Veel woromen, bruinwier te zien dat ligt op de bodem, schelpengruis, Noordzeekrab, zwemkrabben. Zand met enige kleine ribbels, paar wormen per vierkante meter, pitvis, schar, zandribbels,
Overgang; plattere bodem, veel slangsterren, ($5/m^2$), slibanemonen, bodem lijkt meer silt te bevatten. Heremiet kreeft.

20:00 Nog steeds in 'donkere' zachte gebied (silt rijker). Mul, heremietkreeft. Veel heremietkreeft.
20:03 Weer in de overgang. Meer *Lanice*, platte bodem, Heremietkreeft, zandribbels. Na de overgang weer meer ribbels. Ribbels met veel slibanemonen. Mogelijk zijn de *Lanice* allemaal *Loimia*. Hooiwagenkrab. Platvis. Slangster. *Lanice/Loimia*. Noordzeekrab.
Overgang naar gebied met lagere reflectie. Plattere bodem. Lege *Ensis* schelpen. Noordzeekrab.
20:24 Heuveltjes, gaten. Kompaskwal.
20:29 Einde ROV.

Avond/nacht: SSS/MBES scan gebied D.

3.3 Woensdag 28 augustus 2024 (Gebied D: *Lanice* riffen zuid)

Figure 18. We found that Lanice conchilega was mixed with a new species: Loimia ramzega, a giant tube worm that can reach 65 cm, first discovered in Brittany, France in 2017.

’s nachts gebied D gescand, waar we *Lanice* riffen verwachten. Inclusief ca ¼ overlap met een ankergebied, waarvoor RWS al een tijdserie heeft, zodat we goed kunnen vergelijken. Op basis van die data een ROV-track gekozen over ribbelstructuur. Die gaan we ROV-en.

3.3.1 ROV transecten

ROV transect D-BRG-01

Figure 19. Lanice/Loimia reef, shell material.

09:11 ROV down D-BRG-01. We varen van oost naar west
Platte bodem met *Lanice*, zwemkrab, dode kokkelschelpen, veel slangsterren, gewone zeester met 4 poten, algemene indruk: veel leven. Potentieel boxcore punt. Hermemietkreeft, gewone/grijze zwemkrab

09:16 Potentiele boxcore locatie. Medium dichtheid *Lanice/Loimia*

09:18 Veel zeesterren. *Lanice/Loimia*. Schooltje vissen (steenbolken?). Heremietkreeft.

09:21 Veel *Lanice*, slangsterren, zeesterren, dode *Ensis*, zwemkrab, patch *Lanice/Loimia* van 20%. Steenbolkjes (?). Veel schelpmateriaal, harnasmannetje. Scharretje. Veel *Lanice*: 20%. Kamster, viltkokeranemoon, schooltje horsmakreel(?).

9:32 Weduweroos. Vissen zwemmen de hele tijd door beeld.

09:33 Vis met hoge puntige vin, links in beeld. Mul/poon?

09:34 ‘Bijzondere soorten’ = potentiële boxcore locatie medium *Lanice* (nog een paar meer rond dit tijdstip). Grote heremietkreeft 2x, *Lanice* 20% bedekking,
Tussendoor conclusie: veel meer *Lanice/Loimia* dan gisteren.

09:40 Potentiële boxcore locatie voor *Lanice* 50-75%

09:41 Potentiële boxcore locatie 50-75%

09:44 In dit gebied minder schelpen, wel veel *Lanice/Loimia* 20%. *Ophiura albida*.

09:45 Afwisselend patches met hoge en lage dichtheden.

09:48 Zandribbels, veel slangsterren, *Lanice* 20%, zwemkrab, hoge dichtheid *Lanice*. Kamster. Pitvis

09:51 ‘Bijzondere soorten’ = potentiële boxcore locatie 75% *Lanice*.

09:52 ROV stopt, ROV uit het water.

10:00 Timo heeft nieuw ROV-lijntje opgezet over homogeen gebied, onder wrak langs.

ROV transect D_BRG_02

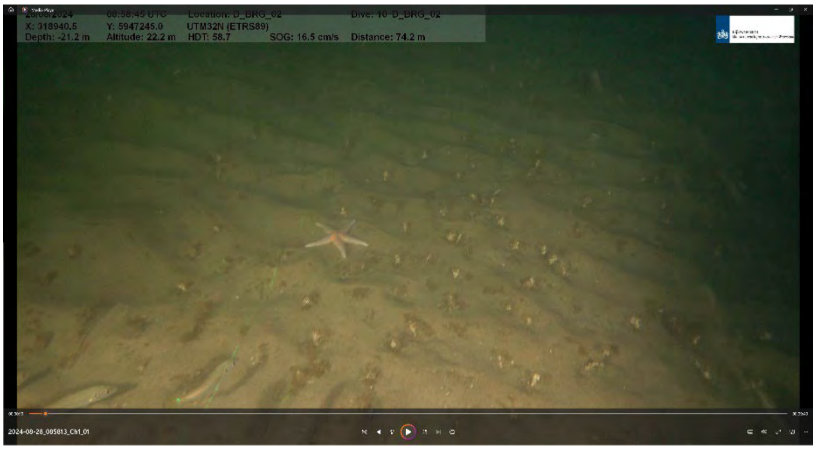


Figure 20. Sand ribbles, seastar, Loimia/Lanice.

10:41 ROV down Transect 28-08-2024 gebied D, ROV track D-BRG-02

10:48 Start. 21 m diepte. Zandgolfjes. Redelijk kaal, kamster. Hydroiedpoliepen. Mini pitvis. *Obelia longissima* (?). 2% *Lanice*. Zwemkrab, Roodkleurige poon, Zandribbels, 1% *Lanice*. Slangster, grote zeenaald

10.54 Zeenaald. Kale zandbodem, 1% *Lanice/Loimia*. Internetstoring op het land. Mogelijk wordt het schip opgeroepen. Was iets met defensie. Maar lijkt mee te vallen.

10:57 Slangster, zandribbels, 1% *Lanice*. Poon.

10:59 Schol/schar, pitvis, 1-5% *Lanice*, vrij homogeen. Patches met 20-30% *Lanice*.

11:05 Gewone strandkrab. Heuveltje. Zand, grover zand, meer schelpgruis.

11:07. Iets omhoog, *Lanice* 20%

11:08 ROV stopt.

ROV transect D-BRG-03

Figure 21. Loimia/Lanice low density reef, seastars, fish (sprat??).

We verwachten hier een homogeen gebied met wat *Lanice*.

11:48 Start camera. *Lanice* 10%, zand, zeesterren. ROV-kabel in beeld. Kamster, blauwpootzwemkrab, *Lanice*, kamster, slangsterren.

11:53 Slangsterren, 5% *Lanice*, zeester, zwemkrab, pitvissen, slangsterren, fluwelen zwemkrab, blauwpootzwemkrab, *Lanice* 5%

11:59 Zand, kleine golfjes, scharretje, veel slangsterren, paar per m^2, dode *Echinocardium cordatum*. Steeds 5 vissen in beeld, platvisjes. Zeesterren, *Lanice* 2%,

12:02 Zeenaald. Zand, 2% *Lanice*,

12:03 annotatie 'Bijzondere soort' = boxcore hap

12:05 Zeenaald. *Lanice* 10%. Kamster, zwemkrab sp.
Algemene indruk: zandig gebied, niet al te grote ribbels, *Lanice* 5-10%, .

12:09 Annotatie 'Bijzondere soort' = potentiele boxcore hap.
Zeenaald. Pitvis.

Conclusie: zandig gebied, *Lanice/Loimia* van weinig 1% tot 25, soms 50%. Veel slangsterren, zeesterren, vissen in beeld, pitvis, zwemkrab, molkreeften.
200 meter

3.3.2 Boxcore sampling

Op basis van ROV transect 1 en 3, 5 boxcore locaties met *Lanice* geselecteerd in gebied D (EPSG:25832-E; ETRS89, UTM32). Locaties met meetdienst doorgesproken en vaarplan gemaakt. Ze liggen dicht bij elkaar.

code	x	y
BS_BX18	317622	5946818
BS_BX19	317583	5946804
BS_BX20	316346	5947231
BS_BX21	316388	5947242
BS_BX22	316467	5947263

Boxcore 18 naar lab

13:15 boxcore 18 genomen. Water van de pomp doet het niet, dus we kunnen monster niet uitspoelen.

13:43 Opnieuw monster boxcore 18 genomen. 2x2.5L potjes. Medium course sediment

Boxcore 19 naar lab

14:00 Boxcore 19 sedimenttype ca 1 mm met schelpfragmenten.

Boxcore 20 naar lab

14:40 box 20. *Loimia* zit erin. Fijner zand dan 1 mm.

Boxcore 21 naar lab

14:58 box 21 niet zoveel organisch matieraal. *Loimia* (reuzenworm)

Boxcore 22 naar lab

15:20 box 22 veel organisch materiaal (zwart zand)
15:53 klaar. Op weg naar gebied A, voor groundtruthing.

Boxcore 23 soortenlijst

16:14 Boxcore 23 – monster voor ground truthing van de nieuwe akoestische data.
Fijn zand, alles door de zeef. Beetje schelpen. Soortenlijst:

- *Echinocardium cordatum* 1x
- *Nephtys sp.*
- Nereis elitoralis/Eunereis longissima 3x
- *Abra alba* 1x
- *Chamelea striatula* 1x
- *Ophiura ophiura* 1x

16:40 door naar punt box 25

Boxcore 25 soortenlijst

16:42 boxcore 25

- *Lanice* 39
- *Notomastus* 1
- Hydrozoa
- *Ophiura albida*
- *Ensis* sp juv 1
- *Ensis leei* 2x.
- *Nephtys* 1
- Pectinariidae sp. 1
- *Echinocardium* sp juv
- *Echinocardium.cordatum* 1
- *Venerupis corrugata* 1
- *Abra alba* 1
- *Fabulina fabula* 1
- Nemertea 1
- *Eteone sp.* 1
- *Macropodia* 1
- *Nereis elitoralis/Eunereis longissima* 2x

Boxcore 24 soortenlijst

17:20 Boxcore 24: Sediment: klei, fijn zand, schelpen.
Beestjes: gravende kreeften. Soortenlijst in telefoon. Klein krabbetje in de formaline gestopt.

- *Scolelepis 1*
- Pectinariidae *sp. 3*
- *Venerupis corrugata 2*
- *Glycera 3*
- *Lanice 1*
- *Cylista undata 1*
- *Upogebia deltaura 9*
- *Abra alba 7*
- *Loimia ramzega 3*
- *Ensis sp 1*
- *Nereis elitoralis/Eunereis longissima 3*

- *Ophira albida 1*
- Veneridae *juv 1*
- *Ensis magnus 1*
- *Ensis sp juv 1* 1?
- *Atelecyclus rotundatus* (1X) juveniel

18:00 Eten

18:20 Met meetploeg de route bepaald: eerst boxcore 8, dan 5, dan 13

Boxcore 8 naar lab
18:24 Boxcore 8. Fijn zand, alles valt erdoor. In een potje gestopt. Beetje schelpmateriaal. (reuzen)worm.

Boxcore 15 naar lab
19:15 Boxcore 5 fijn zand. Alles in een potje gedaan.

Boxcore 13 naar lab
20:00 Boxcore 13 fijn zand met silt. Laatste hap voor vandaag.
20:30 Klaar en zon onder

Side Scan Sonar Gebied B
21:00 SSS vis gaat erin. Timo heeft een gebied uitgekozen vlak onder Gemini windpark, met veel stenen aanwezig.

3.4 Donderdag 29 augustus 2024 (Gebied B: steenrif noord)

08:00 De hele nacht gescand. Resolutie lijkt lager dan van hydrografische dienst. ROV-lijntje over de stenen gepland.
08:55 ROV down

3.4.1 ROV transecten

ROV Transect B_BRG_01

Figure 22. Boulder, length ca 1.50 m (lasers are 50 cm apart).

We hoppen van steen naar steen. Watertemp 19 graden. Zandbodem.
09:03 Start opname. Koers 79 graden. Stroming komt van zijkant. Gladde zeesterren. Kleiige bodem. Hier ergens BOXCORE happen voor klei met megafuana.
09:05 Zeesterren, schepmateriaal, kei van 50 cm vol met *Metridium*, Noordzeekrab in het zand, fluwelen zwemkrab erboven op. Platvis. 2 *Lanice*.

09:08 2 keien, 40+ cm met zeesterren, fluwelen zwemkrabben, *Metridium*,
09:10 grondeltje, *Loimia*,
Eerste indruk: eerst kleiachtig spul, nu zandribbels.
09:12 Kale zandribbels. Platvis. Platvis. Zeesterren. Medium sand. Zeesterren. *Loimia*, heremietkreeften,
09:14 Zandribbels, veel heel gaten, Stenen 40 cm met beetje *Metridium*.
09:17 Dode platte oester
09:17 kei
09:19 kleiige bodem met schelpresten en veel gaten. Visjes in beeld.
09:20 kei 40cm. 2 Noordzeekrabben, fluwelen zwemkrab. *Metridium,* Pitvis
09:21 kamster, zeesterren, kokers, gaten in klei,
09:23 1.30 m, halfvol met *Metriudium*, fluwelen zwemkrab.
09:24 koker. Kokerwormen. Pitvis vrouwtje.
09:26 kokerwormen (*Lanice/Loimia*), pitvis. School visjes in beeld in beeld.
09:28 slecht beeld
09:29 stenenveld 10 cm
09:31 kabel zit even vast, achter steen. Even ontwarren.
09:34 stenenveld 5-10 cm diameter.
09:35 zandribbels, pitvis, platvis, Noordzeekrab
09:35 kei 80 cm, 50% door *Metridium*,
09:36 pitvis. Zandig,
09:37 steen met zeedonderpad, *Metridium*,
09:37 stenenveld 20 cm, kei, pitvis,Noordzeekrab, kamster, vlak sediment, gaten, pitvis,
09:40 zeesterren, pitvis 3x, kamster,

Conclusie: diepere delen: silt met gaten, stenen steenvelden, schelpresten. Hogere delen: zandribbels met 1% *Lanice/Loimia*.

09:43 Steen 50 cm, kaal, Noordzeekrab, zeester,
09:43 diverse stenen, kaal.
09:46 zandribbels, zand, zeesterren, *Loimia*,
09:51 kamster, schar, gewone zeester, kale zandbodem af en toe *Loimia*. Pitvis.
09:53 vlak sediment, gaten
09:54: Noordzeekreeft bij kei van 40 cm.

Algemene conclusie; iets dieper is siltig.
09:55 zandribbels, kaal, zeesterren.
09:57 grote kei, kreeft
09:58 ROV stopt.
10:00 nieuwe ROV-track bepaald. Over grover sediment met ribbels en fijner sediment, zo lijkt het.
Lichtere vlakken

ROV Transect B_BRG_02

Figure 23. B-BRG-02. Shell material

ROV in: 10:35

10:35 grind 2cm grof.

10:38 ROV-hap grind.

10:39 zand met grind, schelpmateriaal, klei. Pitvis, H1170. Zeesterren. Pitvis, Noordzeekrab

10:41 grof sediment, grind, schelpmateriaal. Pitvis. Kamster, zeester, gravel,

10:45 Kamster, *Luidia sarsii* zeester. Kamster, zeesterren, grondeltje, kamster, zeesterren veel, pitvis, pitvis man, pitvis, pitvis, harnasmannetje.

10:50 Zeesterren, zachte bodem. Verandering naar zacht zandig substraat. Heremietkreeft, kamster, kaal zand

10:52 Overgangszone. Pitvis, zeester. Af en toe *Loimia*, glad sediment. Meer zand. Kamsterren.

10:55 Terug naar grind, veel zeesterrren, kamster, veel zeesterren, pitvis, zeesterren, scharretje, goede plek voor oesterherstel, stenen, pitvissen,

10:57 Poon, mantelschelp (*Pectininae*)?, zeesterren, Noordzeekrab, platvissen, pitvissen,

11:00 overgang naar zandribbels, kaal. Er zitten wat gaten in. Kamster, gewone zeester, veel kleine zeesterren 3 cm, kamster, gewone zeester, grondeltje, kamster.

11:03 zand, oranje is zandgolven, kamster, zeester, platvis, vrij kale bodem,

11:08 harnasmannetje, zeesterren, kaal zand -32 m diep. Zand, kaal, af en toe een gat, zeesterren.

11:11 richting de overgang. Van kaal zand met golven met zeesterren en een paar gaten.

11:12 pitvis, krab, grind, silt klei met beetje grind. Silt met fijn schelpgruis. Grind schelpgruis, duidelijk minder grind en schelpgruis aan de oppervlakte als net. Pitvis, zeesterren, pitvis, schepgruis, dode *Ensis*, zeester.

11:16 Overgang. Kaal zand, zandribbels, pitvis, stuk omhoog, zandribbels.

Einde ROV track.

ROV Transect B_BRG_03

Figure 24. ROV BRG 03: shell fragments and Lanice/Loimia.

11:47 ROV track 3 B_BRG_03
ROV down
11:50 schelpen, *Lanice/Loimia*. Bodem is vol met structuur. Harde reflectie. Slibanemoon, pitivs, kamster, rif H1170.
11:53 dood schelpmateriaal, grote heremietkreeft, kamster zeesterren. Mogelijk. Minder schelpenfragmenten.
11:55 Zeester, *Lanice* kokers,
11:56 Mannetjespitvis, zeester.
11:57 Vlakker sediment. Zandribbels. Kamster. Rode deel op mulitbeam plaatje is dus zand.
12:01 Pitvis, veel zand, zand, ribbels, af en toe een *Loimia*, af en toe zeester, een kamster, we gaan nu 0.3m per seconde om even op te schieten.
12:02 overgangetje. Zand met zandribbels. Krab. Schol. Kamster
12:03 af en toe een koker paar per m2. Fijn zand, vlak.
12:07 Kei, zeezonderpad, 1 Noordzeekrab, Blauwpootzwemkrab.
12:09 Plat, slikkig, grondels, paar schelpresten, beetje *Lanice* 1%. Pitvis.
12:12 stop

3.4.2 Boxcore sampling

13:02 Met RWS planner de route bepaald: volgorde boxcores: 27, 26, 28, 6, 1, 9

Boxcore 27 soortenlijst
13:11 Boxcore 27.

- Vuurstenen, fijn zand, gravende kreefjes, schelpen.
- Heel veel schelpen, grotere stenen 3 tot 20 cm
- *Upogebia deltaura 24*
- *Abra alba 40*
- *Notomastus sp. 1*
- *Loimia 6*
- *Pectinariidae sp. 2*
- ***Sabellaria spinolusa levend*** *1*
- *Polititapes rhomboides (3X, waarvan 2 volwassen en 1 juveniel)*
- *Lutraria lutraria (1X) juveniel (op foto)*
- *Nereidinae 1*
- *Glycera sp 2*
- *Polynoidae 1*
- *Dosinia exoleta (1X)*

Boxcore 26 soortenlijst

13:30 Box 26 heel veel dood schelpmateriaal, veel abra.

- Gezeefd over 4mm vierkante gaten i.p.v. 1 mm!
- *Abra alba 26*
- *Echinocardium juv 3*
- *Loimia ramzega 3*
- *Lucinoma borealis 1*
- *Glycera sp.1*
- *Upogebia deltaura 2*

Boxcore 28 soortenlijst

14:16 Box 28. Fijn zand, enkele kokers. Zand 1mm zeef

- *Gilvossius tyrrhenus 1*
- *Nephtys sp. 3*
- *Loimia ramzega 2*
- *Corystes cassivelaunus 1*
- Spionidae 1
- Cephalochordata 1

Boxcore 06 naar lab

14:38 Box 6 zandmonster Sander. 3 *Upogebia's*. Gaan mee naar lab.

Boxcore 01 soortenlijst

15:07 Boxcore 1

- Fijn zand,klein beetje klei/silt
- *Upogebia deltaura 2*
- *Echinocardium sp. juv. 1*
- *Gilvossius tyrrhenus 2*
- *Lanice 1*
- *Nereis elitoralis/Eunereis longissima 1*
- *Abra alba 1*
- *Chamelea striatula 1*
- *Lutraria lutraria* 1

Boxcore 09 naar lab

15:42 box 9 meenemen naar lab.

16:00 Varen naar volgende bestemming. Besloten om de rest van de boxcores ook te doen in het zuiden. Met vaarploeg vaarroute bepaald. Volgende Boxcore punten: 12-10-3-11. Zo hebben we de meeste punten voor de BISI EUNIS habitats te pakken.

Boxcore 12 soortenlijst

17:05 boxcore 12. Zand, veel jonge *Echinocardium*: 139 in deze boxcore

- *Liocarcinus holsatus 1*
- *Echinocardium cordatum juv 139*
- *Lanice 8*
- *Owenia sp. 8 klein*
- *Lutraria lutraria 1*
- *Nephtys 3*
- Pectinariidae *sp 1*
- *Ophiura albida 2*
- *Gilvossius tyrrhenus 1*
- *Notomastus sp 1*

Boxcore 10 naar lab

18:00 box 10 in een potje gestopt. Fijn tot medium zand

Boxcore 3 soortenlijst
18:36

- Zware klei met beetje fijn zand en schelpgruis
- *Thia scutellata 1*
- *Gilvossius tyrrhenus 1*
- *Nephtys spp 2*
- Nereidinae 1

Boxcore 11 soortenlijst
19:16

- fijn zand
- *Echinocardium cordatum volw 1*
- *Echinocardium juv 5*
- *Fabulina fabula 2*
- *Nephtys sp. 1*

4 Acoustic surveys

Three areas (A, B and D) were surveyed by side scan sonar (SSS) and multibeam echosounder (MBES). Area A and B was assumed to be H1170 reef. Area A was surveyed during the first night and Area B during the third night of the trial. The historic SSS data from the Hydrographic office already indicated the presence of rocks on the seabed and consequently the surveyed area were chosen to cover the rock fields. These datasets were acquired roughly in the years between 2008 and 2013. Since rocks are relatively stationary on these time scales, the likelihood to relocate the rocks were considered high. Based on the findings in the Hydrographic office datasets the originally planned survey areas, also outlined in the trial report, were slightly modified and adapted. Area D was assumed to be a *Lanice* field. The historic SSS data and SSS data from the so called “ankergebied”, which overlaps with Area D and is yearly survey by the ARCA, showed promising acoustic patterns for *Lanice* fields. The survey area D was accordingly adapted. The data was acquired in the second night and further extended in evening of the fourth day. These new and old datasets were processed on board of the ARCA with SonarWiz.

4.1 Area A stony reef

Area A is located in the south-east of the Borkum Stones, where previously a H1170 reef was mapped. The surveyed area is 3.2 x 1.7 km with a water depth between 22 and 27 m (Figure 25, top). Due to the transit to the Borkum Reef Grounds on the first day, the survey of area A was started around midnight and therefore the total size of the surveyed area is slightly smaller than in area B and D. Since the water depth is deeper than for example in Area D, the original track line spacing of 100 m was kept compared to area D where the spacing was reduced to 70 m. High MBES backscatter variability was observed indicating a heterogenous sediment in the area (Figure 25, middle). This observation was also confirmed by boxcore samples and video recordings. This should facilitate the creation of a sediment map from the MBES backscatter. In addition, several rocky areas were detected. An example for a rock field is given in Figure 26.

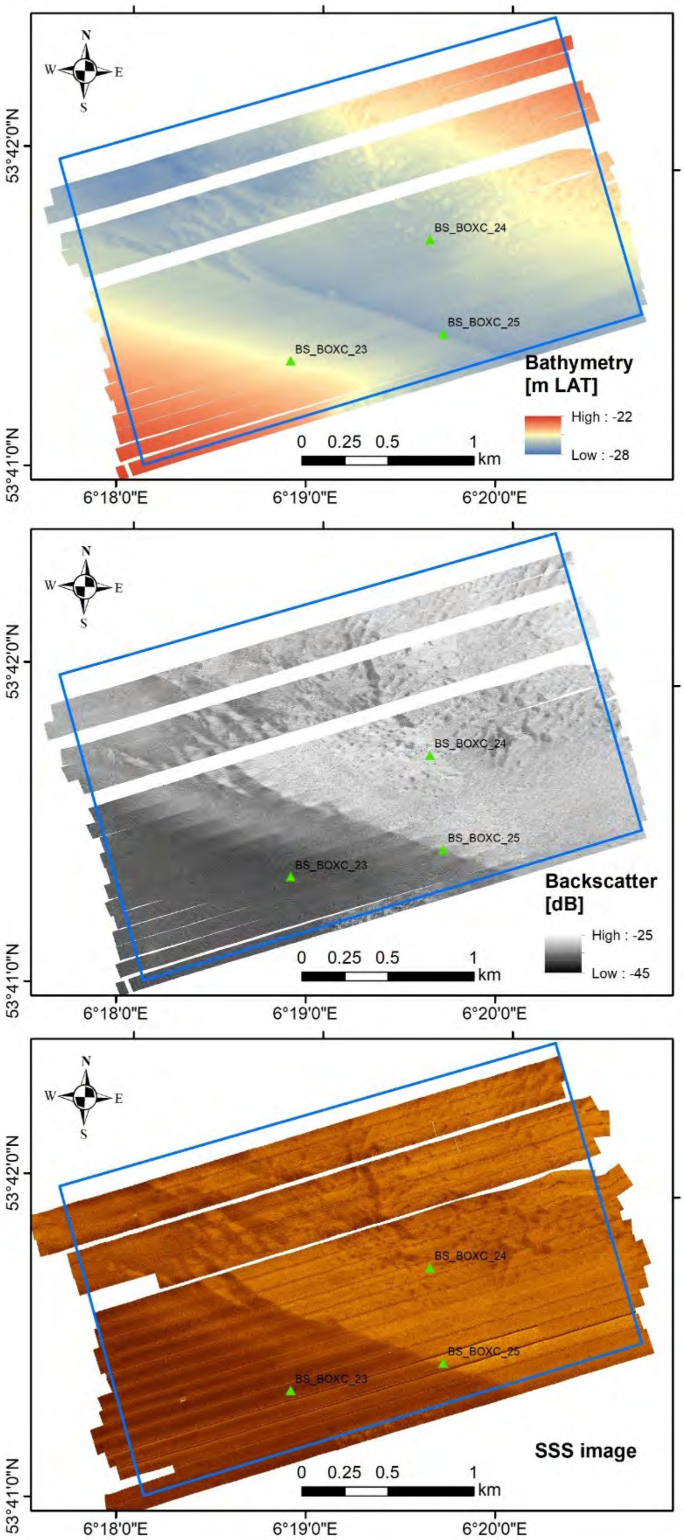


Figure 25. Acoustic data acquired in survey area A. (Top) MBES bathymetry with a grid resolution of 50 x 50 cm. (Middle) MBES backscatter with a grid resolution 25 x 25 cm and (bottom) SSS backscatter with a grid resolution of 10 x 10 cm. The data is processed in QPS Qimera, QPS FMGT Geocoder and SonarWiz, respectively. Boxcore samples are shown by green triangle.

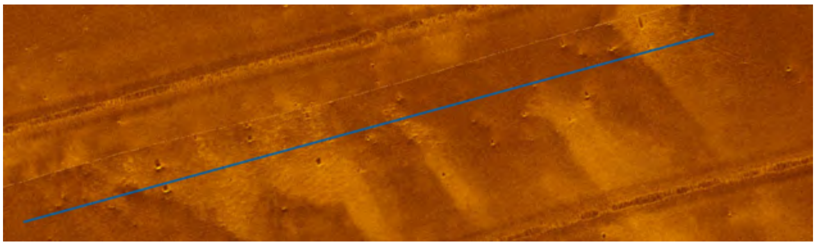


Figure 26. SSS backscatter image indicating several rocks on the seabed in survey Area A. The rocks are visible via the dark acoustic shadow behind the bright high reflectivity spot.

4.2 Area B stony reef

Area B is located in the north of the Borkum Stones, where previously a potential H1170 reef was mapped. The surveyed area is 3.8 x 2.0 km with a water depth between 28 and 34 m. This survey area is slightly larger than Area A because the survey started around 20.00. Since the water is relatively deep, the original track line spacing of 100 m was kept. High MBES backscatter variability, similar to area A, was observed indicating a heterogenous sediment in the area. This observation was also confirmed by Box core samples and video recordings. In addition, several rocky areas were detected. Figure 28 shows an example of a rocky area with several stones on the seabed.

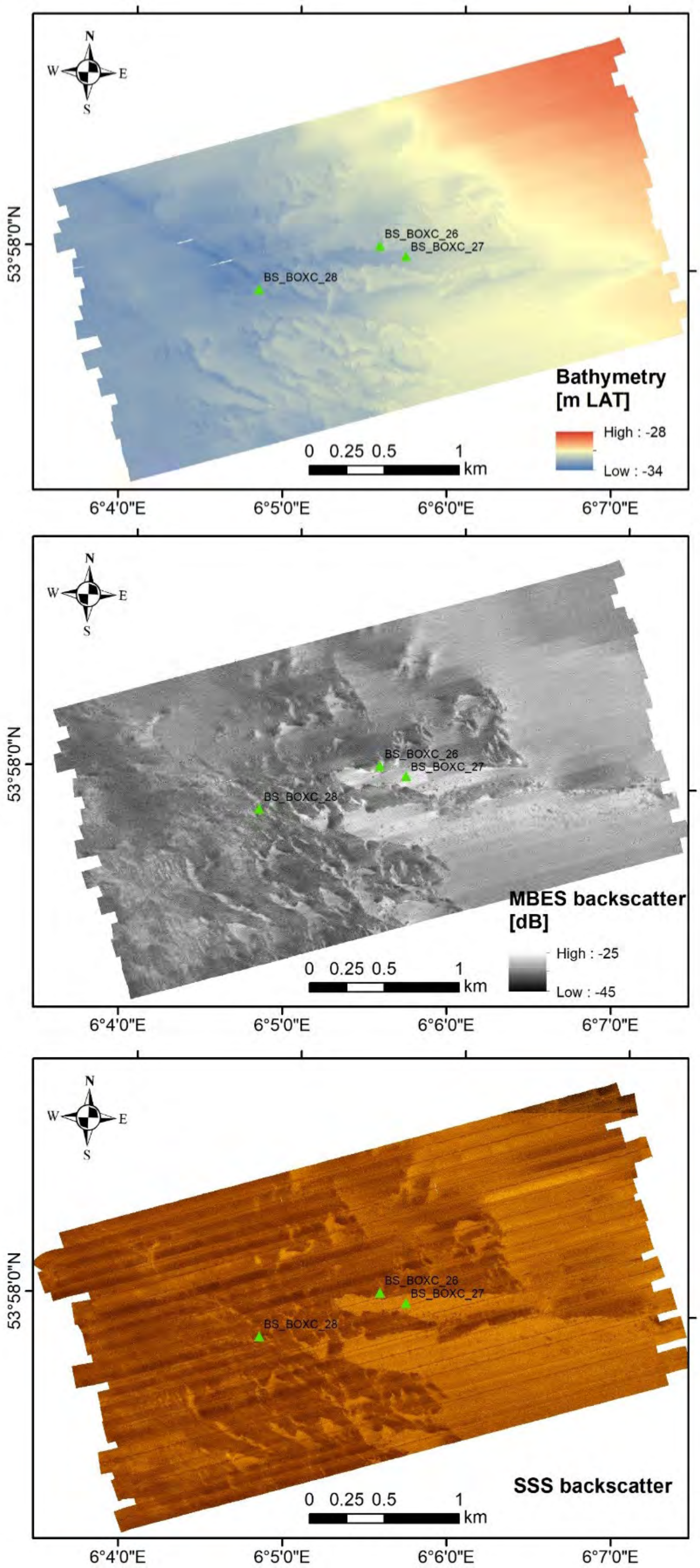


Figure 27. Acoustic data acquired in survey area B. (Top) MBES bathymetry with a grid resolution of 50 x 50 cm. (Middle) MBES backscatter with a grid resolution 25 x 25 cm and (bottom) SSS backscatter with a grid resolution of 10 x 10 cm. The data is processed in QPS Qimera, QPS FMGT Geocoder and SonarWiz, respectively. Box core samples are shown by green triangle.

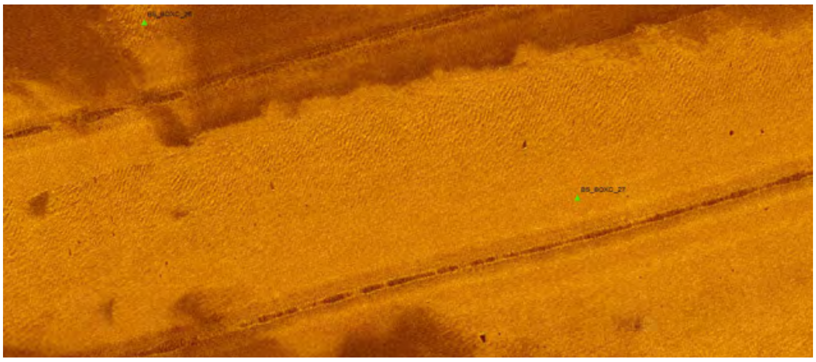


Figure 28. SSS backscatter image indicating several rocks on the seabed in survey Area B. The rocks are visible via the dark acoustic shadow behind the bright high reflectivity spot. See Figure 27 for geographical orientation using the boxcore sample location.

4.3 Area D *Lanice* reef (south)

Area D is located in the south-west of the Borkum Stones, where previously *Lanice* reefs were mapped. The surveyed area is 6.0 x 1.2 km with a water depth between 19 and 25 m. The shallower water depth leaded to the decision to decrease the track line spacing to 70 m to still have fill coverage of the MBES data. Since the ground range of the SSS was still fixed to 75 m, as it was done in the other areas, a higher overlap of the SSS data was achieved. The variation in the MBES backscatter was significantly lower than in Area A and B indicating a more homogeneous properties of the seabed. A large area with interesting acoustic patterns in the SSS backscatter and MBS bathymetry (Figure 30) were observed. The video recordings revealed that this area is linked to *Lanice/ Loimia* fields.

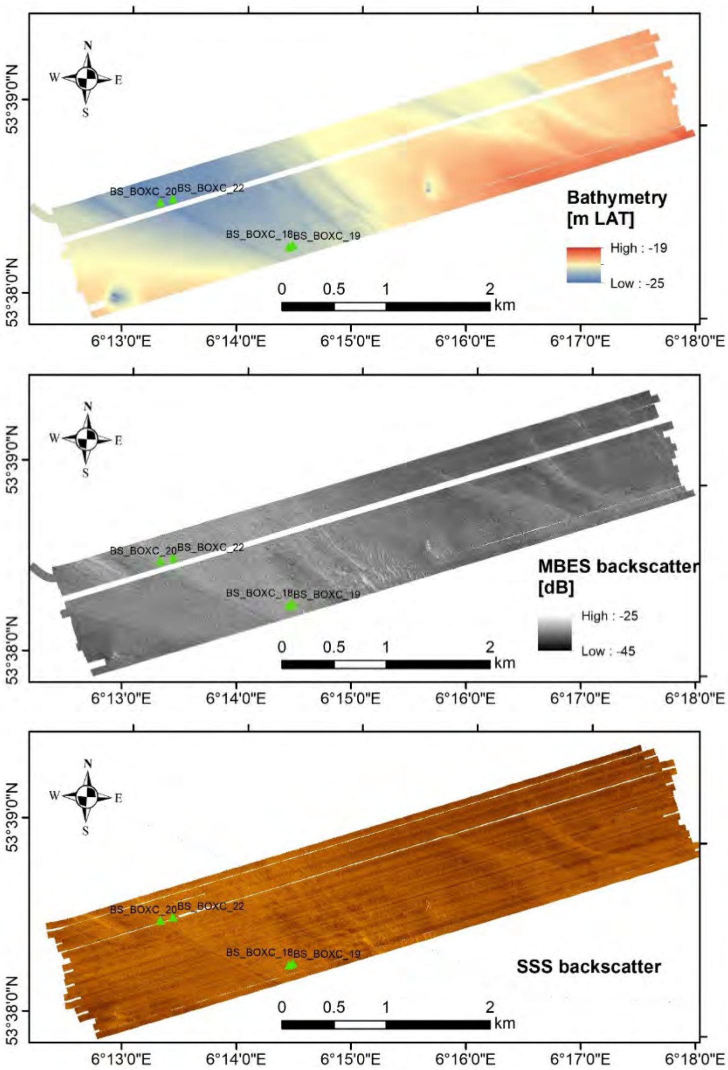


Figure 29. Acoustic data acquired in survey area D. (Top) MBES bathymetry with a grid resolution of 50 x 50 cm. (Middle) MBES backscatter with a grid resolution 25 x 25 cm and (bottom) SSS backscatter with a grid resolution of 20 x 20 cm. The data is processed in QPS Qimera, QPS FMGT Geocoder and SonarWiz, respectively. Box core samples are shown by green triangle.

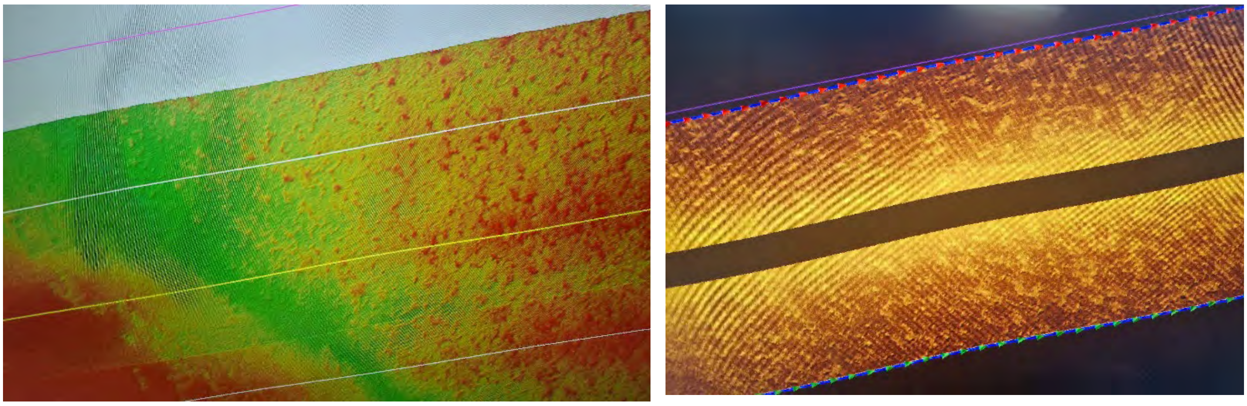


Figure 30. (right) MBES bathymetry and (left) SSS backscatter indicating the presence of Lanice.

5 ROV surveys

5.1 Area A stony reef (south)

Figure 31. Boulder covered with hydroids, European lobster (Homarus gammarus), shell fragments.

Figure 32. Boulder covered two fig sponges (Suberites ficus, vijgspons) and hydroids

Figure 33. Trisopterus luscus (bib, steenbolk)

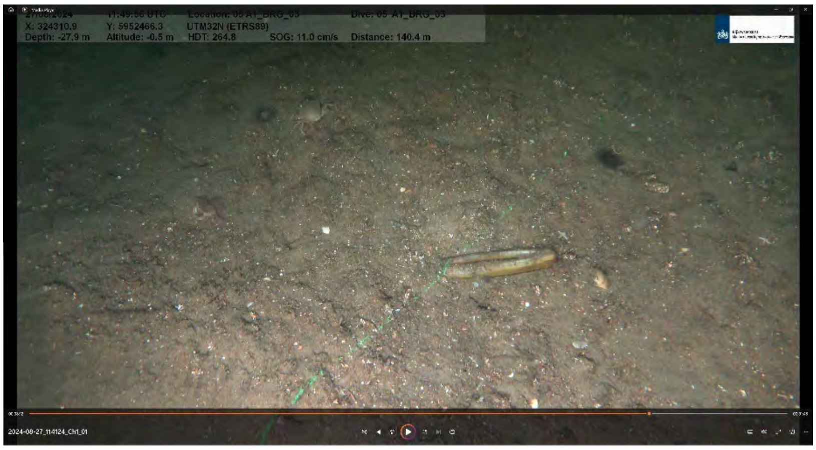


Figure 34. Course material

Figure 35. Boulder covered with plumose anemone (Metridium dianthus, zeeanjelier). Lots of dead shell material on the seafloor.

Figure 36. Dead shell material (Ensis sp.) at the base of the boulder.

Figure 37. Lanice/Loimia reef, low density.

Figure 38. Medium sand, Ensis sp shells.

5.2 Area D *Lanice/ Loimia* reef (south)

Figure 39. Low density reef

Figure 40. Low density reef

Figure 41. Medium density reef

Figure 42. Low density reef (and horse mackerel Trachurus trachurus)

Figure 43. Low density reef

Figure 44. Medium density reef

Figure 45. Low density reef, shell fragments.

5.3 Area B stony reef (north)

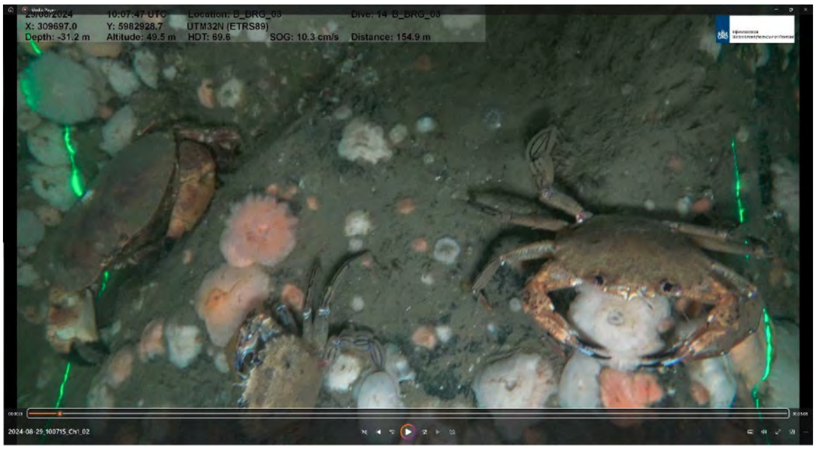


Figure 46. Close-up of North Sea crab and two velvet swimming crabs (Necora puber, fluwelen zwemkrab) and plumose anemone (Metridium dianthus, zeeanjelier).

Figure 47. Sandy seafloor with some Lanice/Loimia tubes.

Figure 48. Sand ribbles, shell fragments

Figure 49. Stoney/sandy seafloor. Shell fragments.

Figure 50. Low density Lanice/Loimia reef

Figure 51. Boulder

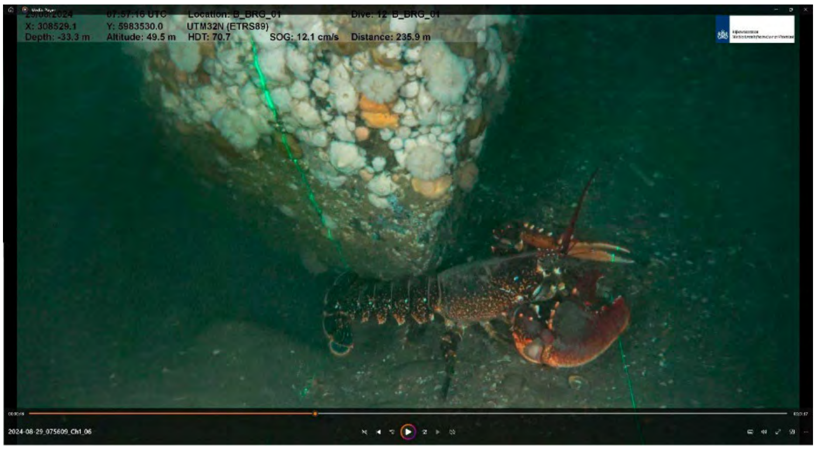


Figure 52. Lobster and boulder covered with plumose anemone (Metridium dianthus, zeeanjelier)

Figure 53. Gravelley seafloor, dead shell material.


Figure 54. Gravelly seafloor, shell fragments, some tube worms.


Figure 55. Gravelly seafloor, shell fragments, common seastars


Figure 56. Sand ribbels and holes marking biological activity.

Figure 57. Lanice/Loimia on a sandy seafloor.

6 Boxcore survey

A map of the boxcore stations is given in (Figure 3) and an overview of boxcore samples in Table 1 (photos per sample), in Table 2 (metadata) and Table 3 (species biodiversity).

Table 1. Overview of boxcores before and after sieving.

Nr	Boxcore	Before sieving	After sieving
1	BS_BOXC_01		
3	BS_BOXC_03		
4	BS_BOXC_04	No photo	
5	BS_BOXC_05		

6	BS_BOXC_06		
7	BS_BOXC_07	No photo	no photo
8	BS_BOXC_08		
9	BS_BOXC_09	No photo	
10	BS_BOXC_10		
11	BS_BOXC_11		

12	BS_BOXC_12		
13	BS_BOXC_13		
14	BS_BOXC_14	No photo	
15	BS_BOXC_15	No photo	No photo
16	BS_BOXC_16	No photo	No photo
17	BS_BOXC_17		
18	BS_BOXC_18 Lab, prioriteit hoog		

19	BS_BOXC_19		
20	BS_BOXC_20 (lab, prioriteit hoog)		
21	BS_BOXC_21		
22	BS_BOXC_22 (lab: prioriteit hoog)		
23	BS_BOXC_23		

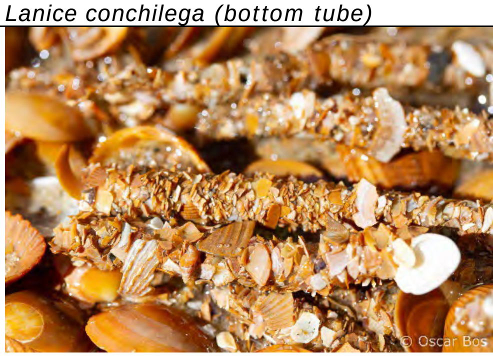
24	BS_BOXC_24		
25	BS_BOXC_25		
26	BS_BOXC_26		
27	BS_BOXC_27a		
27	BS_BOXC_27b		

28	BS_BOXC_28		

Table 2. Overview of boxcores

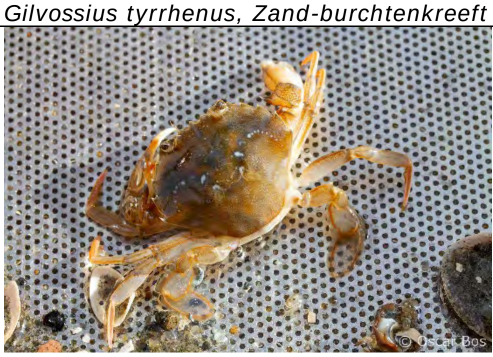
Locatie	Gebied	Datum	Starttijd	Eindtijd	Opmerking	Aan boord uitgezocht	Naar benthos-lab WMR	Zeef
			local time	local time		ja/nee	ja/nee	1 mm rond of 4 mm vierkant
BS_BOXC_16	AreaA	27-08-24	17:00	17:10	Loimia	NEE	JA	
BS_BOXC_14	NVT	27-08-24	18:05	18:15	zand	NEE	JA	1 mm rond
BS_BOXC_04	NVT	27-08-24	18:55	19:10	zand	NEE	JA	1 mm rond
BS_BOXC_18	AreaD	28-08-24	13:12	15:05	Medium course sediment	NEE	JA	1 mm rond
BS_BOXC_19	AreaD	28-08-24	14:00	14:015	ca 1 mm zand met schelpfragmenten	NEE	JA	1 mm rond
BS_BOXC_20	AreaD	28-08-24	14:30	14:41	Fijner zand dan 1 mm	NEE	JA	1 mm rond
BS_BOXC_21	AreaD	28-08-24	14:46	15:00	weinig organisch materiaal	NEE	JA	1 mm rond
BS_BOXC_22	AreaD	28-08-24	15:12	15:26	veel organisch materiaal (zwart zand)	NEE	JA	1 mm rond
BS_BOXC_23	AreaA	28-08-24	16:11	16:26	Fijn zand, alles door de zeef	JA	NEE	1 mm rond
BS_BOXC_25	AreaA	28-08-24	16:39	16:48		JA	NEE	1 mm rond
BS_BOXC_24	AreaA	28-08-24	17:03	17:15	klei, fijn zand, schelpen	JA	NEE	1 mm rond
BS_BOXC_08	NVT	28-08-24	18:24	18:27	Fijn zand, alles valt erdoor	NEE	JA	1 mm rond
BS_BOXC_05	NVT	28-08-24	19:15	19:19	fijn zand.	NEE	JA	1 mm rond
BS_BOXC_13	NVT	28-08-24	19:56	19:59	fijn zand met silt	NEE	JA	1 mm rond
BS_BOXC_27	AreaB	29-08-24	13:01	13:14	gravel, rocks, silt, shells	JA	NEE	
BS_BOXC_26	AreaB	29-08-24	13:18	13:31	gravel, shells, silt.	JA	NEE	4 mm vierkant
BS_BOXC_28	AreaB	29-08-24	14:06	14:25	fijn zand	JA	NEE	1 mm rond
BS_BOXC_6	NVT	29-08-24	14:37	14:43		NEE	JA	
BS_BOXC_1	NVT	29-08-24	15:05	15:15	fijn zand, beetje klei	JA	NEE	1 mm rond
BS_BOXC_9	NVT	29-08-24	15:45	15:47		NEE	JA	1 mm rond
BS_BOXC_12	NVT	29-08-24	17:12	17:19	zand, veel jonge Echnocardium cordatum	JA	NEE	1 mm rond
BS_BOXC_10	NVT	29-08-24	18:05	18:15		NEE	JA	4 mm vierkant
BS_BOXC_03	NVT	29-08-24	18:35	18:40	vette klei	JA	NEE	
BS_BOXC_11	NVT	29-08-24	19:10	19:20	fijn zand	JA	NEE	1 mm rond

Table 3. Overview of species encountered in the boxcores (not all species have been photographed).

	Species	
	Echinoderms	
	 *Echinocadium cordatum*, hartegel, sea potato	 *Echinocadium cordatum*, hartegel, sea potato
	 *Echinocadium cordatum*, hartegel, sea potato	 *Echinocadium cordatum*, hartegel, sea potato
	Polychaetes	
	 *Lanice conchilega/Loimia ramzega*	 *Loimia ramzega (upper two tubes) and Lanice conchilega (bottom tube)*
	 *Lanice conchilega, schelpkokerworm, sand mason*	 *Lanice conchilega/Loimia ramzega*

	 *Lepidonotus squamatus, geschubde zeerups, twelve-scaled worm*	 *Sabellaria spinulosa, Gestekelde zandkokerworm, Ross worm* on a shell
	Bivalves	
	 *Ensis leei, Amerikaanse zwaardschede, American jack knife clam*	
	 *Lutraria lutraria,* Otterschelp, Otter shell	 *Lutraria lutraria,* Otterschelp, Otter shell
	 Tapijtschelp, pullet carpet shell, *Venerupis corrugata*	 *Lutraria lutraria,* Otterschelp, Otter shell

	 *Lutraria lutraria,* Otterschelp, Otter shell	 *Polititapes rhomboides, Gevlamde tapijtschelp, banded carpet shell*
	 *Dosinia exoleta,* Gewone artemisschelp, rayed artemis	 *Dosinia exoleta,* Gewone artemisschelp, rayed artemis
	 *Aporrhais pespelecani,* Pelikaansvoetje, Pelican's foot	 *Ostrea edulis,* Fossiele platte oesterschelp, (Fossil) European flat oyster
	Crustaceans	
	 *Upogebia deltaura*	 *Upogebia deltaura*

	 *Corystes cassivelaunus,* Helmkrab vrouwtje met eieren, Helmet crab female with eggs	 *Corystes cassivelaunus,* Helmkrab vrouwtje met eieren, Helmet crab female with eggs
	 *Gilvossius tyrrhenus, Zand-burchtenkreeft*	
	 *Polybius holsatus, gewone zwemkrab, common swimming crab*	

Wageningen Marine Research levert met kennis, onafhankelijk wetenschappelijk onderzoek en advies een wezenlijke bijdrage aan een duurzamer, zorgvuldiger beheer, gebruik en bescherming van de natuurlijke rijkdommen in zee-, kust- en zoetwatergebieden.

De missie van Wageningen University & Research is ‘To explore the potential of nature to improve the quality of life’. Binnen Wageningen University & Research bundelen Wageningen University en gespecialiseerde onderzoeksinstituten van Stichting Wageningen Research hun krachten om bij te dragen aan de oplossing van belangrijke vragen in het domein van gezonde voeding en leefomgeving. Met ongeveer 30 vestigingen, 7.700 medewerkers (7.000 fte), 2.500 PhD- en EngD-kandidaten, 13.100 studenten en ruim 150.000 Leven Lang Leren-deelnemers behoort Wageningen University & Research wereldwijd tot de aansprekende kennisinstellingen binnen haar domein. De integrale benadering van de vraagstukken en de samenwerking tussen verschillende disciplines vormen het hart van de unieke Wageningen aanpak.

Annex E Benthos biodiversity

Table E1. Taxa/species list per habitat (box cores and video combined).

			Habitat				TAXA	SPECIES
Phylum	Class	Taxa-species	H1170_sand	H1170-rocks	Lanice/Loimia	sand		
Annelida								
	Clitellata							
		Clitellata			1	1	1	
	Polychaeta							
		Aonides paucibranchiata			1		1	1
		Capitella			1	1	1	
		Chaetozone christiei			1	1	1	1
		Eteone	1				1	
		Eteone flava			1	1	1	1
		Eulalia viridis			1		1	1
		Eumida			1	1	1	
		Eunereis longissima			1	1	1	1
		Gattyana cirrhosa			1		1	1
		Glycera	1				1	
		Glyceridae			1		1	
		Goniadidae			1	1	1	
		Harmothoe glabra			1	1	1	1
		Hypereteone foliosa			1	1	1	1
		Lagis koreni			1	1	1	1
		Lanice conchilega	1		1	1	1	1
		Loimia ramzega	1		1		1	1
		Magelona			1		1	
		Magelona alleni				1	1	1
		Magelona filiformis			1	1	1	1
		Magelona johnstoni			1	1	1	1
		Malmgrenia arenicolae			1		1	1
		Mediomastus fragilis			1		1	1
		Microphthalmus			1		1	
		Myrianida			1		1	
		Nephtys	1		1	1	1	
		Nephtys assimilis				1	1	1
		Nephtys caeca			1	1	1	1
		Nephtys cirrosa				1	1	1
		Nephtys hombergii			1	1	1	1
		Nereididae	1		1	1	1	
		Nereis elitoralis	1				1	1
		Notomastus latericeus	1		1	1	1	1
		Ophelia			1		1	
		Ophelia borealis			1	1	1	1
		Owenia			1	1	1	
		Pectinariidae	1			1	1	
		Pholoe baltica			1	1	1	1
		Phyllodoce mucosa			1		1	1
		Phyllodoce rosea			1		1	1
		Phyllodocidae			1	1	1	
		Podarkeopsis helgolandicus				1	1	1
		Poecilochaetus serpens			1	1	1	1
		Polynoidae	1		1	1	1	
		Sabellaria spinulosa	1				1	1
		Scalibregma inflatum				1	1	1
		Scolelepis	1		1		1	
		Scolelepis (Scolelepis) foliosa				1	1	1
		Scolelepis bonnieri			1		1	1
		Scoloplos armiger			1	1	1	1
		Sigalion mathildae			1	1	1	1
		Spio decorata			1	1	1	1
		Spio symphyta			1		1	1
		Spionidae	1				1	
		Spiophanes bombyx			1	1	1	1
		Terebellidae			1	1	1	
Arthropoda								
	Malacostraca							
		Akanthophoreus gracilis			1	1	1	1
		Ampelisca brevicornis			1		1	1
		Aora gracilis			1		1	1
		Aoridae			1		1	
		Argissa hamatipes				1	1	1
		Atelecyclus rotundatus	1				1	1
		Bathyporeia				1	1	
		Bathyporeia elegans				1	1	1
		Callianassa subterranea				1	1	1
		Callianassidae			1	1	1	
		Cancer pagurus	1	1			1	
		Corophiidae			1		1	
		Corystes cassivelaunus	1				1	1
		Decapoda				1	1	
		Diastylis goodsiri				1	1	1
		Diastylis lucifera				1	1	1
		Diogenes	1				1	
		Gilvossius tyrrhenus	1		1	1	1	1
		Homarus gammarus	1	1			1	1

		Iphinoe trispinosa			1	1	1	1
		Ischyroceridae			1		1	
		Leucothoe				1	1	
		Leucothoe incisa			1	1	1	1
		Liocarcinus			1		1	
		Macropodia	1	1			1	
		Megaluropus agilis			1	1	1	1
		Melitidae			1		1	
		Microprotopus maculatus			1		1	1
		Monocorophium acherusicum			1		1	1
		Necora puber	1	1			1	1
		Pagurus bernhardus	1				1	1
		Palaemon	1	1			1	
		Pariambus typicus			1		1	1
		Perioculodes longimanus				1	1	1
		Photis longicaudata			1		1	1
		Phtisica marina			1		1	1
		Polybius	1	1			1	
		Polybius holsatus				1	1	1
		Pontocrates altamarinus			1	1	1	1
		Processa			1	1	1	
		Thia scutellata			1	1	1	1
		Upogebia deltaura	1			1	1	1
		Urothoe poseidonis			1	1	1	1
	Thecostraca							
		Balanomorpha	1				1	
		Balanus		1			1	
Bryozoa								
	Gymnolaemata							
		Conopeum reticulum			1	1	1	1
		Electra pilosa	1	1	1		1	1
Chordata								
	Leptocardii							
		Branchiostoma lanceolatum	1				1	1
	Teleostei							
		Agonus cataphractus	1				1	1
		Callionymus lyra	1	1			1	1
		Cottidae	1	1			1	
		Limanda limanda	1				1	1
		Mullus surmuletus	1				1	1
		Pholis gunnellus	1	1			1	1
		Pleuronectiformes	1				1	
		Pomatoschistus	1	1			1	
		Trisopterus luscus	1	1			1	1
Cnidaria								
	Hexacorallia							
		Actiniaria	1	1	1		1	
		Cylista troglodytes	1	1			1	1
		Metridium senile	1	1			1	1
		Sagartia undata	1	1			1	1
		Sagartiidae	1	1			1	
		Synarachnactis lloydii	1				1	1
	Hydrozoa							
		Bougainvilliidae			1		1	
		Campanulariidae			1	1	1	
		Hydrozoa	1				1	
		Obelia			1	1	1	
		Obelia bidentata			1		1	1
		Tubulariidae	1	1		1	1	
	Octocorallia							
		Alcyonium digitatum	1	1			1	1
Echinodermata								
	Asteroidea							
		Asterias rubens	1	1	1		1	1
		Astropecten irregularis	1				1	1
	Echinoidea							
		Echinocardium cordatum	1		1	1	1	1
		Spatangoida	1		1	1	1	
	Ophiuroidea							
		Ophiura	1		1		1	
		Ophiura albida	1		1	1	1	1
		Ophiura ophiura	1				1	1
		Ophiuroidea			1	1	1	
Hydrozoa/Bryozoa							1	
		Hydrozoa/Bryozoa	1	1			1	
Mollusca								
	Bivalvia							
		Abra			1		1	
		Abra alba	1		1	1	1	1
		Abra prismatica			1	1	1	1
		Bivalvia				1	1	
		Chamelea striatula	1		1	1	1	1
		Dosinia exoleta	1				1	1
		Ensis	1		1	1	1	
		Ensis leei	1		1		1	
		Ensis magnus	1		1		1	

		Fabulina fabula	1		1	1	1	1
		Kurtiella bidentata			1	1	1	1
		Lucinoma borealis	1				1	1
		Lutraria lutraria	1			1	1	1
		Mulinia lateralis				1	1	1
		Nucula				1	1	
		Nucula nitidosa				1	1	1
		Phaxas pellucidus			1		1	1
		Tellimya ferruginosa			1	1	1	1
		Tellinidae			1		1	
		Thracia				1	1	
		Varicorbula gibba				1	1	1
		Veneridae	1				1	
		Venerupis corrugata	1		1		1	1
	Gastropoda							
		Crepidula fornicata			1		1	1
Nemertea								
		Nemertea	1		1	1	1	
Phoronida								
		Phoronida			1	1	1	
Platyhelminthes								
		Platyhelminthes				1	1	
Porifera								
	Demospongiae							
		Suberites ficus	1	1			1	1
	Porifera		1	1			1	

Table E1. Video data Areas A and B: biodiversity of the sandy seafloor (in between the stones). Numbers and SACFOR categories per taxa for the sediment between the stones in the stony reef areas A and B, based on 3 minutes video analysis per 10 min video. Estimates of covered surfaces are given (m2). Codes refer to video transects (A=area A, BRG= Borkum Reef Grounds, _01 = transect 1, etc.).

Species/taxa	A1_BRG_01	SACFOR 51 - 76,5 m2	A1_BRG_03	SACFOR 54 - 81 m2	A1_BRG_04	SACFOR 9 - 13,5 m2	B_BRG_01	SACFOR 78 - 117 m2	B_BRG_02	SACFOR 27 - 40,5 m2	B_BRG_03	SACFOR 27 - 40,5 m2	taxa	species
Asterias rubens	148	C	291	C	74	C	254	C	254	C	83	F - O	1	1
Astropecten irregularis			1	O - R			7	O - R	12	F - O	6	O - R	1	1
Ophiura albida	2	O	8	O - R									1	1
Ophiura sp.									1	O - R			1	0
Cancer pagurus	7	F - O					9	C - F			1	F - O	1	1
Homarus gammarus	1	F - O	1	F - O			2	F - O					1	1
Pagurus bernhardus							1	O - R	1	O - R	1	O - R	1	1
Diogenes sp.			2				1	O - R					1	0
Polybius sp.	13	F - O	26	F - O	16	C	4	O	1	O - R	1	O - R	1	0
Necora puber	17	F	14	F	1	C - F	19	F			1	O - R	1	1
Palaemon sp.	11	F - O											1	0
Macropodia sp.	4	R											1	0
Balanomorpha							6						1	0
Cylista troglodytes	49	R	112	O	54	O	3	RR			1	RR	1	1
Cerianthus lloydii					2	R							1	1
Sagartia undata	6												1	1
Sagartiidae	5												1	0
Metridium senile	14						14				2		1	1
Actiniaria	16						3		2				1	0
Hydrozoa	19												1	0
Hydrozoa/Bryozoa	14						1		3		1		1	0
Tubulariidae	2												1	0
Alcyonium digitatum	6												1	1
Electra pilosa	14		3										1	1
Porifera	5						3						1	0
Suberites ficus	2												1	1
Cottidae	3						6						1	0
Pholis gunnellus	3				1								1	1
Trisopterus luscus	1												1	1

Limanda limanda	2		3				13		2		2		1	1
Pomatoschistus sp.	5						7		1		3		1	0
Callionymus lyra	4		2		6		16		1		5		1	1
Mullus surmuletus					1								1	1
Pleuronectiformes							4						1	0
Agonus cataphractus									2				1	1
TOTAL													35	20

Table E2. Video data Areas A and B: biodiversity of the stones: Numbers and SACFOR categories per taxa for the stones in the stony reef areas A and B, based on 3 minutes video analysis per 10 min video. Dark blue: a transect. Light blue: video within a transect.

Position	Min. analysed	Video file	M. senile	Hydrozoa/Bryozoa	Tubulariidae	E. pilosa	C. troglodytes	S. undata	Sagartiidae	Actiniaria	A. digitatum	Balano	A. rubens	S. ficus	Porifera	N. puber	Polybius sp.	C. pagurus	H. gammarus	Palaemon sp.	Macropodia sp.	Cottidae	C. lyra	Pomatoschistus sp.	P. gunnellus	T. luscus
A1_BRG_ 01	17	2024-08-27_071432_Ch1_00																								
						S							C											present		
		2024-08-27_072432_Ch1_01																								
						S							C		O	C										
			O			A	R						C			C	C					present			present	
			O			S			F	F						C		A		A						
				S																						
		2024-08-27_073432_Ch1_02																								
			O			C	O			O						C										
			O		O	A	O				O					C		A	A							present
						S												A								
			O			A			O	O	O			O			C	A			F				present	
		2024-08-27_074432_Ch1_03																								
		2024-08-27_075432_Ch1_04																								
			O	F		C							C		O	C					F					
				F		A	O				R			O	F	C					F			present		
		2024-08-27_080432_Ch1_05																								
A1_BRG_ 02		no files																								
A1_BRG_ 03	18	2024-08-27_113124_Ch1_00																								
				C						R			C													
		2024-08-27_114124_Ch1_01																								
				F			O	R					C			C										
						O	O						C			C										
		2024-08-27_115124_Ch1_02																								
				F						R			C													
			O			F									R				A							
		2024-08-27_120124_Ch1_03																								
			A	F		C		R					C		R	C										present
		2024-08-27_121124_Ch1_04																								
			C	F									C			C										

		2024-08-27_122124_Ch1_05																								
A1_BRG_04	3	2024-08-27_131110_Ch1_00																								
		2024-08-27_132110_Ch1_01																								
A1_BRG_05		2024-08-27_174707_Ch1_00																								
		2024-08-27_175707_Ch1_01																								
		2024-08-27_180707_Ch1_02																								
		2024-08-27_181707_Ch1_03																								
		2024-08-27_182707_Ch1_04																								
B_BRG_01	26	2024-08-29_065609_Ch1_00																								
			A										C			C		A								
		2024-08-29_070609_Ch1_01																								
			S										A									present				
			A	C									A			C										
		2024-08-29_071609_Ch1_02																								
			O	O								A	F													
			R	O								R				C										
			F	O								F				C										
			A													C		A								
			A													C										
			C	C																						
		2024-08-29_072609_Ch1_03																								
			A										F			C		C								
		2024-08-29_073609_Ch1_04																								
				F								R	F									present				
			C	O											R	C						present				
													F			C							present			
				C								C	F					A								
				F														A								
				A																						
			A	O									F			C		A				present				
		2024-08-29_074609_Ch1_05																								
			O									C					C		A							
		2024-08-29_075609_Ch1_06																								
			S												R				A							
B_BRG_02	9	2024-08-29_083707_Ch1_00																								
		2024-08-29_084707_Ch1_01																								
		2024-08-29_085707_Ch1_02																								
		2024-08-29_090707_Ch1_03																								
		2024-08-29_091707_Ch1_04																								
B_BRG_03	9	2024-08-29_094715_Ch1_00																								
		2024-08-29_095715_Ch1_01																								
			S	F									C			C	C	C								
		2024-08-29_100715_Ch1_02																								

Table E3. Box corer data D: Densities and wet weights (g WW) of Lanice conchilega and Loimia ramzega per sample (0.078 m2) and per m2 based on box corer samples 18, 20 and 22.

	N/0.078m2		N/m2		WW/0.078m2		WW/m2		%N Lanice	%N Loimia	%WW Lanice	%WW Loimia
	Lanice	Loimia	Lanice	Loimia	Lanice	Loimia	Lanice	Loimia				
BS_BOXC_18	20	2	256	26	5.6	0.3	71.6	3.7	91	9	95	5
BS_BOXC_20	28	28	359	359	5.8	11.9	73.8	151.9	50	50	33	67
BS_BOXC_22	133	39	1705	500	27.3	18.9	350.6	241.9	77	23	59	41

Table E4. Box corer data of areas A, B, C and D: Densities per sample (0.078 m2) . LAB = sorted in the lab. SHIP = sorted on board.

Phylum	Familie	Soortcode	AphiaResolved	BS_BOXC_01 SHIP	BS_BOXC_03 SHIP	BS_BOXC_06 LAB	BS_BOXC_08 LAB	BS_BOXC_11 SHIP	BS_BOXC_12 SHIP	BS_BOXC_18 LAB	BS_BOXC_20 LAB	BS_BOXC_22 LAB	BS_BOXC_23 SHIP	BS_BOXC_24 SHIP	BS_BOXC_25 SHIP	BS_BOXC_26 SHIP	BS_BOXC_27 SHIP	BS_BOXC_28 SHIP
AREA				C	C	C	C	C	C	D	D	D	A	A	A	B	B	B
Annelida		OLIGOCSP	2036				1			3	20							
Annelida	Capitellidae	CAPISPEC	129211				4			7	54	42						
Annelida	Capitellidae	MEDIFRAG	129892								4	7						
Annelida	Capitellidae	NOTOLATE	129898			1	2		1	1	5	1			1		1	
Annelida	Cirratulidae	CHATCHRI	152217			4	16			2	7							
Annelida	Glyceridae	GLYCERSP	952								1							
Annelida	Glyceridae	GLYCSPEC	129296											3		1	2	
Annelida	Goniadidae	GONIADSP	953			7	1			2	3							
Annelida	Hesionidae	PODAHELG	130197			6												
Annelida	Magelonidae	MAGEALLE	130266			1	1											
Annelida	Magelonidae	MAGEFILI	130268			2	11				5							
Annelida	Magelonidae	MAGEJOHN	130269			6	31			3	15							
Annelida	Magelonidae	MAGESPEC	129341								2							
Annelida	Microphthalmidae	MICRSPEC	129313							3								
Annelida	Nephtyidae	NEPHASSI	130353				1											
Annelida	Nephtyidae	NEPHCAEC	130355				1			6	2	1						
Annelida	Nephtyidae	NEPHCIRR	130357				3											
Annelida	Nephtyidae	NEPHHOMB	130359			3				1	3							
Annelida	Nephtyidae	NEPHSPEC	129370		2	1	16	1	3	3	7	3	1		1			3
Annelida	Nereididae	EUNELONG	130375			1				2	8	6						
Annelida	Nereididae	NEREDDSP	22496	1	1	1				1	6		3		2		1	
Annelida	Nereididae	NEREELIT	339286											3				
Annelida	Opheliidae	OPHEBORE	130491				1			5	1	1						
Annelida	Opheliidae	OPHESPEC	129413							5								
Annelida	Orbiniidae	SCOPARMI	130537			4	15			5	9	25						

Annelida	Oweniidae	OWENSPEC	129427						8		1							
Annelida	Pectinariidae	LAGIKORE	152367			1	1				6	4						
Annelida	Pectinariidae	PECTINSP	980						1					3	1		2	
Annelida	Phyllodocidae	ETEOFLAV	130613			1	8			11	21	12						
Annelida	Phyllodocidae	ETEOSPEC	129443												1			
Annelida	Phyllodocidae	EULAVIRI	130639									22						
Annelida	Phyllodocidae	EUMISPEC	129446				16			30	101	14						
Annelida	Phyllodocidae	HYPTFOLI	152250				1				1							
Annelida	Phyllodocidae	PHYLLOSP	931			1				4	1							
Annelida	Phyllodocidae	PHYLMUCO	334512							17	3	8						
Annelida	Phyllodocidae	PHYLROSE	334514							3	2	2						
Annelida	Poecilochaetidae	POECSERP	130711				22			26	2	26						
Annelida	Polynoidae	GATTCIRH	130749							8	3	1						
Annelida	Polynoidae	HARMGLAB	571832				1				1							
Annelida	Polynoidae	MALGAREN	152276							1	4	44						
Annelida	Polynoidae	POLNOISP	939				2			3	19	28					1	
Annelida	Sabellariidae	SABESPIN	130867														1	
Annelida	Scalibregmatidae	SCALINFL	130980			11												
Annelida	Sigalionidae	PHOLBALT	130599			1					1							
Annelida	Sigalionidae	SIGAMATH	131072				1				5							
Annelida	Spionidae	AONIPAUC	131107							7	1	12						
Annelida	Spionidae	SCOLBONN	131171							2								
Annelida	Spionidae	SCOLFOLI	334741				1											
Annelida	Spionidae	SCOLSPEC	129623							1				1				
Annelida	Spionidae	SPIODECO	152314			8	4			6	8	2						
Annelida	Spionidae	SPIONDSP	913															1
Annelida	Spionidae	SPIOSYMP	596189									1						
Annelida	Spionidae	SPIPBOMB	131187			8				1	13	3						
Annelida	Syllidae	MYRNSPEC	129659								12	2						
Annelida	Terebellidae	LANICONC	131495	1			4		8	20	28	133		1	39			
Annelida	Terebellidae	LOIMRAMZ	1036014							2	28	39		3		3	6	2
Annelida	Terebellidae	TEREBESP	982				14			1		1						
Arthropoda		BRACHYUR	106673			1												
Arthropoda	Akanthophoreidae	AKANGRAC	136340				1			1								
Arthropoda	Ampeliscidae	AMPEBREV	101891							8	16	15						
Arthropoda	Aoridae	AORAGRAC	102012									4						
Arthropoda	Aoridae	AORIDASP	101368							3	10	14						
Arthropoda	Argissidae	ARGIHAMA	102064			1												
Arthropoda	Atelecyclidae	ATELROTU	107273											1				
Arthropoda	Bathyporeiidae	BATHELEG	103058			6	9											
Arthropoda	Bathyporeiidae	BATHSPEC	101742				2											
Arthropoda	Bodotriidae	IPHITRIS	110462			1	4				7							
Arthropoda	Callianassidae	CALLIASP	106800			1					1	1						
Arthropoda	Callianassidae	CALLSUBT	107729			5												
Arthropoda	Callianassidae	GILVTYRR	1398927	2	1		1		1	1		1						1
Arthropoda	Caprellidae	PARITYPI	101857								9	18						
Arthropoda	Caprellidae	PHTIMARI	101864									1						

Arthropoda	Corophiidae	COROPHSP	101376								4	42						
Arthropoda	Corophiidae	MONCACHE	225814							3	24	38						
Arthropoda	Corystidae	CORYCASI	107277															1
Arthropoda	Diastylidae	DIASGOOD	110479			2												
Arthropoda	Diastylidae	DIASLUCI	110483				1											
Arthropoda	Inachidae	MACRSPEC	205077												1			
Arthropoda	Ischyroceridae	ISCHYDSP	101389									1						
Arthropoda	Leucothoidae	LEUCINCI	102460			1	8			3	2	3						
Arthropoda	Leucothoidae	LEUCSPEC	101580			1												
Arthropoda	Megaluropidae	MEGAAGIL	102783			1	1				1							
Arthropoda	Melitidae	MELITISP	101397								1							
Arthropoda	Microprotopidae	MICPMACU	102380							8	3	2						
Arthropoda	Oedicerotidae	PERILONG	102915				1											
Arthropoda	Oedicerotidae	PONTALTA	102916			3	1				2							
Arthropoda	Photidae	PHOTLONG	102383							1	1							
Arthropoda	Polybiidae	LIOCSPEC	106925									1						
Arthropoda	Polybiidae	POLBHOS	1748246						1									
Arthropoda	Processidae	PROCMOMO	108343			1	1			2								
Arthropoda	Thiidae	THIASCUT	107281		1		1					1						
Arthropoda	Upogebiidae	UPOBDELT	107739	2		4								9		2	24	
Arthropoda	Urothoidae	UROTPOSE	103235				80			2	15							
Chordata	Branchiostomatidae	BRANLANC	104906															1
Cnidaria		ACTINASP	1360								1							
Cnidaria	Sagartiidae	SAGAUNDA	854485											1				
Echinodermata		OPHIURSP	123084			6	2				1	1						
Echinodermata		SPATANSP	123106	1			8	5	139	3	8	5			1	3		
Echinodermata	Asteriidae	ASTERUBE	123776								2	4						
Echinodermata	Loveniidae	ECHICORD	124392			2		1		1	2	5	1		1			
Echinodermata	Ophiuridae	OPHIALBI	124913						2		6	1		1	1			
Echinodermata	Ophiuridae	OPHIOPHI	124929										1					
Echinodermata	Ophiuridae	OPHISPEC	123574								22							
Mollusca		BIVALVSP	105				0											
Mollusca	Calyptraeidae	CREPFORN	138963							1								
Mollusca	Corbulidae	VACOGIBB	378492			4												
Mollusca	Lasaeidae	KURTBIDE	345281			2					15	3						
Mollusca	Lasaeidae	TMYAFERR	146952			1	2			1	5	15						
Mollusca	Lucinidae	LUCIBORE	140283													1		
Mollusca	Mactridae	LUTRLUTR	140295	1					1								1	
Mollusca	Mactridae	MULILATE	156870				1											
Mollusca	Nuculidae	NUCUNITI	140589			7												
Mollusca	Nuculidae	NUCUSPEC	138262			2												
Mollusca	Pharidae	ENSILEEI	876640								2				2			
Mollusca	Pharidae	ENSIMAGN	160539									5		1				
Mollusca	Pharidae	ENSISPEC	138333			1	1				4	3		2	1			
Mollusca	Pharidae	PHAXPELL	140737									1						
Mollusca	Semelidae	ABRAALBA	141433	1		3	1				4	12	1	7	1	26	40	
Mollusca	Semelidae	ABRAPRIS	141436			1	1					1						

Mollusca	Semelidae	ABRASPEC	138474							3	24	26						
Mollusca	Tellinidae	FABUFABU	146907			2	10	2		2	38	23			1			
Mollusca	Tellinidae	TELLINSP	235									10						
Mollusca	Thraciidae	THRASPEC	138549			1												
Mollusca	Veneridae	CHAMSTRI	141908	1								1	1					
Mollusca	Veneridae	DOSIEXOL	141911														1	
Mollusca	Veneridae	VENECORR	181364									1		2	1			
Mollusca	Veneridae	VENERISP	243											1			3	
Nemertea		NEMERTSP	152391			10	66			10	89	98			1			
Phoronida		PHORONID	1789			337	142			34	274	1						
Platyhelminthes		PLATYHSP	793			8												

Annex F Locations

Table F1: Box corer locations (WGS84)

CODE	LONGITUDE	LATITUDE	Area	Depth (m)
BS_BOXC_01	6.0501465	53.949977	AreaC	32
BS_BOXC_03	6.0002026	53.710091	AreaC	
BS_BOXC_04	6.2600127	53.679994	AreaC	21
BS_BOXC_05	6.0799107	53.820027	AreaC	
BS_BOXC_06	6.0198448	53.969932	AreaC	32.3
BS_BOXC_08	6.1899778	53.809997	AreaC	
BS_BOXC_09	6.0197882	53.899948	AreaC	30.3
BS_BOXC_10	6.0799516	53.730065	AreaC	25.4
BS_BOXC_11	5.9999803	53.680214	AreaC	
BS_BOXC_12	6.1902006	53.729974	AreaC	24.4
BS_BOXC_13	6.1299005	53.890064	AreaC	
BS_BOXC_14	6.349987	53.659991	AreaC	19
BS_BOXC_16	6.3308313	53.691458	AreaA	26.7
BS_BOXC_18	6.2412472	53.63831	AreaD	23.1
BS_BOXC_19	6.2406704	53.638172	AreaD	23.1
BS_BOXC_20	6.2217247	53.641568	AreaD	24.2
BS_BOXC_21	6.2223578	53.641685	AreaD	24.4
BS_BOXC_22	6.2235297	53.641904	AreaD	24.1
BS_BOXC_23	6.3150718	53.689285	AreaA	25.1
BS_BOXC_24	6.3269187	53.695898	AreaA	26.3
BS_BOXC_25	6.3283875	53.691009	AreaA	26.7
BS_BOXC_26	6.0923304	53.967426	AreaB	32.5
BS_BOXC_27	6.0950378	53.966849	AreaB	32.6
BS_BOXC_28	6.0802503	53.964524	AreaB	32.8

Table F2: ROV Video trasects (WGS84) (start and end point, determined by hand in QGIS)

CODE	Lon-start	Lat-start	Lon-end	Lat-end	Area
0078_A1_BRG_05	6.307794	53.693835	6.311459	53.694676	AreaA
0075_A1_BRG_01	6.326604	53.695789	6.330244	53.696581	AreaA
0076_A1_BRG_02	6.318489	53.686511	6.322566	53.687380	AreaA
0080_B_BRG_03	6.096942	53.959133	6.100025	53.959829	AreaB
0079_B_BRG_02	6.089182	53.966975	6.092690	53.967547	AreaB
0078_B_BRG_01	6.077636	53.964110	6.081098	53.964634	AreaB
0077_D_BRG_03	6.239108	53.637809	6.242018	53.638540	AreaD
0075_D_BRG_01	6.220315	53.641306	6.223597	53.641914	AreaD
0076_D_BRG_02	6.259782	53.642294	6.262143	53.642866	AreaD

Table F3: On board registered data.

Boxcores

Vaartuig	MS Arca
Datum	27/28-8-2024
Werkgebied	Borkumsestenen, Noordzee
Project	MONS_wk35

Locatie	Gebied	Date	Start time	End time	Position ETRS89 UTM Zone 32N		Depth (LAT)	Current direction	Current speed	Wave height	Wind force	Wind direction	Remark	MSPAL Sorted on board	To benthos lab WMR
			local time	local time	Easting	Northing	m	gr.	m/s	m	Bft.	gr.		ja/nee	ja/nee
BS_BOXC_16	AreaA	27/08/2024	17:00	17:10	323765	5952503	26.7	nvt	nvt	0.2	2	var	reuzenworm	NEE	JA
BS_BOXC_14	NVT	27/08/2024	18:05	18:15	324899	5948956	19 (KAART)	nvt	nvt	0.2	2	var	zand	NEE	JA
BS_BOXC_04	NVT	27/08/2024	18:55	19:10	319041	5951406	21(KAART)	nvt	nvt	0.2	2	var	zand	NEE	JA
BS_BOXC_18	AreaD	28/08/2024	13:12	15:05	317622	5946818	23.1	W	nvt	0.1	2	var	Medium course sediment	NEE	JA
BS_BOXC_19	AreaD	28/08/2024	14:00	14:015	317583	5946804	23.1	W	nvt	0.1	2	var	ca 1 mm zand met schelpfragmenten	NEE	JA
BS_BOXC_20	AreaD	28/08/2024	14:30	14:41	316346	5947231	24.2	W	nvt	0.2	3	var	Fijner zand dan 1 mm	NEE	JA
BS_BOXC_21	AreaD	28/08/2024	14:46	15:00	316388	5947242	24.4	W	nvt	0.2	4	var	weinig organisch materiaal	NEE	JA
BS_BOXC_22	AreaD	28/08/2024	15:12	15:26	316467	5947263	24.1	W	nvt	0.2	4	var	veel organisch materiaal (zwart zand)	NEE	JA
BS_BOXC_23	AreaA	28/08/2024	16:11	16:26	322716	5952301	25.1	W	nvt	0.4	5	var	Fijn zand, alles door de zeef	JA	NEE
BS_BOXC_25	AreaA	28/08/2024	16:39	16:48	323602	5952459	26.7	W	nvt	0.4	4	var		JA	NEE
BS_BOXC_24	AreaA	28/08/2024	17:03	17:15	323525	5953007	26.3	W	nvt	0.5	4	var	klei, fijn zand, schelpen	JA	NEE
BS_BOXC_08	NVT	28/08/2024	18:24	18:27	314989	5966045		NW	nvt	0.4	3	ZO	Fijn zand, alles valt erdoor	NEE	JA
BS_BOXC_05	NVT	28/08/2024	19:15	19:19	307790	5967453		NW	nvt	0.4	3	ZO	fijn zand.	NEE	JA
BS_BOXC_13	NVT	28/08/2024	19:56	19:59	311395	5975108		W	nvt	0.4	4	ZO	fijn zand met silt	NEE	JA
BS_BOXC_27	AreaB	29/08/2024	13:01	13:14	309455	5983741	32.6	NO	kentering	0.4	3	WNW	gravel, rocks, silt, shells	JA	NEE
BS_BOXC_26	AreaB	29/08/2024	13:18	13:31	309280	5983812	32.5	NO	kentering	0.4	3	WNW	gravel, shells, silt.	JA	NEE
BS_BOXC_28	AreaB	29/08/2024	14:06	14:25	308475	5983522	32.8	NO	kentering	0.4	3	WNW	fijn zand	JA	NEE
BS_BOXC_6	NVT	29/08/2024	14:37	14:43	304539	5984289	32.3	NO	kentering	0.4	4	WNW		NEE	JA
BS_BOXC_1	NVT	29/08/2024	15:05	15:15	306433	5981986	32.0	WNW	0.5	0.5	5	WNW	fijn zand, beetje klei	JA	NEE
BS_BOXC_9	NVT	29/08/2024	15:45	15:47	304207	5976506	30.3	WNW	0.5	0.5	5	WNW		NEE	JA
BS_BOXC_12	NVT	29/08/2024	17:12	17:19	314651	5957145	24.4	wnw	0.5	0.5	5	wnw	zand, veel jonge Echnocardium cordatum	JA	NEE
BS_BOXC_10	NVT	29/08/2024	18:05	18:15	307381	5957448	25.4	wnw	0.5	0.5	5	wnw		NEE	JA
BS_BOXC_03	NVT	29/08/2024	18:35	18:40	302028	5955446			0.7	0.5	5	wnw	vette klei	JA	NEE
BS_BOXC_11	NVT	29/08/2024	19:10	19:20	301873	5952124			0.7	0.5	5	wnw	fijn zand	JA	NEE

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