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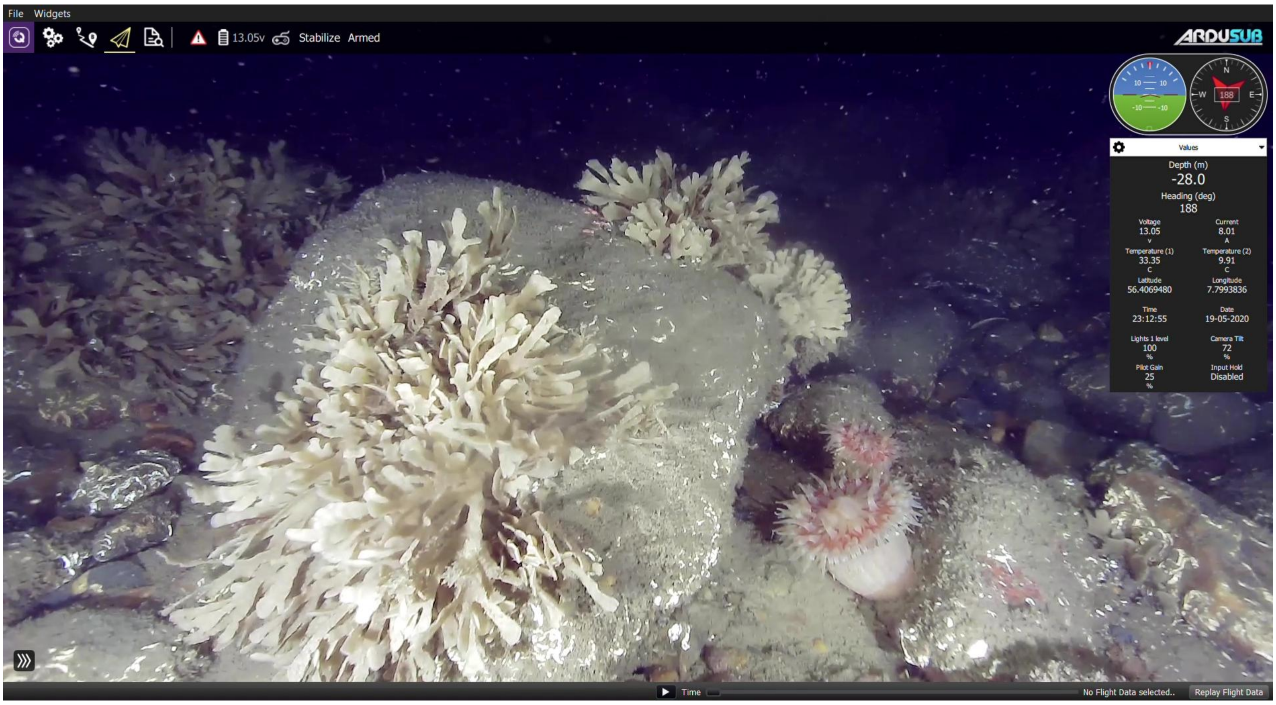
THOR OWF
TECHNICAL REPORT –
BENTHIC FAUNA AND FLORA



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THOR OWF
TECHNICAL REPORT – BENTHIC FAUNA AND FLORA

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Description	**Technical report on strategic environmental assessment (SEA) of Thor Offshore Wind Farm on benthic fauna and flora.**

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CONTENTS

Abbreviation	Explanation
CC	The two cable corridor alternatives, one or both may be used
DEA	Danish Energy Agency
R2 (CC_R2)	Northern cable corridor
R3 (CC_R3)	Southern cable corridor
Thor OWF	The future Thor Offshore Wind Farm area of approximately 220 km^2
The gross area for Thor Offshore Wind Farm (OWF)	The larger investigated area in this report of approximately 440 km^2 within which the future Thor OWF will be placed.
Gross area	Gross area for Thor OWF
GA	Gross area for Thor OWF
GA1	Northern part of gross area for Thor OWF
GA2	Central part of gross area for Thor OWF
GA3	Western part of gross area for Thor OWF
Investigated area	Gross area for Thor OWF plus the two cable corridors (GA+R2+R3)
Subarea	The gross area for Thor OWF has been divided into 3 subareas: GA1, GA2 and GA3
SEA	Strategic Environmental Assessment
DW	Dry weight
TW	Total weight
LOI	Loss on ignition
TOC	Total Organic Carbon
ROV	Remotely Operated Vehicle
CTDO	Conductivity-Temperature-Depth-Optical
PSU	Practical Salinity Unit
EOX	Extractable organohalogen compounds
TN	Total nitrogen
TP	Total phosphorus
LOD	Limit of detection
SPA	Special Protection Areas

1. SUMMARY AND CONCLUSION

Introduction
As part of the Energy Agreement of June 29th 2018 all political parties in the Danish Parliament have agreed to establish three new offshore wind farms before 2030. Thor offshore Wind Farm (Thor OWF) is one of the three planned Offshore Wind Farms.

The plan for Thor OWF defines the overall framework for establishment of an offshore wind farm approx. 20 km off the coast of Thorsminde on the west coast of Denmark and includes two cable corridors. One or both cable corridor alternatives may be used.

Objective
The purpose of this technical report is to describe and document the baseline conditions of benthic fauna and flora in the gross area for Thor OWF (GA) and the two cable corridors (R2 and R3 = CC) and perform a sensitivity analysis in relation to the establishment of the planned Thor OWF in the investigated area (GA, R2 and R3).

Baseline conditions
There was no evidence for the presence of benthic flora communities in the cable corridors and only two small specimens of Rhodophyta, crust algae, were found in the gross area for Thor OWF.

Benthic habitats in the gross area for Thor OWF and the two cable corridors were mainly characterised by infaunal benthic communities on the dominating sandy bottom. In sandy-bottom areas horseshoe worm (*Phoronis* sp.) and bristle worms dominated, whereas in mixed bottom areas and hard bottom areas where stones were available epifauna such as tube worms (*Pomatoceros triqueter* and *Spirorbis tridentatus*), hydroids, leafy bryozoans (*Flustra foliacea*), dead man´s fingers (*Alcyonium digitatum*) and anthozoans dominated.

Stone reef habitats were located in small patches and constituted 2-4 % of the gross area for Thor OWF and each cable corridor.

The benthic communities in the gross area for Thor OWF and the two cable corridors are common in the North Sea and along the west coast of Denmark. No red-list species or protected species or habitat types were observed in the investigated areas. There was no evidence for any biogenic reef structures such as blue mussels (*Mytilus edulis*), oysters (*Ostrea edulis* and *Crassostrea gigas*) or *Sabellaria* reef structures.

Statistical analysis shows that the infauna species in the gross area for Thor OWF and the two cable corridors are dominated by robust generalists, generally belonging to one infauna community with similar species composition in the three investigated areas (GA, R2 and R3).

Sensitivity analysis
The registered benthic fauna species are robust and distributed throughout the investigated area due to their adaptation to the dynamic conditions along the exposed west coast of Denmark with strong currents and wave action during stormy weather events and periodic occurrence of large amounts of resuspended material in the water column, which result in frequent scrubbing of the stones and covering of the fauna with sand. Recovery time is assessed as 1-5 years for the benthic fauna (infauna and epifauna), and benthic fauna is assessed as having low sensitivity in relation to the potential impacts of the planned Thor OWF.

Assessment of potential impacts
Benthic flora was generally not observed in the investigated area and there is, therefore, no impact on benthic flora from the planned Thor OWF.

Regardless of location of the planned Thor OWF and cable corridors the potential impacts on benthic fauna (epifauna and infauna) are assessed as *none to minor*.

No significant cumulative effects were assessed in relation to other projects or plans in the area including Vesterhav Nord and Vesterhav Syd OWFs, sand extraction and coastal nourishment along the west coast of Denmark.

Mitigation measures
No mitigation measures are necessary since no significant impacts are expected from the project plan of Thor OWF on benthic fauna and flora.

Conclusion
The conclusion is that no matter where the turbines and cables are placed within the gross area for Thor OWF and the two cable corridors the impacts on the benthic communities will be only *minor.*

The main impact is from the footprint of the foundations, which causes death of the benthic fauna under the foundations. The impact of the footprints is assessed as *minor* for the benthic community in the future Thor OWF, since the footprint of the foundations for both 8 and 15 MW turbines covers a very small area (0.02 to 0.01 % of the future Thor OWF area, 220 km^2), and since the footprint impacts common, robust benthic communities with a low sensitivity that are distributed along the entire west coast of Denmark.

The distribution of infauna species is indicated in Figure 1-1. Highest species numbers, abundance and biomass is observed in the sandy southwestern part of the gross area for Thor OWF. Lowest numbers in general are found in the eastern sandy part (sediment type 1b) of the gross area for Thor OWF.

Furthermore, the difference between the benthic communities in the two cable corridors is small and the potential impacts caused by the cables on the benthic communities will only be *minor* regardless of the use of one or two cable corridors for Thor OWF.

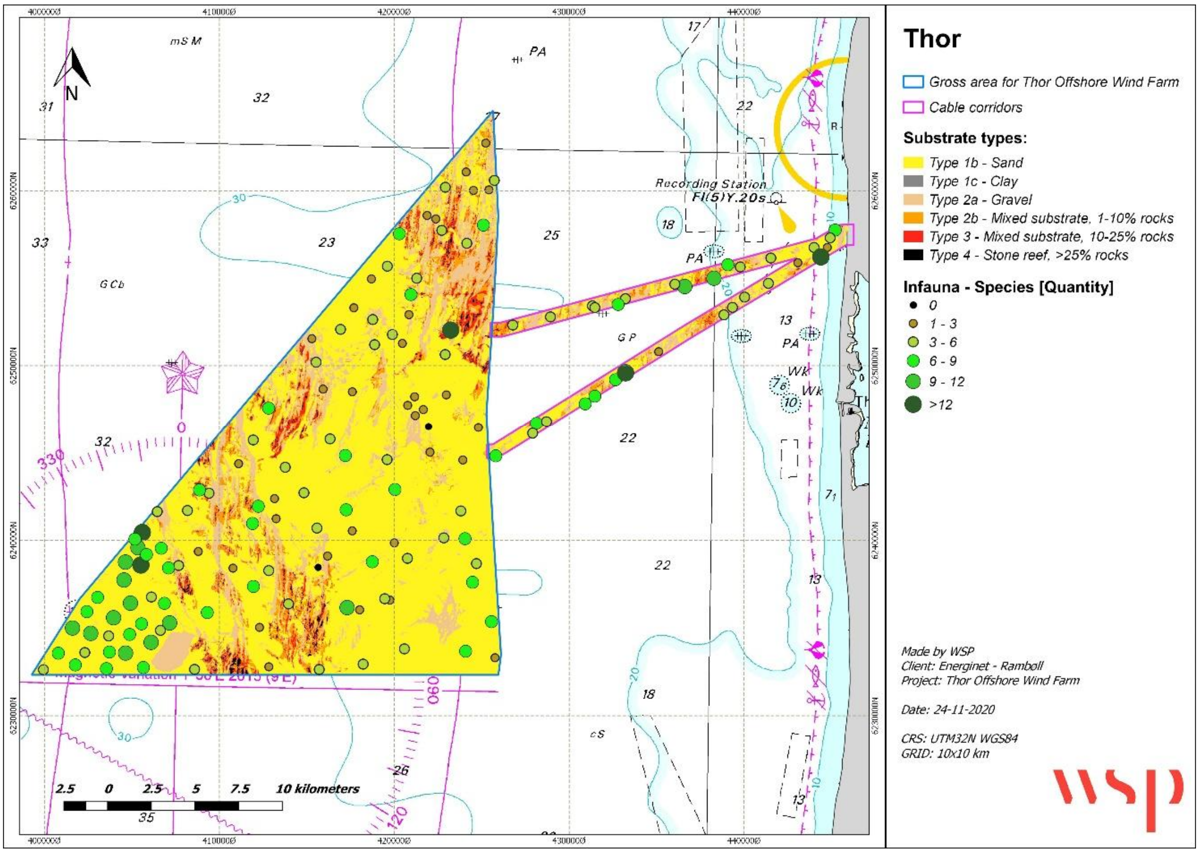


Figure 1-1 Number of infauna species at the sampled stations. Note lowest numbers in the eastern sandy part of the gross area for Thor OWF.

2. INTRODUCTION

2.1 Background

In June 2018 the Danish Parliament agreed on the Danish Parliament's Energy Agreement 2018 which among other parts includes the construction of approximately 800 MW Danish offshore wind to be grid-connected by 2024 to 2027.

Based on a screening study the Danish Energy Agency made the decision in February 2019 for the project development of an area in the North Sea approx. 20 km off the west coast of Denmark for the new Thor OWF with a capacity of 800-1000 MW.

In February 2019 the Danish Energy Agency instructed Energinet to initiate site investigations, environmental and metocean studies and analysis for grid connection for this area. Energinet is therefore carrying out environmental surveys for the project area (Figure 3-1) and a Strategic Environmental Assessment (SEA) of the plan for Thor OWF.

The purpose of this technical report is to describe and document the baseline conditions of benthic fauna and flora in the gross area for Thor OWF and the two cable corridor alternatives, and perform a sensitivity analysis in relation to the establishment of the planned Thor OWF in the area.

3. PLAN FOR THOR OWF

The plan for the Thor OWF sets out the overall framework for designing an offshore wind farm approx. 20 km from the coast of Thorsminde on the west coast of Denmark (Figure 3-1). The planned OWF must be able to provide a minimum of 800 MW and a maximum of 1,000 MW to the national Danish power grid. The decision on the location for the possible OWF is based on a fine screening of possible installation areas carried out by COWI for the Danish Energy Agency in December 2018.

The plan establishes a framework for a future OWF with associated onshore facilities, but only at an overall level. At this stage there is thus no knowledge of the offshore wind farm's specific design, including the number, size and location of offshore wind turbines and the cable corridor. Furthermore, it is unknown whether one or two cable corridors will be used.

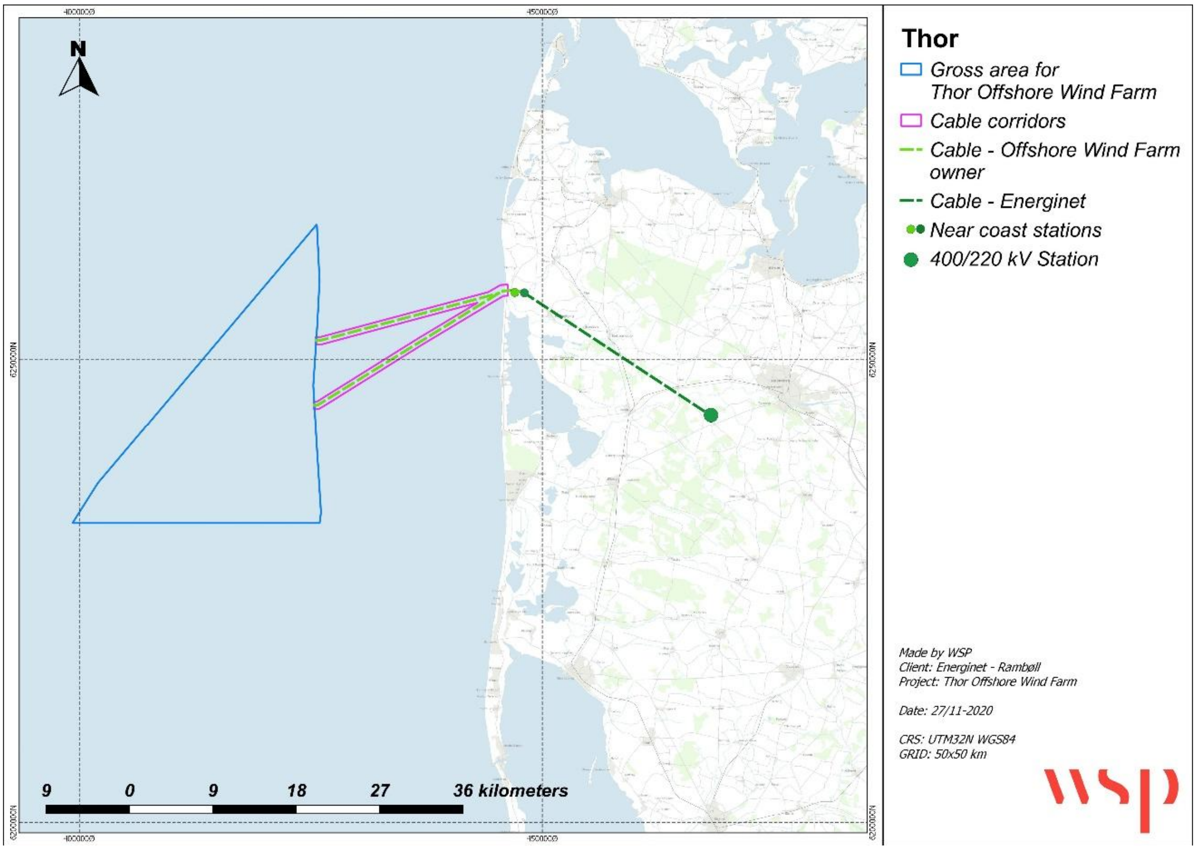


Figure 3-1. The gross area for Thor OWF and the two cable corridors. The gross area for Thor OWF , which is located west of Thorsminde in the North Sea, consists of a 440 km^2 triangular area and additional areas around two cable corridors leading to one landfall on the coast north of Nissum Fjord (Energinet, 2020).

The project plan includes the following elements for the future Thor OWF:

- the OWF area with wind turbines,
- the offshore substation (transformer platform),
- two alternative cable corridors R2 (Northern corridor) and R3 (Southern corridor) leading to one landfall on the north coast of Nissum Fjord,
- a nearshore and onshore substation,
- and land cables to the grid connection point at Idomlund, which is east of Nissum Fjord (Figure 3-2).

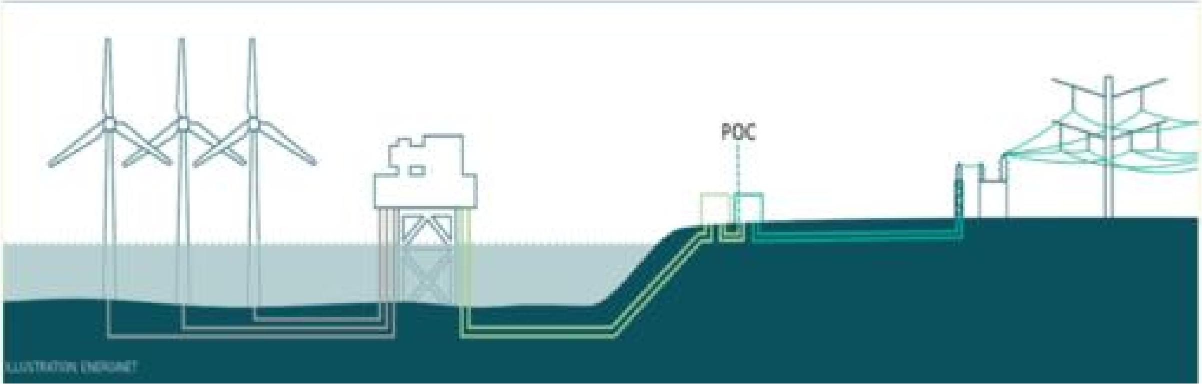


Figure 3-2. The planned Thor OWF (Energinet, 2020).

The project plan elements relevant for assessment of potential impacts for benthic flora and fauna in this report are presented below.

3.1 Wind turbines

Wind turbines with a capacity in the range of 8 to 15 MW are expected. The minimum turbine capacity of 8 MW corresponds to the installation of up to 125 turbines and the maximum turbine capacity of 15 MW corresponds to the installation of up to 67 turbines. In order to take into account the possible technological development, the starting point for this study is therefore the turbine sizes.

As described, the park layout and turbine design is not decided at this stage, and the assessments in this study are therefore performed on a general level taking into account various possible variations in park size, variations in turbine design and the resulting variation in the number of wind turbines, as well as variation in parklayout and the use of one or two cable corridors. In principle, there are endless different layouts, that can lead to the final, concrete project. The specific project including park layout will therefore have to undergo an EIA at a later stage.

3.2 Foundations

Based on the foundation methods used for ongoing offshore wind projects at up to 55 m water depth, it is most likely that the offshore turbines will be based on monopiles, which are installed in the seabed by pile driving.

However, jacket or bucket foundations are included as possible alternatives. These foundation methods are generally more expensive but may come into play in special circumstances.

Possible foundation methods therefore include:

- Monopiles
- Jacket foundations
- Bucket foundations

Erosion protection/scour protection around the foundations are also a possibility. Experience from other wind farm projects along the west coast of Denmark indicates that this could potentially be done with stones placed in a circle in a diameter of 15-20 m around each foundation (Vattenfall, 2020a; Vattenfall, 2020b) (Vattenfall, 2020b).

3.3 Cable corridors

Export cables from the transformer platform (offshore substation) to landfall are installed in one or both of the two cable corridors: R2 or R3. The final number of cables and dimensions of export cables are not known at this point.

3.4 Investigated area

The investigated area in this report is identified as "the gross area for the Thor OWF" and the two cable corridor alternatives and are shown in Figure 3-1.

The gross area is expected to be at least 50% larger than the planned future Thor OWF area, which will be assessed in a future EIA. The gross area for Thor OWF, which is investigated in this report, is approximately 440 km^2, whereas the planned Thor OWF area is expected to be approximately 220 km^2.

The two cable corridor alternatives are expected to be approximately 21.4 km (R2) and 24.4 km (R3) long from landfall to the edge of the gross area for Thor OWF (Figure 3-1). The area coverage of the cable corridors will be either 17.27 km^2 for the northern corridor (R2) or 19.86 km^2 for the southern corridor (R3), and 35.14 km^2 if both cable corridors are used for the planned Thor OWF.

4. METHODS AND MATERIALS

Materials and methods relevant for the baseline mapping and potential impact assessment of benthic flora and fauna in this report are presented below. Statistical analysis of infauna is presented in Appendix 8.

Materials and methods related to the benthic field survey conducted by WSP in March/May 2020 are presented below in section 4.1 - Benthic Seabed Survey. CTDO-data and physical sediment parameters are included in this report for the statistical analysis of the controlling abiotic parameters for infauna composition (see section 5.5.3.3). Chemical data are used to exclude impact caused by potential nutrient release from the sediment during the construction phase of the planned project (see section 6.1.1).

Geophysical data used in the baseline mapping of benthic fauna and flora are included in section 4.2 – Geophysical data. These data were collected during the Geophysical Survey conducted by MMT Sweden in August to December 2019.

Data used from the geophysical survey include sediment types and depth data. Mapping of the sediment types in the investigated area were used to plan placement of ROV-stations to insure mapping of benthic flora and fauna in all represented sediment types in the investigated area. The map of sediment types together with ROV-video observations of the existing benthic communities makes it possible to create maps of the epifauna communities (see Figure 5-35) and benthic habitats (see Figure 5-37) in the investigated area. Water depth data are used to describe the distribution of infauna with depth in the investigated area both for the map of benthic habitats and for the statistical analysis of infauna species composition in the investigated area.

4.1 Benthic Seabed Survey

The benthic survey was conducted in the gross area for Thor OWF and the cable corridors (CC) in March and May 2020 by WSP. The benthic survey was conducted to provide baseline data for benthic flora and fauna in the gross area for Thor OWF and the two cable corridors.

4.1.1 Survey area

The benthic seabed survey was conducted within the investigated area consisting of the gross area for Thor OWF and the two cable corridors (Figure 4-1). These areas are located west of Thorsminde in the North Sea and the cable corridors makes landfall north of Nissum Fjord.

Local Natura 2000 sites are shown in Figure 4-1. Potential impact on the local Natura 2000 sites is discussed in chapter 8.

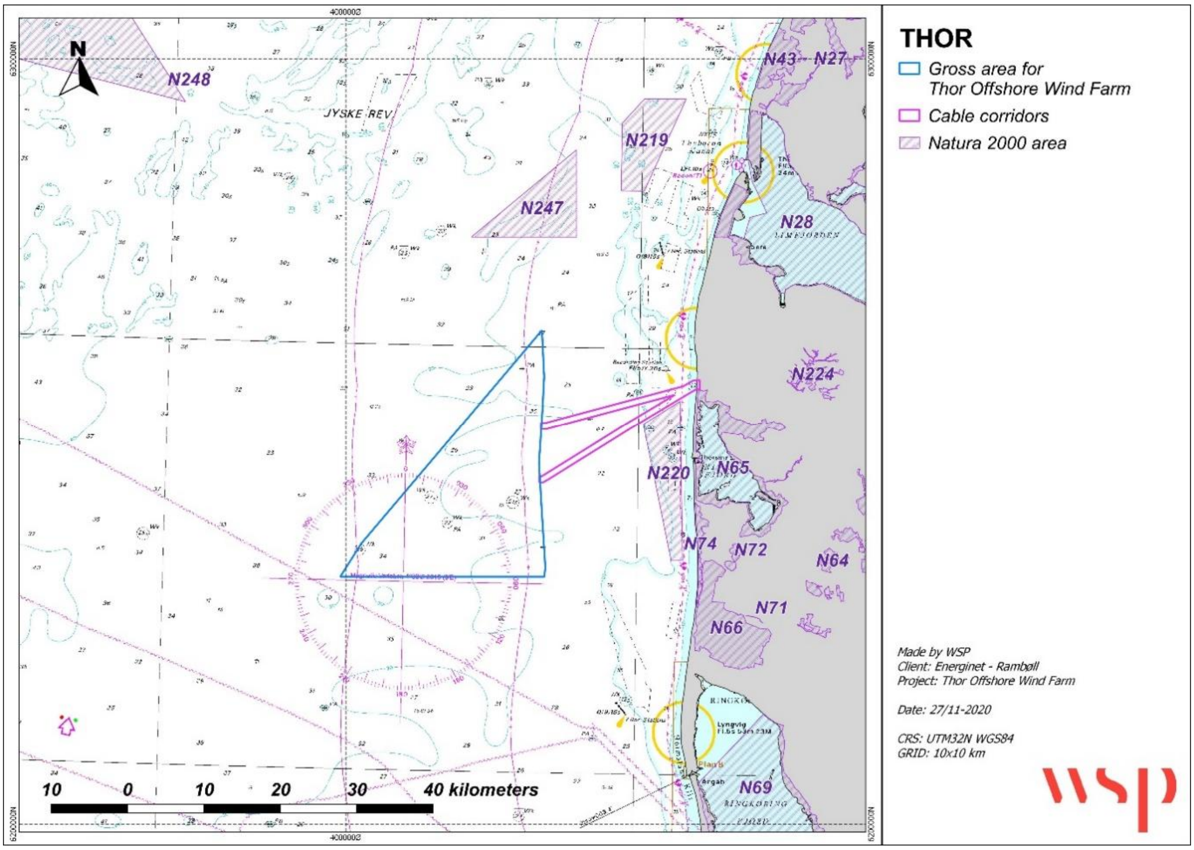


Figure 4-1. Location of the gross area for Thor OWF, the two cable corridors (CC) and local Natura 2000 sites.

4.1.2 Survey programme

The benthic survey was undertaken in 2020 on the survey vessels "Skoven" (March 28th) and "Cecilie" (May 7th-9th & 18th-19th).

A total of 150 stations were sampled in the gross area for Thor OWF (Figure 4-2) and 20 stations in each of the two cable corridors (see Figure 4-3).

The survey programme included the following activities at each station:

1. Visual verification of the seabed, including sediment type and epifauna communities using ROV (Remotely Operated Vehicle)
2. Measurement of CTDO (Conductivity-Temperature-Depth-Optical)
3. HAPS core sample for sediment analyses including grain size analyses and chemical analyses*
4. HAPS core sample for infauna analyses*

*HAPS core samples were taken where the sediment was suitable for core sampling. Suitable sediment for HAPS sampling is non compact sediment such as mud, silt and sand.

Stations were placed according to the sediment type map (see Figure 5-6) in order to describe all sediment types in the investigated areas, and therefore not placed evenly in the OWF as not all sediment types would have been sampled. A sediment type map was constructed from the geophysical data collected on the geophysical survey and used for the planning of the benthic seabed survey.

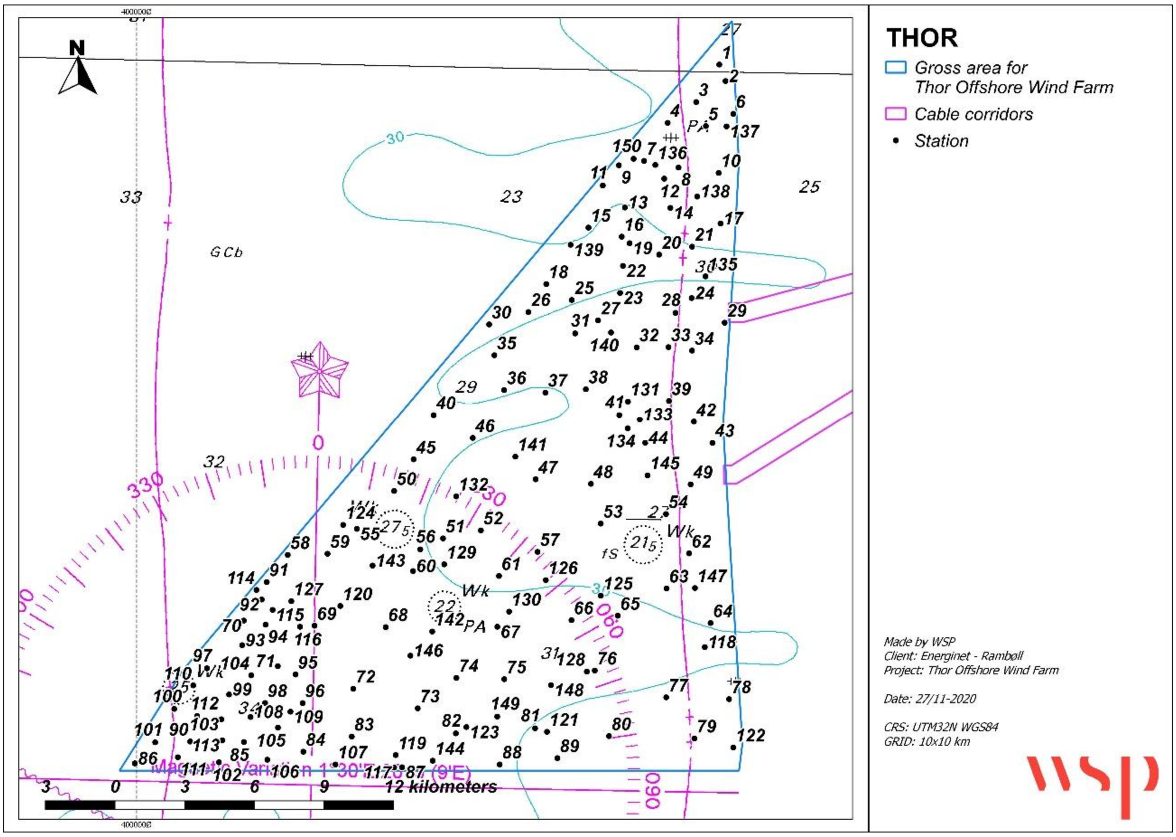


Figure 4-2. Sampling stations in the gross area for THOR OWF.

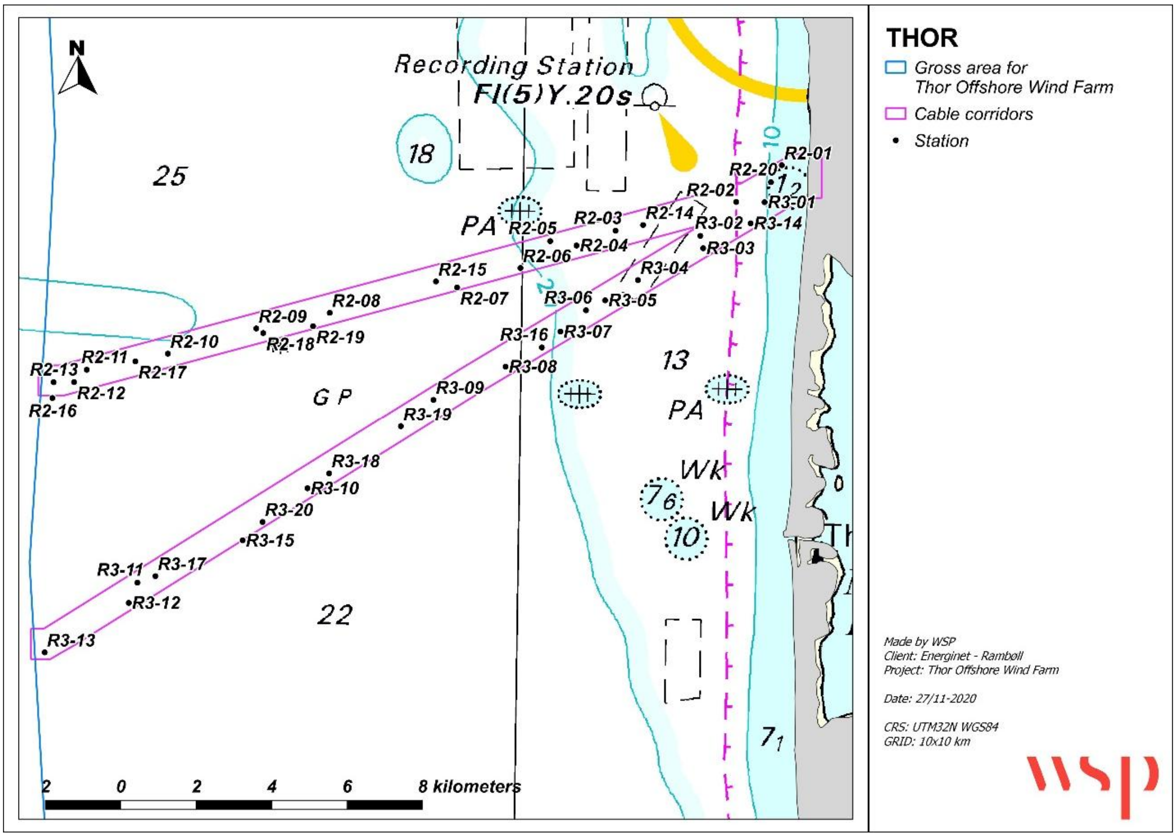


Figure 4-3. Sampling stations in the two cable corridors (CC). The northern corridor is called R2 and the southern corridor R3.

The number of samples collected during the different activities and sampling method is presented in Table 4-1. A detailed overview illustrating all conducted survey activities at each benthic station within the investigated area is presented in Appendix 1.

Table 4-1 Overview of activities during the "Benthic Seabed Survey" e.g. number of samples, sampling method and the Appendices where the data is presented. * HAPS core sampling for infauna was not possible at all stations due to hard substrate making sampling impossible.

Samples for:	Sampling method	Wind farm area (OWF)	Cable corridors (R2/R3)	Data presented in
CTDO bottom measurements	CTDO mounted on ROV	150	20/20	Appendix 2a
CTDO profiles	CTDO mounted on ROV	33	20/20	Appendix 2b
Physical analyses				
Grain size data	HAPS sampler	123	15/17	Appendix 3
DW, TOC and LOI	HAPS sampler	123	15/17	Appendix 4
Chemical analyses				
Heavy metals mm.	HAPS sampler	0	15/17	Appendix 5
Infauna data	HAPS sampler	119*	15*/16*	Appendix 6
Infauna statistical analysis				Appendix 8
Visual verifications	ROV	150	20/20	Appendix 7a Appendix 7b

For further details on sampling methods se section 4.1.3 below.

4.1.3 Sampling methods

In the following sampling methods for the "Benthic seabed survey" used during the survey activities are presented in detail.

4.1.3.1 Visual verifications

Visual verifications at the ROV-stations were used to verify the sediment type and to map benthic flora, fauna and fish species and coverage in the investigated area.

Visual verifications were carried out using WSP's customised ROV (Remotely Operated Vehicle, BlueROV2 from BlueRobotics) with positioning system (Figure 4-4). Before sediment sampling a ROV video sequence, covering the sediment surface at and around each sampling station was recorded and stored. On the sea floor, full-HD video was recorded while position, depth, seabed sediment types/composition, observed species (flora and fauna), coverage, and biogenic structures observed on the seabed surface (e.g. sandworms piles, fish foraging holes in the seabed, mysids/shrimps in the seabed etc.), was noted in a field log book. Two logbooks were made, one for the gross area for Thor OWF (Appendix 7a) and one for the cable corridors (CC) (Appendix 7b).

In the laboratory, the video content was analysed and entered in the logbook by a marine biologist for the following parameters:

- Sediment type
- Sediment description
- Flora and fauna species
- Flora and fauna area coverage on the seabed

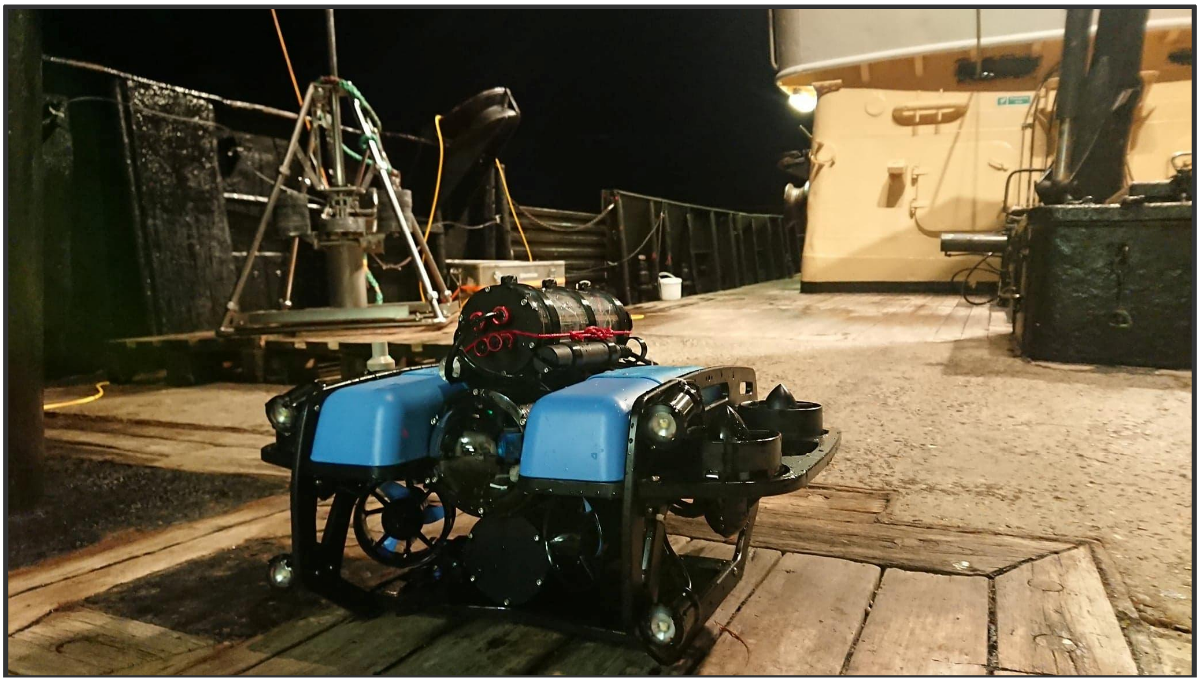


Figure 4-4 Remotely Operated underwater Vehicle (ROV) with integrated CTDO (on top) onboard the vessel *"Cecilie"*.

4.1.3.2 CTDO measurements

CTDO measurement were used for statistical analysis of the controlling abiotic parameters for infauna composition in the investigated area. Parameters used for the statistical analysis were salinity and oxygen content of the water (see section 5.5.3.3).

CTDO sampling was performed using a ROV-integrated CTDO (Figure 4-4). The core element in the CTDO is a Campbell Scientific CR310 datalogger with online ethernet connection to the surface, which can host a wide variety of sensors. The following sensors were used: Conductivity with a digital Ponsel C4E sensor, temperature and pressure with a SensorsOne S12S sensor, oxygen with a Ponsel OPTOD (Optical Dissolved Oxygen) sensor. CTDO data is presented in Appendix 2a – CTDO bottom measurements 1 m above the seabed and Appendix 2b – CTDO profiles.

4.1.3.3 Sediment sampling and analysis

Physical sediment parameters are included in this report for the statistical analysis of the controlling abiotic parameters for infauna composition (see section 5.5.3.3). Chemical data are used to exclude impact caused by potential nutrient release from the sediment in the construction phase of the planned project (see section 6.1.1).

Two individual HAPS core samples (each 0.0145 m^2) were extracted per station (Figure 4-5), one sample for physical and chemical analysis as well as one sample for infauna analysis (see section 4.1.3.4 below). Three attempts were made before moving to the next location. Stations not sampled had a rocky bottom making it impossible to use the HAPS core sampler.

The HAPS core sample was analysed for gran size distribution (Appendix 3), for dry weight, organic matter content and loss on ignition (Appendix 4), and additionally for chemical content in the cable corridors (Appendix 5).

The physical parameters are used as supporting parameters in the statistical analysis of infauna composition and distribution in the investigated areas.

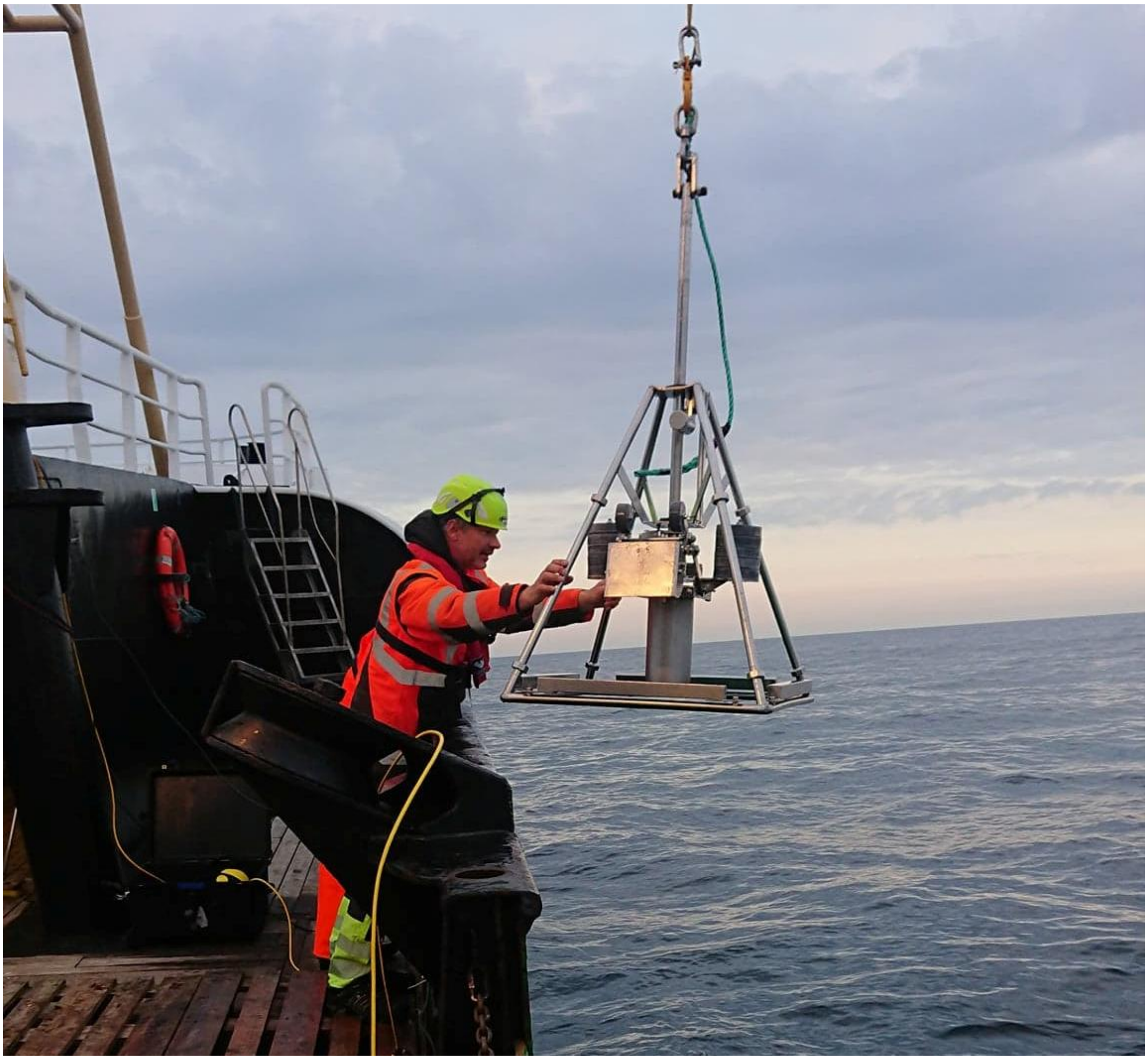


Figure 4-5. The HAPS-core sampler in action.

Subsampling for physical analysis:
The following physical parameters were analysed in the gross area for Thor OWF and cable corridors:

- Dry matter = Dry weight
- Loss on ignition
- Grain size distribution, including median grain size (d50) of the sediment and silt/clay fraction.
- Uniformity coefficient (d60/d10)
- Sediment sorting and grading
- Total Organic Content (TOC)

An overall description of the physical results is presented in section 5.3.5.1.

Subsampling for chemical analysis:
The following chemicals and compounds were analysed in the cable corridors:

- Total nitrogen (TN) and total phosphorus (TP)
- Heavy metals (8): Arsenic (As), lead (Pb), cadmium (Cd), chromium (Cr), copper (Cu), mercury (Hg), nickel (Ni) and zinc (Zn)

- PAH compounds (9): Phenanthrene, anthracene, fluoranthene, pyrene, benz(a)anthracene, chrysene, benz(a)pyrene, indeno(123cd)pyrene and benzo(ghi)perylene
- Hydrocarbons: n-C6 to n-C10, n-C10 to n-C15, n-C15 to n-C20 and n-C20 to n-C35
- Extractable organohalogen compounds (EOX)

An overall description of the chemical results is presented in section 5.3.5.2.

4.1.3.4 Infauna sampling and analysis

Infauna sampling and analysis was used for the baseline mapping and statistical analysis of the infauna community in the investigated area.

The extent of the infauna sampling programme in the gross area for Thor OWF and in the two cable corridors are listed in Table 4-2. Positions and depths for infauna sampling are shown in Appendix 1 and an overview of the sediment characteristics at infauna stations is presented in Appendix 3 and 4. The full data report for infauna analyses from the laboratory at WSP is shown in Appendix 6. The illustration of all 150 stations sampled for infauna is illustrated in Figure 4-6.

Table 4-2 Infauna sampling programme in the gross area for Thor Offshore Wind Farm and the two cable corridors.

	Gross area	R2	R3
Infauna samples	119	15	16
Samples without animals	2	0	0

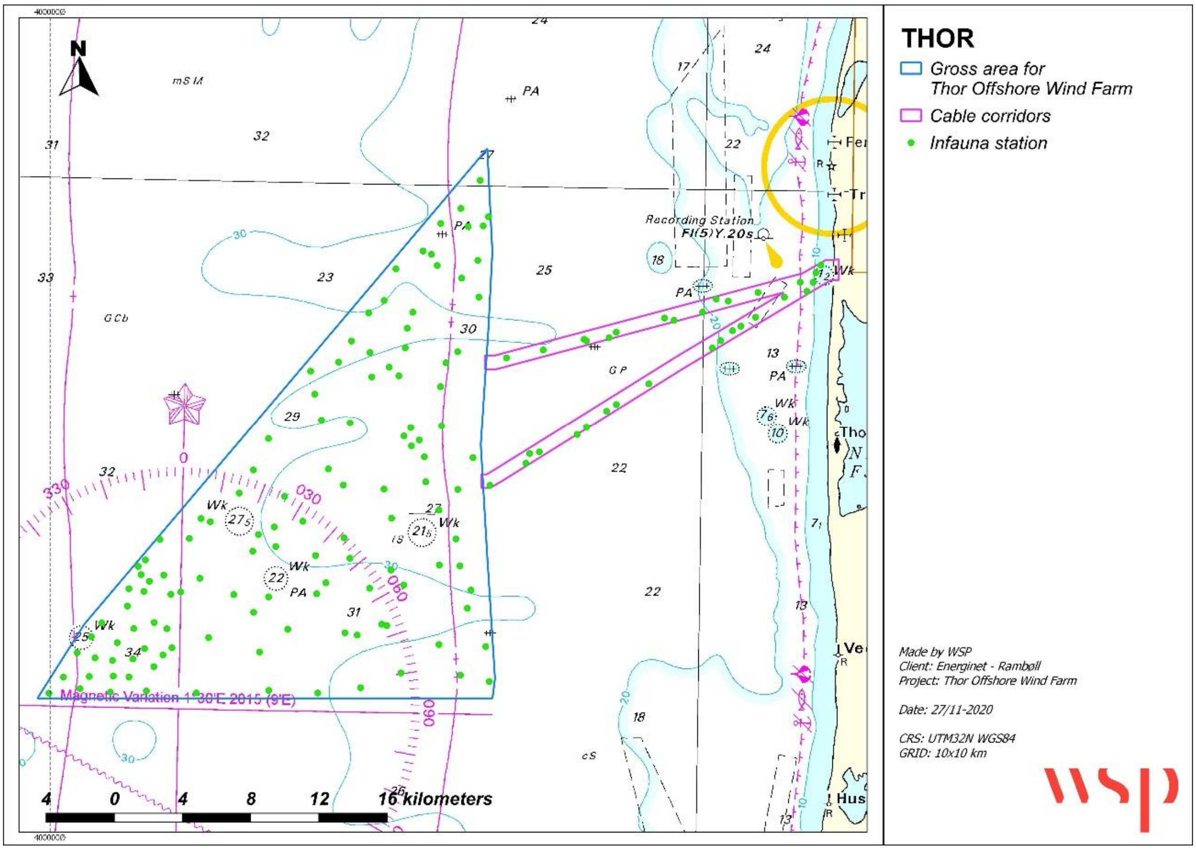


Figure 4-6 Illustration of all sampled infauna stations.

One HAPS core sample (0.0145 m^2) was extracted per station and used for infauna sampling and analysis. This instrument complies with the technical requirements for soft bottom fauna in the NOVANA program (Jørgen L.S. Hansen, Alf Josefson, 2014). The same HAPS core sampler was used for infauna and sediment sampling. Three attempts were made before moving to the next location at all 150 stations. Stations not sampled for infauna due to hard substrate included: 31 stations in the gross area for Thor OWF, 5 in R2 and 4 in R3 cable corridor.

Sample sieving (1 mm sieve) (Figure 4-7), preservation and storage of samples was carried out in accordance with the technical requirements for soft bottom fauna (Jørgen L.S. Hansen, Alf Josefson, 2014). All samples were stored in 96% ethanol in plastic buckets with a tight lid and secured in a dedicated safe area on the vessel.

Figure 4-7. Infauna and bigger sized inorganic material retained on sieve.

Infauna laboratory analysis

All samples were treated individually in WSP's laboratory by a certified Danish infauna expert. The samples were sieved in a 0.5 mm sieve to remove ethanol before sorting. All animals were sorted out using a low power stereo microscope and identified to species level where possible. The total biomass of the individual species, including shells of bivalves, was determined as total wet weight and dry weight after 105°C for 18-24 hours or until stable weight was reached. The polychaete *Pygospio elegans* was weighed with tubes after prior removal of "excess tube material" without content. Barnacles were counted and indicated as being present, i.e. no biomass determination. The infauna data was analysed both qualitatively and quantitatively.

All infauna data are presented in Appendix 6.

Statistical analysis of infauna
Statistical analysis was conducted for infauna to explain patterns in infauna composition and distribution within the gross area for THOR OWF and the two cable corridors.

Statistical analysis of infauna is described in Appendix 8.

4.2 Geophysical data

The geophysical survey was conducted to provide baseline data for water depth, surface geology, seabed features, shallow geology and man-made-objects present in the investigated area. Instruments used during the geophysical survey were multibeam echosounder, side scan sonar and sub-bottom profiler. The survey period for the geophysical survey was August to December 2019 (MMT, 2020a) (MMT, 2020b). For more details regarding the geophysical survey and results see the Benthic Scope Report conducted by MMT for the gross area for Thor OWF (MMT, 2020a) and cable corridors (MMT, 2020b).

Geophysical data were included in this report to plan the benthic seabed survey and to map the benthic flora and fauna communities on the different sediment types. Water depth was used to describe the distribution of epifauna and infauna in the investigated areas.

4.2.1 Depth

Water depth was collected using a multibeam echosounder system in order to provide a detailed bathymetric mapping of the gross area for Thor OWF and the two cable corridors (CC) (MMT, 2020a).

WSP has received the processed multibeam echosounder data. The bathymetric data has supported the interpretation of the seabed surface sediment and the benthic data analysis.

4.2.2 Seabed sediment type characterization

Side scan sonar data was collected by using an acoustic sonar instrument in order to provide a detailed seabed surface mapping of the entire investigated area including the gross area for Thor OWF and the two cable corridors (MMT, 2020a).

WSP has received the processed side scan sonar data as a merged mosaic, which was prepared for interpretation. The interpretation of side scan data and the classification of seabed sediments have been conducted by WSP.

In order to classify the seabed sediments, the following substrate classification method has been used to determine the roughness of the seabed sediment and the stone coverage cf. the Danish raw material order 780 of 20-06-2017 (Ministry of environment and food of Denmark, 2018). This clarification is used in order to implement the seabed surface mapping. The seabed sediment classification method is based on the following seabed sediment types (substrates):

- **Type 1 – Sand and soft sediments:** Areas that consist of soft sediments as gyttja or silt, to hard sediments of sand (0.06 – 2.0 mm) and gravel fraction grain size, with a variation of bed forms (often dynamical). This type is further subdivided into 1a (gyttja or silty soft bottom sediments), 1b (hard bottom sediments of sand and gravel) and 1c (clayish sediments).
- **Type 2a – Sand, gravel and small rocks:**
  Area consisting of coarse sediment types, as gravels, pebbles and small cobbles with varying content of sand. The sediment contains less than 1% area coverage of larger rocks (>10 cm).

- **Type 2b – Sand, gravel and small rocks and a few larger rocks (area coverage 1-10%):** Areas consisting of mixed sediment types but dominated by sand with a little content of gravel and rocks. Varying sediment content of gravel/pebble size fraction (<2 cm), small rocks of pebble and cobble grain sizes (2-10 cm) and a spread of larger rocks of cobble to boulder grain sizes with an area coverage of 1-10% (>10 cm).
- **Type 3 – Sand, gravel, small rocks and several larger rocks (area coverage 10-25%):** Areas consisting of mixed sediment types dominated by sand, gravel and smaller rocks. This sediment type consists of a spread of larger rocks with an area coverage of 10-25% and can be associated with rocky reefs.
- **Type 4 – Rocky areas (reefs), consisting of many larger rocks (area coverage >25%):** Dense spreading of larger rocks or rock reefs (stone reefs) with forming of cavities / rock shelters, and can have a bathymetric anomaly due to the high ground of large rocks compared to the adjacent sediment.

The sediment type mapping is produced by the integration of several data sources, and in two steps:

Firstly, by the construction of a 1st generation map of seabed sediment types based on the geophysical survey (MMT, 2020a) and (MMT, 2020b). The mapping is generated by the interpretation on an already processed side scan sonar (SSS) dataset and a bathymetric dataset from a multibeam (MBES) data source. Additionally, this map is used for organizing the biological field programme, in order to verify all seabed sediment types.

Secondly, the construction of the 2nd generation map of seabed sediment types (see Figure 5-6) is generated from the integration of the biological survey data – more specific the physical results. The 1st generation map is adjusted based on the ground truthing data related to the visual verifications (ROV documentation) and the grain size analysis of the seabed sediment samples.

5. BASELINE SITUATION

5.1 Introduction

The results of baseline mapping of the existing conditions in the gross area for Thor OWF and cable corridors relevant for the baseline description of benthic flora and fauna are presented below. These data include abiotic parameters as well as biological parameters.

Abiotic conditions include water depth (section 5.2.1), CTDO-measurements (section 5.2.2), physical and chemical parameters (section 5.3.5) and seabed substrates (section 5.3). Biological parameters include benthic flora (section 5.4) and benthic fauna divided into epifauna (living on surface of seabed) (section 5.5.2) and infauna (living in the seabed) (section 5.5.3). Finally, an overview of the benthic habitats combining the distribution of epifauna and infauna in the different sediment types are presented in section 5.6.

Relevant existing data for benthic flora, epifauna and infauna has been compared to the data from Thor OWF. Existing data presented from nearby projects include: Vesterhav Nord (Vattenfall, 2020a)and Vesterhav Syd (Vattenfall, 2020b) OWFs, Horns Rev III OWF (Orbicon, 2014), the EIA for the coast nourishment project along the west coast of Denmark from Lodbjerg to Nymindegab (Rambøll, 2020a), further from the coast at different raw material extraction sites at and around Jyske Rev (Orbicon, 2019; Orbicon, 2018a; Orbicon, 2018b), the nearby Natura 2000 sites: N220 Sandbanker ud for Thorsminde (Naturstyrelsen, 2013a) and N247 Thyborøn Stenvolde (Naturstyrelsen, 2013b) (see Figure 5-1).

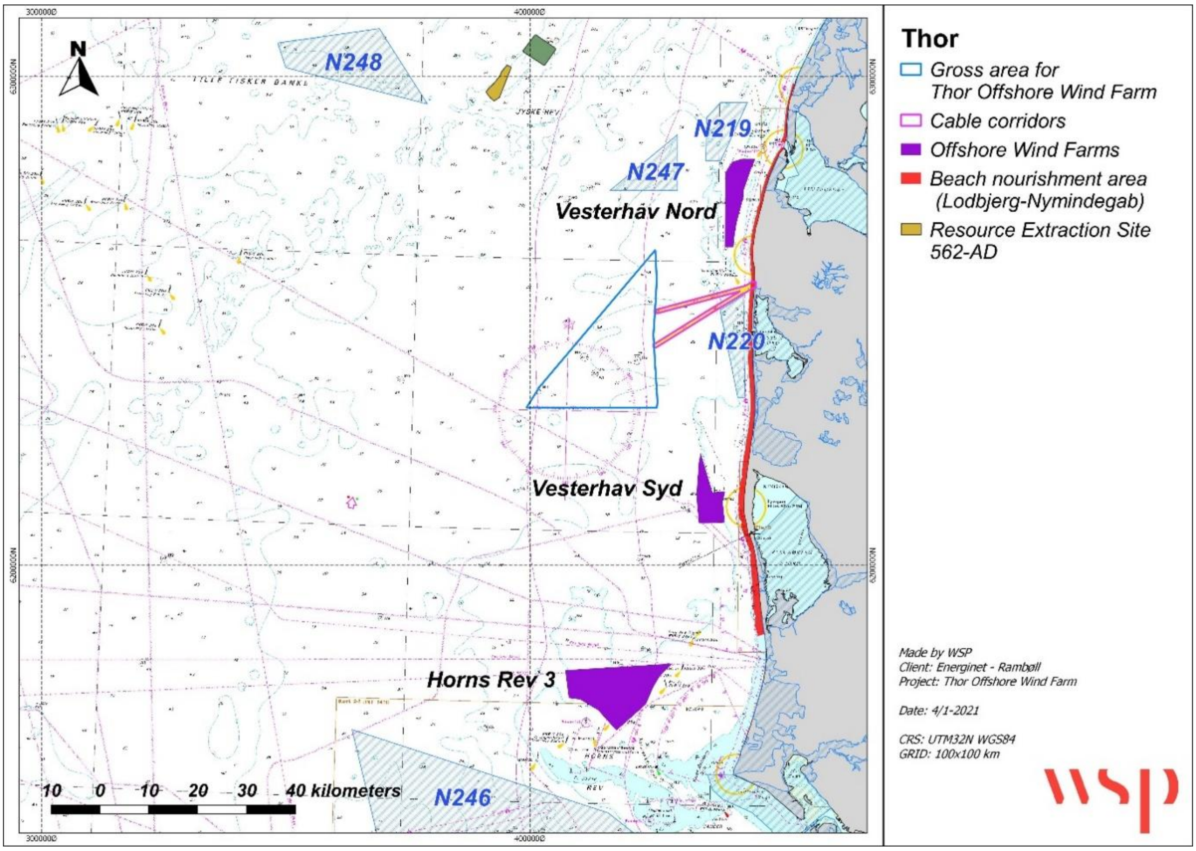


Figure 5-1. Sources of existing data used to describe existing data.

5.2 Abiotic data

Abiotic data are presented in the following. Abiotic data are based on sampling data collected during the geophysical survey acquired in August-December 2019 by MMT Sweden AB; (MMT, 2020a) for the gross area for Thor OWF and (MMT, 2020b) for the cable corridors.

5.2.1 Water depth

Depth data are used to describe the distribution of infauna with respect to water depth in the area both for the map of benthic habitats (see section 5.6) and for the statistical analysis of infauna species composition in the investigated area (se section 5.5.3.3).

Water depths in the investigated area including the gross area for Thor OWF and cable corridors were assessed through use of multibeam echosounder acquired during the geophysical survey; for the gross area (MMT, 2020a) and for CC (MMT, 2020b).

The bathymetric map (water depth) in Figure 5-2 shows water depth ranges between -21 to -35 meters in the gross area for Thor OWF and between 0 to -30 meters in the two cable corridors (CC).

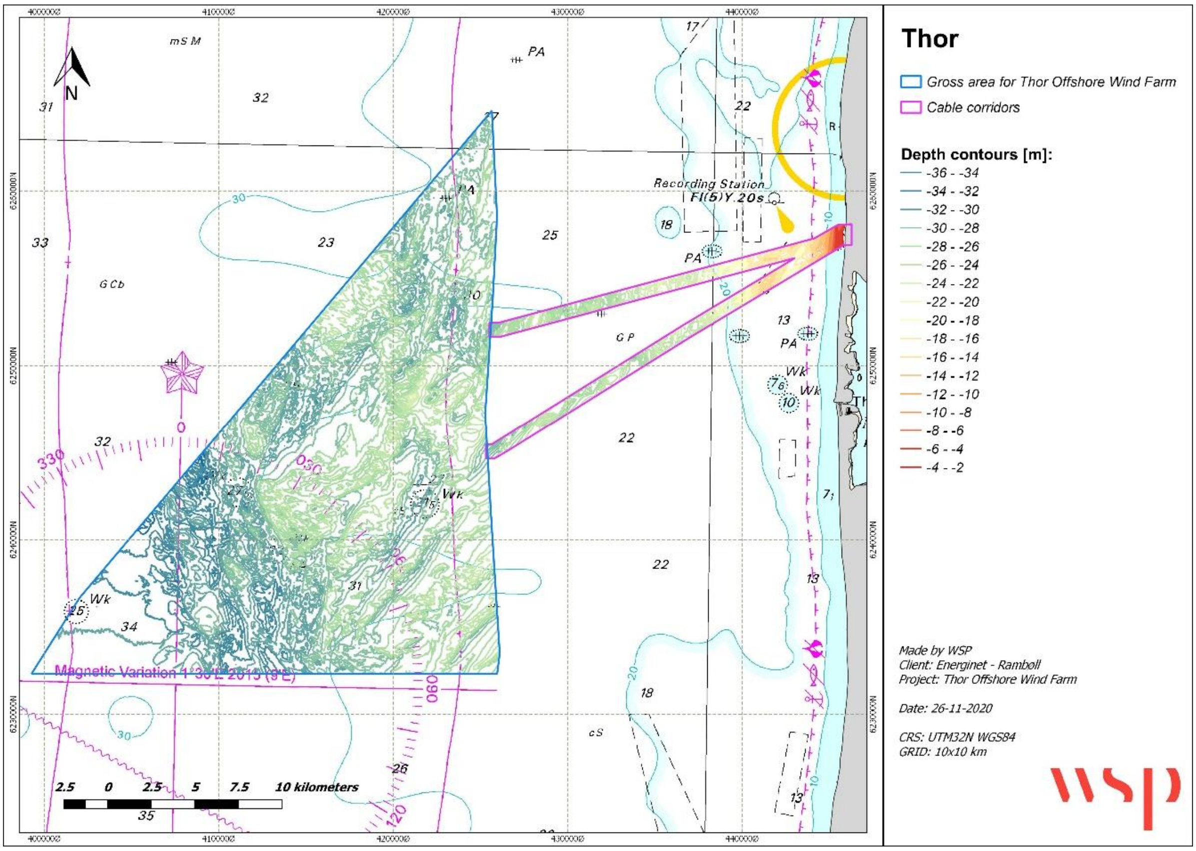


Figure 5-2 Bathymetric map (depth) of the gross area for Thor OWF and cable corridors by 2 meter interval depth contours, for the gross area (MMT, 2020a) and for the two cable corridors (MMT, 2020b).

5.2.1.1 Gross area for Thor OWF

The deepest part is located in the southwestern part, whereas the shallowest part is located mainly in the eastern and southeastern part of the gross area for Thor OWF (Figure 5-2).

5.2.1.2 Cable corridors

In the cable corridors water depth increases towards west with the lowest water depth closest to the coast and the largest water depth when reaching the gross area for Thor OWF (Figure 5-2).

The bathymetry shows a dramatic steepening trend close to land in the surf zone, where the bathymetry rises from -7,5 m depth to 0 m depth over a distance of only 600 m. The surf zone close to the shore is more dominated by sandy sediments (substrate 1b) and gravelly coarse sediments (substrate 2a) (Figure 5-2). The water depth conditions are very similar for the northern corridor (R2) and the southern corridor (R3).

5.2.2 CTDO – salinity, temperature and oxygen

CTDO measurement were used for statistical analysis of the controlling abiotic parameters for infauna composition in the investigated area. Parameters used for the statistical analysis were salinity and oxygen content of the water (see section 5.5.3.3).

Salinity, temperature and oxygen - concentration and saturation % was measured approximately 1 m above the seabed at 190 stations – 150 stations in the gross area for Thor OWF, 20 stations in the northern cable corridor (R2) and 20 stations in the southern cable corridor (R3). Full CTDO-data is presented in Appendix 2a. The range of data is presented in the table below (Figure 5-1).

Table 5-1. Range of oxygen (saturation %), salinity, temperature and depth at the sea floor.

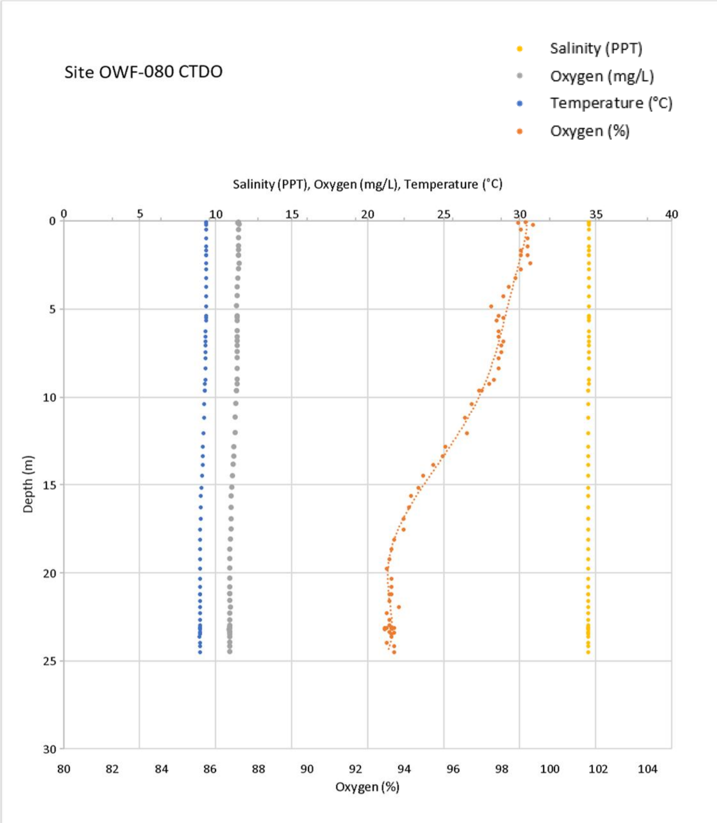
	Oxygen (%)	Oxygen (mg/L)	Salinity (PSU)	Temperature (°C)	Depth (m)
GA	88.7-104.6	10.4-12.3	34-35	7.9-9.1	21.8-35.6
CC_R2	94.4-99.5	10.7-11.5	34.1-34.5	9.4-10	8.4-28
CC_R3	92.1-102.8	10.5-11.9	34.2-35	9.3-9.9	14.3-29.6

Moderate oxygen deficiency is defined as oxygen concentrations between 2-4 mg O_2/l and severe oxygen deficiency as <2 mg O_2 l^{-1}. No CTDO data indicated oxygen deficiency at any stations in the gross area for Thor OWF nor in the cable corridors.

CTDO bottom data is available for all stations (see Appendix 2a). CTDO profiles are available for all stations in the cable corridors (see Appendix 2b). However due to mechanical failures in the CTDO logger, 119 stations in the gross area for Thor OWF lack data for CTDO profiles resulting in a total of 33 CTDO-profiles available for the gross area for Thor OWF (Appendix 2b).

5.2.2.1 Gross area for Thor OWF

No stratification of the water column could be interpreted from the available CTDO data from the gross area for Thor OWF. In general optimal oxygen conditions were present (Figure 5-3), except at station OWF-078, where small, local spots of a few meters in diameter with white sulfur bacteria as indication of anoxic areas were observed (Figure 5-4). This, however, could not be concluded from the CTDO bottom data, which showed an oxygen concentration of 11,4 mg/L (Appendix 2a). The local spots are therefore most likely an artifact of anthropogenic origin such as fish waste or some other unknown man-made source.



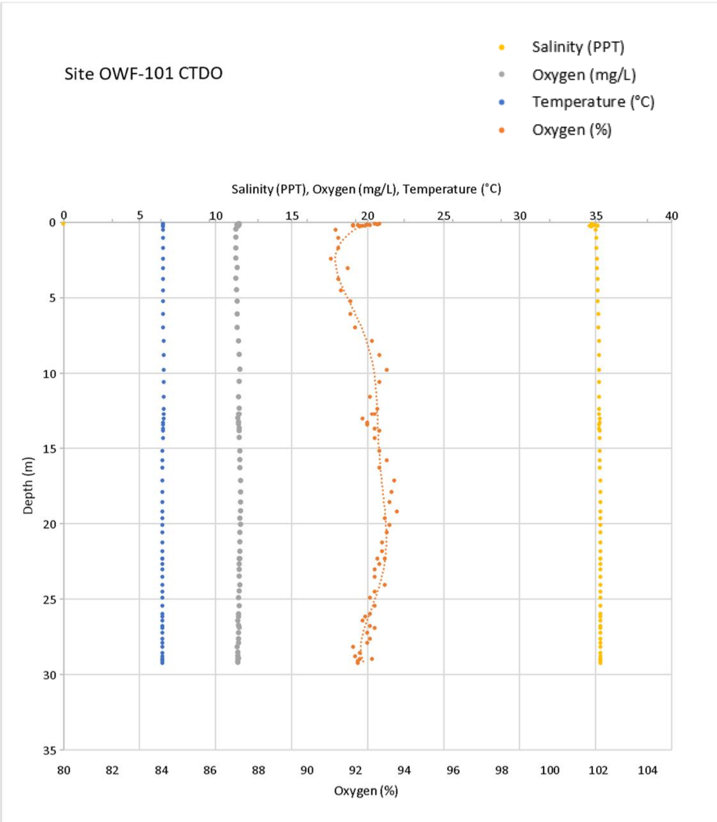


Figure 5-3. CTDO-profile from eastern (upper panel) and western (lower panel) part of the gross area for Thor OWF, at station OWF-080 and OWF-101, respectively.

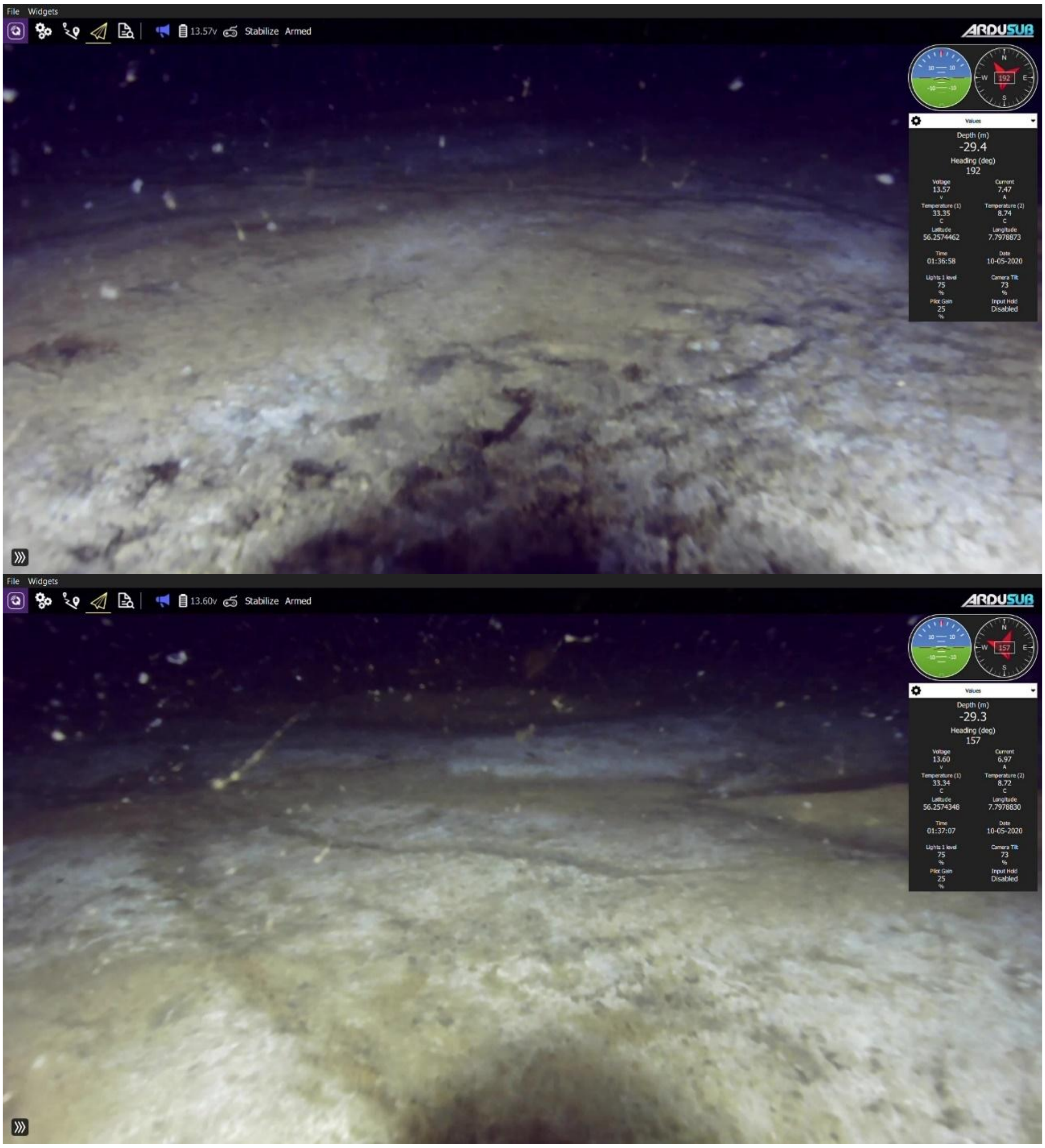
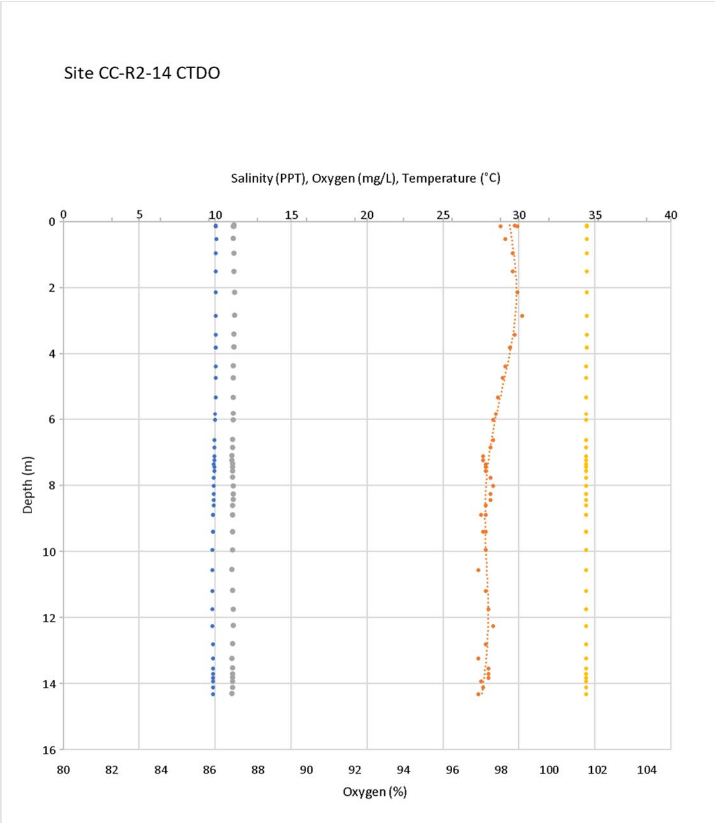


Figure 5-4. Local spots with white sulphur bacteria at station OWF_078 as an indication of localized anoxic conditions on the seabed.

5.2.2.2 Cable corridors

No stratification of the water column was observed in the cable corridors and fully oxygenized water columns were observed throughout both cable corridors (Figure 5-5). No difference in oxygen, temperature and salinity was observed between the two cable corridors.



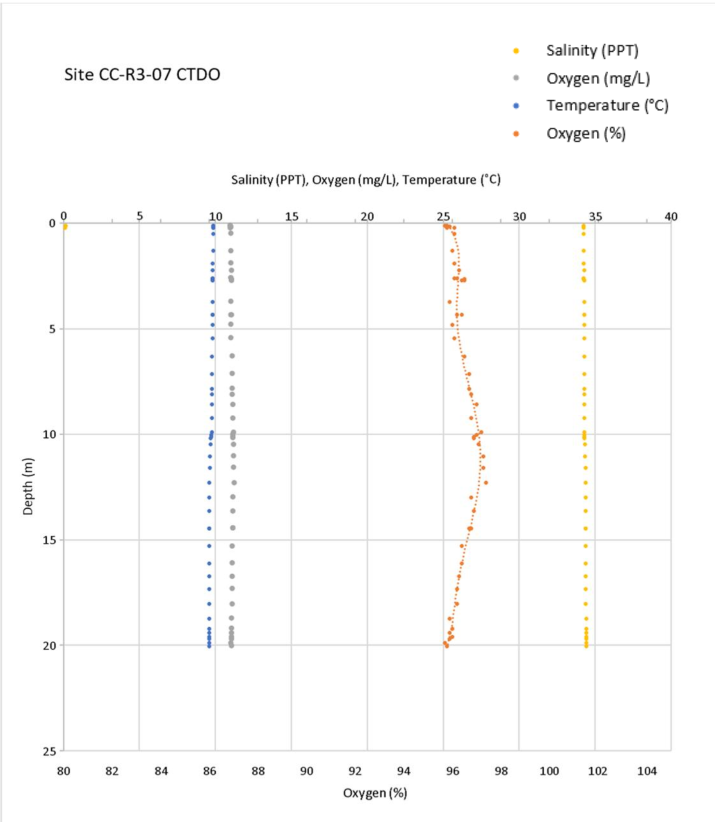


Figure 5-5. CTDO-profiles for R2 and R3, at station CC-R2-14 and CC-R3-07, respectively.

5.3 Seabed sediment characteristics

In the following the seabed sediment types are described for the gross area for Thor OWF and cable corridors.

5.3.1 Seabed sediment types and distribution

Seabed sediment types are included for the mapping of the benthic flora and fauna communities in the gross area for Thor OWF and the cable corridors. The map of the sediment types combined with the visual observations (ROV-stations) of the benthic flora and fauna present in the different sediment types are used to describe the different benthic flora and fauna communities in the investigated area and to create the map of epifauna communities (see Figure 5-24) and benthic habitats in section 5.6.

The final map of seabed sediment types (Sediment type map), based on data from the geophysical survey and ground truthing data (ROV documentation and HAPS sampling) from the benthic field survey, are shown as an overview for the gross area for Thor OWF and the cable corridors below (Figure 5-6). The ROV-stations used for the ground truthing/visual verification are presented in the figures for each subarea of the gross area for Thor OWF (GA) (GA1 - Figure 5-7, GA2 - Figure 5-8, GA3 - Figure 5-9) and for the cable corridors (Figure 5-10) below. The results from the HAPS sampling program in terms of physical and chemical analysis are presented in Appendix 3, 4 and 5. The results from the ROV documentation are presented in Appendix 7.

Basically, the overview map illustrates the overall distribution of interpreted seabed sediment classified as various sediment types. The overview has been subdivided into four subareas (GA1 - Figure 5-7, GA2 - Figure 5-8, GA3 - Figure 5-9 and CC - Figure 5-10), to be able to show zooms of the sediment types in the gross area for Thor OWF.

Based on the interpretation of the collected side scan sonar data a total of six different sediment types have been identified, cf. sediment type 1b, 1c, 2a, 2b, 3 and 4. These six sediment types have both been identified within the gross area for Thor OWF and the cable corridors (Figure 5-6).

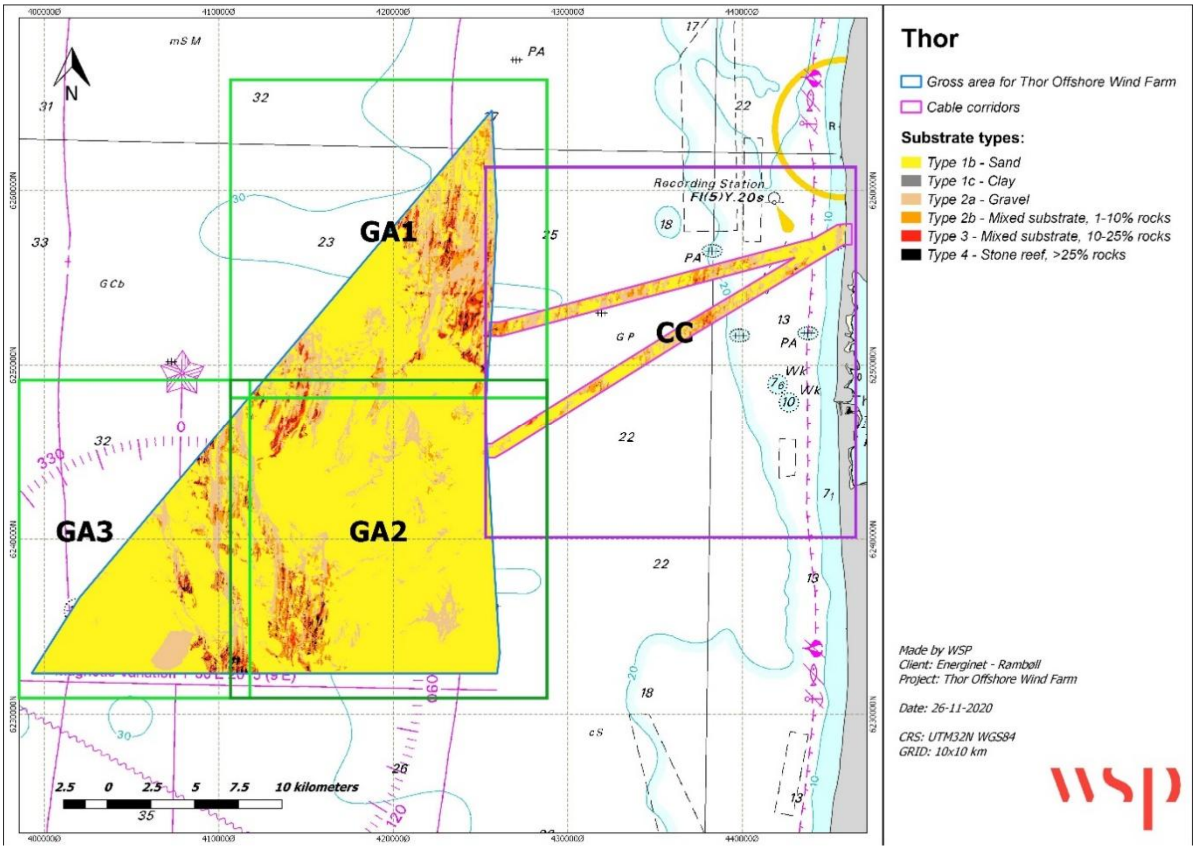


Figure 5-6 Sediment type map with overview of OWF and CC areas and indication of subareas shown as zooms in Figure 5-7, Figure 5-8, Figure 5-9 and Figure 5-10. All seabed sediment types have been verified by ground truthing (visual verification on ROV video recorded at the stations) obtained during the "Benthic Seabed survey".

The stations used for visual verification of the observed sediment types are listed in Table 5-2 below. For both the gross area for Thor OWF and the cable corridors sediment type 1b - sand is verified at most stations, whereas sediment type 2a is the second most verified type. Sediment type 1c is only verified as a secondary sediment type and not observed as primary sediment type on any of the ROV videos from the stations in either the gross area for Thor OWF or cable corridors.

Table 5-2 Visual verification of the sediment types at stations in the gross area for THOR OWF (Gross area) and the two cable corridors (CC area). Only the primary sediment types are shown here.

	Number of ROV stations	
Sediment type	**Gross area**	**CC area**
1b	105	29
1c	0	0
2a	21	5
2b	10	2
3	10	1
4	4	3
Total	150	40

Overall, the area distribution of sediment types is relatively comparable for both the gross area and the cable corridors. Sediment type 1b "sand" dominates both areas, while sediment type 2a "gravel" is the second most dominant type. In general, the area coverage of the sediment types decreases with increasing rock coverage. Thus, sediment type 3 and 4 together with sediment type 1c are the least common types in both areas. Table 5 3 below shows the area distribution of the various sediment types in the gross area for Thor OWF and the cable corridors.

Overall, the area distribution of sediment types is relatively comparable for both the gross area and the cable corridors. Sediment type 1b "sand" dominates both areas, while sediment type 2a "gravel" is the second most dominant type. In general, the area coverage of the sediment types decreases with increasing rock coverage. Thus, sediment type 3 and 4 together with sediment type 1c are the least common types in both areas.

Table 5-3 Area distribution in square meters and percentage of interpreted sediment types within the gross area for Thor OWF (Gross area) and the cable corridors (CC area).

	Gross area		CC area	
Sediment type	**km²**	**%**	**km²**	**%**
1b	330.1	75	19.9	56
1c	-	-	0.04	<1
2a	61.8	14	9.3	26
2b	31.7	7	5.1	14
3	13.4	3	0.8	2
4	3.0	<1	0.04	<1
Total	440.0	100	35.6	100

5.3.2 Gross area for Thor OWF

The gross area for Thor OWF (GA) is divided into subareas i.e. GA1, GA2 and GA3 and are described in more detail below.

5.3.2.1 GA1

The GA1 subarea is presented in Figure 5-7 and shows the northern part of the gross area for Thor OWF. GA1 is dominated by large elongated rocky areas and stone reefs (sediment type 2b, 3 and 4) with interlaying gravel (sediment type 2a) and sand (sediment type 1b), striking north to south especially in the north-eastern part of GA1 subarea. These elongated structures are parallel with the coast of western Denmark. The reef areas are visible on the bathymetry map (Figure 5-2) and they are related to local high grounds. In the southwestern part of GA1 subarea, sandbank areas dominate the seabed in between more rocky areas.

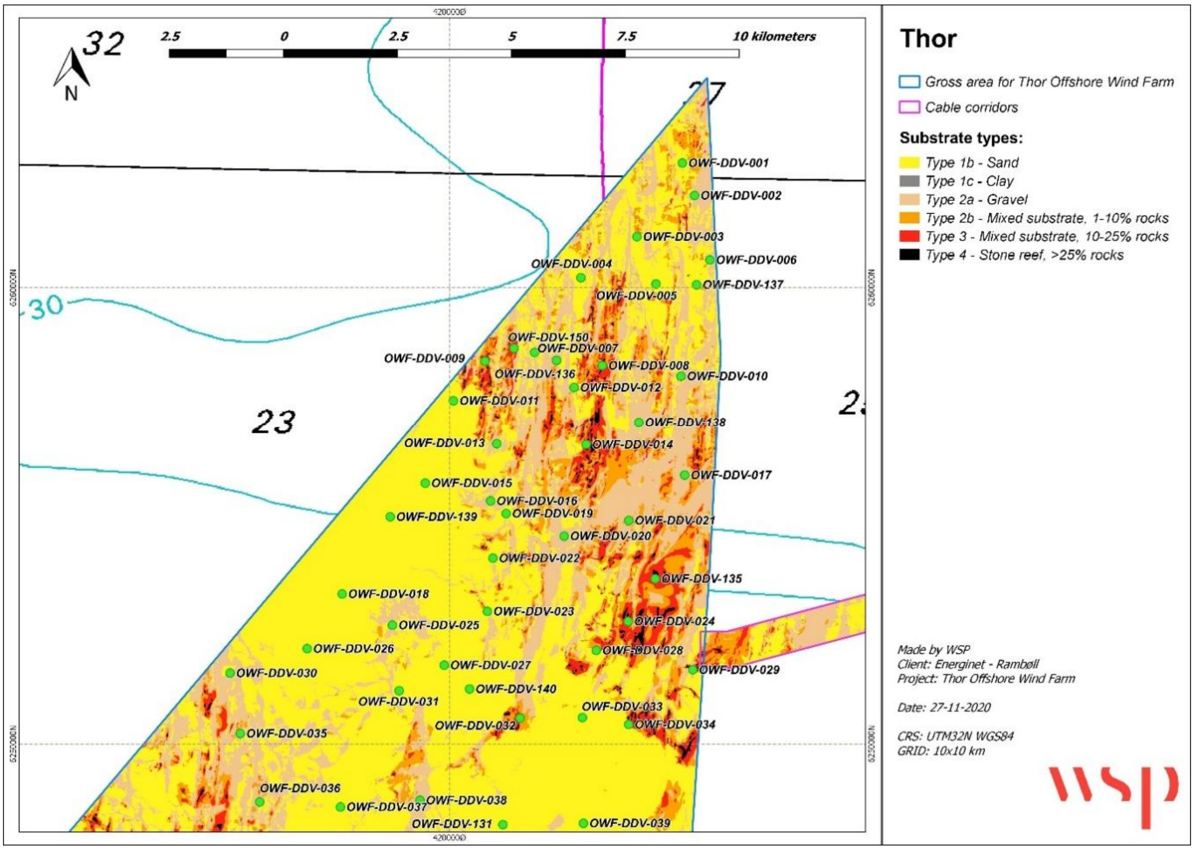


Figure 5-7 Sediment type map of subarea GA1 with ROV-stations. The full gross area for Thor OWF is shown in Figure 5-6.

5.3.2.2 GA2

The eastern and southeastern part of GA2 subarea is largely dominated by sandy banks (sediment type 1b) striking NE-SW, with gravelly sands (sediment type 2a) in between the bank structures (see Figure 5-8). The sandbank structures are clearly shown on the bathymetry by NW-SW striking hills (Figure 5-2). The western part of GA2 subarea consists of coast-parallel N-S striking rocky moraines and gravels (sediment type 2b, 3 and 4). The rocky moraines contain stone reef areas, particularly in the northwestern and southwestern part of GA2 subarea (Figure 5-8).

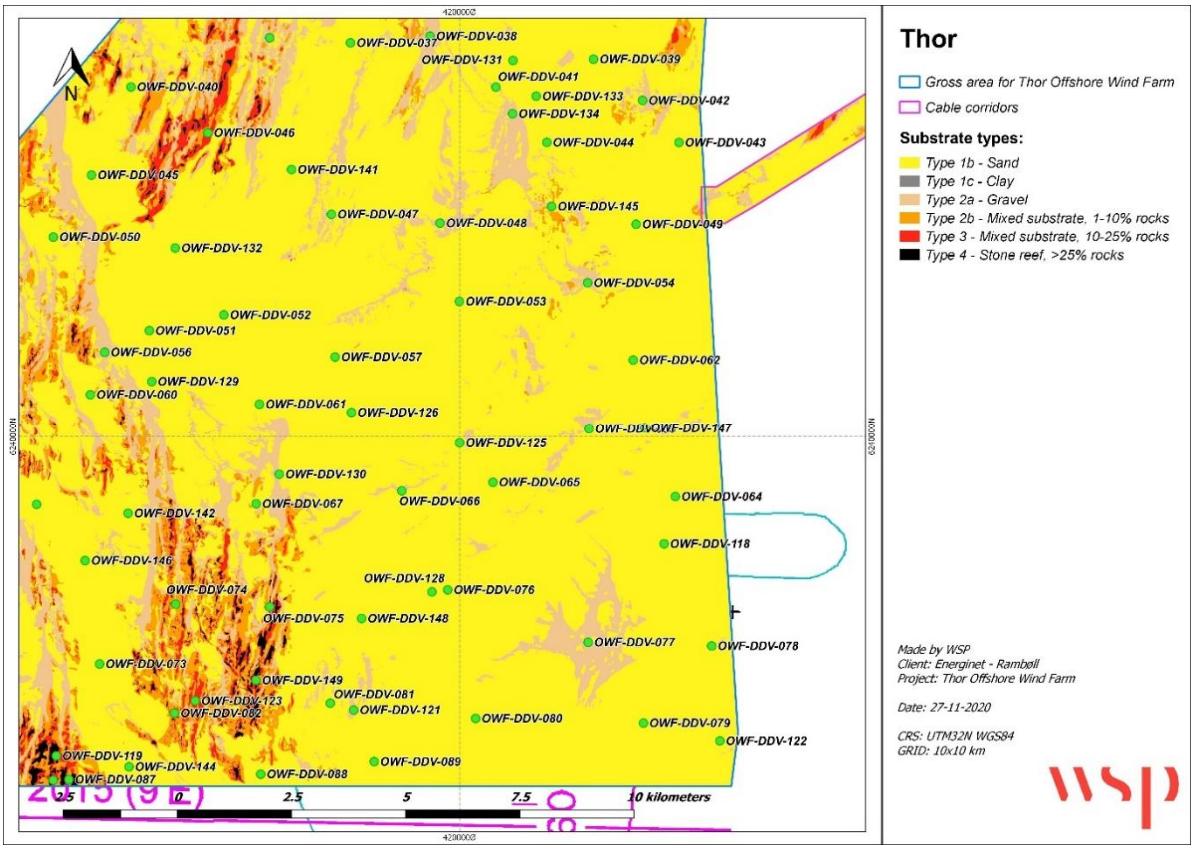


Figure 5-8 Sediment type map of subarea GA2 with ROV-stations. The full gross area for Thor OWF is shown in Figure 5-6

5.3.2.3 GA3

The GA3 subarea is located in the western and deepest part of the gross area for Thor OWF (Figure 5-9). GA3 is dominated by a deeper basin consisting of fine-grained sand (sediment type 1b) towards the west bordered by N-S striking moraines (sediment type 2b, 3 and 4). This sandy basin is characterized by dynamic seabed features, which was illustrated by sampling of two different sediment types in the same area in 2019 and 2020. Grab sampling in 2019 by MMT, showed muddy sediment in the area in a period of good weather conditions (MMT, 2020a). However, HAPS sampling in the spring of 2020 by WSP, showed a fine sandy sediment which was sampled in a period of more rough weather conditions - i.e. two very different sediment textures sampled from the same area in the two different years indicating a very dynamic seabed in the area.

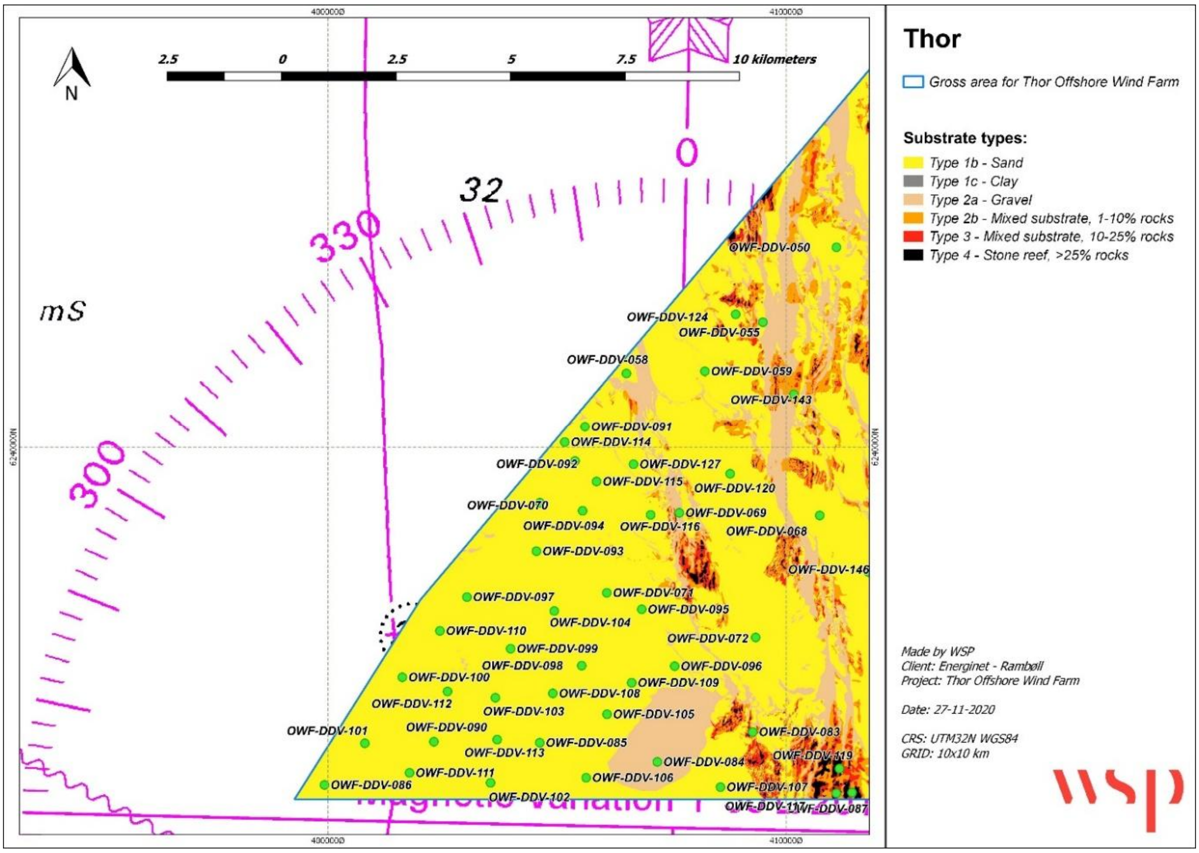


Figure 5-9 Sediment type map of subarea GA3 with ROV-stations. The full gross area for Thor OWF is shown in Figure 5-6.

5.3.3 Cable corridors

The project plan includes two cable corridor alternatives: R2 – the northern corridor and R3 – the southern corridor. The sediment types found in the two corridors are presented in Figure 5-10.

The cable corridors are dominated by sediment type 1b "sand" with coast parallel N-S striking rocky areas (sediment type 2b, 3 and 4) with surrounding gravel deposits (sediment type 2a). These rocky areas and gravel deposits seems to continue through both cable corridors.

Overall, the seabed sediments seem to be more fine-grained in the southern corridor (R3) compared to the northern corridor (R2). For the southern corridor the coverage of stony substrates (sediment type 2b, 3 and 4) as well as gravelly sediment (sediment type 2a) is smaller compared to the northern corridor. Further, the content of sandy sediment (sediment type 1b) is larger for the southern corridor (R3) relatively to the northern corridor (R2) (Figure 5-10).

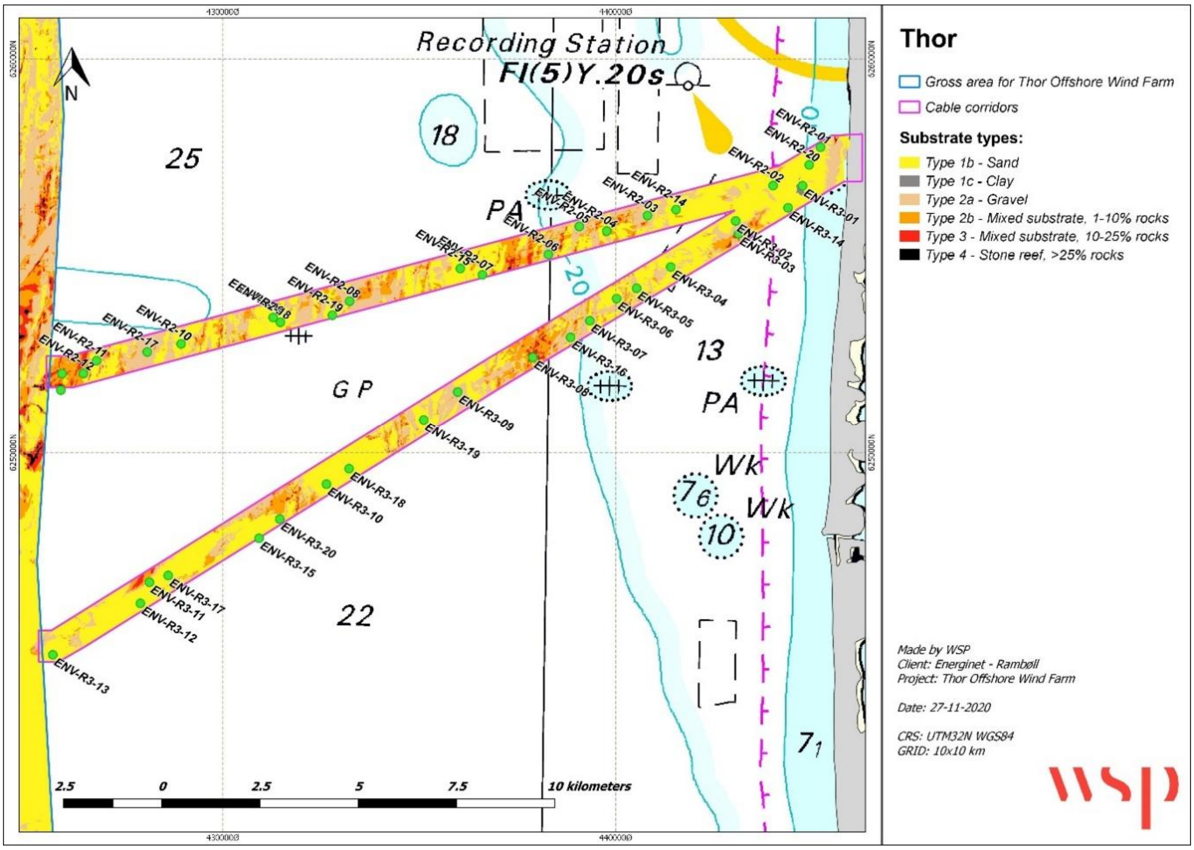


Figure 5-10 The substrate map with ROV-stations of the cable corridor alternatives: R2 – the northern cable corridor and R3 – the southern cable corridor.

Table 5-4. Area distribution in square meters and percentage of interpreted sediment types in the cable corridors: R2 – the northern cable corridor and R3 – the southern cable corridor.

	Northern corridor (R2)		Southern corridor (R3)	
Sediment type	**km²**	**%**	**km²**	**%**
1b	8.8	51	12.6	63
1c	-	0	0.05	<1
2a	5.1	30	4.6	23
2b	2.8	16	2.3	12
3	0.5	3	0.3	2
4	0.02	<1	0.02	<1
Total	17.2	100	19.9	100

5.3.4 Description of the sediment types

In the following section the characteristics of each sediment type is described.

Sediment type 1b

Sediment type 1b is a sandy seabed with shell fragments, and a varying content of coarser and finer grain sizes. The seabed is very dynamic and has wave ripple marks and sand ridge structures (Figure 5-11). The substrate is the most dominant of the sediment types covering 75% of the gross area for Thor OWF and 56% of the cable corridors (CC). The sediment type has been identified in the majority of the gross area for Thor OWF and cable corridors, however it is most dominant in the central part as well as in the southeastern and southwestern part of gross area for Thor OWF (Figure 5-6). Sediment type 1b is located in water depths of -36 to -22 meters (Figure 5-2).

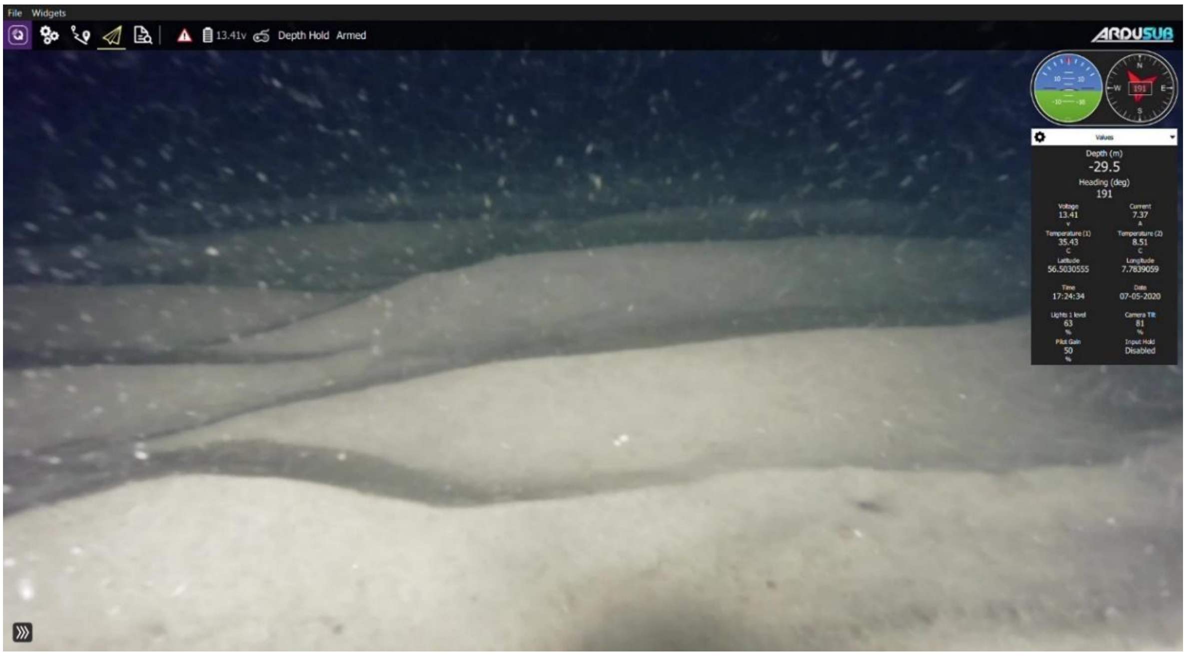


Figure 5-11. Sediment type 1b – sand dominated by dynamic conditions. ROV-station OWF_001. STILL picture: THOR_WP-E_STILL_OWF_001_01.

Sediment type 1c

Sediment type 1c is a clayish sediment typically related to clay outcrops on the seabed (Figure 5-12). Very often clayish sediment is related to peat. Sediment type 1c is only verified in the eastern part of the southern cable corridor at ROV station R3-001 and covers less than 1% of the area (Table 5-4). Thus, this sediment type is one of the least common substrates.

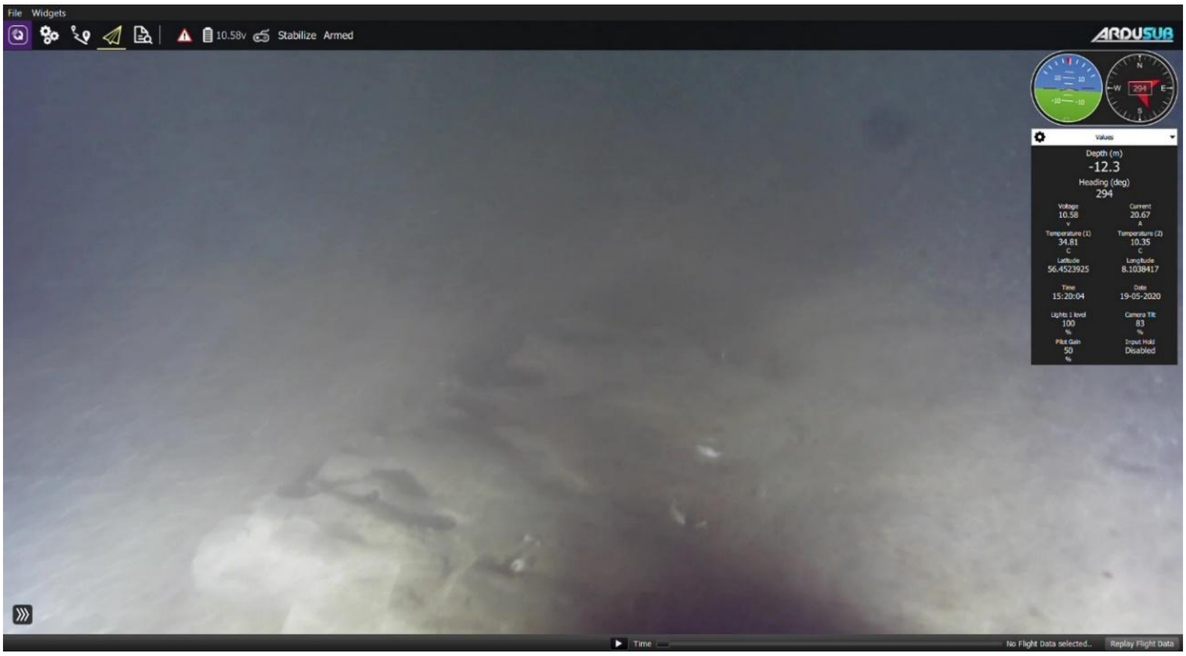


Figure 5-12. Sediment type 1c – clay outcrop. ROV station R3_001. Still-picture: THOR_WP-E_STILL_CC_R3_001_06.

Sediment type 2a
Sediment type 2a is a seabed type with a high content of gravel and smaller rocks. It has a varying content of sand (Figure 5-13). It is mainly visible between ridges and in ripple troughs, or locally as a well sorted gravel flat. The sediment type is the second most dominant covering 14% of the gross area for Thor OWF and 26% of the CC area. Sediment type 2a is located in depths of -34 to -24 (Figure 5-2).

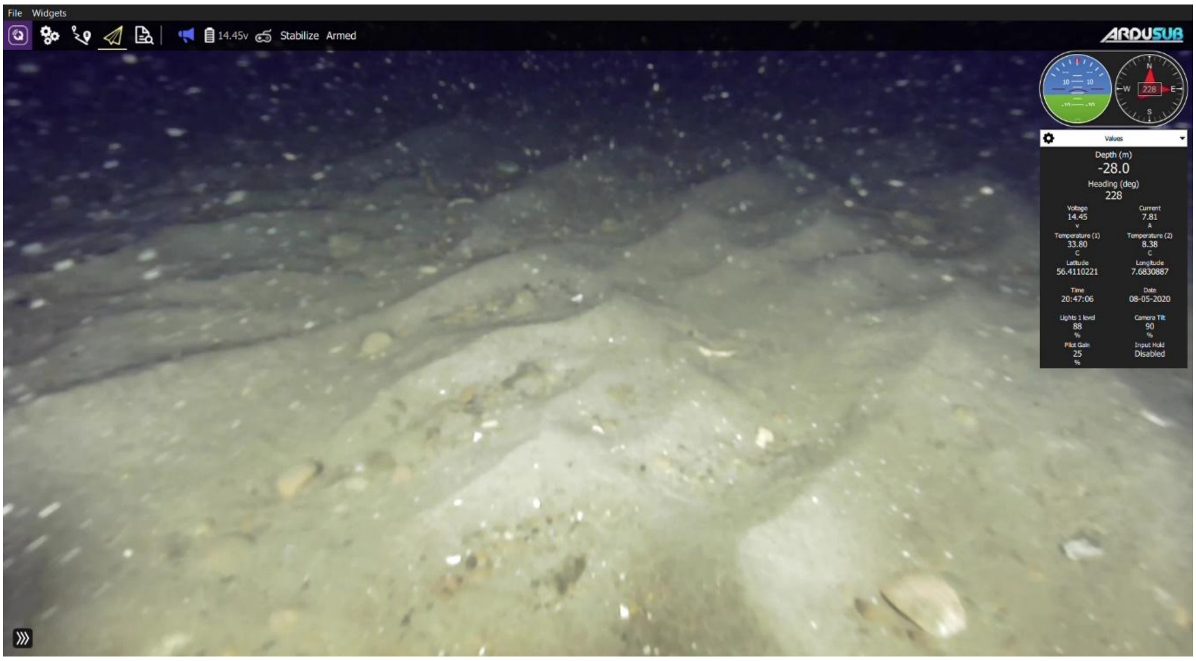


Figure 5-13. Sediment type 2a – sand and gravel. ROV-station OWF_025. Still-picture: THOR_WP-E_STILL_OWF_025_03.

Sediment type 2b
Sediment type 2b is seen as a sandy seabed with scattered large rocks of 1-10% coverage (Figure 5-14). It is mainly seen as a transition from sediment type 1b to sediment type 3.

This sediment type is the third most dominant covering 7% in the gross area for Thor OWF and covers 14% of the cable corridors. It has mainly been identified in the northern, western and southern parts of the gross area for Thor OWF (Figure 5-6). Sediment type 2b is located at varying depths between -32 to -22 meters in the gross area for Thor OWF (Figure 5-2).

Figure 5-14. Sediment type 2b. ROV-station OWF_083. STILL-Picture: THOR_WP-E_STILL_OWF_083_06.

Sediment type 3

Sediment type 3 is seen as a rocky seabed with scattered large rocks of 10-25% coverage, with a matrix of sand, gravel and smaller rocks (Figure 5-15). It is mainly seen as a transition from substrate 2b to substrate 4. Sediment type 3 and 4 are often found together and collectively defines stony reef structures. The substrate is the second rarest sediment type covering 3% of the gross area for Thor OWF and 2% of the cable corridors (CC). It has mainly been identified in local patches in the northern, western and southern parts of the gross area for Thor OWF (Figure 5-6). Sediment type 3 is located at varying depths of -28 to -24 meters in the gross area for Thor OWF (Figure 5-2).

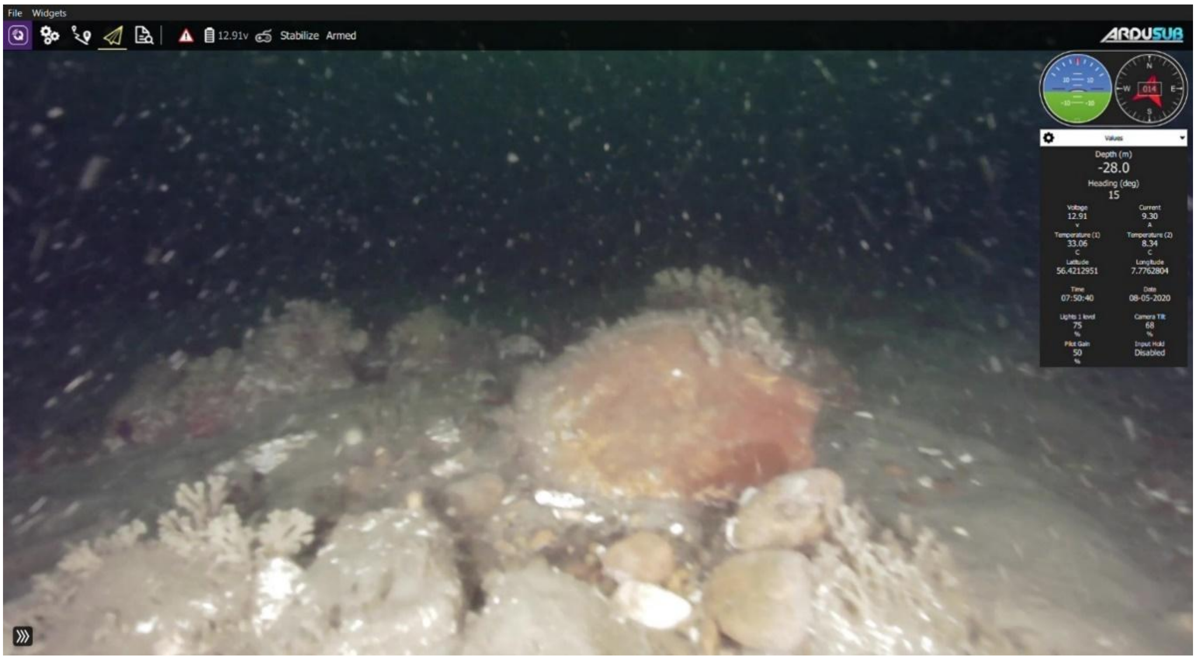


Figure 5-15. Sediment type 3. ROV-station OWF_135. STILL-picture: THOR_WP-E_STILL_OWF_135_09.

Sediment type 4
Sediment type 4 is seen as stony reef structures with a rock content of large rocks (>10 cm) greater than 25% (Figure 5-16), with cavities between the rocks. The substrate has a various matrix content of sand, gravel and smaller rocks. It is mainly seen in relation to sediment type 3. This sediment type is the rarest having an area coverage of <1% for both the gross area and CC areas. It has mainly been identified in small local patches in the northern, western and southern parts of the gross area for Thor OWF (Figure 5-6). Depths varies from -28 to -24 meters (Figure 5-2).

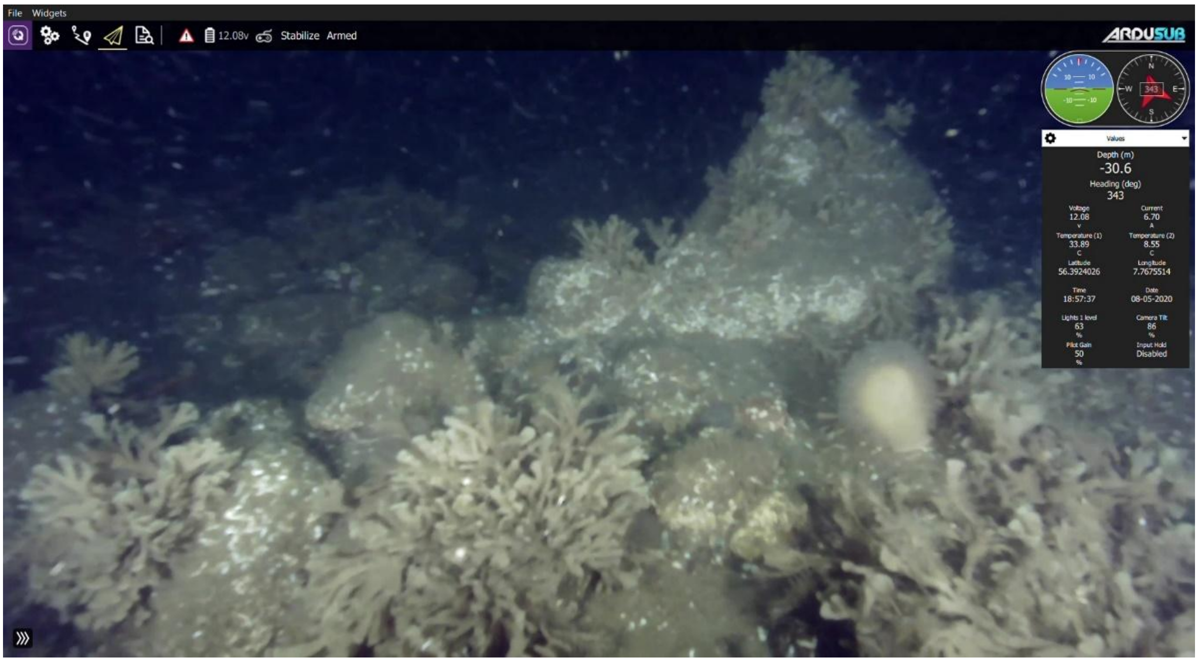


Figure 5-16. Sediment type 4 – stone reef. ROV-station THOR_WP-E_STILL_OWF_034_02.

5.3.5 Physical and chemical characteristics
Physical sediment parameters are included in this report for the statistical analysis of the controlling abiotic parameters for infauna composition (see section 5.5.3.3). Chemical data from the cable corridors are used to exclude impact caused by potential nutrient release from the sediment the construction phase of the planned project (see section 6.1.1).

Below the physical and chemical characteristics of the sediment are presented. Data is presented in Appendix 3 – Grain size analyses, Appendix 4 – dry weight, organic matter and loss on ignition, Appendix 5 – chemical analyses in the cable corridors.

5.3.5.1 Physical parameters
The following physical parameters were analysed in the gross area for Thor OWF and cable corridors:

- Grain size distribution, including median grain size (d50) of the sediment and silt/clay fraction.
- Uniformity coefficient (d60/d10)
- Total Organic Carbon (TOC)

Presented in Appendix 4 only:

- Dry matter = Dry weight
- Loss on ignition
- Sediment sorting and grading

In the following data used for the statistical analysis of infauna are presented (see section 5.5.3.3) including grain size distribution, uniformity coefficient and TOC. All analysed data are presented in Appendix 4.

Grain size analysis
The physical analysis in terms of particle size have been conducted and analysed at 123 stations within the Thor OWF and 32 stations within the two cable corridors (15 station at R2 and 17 stations at R3). All analysed particle size data are presented in Appendix 3.

According to the particle size analysis the following three main elements have been determined: median grain size (d50) measured in mm, coefficient of uniformity (d60/d10) measured as an index and silt-clay fraction measured in percentage. These elements are used as supporting parameters in the statistical analysis of infauna distribution in the investigated area e.g. to explain the composition of infauna.

Median grain size
Overall, the analysis of median grain size shows, that the sediment is very heterogeneous in the investigated area (Table 5-5). For instance, within the gross area for Thor OWF median grain size (d50) varies between 0.04 and 28.5 mm, illustrating large sediment variation (see Figure 5-17). This illustrates that sediment types between coarse silt and coarse gravel is represented within the gross area for Thor OWF. Within the two corridors the variation is lower. In the gross area for Thor OWF and the northern corridor (R2) the average median grain size is coarse sand, whereas it is medium sand in the southern corridor (R3). Generally, the results show that sediment within R2 is more coarse-grained relatively to R3.

Table 5-5. Minimum, maximum and average determinations in relation to median grain size (d50) measured in mm for the gross area for Thor OWF (Gross area) and the cable corridors: R2 – the northern cable corridor and R3 – the southern cable corridor.

d50	Min (mm)	Max (mm)	Average (mm)
Gross area	0.04 (coarse silt)	28.5 (coarse gravel)	0.9 (coarse sand)
R2	0.2 (fine sand)	3.1 (fine gravel)	0.6 (coarse sand)
R3	0.2 (fine sand)	0.7 (coarse sand)	0.3 (medium sand)

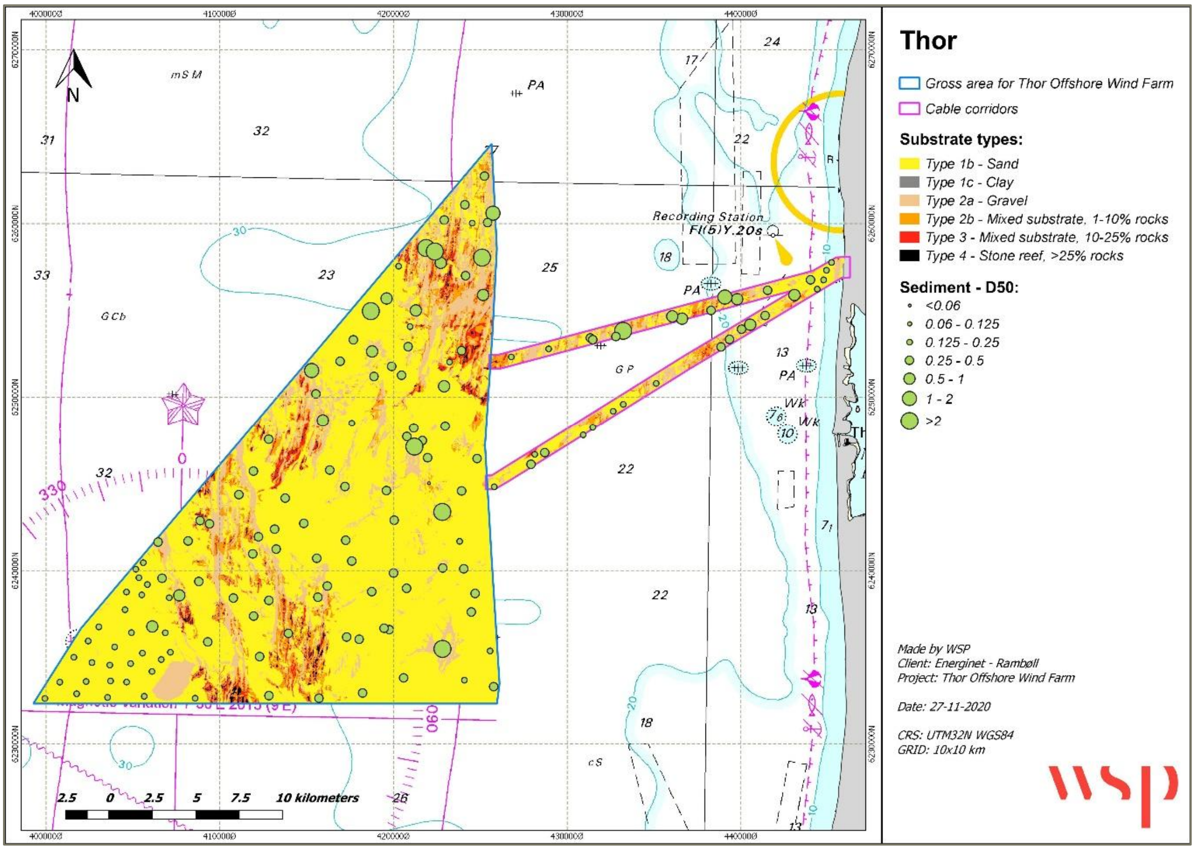


Figure 5-17. Analysed median grain size for each benthic station within the investigated area.

Coefficient of uniformity

The coefficient of uniformity is an expression of the uniformity (same grain size) of the sediment and is determined by d60 divided by d10. The coefficient of uniformity is called U index. A large U index indicates no uniformity (unsorted and non-uniformed sediment), whereas a low U index indicates great uniformity (well sorted and well graded uniformed sediment). Typically, the uniformity referrers to the sorting and grading of the sediment e.g. similar grain size.

The analysis shows that the coefficient of uniformity varies significantly within the investigated area, particularly in the gross area for Thor OWF where highly diverse conditions prevail (from well sorted to highly unsorted – from non-uniformed to uniformed). The coefficient of uniformity is significantly more uniform for the southern cable corridor (R3) where the sediment either is well sorted or sorted (Table 5-6) (Figure 5-18).

Table 5-6 Minimum, maximum and average determinations in relation to uniformity coefficient (d60/d10 presented in index for the gross are for Thor OWF (Gross area) and the cable corridors: R2 – the northern cable corridor and R3 – the southern cable corridor. Sorting: Well sorted (U<2), sorted (2<U<3.5), poorly sorted (3.5<U<7) and unsorted (U>7). Grading: Uniform (U<4), graded (4<U<6) and well graded (U>6) (Larsen et al, 2009).

Uniformity Coefficient (d60/d10)	Min (Index)	Max (Index)	Average (Index)
Gross area	1.5 (well sorted, uniform)	82.8 (unsorted, well graded)	4.2 (poorly sorted, graded)
R2	1.6 (well sorted, uniform)	5.3 (poorly sorted, graded)	2.3 (sorted, uniform)
R3	1.5 (well sorted, uniform)	2.8 (sorted, uniform)	2.0 (well sorted, uniform)

There is a significant correlation between the coefficient of uniformity and median grain size. Lower median grain size means greater sediment uniformity and more sorted sediment conditions.

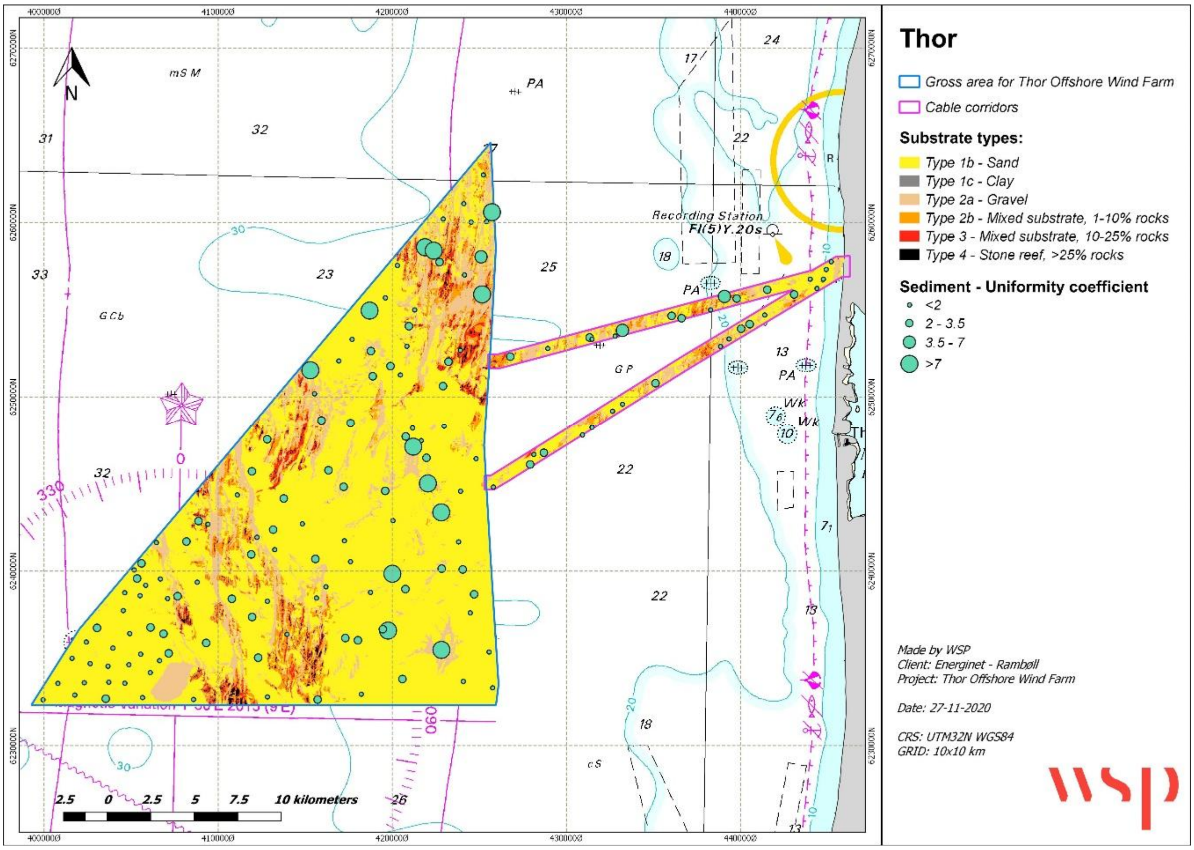


Figure 5-18. Analysed uniformity coefficient for each benthic station within the investigated area.

Silt-clay fraction

Overall, the analysis of silt-clay fraction (finer sediment) shows, that the content of silt and clay in the sediment varies significantly within the investigated area (Table 5-7). Particularly, in the gross area for Thor OWF the silt-clay content fluctuates greatly between almost 0% up to around 56% (Figure 5-19). In general, the silt-clay content is higher within the gross area for Thor OWF relatively to the two cable corridors. Between the two cable corridors R3 has a significant higher content of silt and clay relatively to R2.

Overall, the lower silt-clay content in R3 reflects the greater water depth and lower sediment dynamics relatively to R2.

Table 5-7. Minimum, maximum and average determinations in relation to silt-clay fraction measured in percentage relatively to full sample for the gross are for Thor OWF (Gross area) and the cable corridors: R2 – the northern cable corridor and R3 – the southern cable corridor.

Silt-clay fraction	Min (%)	Max (%)	Average (%)
Gross area	0.01	55.8	2.7
R2	0.04	2.5	0.4
R3	0.1	7.0	1.8

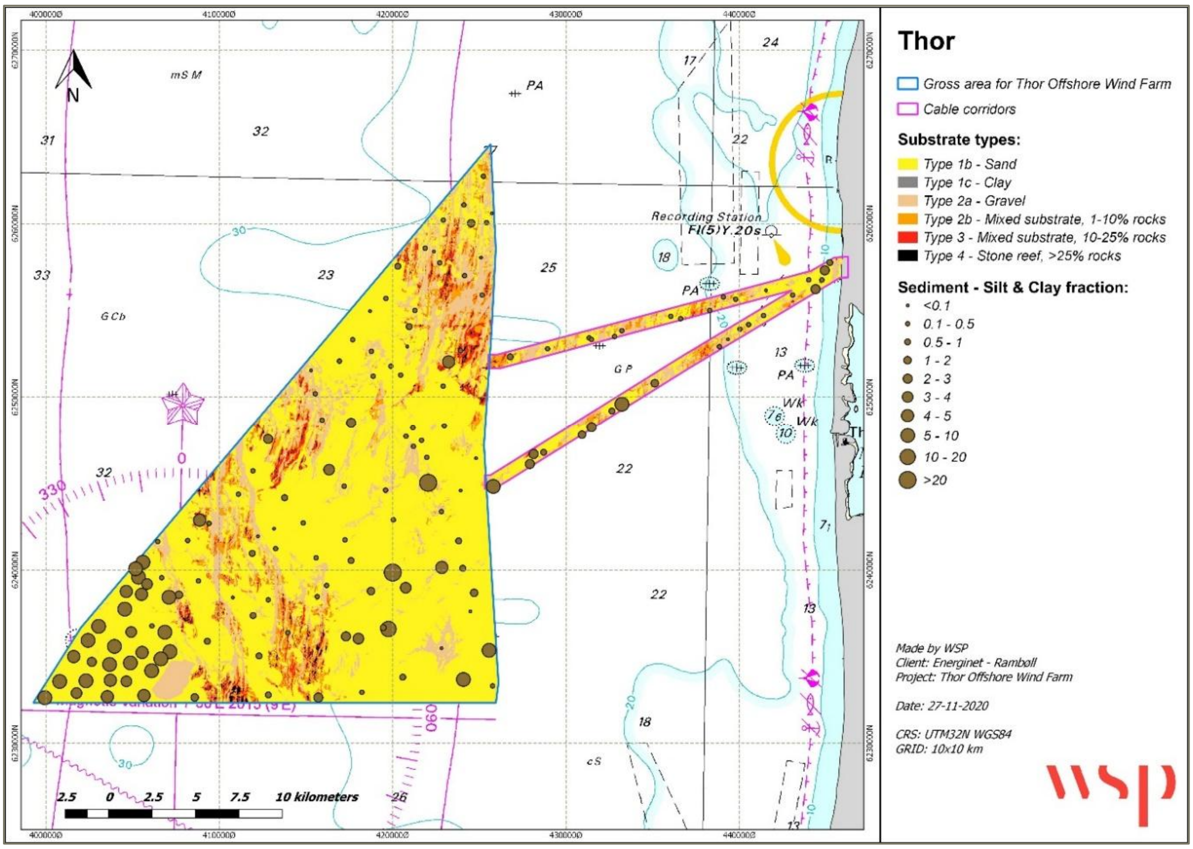


Figure 5-19. Analysed silt-clay content (%) for each benthic station within the investigated area.

High silt-clay content is found mainly in the southwestern and southeastern parts of the gross area for Thor OWF as well as in the southwestern part of the southern cable corridor (R3). The southwestern part of the gross area also has the highest species, abundance and biomass numbers for infauna (see section 5.5.3.1).

Sediment dynamics

Overall, these three physical parameters illustrate that the sediment conditions within the investigated area are very heterogenous. The results show that the sediment conditions are most diverse in the gross area for Thor OWF, whereas the sediment conditions are more uniform in the cable corridors. The highly diverse conditions are mainly controlled by variation in water depth as well as variation in magnitude of sedimentary dynamics. Generally, the investigated area is dominated by highly dynamic conditions with significant sediment transport and the existence of dynamic sediment features on the seabed. The sediment dynamics tend to increase with decreasing distance to the coastline. Variation in magnitude of sediment dynamic results in periodic movements of fine-grained as well as coarse-grained sediment. The orientation of gravel beds and stony patches within the investigated area also reflects the direction and magnitude of the sediment transport. Due to the dynamic conditions the extension of gravel beds and stony patches will change over time both in terms of short-term and long-term alterations. Further, the variation in magnitude of sediment transport effect in-situ silt-clay content on the seabed.

The deeper basin towards southwest in the gross area for Thor OWF is dominated by very homogenous sediment conditions and differs greatly from the rest of the investigated area. Here there is a uniformed level of low median grain size values, a uniformed level of high sediment uniformity and an uniformed content of high silt and clay fractions.

Basically, the sediment conditions are very different in the two cable corridors. The southern cable corridor (R3) is dominated by more fine-grained sediments (low d50, high uniformity and high silt-clay fraction) relative to the northern corridor (R2). Thus, the sediment conditions for R3 tend to be more comparable to the sediment conditions within the gross area for Thor OWF rather than in R2.

Total Organic Carbon
TOC refers to the total amount of organic carbon in sediment relative to the dry weight. Thus, a high TOC value reflects a high organic content in sediment and vice versa.

The average content of TOC is generally very comparable for the samples within the gross area for Thor OWF and the two cable corridors. However, there is a significant difference in maximum values of TOC. Within the gross area for Thor OWF significant higher maximum TOC values are found relatively to the two cable corridors (Table 5-8). This means, that more organic sediments are located in patches in the gross area for Thor OWF relative to the cable corridors.

As for the dry weight determination this reflects greater water depth and less sediment transport particularly in the most southwestern part of the gross area for Thor OWF e.g. station OWF-DDV-099, -144 and -145 where TOC content exceeds 0.5% of DW.

Scientific studies show the average TOC content in sediment is 0.5% in the deep ocean. In the coastal zone the TOC content in sediment varies significantly with a median TOC content of 1.5% (Seiter et al., 2004). Therefore, these baseline data for TOC in the investigated area corresponds to natural background levels for marine sediments.

Table 5-8. Minimum, maximum and average determinations in relation to total organic carbon in surficial sediment measured in percentage relatively to dry weight for the gross are for Thor OWF (Gross area) and the cable corridors: R2 – the northern cable corridor and R3 – the southern cable corridor. DW = Dry weight.

TOC	Min (% of DW)	Max (% of DW)	Average (% of DW)
Gross area	0.1	1.7	0.2
R2	0.1	0.3	0.1
R3	0.1	0.4	0.2

5.3.5.2 Chemical parameters
The chemical analyses have been conducted at 32 stations within the two cable corridors (15 station at R2 and 17 stations at R3). No sampling was conducted in the gross area for Thor OWF. Data for the chemical analyses for all measurements are presented in Appendix 5. The measurements were compared to the Lower and Upper Action levels for specified chemical substances defined in "the Danish guideline for disposal of dredged material" (Miljøstyrelsen, 2005).

The Lower Action Level corresponds to background concentrations/natural concentrations for the area or insignificant concentrations. The Upper Action Level indicates the level where there could be incipient effects. Measurements of concentrations between these two levels, results in requirements for an assessment before a dredging permit can be granted (Miljøstyrelsen, 2005).

In general, the chemical analyses at all stations show chemical concentrations below Lower Action Level, indicating background levels of all chemical substances, natural for the area.

Exceedance was observed only in two samples (ENV_R2_019 = 25 mg/kg DW and ENV_R3_020 = 21 mg/kg DW) with cobber concentrations (Cu) above Lower Action Level (20 mg/kg DW) but not above Upper Action Level (90 mg/kg DW), indicating above natural concentrations/background concentrations. Both subsamples were taken at stations in the western part of the cable corridors (see Figure 4-3).

Besides cobber all subsamples showed concentrations of heavy metals (arsenic (As), lead (Pb), cadmium (Cd), chromium (Cr), mercury (Hg), nickel (Ni) and zinc (Zn)) below Lower Action Level.

For all subsamples, the sum of all nine PAH compounds (Phenanthrene, anthracene, fluoranthene, pyrene, benz(a)anthracene, chrysene, benz(a)pyrene, indeno(123cd)pyrene and benzo(ghi)perylene) were below Lower Actions Level (3 mg/kg DW). Besides subsample ENV-R2-07 the measured sum of all PAH compounds were below detection limit (<0,010 mg/kg DW).

For all subsamples, the sum of all four hydrocarbons (n-C6 to n-C10, n-C10 to n-C15, n-C15 to n-C20 and n-C20 to n-C35) were below detection limit.

In relation to total nitrogen (TN) the measured concentrations varied between detection limit (300 mg/kg DW) and 570 mg/kg DW. In relation to total phosphorus (TP) the measured concentrations varied between detection limit (50 mg/kg DW) and 210 mg/kg DW.

For all subsamples, the measured concentration of extractable organohalogen compounds (EOX) were below detection limit (<1,0 mg/kg DW).

5.4 Benthic flora

In the following existing data for benthic flora and observed data from the gross area for Thor OWF and the two cable corridors are presented.

5.4.1 Existing data

Benthic flora was not observed in the investigated areas of the nearby OWFs: Vesterhav Syd (MariLim, 2015), Vesterhav Nord (MariLim, 2015) and Horns Rev III (Orbicon, 2014); and further more in the EIA report of coastal nourishment along the West Coast of Denmark from Nymindegab to Lodbjerg (Rambøll, 2020a).

5.4.2 Benthic flora data in the gross area and cable corridors

There was no evidence for the presence of benthic flora communities in the cable corridors (CC) and two small specimens of Rhodophyta, crust algae were found in the gross area for Thor OWF.

One specimen of *Hildenbrandia rubra* was observed on ROV-video OWF_046 at 29.8 meters depth, which is right at the expected depth limit for this algae type in the Danish part of the North Sea (Køie M. & Kristiansen A., 1999, 2014). Two small spots (approx. 5 cm in diameter) of *Phymatolithon laevigatum* was observed at station OWF_013 at approx. 27.8 m depth, which is below its reported depth limit in the Danish waters of approximately 20 m depth (Køie M. & Kristiansen A., 1999, 2014).

Figure 5-20. Two observed specimens (red arrows) of the red crust alga *Phymatolithon laevigatum*. ROV-station OWF_013. STILL-picture: THOR_WP-E_STILL_OWF_013_04.

The lack of benthic flora communities is expected due to the very exposed and dynamic nature of the West Coast of Denmark and light limitation at greater depth in the gross area for Thor OWF. This is also the reason no sea grass (*Zostera marina*) is observed (Rambøll, 2020a).

These results are supported by similar results of no observed benthic flora in the investigated areas of the nearby OWFs: Vesterhav Syd (MariLim, 2015), Vesterhav Nord (MariLim, 2015) and Horns Rev III (Orbicon, 2014); and further more in the EIA report of Beach nourishment along the West Coast of Denmark from Nymindegab to Lodbjerg (Rambøll, 2020a).

Benthic flora will therefore not be impacted by the establishment of Thor OWF and this parameter is therefore not assessed under the assessment of potential impacts (see chapter 6).

5.5 Benthic fauna

In the following existing data and observed data from the gross area for Thor OWF, the two cable corridors and other wind farms are presented for epifauna and infauna. Epifauna is benthic fauna that lives on the surface of the seabed – e.g. on the surface of sand, gravel, rocks etc. Infauna is benthic fauna that lives buried in the seabed.

Method for collection of samples and work up of samples is described in chapter 4.

5.5.1 Existing data from the area

In the following existing data from the North Sea and the west coast of Denmark are presented for both epifauna and infauna. This is done to provide comparable data for epifauna and infauna distribution, species numbers, abundance, biomass and ecological indexes and to show that the species found in this study are common species for the North Sea and for the local area off the west coast of Denmark (se section 5.5.3.3).

5.5.1.1 Benthic fauna species in the North Sea

In general, the benthic fauna in the North Sea is very variable and heterogeneous. It can therefore be difficult to directly compare areas such as the gross area for THOR OWF with adjacent, deeper areas or other sandbanks, which are situated elsewhere in the North Sea (Vanosmael et al., 1982; Salzwedel et al., 1985; Degraer et al., 1999). Generally, local fauna communities display high variability in spatial and temporal distribution patterns (Rambøll, 2020a; Neumann et al., 2009).

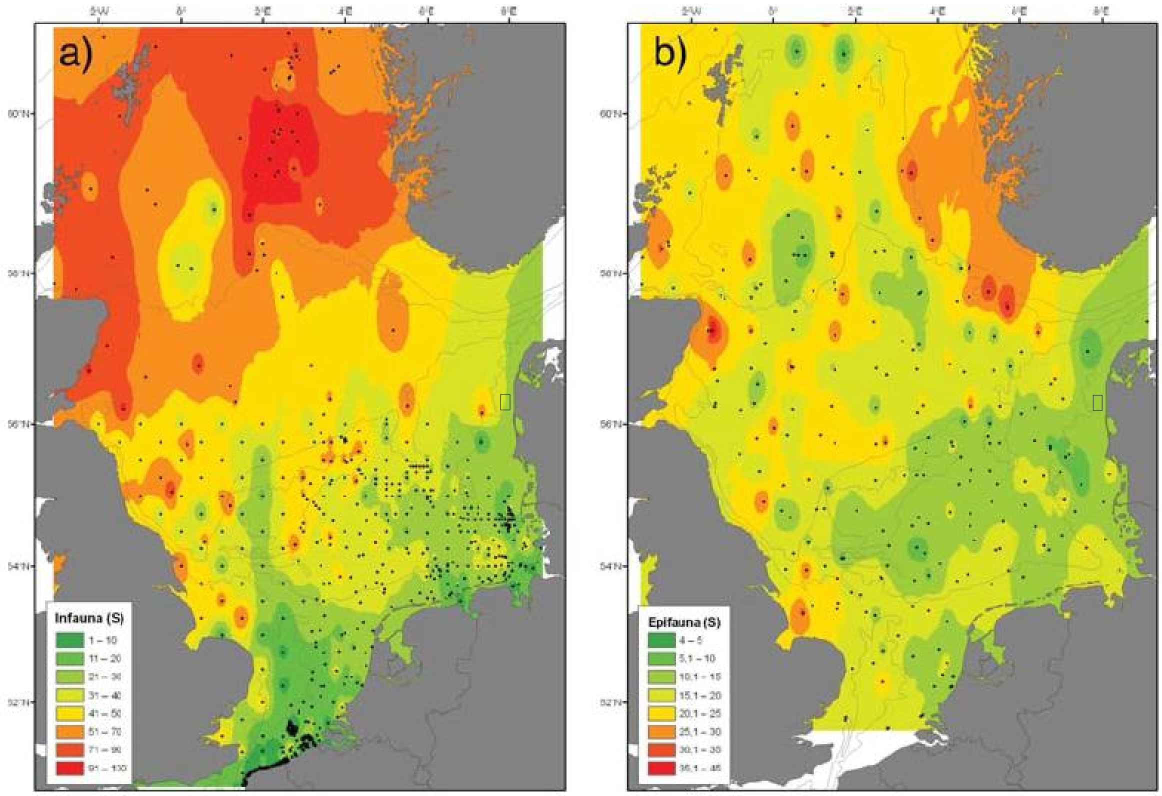


Figure 5-21 Number of species in the North Sea. Left: Infaunal species, Right: Epifaunal species (Modified from Reiss et al., 2010) in (Orbicon, 2014). Thor OWF location is indicated by black square.

Infauna and epifaunal species diversity are highest in the northern parts of the North Sea, and generally quite low along the west coast of Denmark where the gross area for Thor OWF is located (see Figure 5-21). While, the abundances of infauna and - particularly so - epifauna are generally higher in the southern parts of the North Sea (see Figure 5-22).

The benthic fauna along the West Coast of Denmark is transported with the currents and distributed along the entire West coast (Göke et al , 2019), and therefore has a god recovery and reestablishment potential in affected areas. The benthic fauna´s ability to re-establish themselves after disturbance is discussed further in section 6.2 – sensitivity of benthic fauna.

This is supported by a recent study from 2018 of the infauna community along the west coast of Jutland, Denmark (0-8 meters depth), which showed that it is generally the same infauna community that exists along the shallow part of west coast of Jutland (Nymindegab-Lodbjerg), the larvae being transported and distributed along the coast by the coastal currents (Rambøll, 2020a). Benthic fauna populations along this dynamic coast are therefore also very varying with large natural variation in the spatial and temporal distribution of species, individual numbers and biomass (Rambøll, 2020a; Neumann et al., 2009).

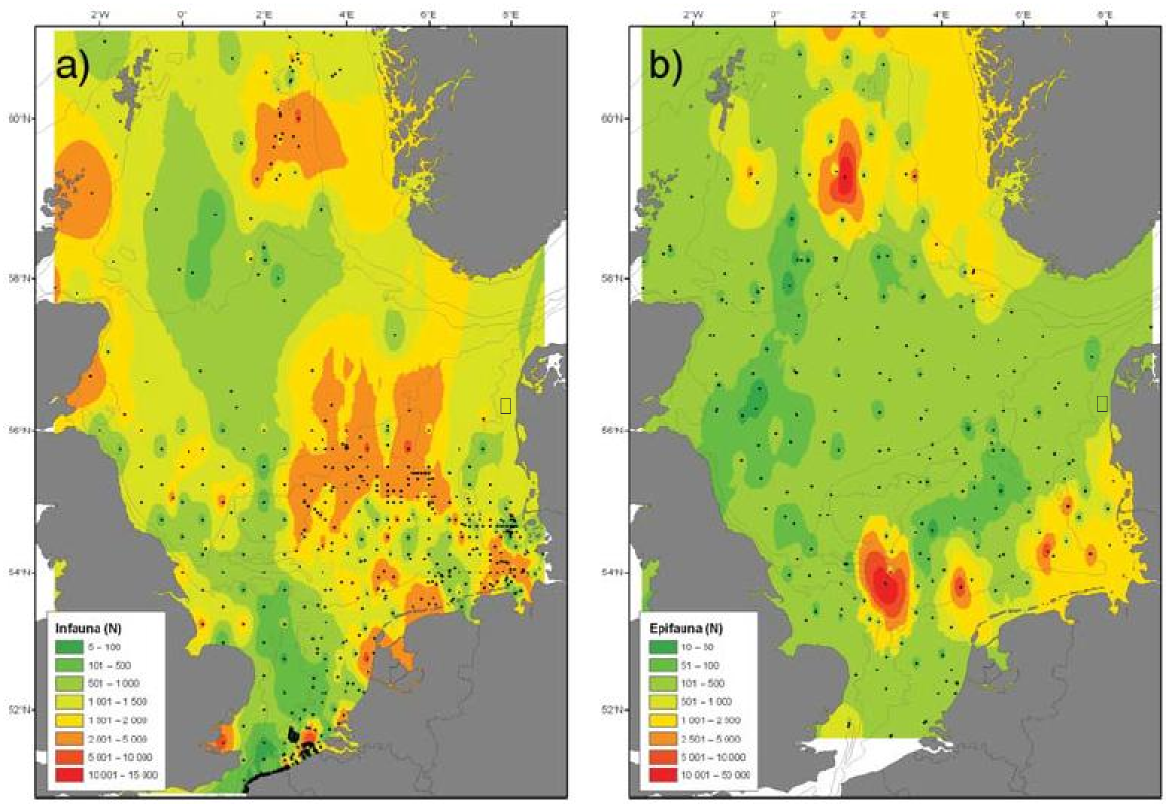


Figure 5-22 Abundance of infauna and epifauna the North Sea. Right: Infauna species (ind./m²), Left: Epifauna species (ind./500 m²). Black dots indicate samples taken. (Modified from: Reiss et al. 2010) in (Orbicon, 2014). Thor OWF location is indicated by black square.

5.5.1.2 Epifauna

Data for epifauna communities observed in the nearby Vesterhav Nord OWF and extraction areas are included to provide comparable data with this study illustrating whether the data in this study are common for the area or not.

Vesterhav Nord and Syd OWFs

Drop-camera investigations in the nearby Vesterhav Nord (Vattenfall, 2020a) and Vesterhav Syd (Vattenfall, 2020b) OWFs and cable corridors conducted in 2015 showed comparable epifauna communities to what was found in the visual verifications in 2020 in this study (se section 5.5.2 – Epifauna). The number of species found in these investigations was generally lower than in the "Benthic Seabed survey" in this study.

Video from the baseline studies in Vesterhav Nord and Vesterhav Syd OWF and CCs showed similar epifauna communities (Figure 5-23). Epifauna living on the seabed surface consisted of few species and individuals dominated by starfish (*Asterias rubens*). The sandy bottom was dominated by starfish (*Asterias rubens*), hermit crab (*Pangurus bernhardus*) and a few unspecified crabs. The larger rocks were either covered with leafy bryozoans (*Flustra foliacea*), sea anemones or without fauna. At many stations no surface-living life was observed presumably due to sand scrubbing of the rocks along the very dynamic North Sea coast of Denmark.

The observed species were common for the North Sea and the west coast of Denmark. No red-list species, protected species or habitat types were observed in the gross area for Thor OWF and CC area. Likewise, there was no evidence for any biogenic reef structures such as blue mussels (*Mytilus edulis*), oysters (*Ostrea edulis* and *Crassostrea gigas*) or *Sabellaria* reef structures.

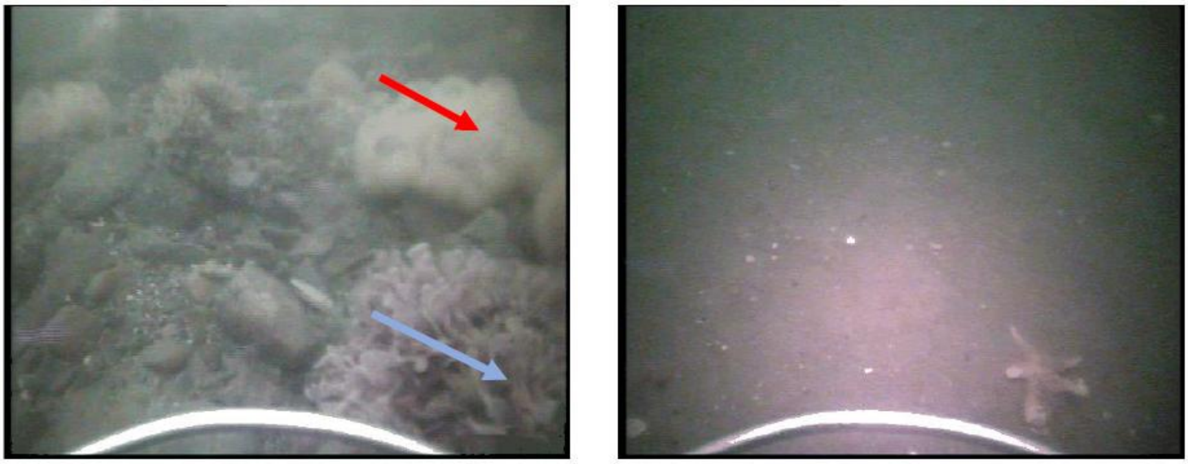


Figure 5-23 Leafy bryozoans (*Flustra foliacea*, blue arrow) and anthozoans (red arrow), as characteristic epifauna species in rocky hard bottom areas (left) and starfish in sandy and silty bottom areas (sand and silt) (right) (Vattenfall, 2020b).

Extraction areas at Jyske rev
ROV-video from the raw-material extraction areas west of the Thor OWF around Jyske Rev finds similar epifauna species and taxa, as observed in this study, on the sandy bottom, hard bottom and mixed bottom (Orbicon, 2019; Orbicon, 2018a; Orbicon, 2018b):

- Sandy bottom is dominated by starfish, sea urchins (*Echinocardium* spp.), crabs and hermit crab
- The hard bottom areas dominated by tube worms, hydroids, leafy bryozoans (*Flustra foliacea*), dead man´s fingers (*Alcyonium digitatum*), anthozoans and sea urchin (*Echinus esculentus*).
- Mixed communities have a combination of the sandy and hard bottom communities.

Similar communities are found in the gross area for Thor OWF and the cable corridors (se section 5.5.2).

5.5.1.3 Infauna
Data for infauna communities observed in comparable areas to this study are included for comparison with this study. This makes it possible to say whether the data from the investigated area in this study are comparable, lower or larger than general for the region. These data are used for comparison with infauna data from this study in section 5.5.3.3.

Infauna can be divided into a number of communities on the basis of the species composition, which depends on the surrounding environment (e.g. sediment type, sediment dynamics, water depth, salinity and oxygen conditions at the bottom).

Comparable infauna surveys and sampling on similar sediment types and depths have been conducted for several projects in the area:

- Vesterhav Nord OWF approx. 14 km from Thor OWF at 15-28 m depth (Vattenfall, 2020a)
- Vesterhav Syd OWF approx. 13 km from Thor OWF at 14-27 m depth (Vattenfall, 2020b)
- Jyske Rev extraction site 2016-A (now 562-QA) and a reference site for the infauna study both approximately 45 km northwest of Thor OWF at 26-32 m depth (Orbicon, 2018) (Orbicon, 2018)
- Horns Rev III OWF 53 km to the south at 10-20 m depth (Orbicon, 2014)
- Coastal nourishment project along the very shallow part of West Coast of Denmark (Nymindegab-Lodbjerg) at 0-8 m depth (Rambøll, 2020a)

The gross area for Thor OWF is placed at depths from 21-35 meters depth. Vesterhav Nord OWF and Jyske Rev raw extraction material site 2016-A are located at comparable depths and sediment types and therefore expected to be representative for the infauna composition in the potential Thor OWF investigated area. Data from these areas are therefore presented below.

Vesterhav Nord

In the Vesterhav Nord OWF (see Figure 5-1) a total of 81 species were found. Species of bristle worm dominated, and the bristle worm *Aonides pauchibranchiata* (16%) was numerically dominant with the highest average occurrence, followed by the seaweed flea *Bathyporeia guilliamsoniana* (11%), bean-like Tellin (*Fabulina fabula*, 10%) and the bristle worm *Glycinde nordmanni* (8%). The number of species and individuals varied greatly between the benthic fauna samples. The biodiversity indexes were high for almost all the stations, which showed that the infauna community was balanced and undisturbed, e.g. without dominance of individual species, but with many species and about the same number of individuals for each species. The generally low number of species is therefore more of an indication of a thin layer of sand on top of the moraine, which rarely has many infauna species due to the compact sediment structure below (Vattenfall, 2020a).

Within the cable corridor at Vesterhav Nord, 15 different infauna species were found. Bristle worms were also the largest group here, as five species of bristle worms were found, followed by crustaceans, which were represented by four species. Molluscs (mostly mussels) were represented by two species. Echinoderms, anthozoans and Nemertini form the group "other", which is also represented by four species/taxa. The most abundant species in the cable corridor is the mussels *Kurtiella bidentata* and bean-like Tellin (*Fabulina fabula*), the bristle worm *Scoloplos armiger* and the seaweed flea *Bathyporeia elegans*. These species are all common on the sandy bottom along the west coast of Denmark. The species richness in the cable corridor was very low (15 species) compared to the study area for the wind farm (81 species), which can be explained by the fact that only sandy bottoms occur in the cable corridor and that fewer species are adapted to the high wave exposure that characterizes the shallow coastal areas along the west coast of Denmark (Vattenfall, 2020a).

Shannon Wiener and Evenness index values were high for nearly all stations which confirms the result of a balanced faunal community without strong dominance of single species/taxa (MariLim, 2015) (see Table 5-16).

Jyske Rev sand extraction site 562-QA (old name 2016-A)

An infauna study at similar depths (26-32 m) as for the Thor OWF was conducted in two sites at Jyske Rev sand extraction site 2016-A in 2016 and a reference site (see Figure 5-1) (Orbicon, 2018). The site name has been changed from 2016-A to 562-QA in the permit for sand extraction. Here a total of 35-37 infauna species were found in total for the two study sites. From 0-9 species were found per sample/station with an average of 3-4 species per sample. Bristle worms dominated followed by Bivalvia. Abundance varied from 363.6 to 391.9 ind./m^2. Biomass was dominated by Echinoderms and bivalves the total dry weight g DW/m^2 was 30-20.

The Shannon Wiener index for the extraction site 2016-A and the reference site both had a value of 3, which despite a few species is due to a relatively uniform number of each species.

The AMBI value for the extraction area indicates a community that is dominated by fauna group I (54%, Species that are very sensitive to organic enrichment and are present under uncontaminated conditions) and the area is classified as undisturbed (AMBI value = 1.18).

In comparison, the AMBI value for the reference site indicates a community dominated by fauna group III (24%, robust generalists, they are "indifferent" to nutrient enrichment, always present in low density without significant variations over time) and the area is classified as slightly disturbed). The AMBI value is 1.4. This is in the lower end of the classification which goes from 1.2 to 3.3 and only 0.26 above the AMBI value for extraction site 2016-A.

Table 5-9. Number of species, abundance (ind./m²), biomass and indexes (Orbicon, 2018).

Area	No. Sam ples	Total number of species	Ind./m²	Wet weight g/m²	Dry weight g/m²	Shannon Wiener (H´)	AMBI
Extraction site 562-QA	25	37	363.6	54.2	29.9	3.1	1.18
Reference site	25	35	391.9	35.7	19.9	3.0	1.44

For comparison, two Natura 2000 sites in the North Sea (H253-A and H254-A) has 41 and 56 numbers of species (42 subsamples per area), respectively, and an abundance of 190 and 792.5 ind./m², respectively (GEUS and Orbicon, 2018). Here especially area H253-A shows that the low number of species and abundance observed in area A-2016 and the reference site are not uncommon in the North Sea. Species numbers and abundances were higher for area H254-A, but still low compared to other areas in the North Sea (Orbicon, 2018).

5.5.2 Epifauna in the gross area for Thor OWF and cable corridors

In the following observed epifauna from ROV-stations in the gross area for Thor OWF (GA) and the two cable corridors (CC) are presented. Epifauna is benthic fauna that lives on the surface of the seabed – e.g. on the surface of sand, gravel, rocks etc.

5.5.2.1 Epifauna species and communities

The epifauna community was mapped in the investigated area by use of ROV video at each station OWF_001-150 (see Figure 4-2), CC_R2_001-040 and CC_R3_001-040 (see Figure 4-3). The epifauna community is described separately for the gross area for Thor OWF and the cable corridors but is similar for the sediment types regardless of location. It is therefore the sediment types that determines the epifauna community. The method description is given in section 4.1.3.1 – Visual verification.

Epifauna species/taxa

In total 33 taxa of benthic fauna were observed in the gross area for Thor OWF (GA, Table 5-10). Fewer taxa of benthic fauna were observed in the cable corridors, e.g. 24 taxa in the northern corridor (R2) and 19 taxa in the southern cable corridor (R2).

All species and taxa observed in the gross area for Thor OWF and the two cable corridors are listed in Table 5-10. It is furthermore indicated whether the species mainly belong to the sandy bottom community (sediment type 1b) or the hard bottom community (sediment type 3 and 4). Mixed communities observed mainly on sediment type 2a and 2b have a mix of sandy and hard bottom communities. Most species were observed on sediment type 3 and 4 and fewest on sediment type 2a – gravel.

Some species such as leafy bryozoan (*Flustra foliacea*), sea urchins and spiny starfish (*Marthasterias glacialis*) are found only on larger stones on the rocky substrates 3 and 4 and belongs almost exclusively to the hard bottom communities. Whereas others mainly belong to the sandy bottom communities, such as sand shrimp (*Crangon crangon*), sea urchins (*Echinocardium spp.*), and some crabs (*Corystes cassivelaunus and Liocarcinus depurator*). The mixed community may have all combinations of the species found in the sandy or hard bottom communities.

Table 5-10. Epifauna taxa or species found in the investigated area divided into the gross area for Thor OWF (GA) and the two cable corridors: R2 – northern corridor and R3 – southern corridor. * Only one specimen found. [1] empty shell. – no common English name found.

Latin name or taxa name	Danish name/ English name	Phylum/class	Substrate type	Investigated area GA	R2	R3
Sandy bottom community:						
Asterias rubens	Almindelig søstjerne/ common starfish	Echinodermata	1b, 2a, 2b,3,4	x	x	x
Astropecten irregularis	Kamstjerne/sand seastar	Echinodermata	1b, 2b	x	x	x
Ophiura sp.	Slangestjerne /brittle star	Echinodermata	1b	x		
Echinocardium spp.	Sømus/Sømusskal/sømushul/Sea potato	Echinodermata	1b,2a[1],3[1]	x	x	x
Echinocardium flavesens	Guldmus/-	Echinodermata	1b	x		
Corystes cassivelaunus	Maskekrabbe/ masked crab	Crustacea	1b	x	x	x
Liocarcinus depurator	Svømmekrabbe/harbour crab	Crustacea	1b	x	x	x
Hyas araneus	Sandkrabbe/great spider crab	Crustacea	1b,4	x		x
Pangurus bernhardus	Eremitkrebs/ hermit crab	Crustacea	1b,2a, 2b	x	x	x
Crangon crangon	Hestereje/ common shrimp	Crustacea	1b		R2_014 *	
Buccinum undatum	Konksnegle-hus/common whelk	Gastropoda	1b	x		
Aporrhais pespelecani	Pelikanfodsnegl/pelikan´s foot	Gastropoda	1b	x		
Bivalve shells	Muslingeskaller	Bivalvia	1b	x	x	x
Ensis spp.	Knivmusling/razor clams	Bivalvia	1b, 3	x		x
Arctica islandica	Molbøsterskal/ black clam shell		1b	x		
Cerastoderma spp.	Hjertemusling spp./common edible cockle		1b	x		
Lanice conchilega	*Lanice* /Sand mason worm	Annelida	1b,2a,2b	x	x	x
Ophiodromus sp.	Ophiodromus sp./ bat star commensal worm	Annelida	1b	x	R2_010 *	
Hard bottom community:						
Tube worms spp.	Kalkrørsorm spp.	Annelida	2a,2b,3,4	x	x	x
Pomatoceros triqueter	Trekantorm/keel worm	Annelida	2a,2b,3,4	x	x	x
Spirorbis tridentatus	Kølet posthornsorm /-	Annelida	2a,2b,3,4	x	x	x

Latin name or taxa name	Danish name/ English name	Phylum/class	Substrate type	Investigated area GA	R2	R3
Hydrozoans	Hydroider spp./hudroids	Cnidaria/ hydrozoa	2a,2b,3,4	x	x	x
Sertularia cupressina	Cyprespolyp/ white weed	Cnidaria/ hydrozoa	2b,3	x	x	
Flustra foliacea	Bredt bladmosdyr, Leafy bryozoan	Bryozoa	3,4	x	x	x
Alcyonium digitatum	Dødningehåndkoral, dead man´s fingers	Anthozoa	2a,2b,3,4	x	x	x
Metridium senile	Sønellike/frilled anemone	Anthozoa	2a,2b,3,4	x	x	x
Stomphia coccinea	Karminrød søanemone/spotted swimming anemone	Anthozoa	2b,4	x	x	
Unspec. sea anemone	Søanemone spp./-	Anthozoa	2a,2b,3,4	x	x	x
Cancer pagurus	Taskekrabbe/ brown crab	Crustacea	(1b), 2a, 2b,3,4	x	x	
Echinus esculentus	Stort søpindsvin/common sea urchin	Echinodermata	3,4	x	x	
Echinoidea	Uspec. Søpindsvin/sea urchin	Echinodermata	3,4	x	x	
Marthasterias glacialis	Pigget søstjerne/spiny starfish	Echinodermata	4	x		
Tunicates	Søpungkoloni sp./sea squit	Chordata	3	x		
Porifera	Havsvampe/ marine fugi	Porifera	2b,3,4	x	x	x
Total number of fauna species/taxa				**33**	**24**	**19**

Epifauna communities

The epifauna communities in the investigated area were mapped combining the sediment types and the species visually verified on these - and are presented in Figure 5-24.

The investigated area (GA+CC) contained three epifauna communities:

1. Sandy bottom communities dominated by infauna end very few epifauna species such as starfish (*Astropecten irregularis*), crabs (*Corystes cassivelaunus and Liocarcinus depurator*), sea urchins (*Echinocardium spp.*) and local patches of sand mason worm/ *Lanice* tubes (Sediment type 1b)
2. Hard bottom communities dominated by tube worms (*Pomatoceros triqueter*), hydroids, leafy bryozoans (*Flustra foliacea*), dead man´s fingers (*Alcyonium digitatum*) and several species of sea anemones (Sediment type 3 and 4)
3. Mixed communities with both sand and hard bottom communities (Sediment type 2a and 2b), which may have any combination of species from the two former communities.

Table 5-11. Area distribution of epifauna communities in the gross area for Thor OWF, the total cable corridor area (CC), and separately for the two cable corridors: R2 -Northern corridor and R3 - Southern corridor.

Community type	Sediment type	Gross area		CC_total		R2		R3	
		km²	%	km²	%	km²	%	km²	%
Sandy bottom	1b	330.1	75	19.9	57	8.8	51	12.6	63
Mixed bottom	2a + 2b	93.6	21	14.4	41	7.9	46	6.9	35
Hard bottom	3+4	16.4	4	0.9	2	0.53	3	0.4	2
Total		440.0	100	35.1	100	17.2	100	19.9	100

The CC area (41%) generally had more mixed-bottom epifauna community compared to the gross area for Thor OWF (21%). The two cable corridors are slightly different with approximately 11% more mixed epifauna community in R2 (46%) compared to R3 (35%). Both corridors are dominated by sandy bottom epifauna communities and have nearly the same % hard bottom community (3% and 2%) (see Table 5-11 and Figure 5-24).

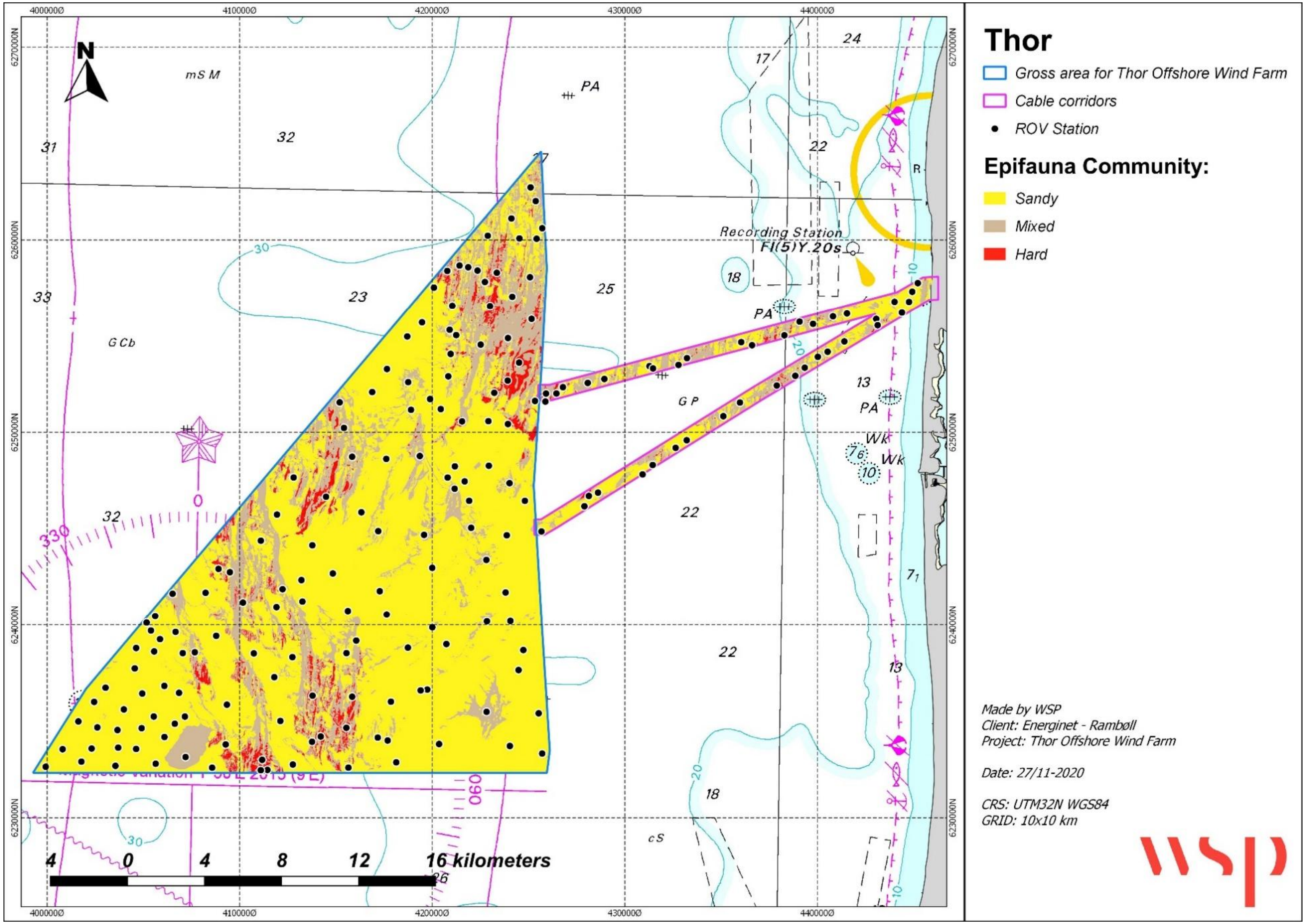
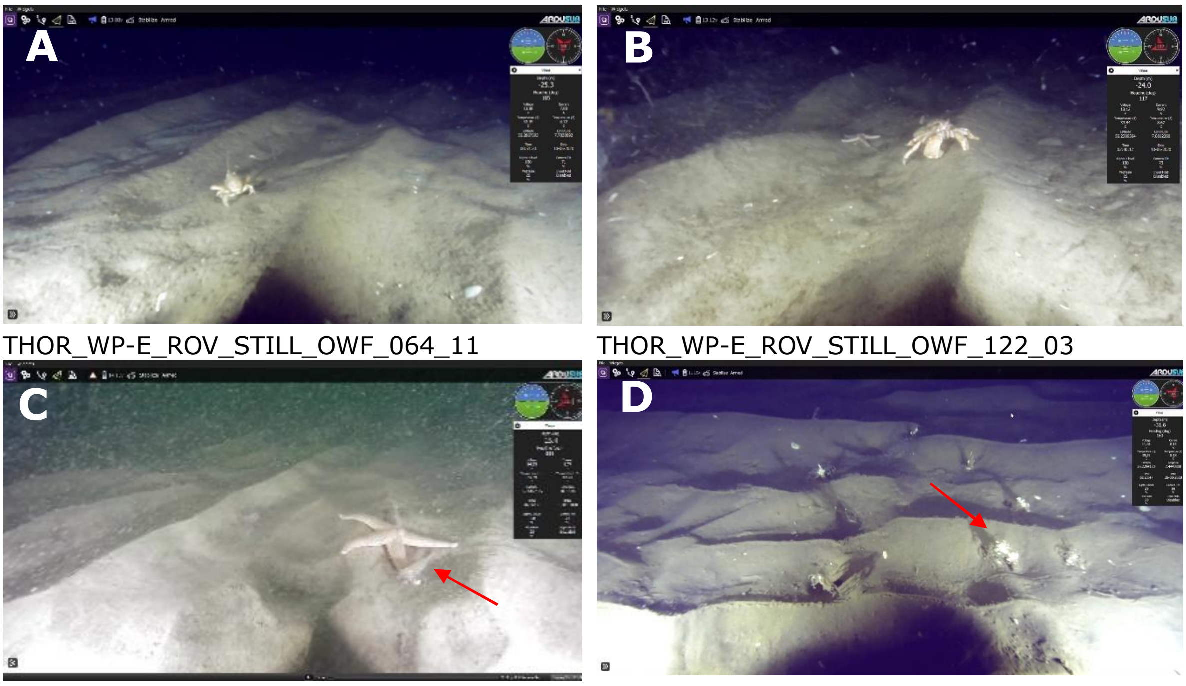


Figure 5-24. Map of epifauna communities in the gross area for Thor OWF and the cable corridors.

Sandy bottom community
The sandy bottom community was observed on sediment type 1b – sand, which dominated in both the gross area for Thor OWF and the cable corridors.

The sandy bottom community was dominated by infauna (lives buried in the seabed) such as phoronid tubes, Lanice tubes (*Lanice conchilega*), bivalve shells, tubes and holes in the seabed (se section 5.5.3).



THOR_WP-E_ROV_STILL_OWF_064_11 THOR_WP-E_ROV_STILL_OWF_122_03
THOR_WP-E_ROV_STILL_CC_R2_014_05 THOR_WP-E_ROV_STILL_OWF_103_10

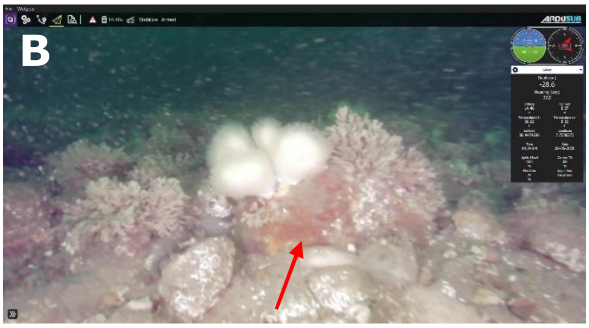
Figure 5-25. Examples of the sandy-bottom epifauna community, with some of the dominating species. A: the masked crab (*Corystes cassivelaunus*). B: hermit crab (*Pangurus bernhardus*) and starfish. C: starfish (*Asterias rubens*) and common shrimp (*Crangon crangon*) (red arrow). D: Lanice tubes (red arrow).

The epifauna community on the sandy bottom (sediment type 1b) was scarce and consisted generally of few starfish (*Asterias rubens* and *Astropecten irregularis*), crabs (*Corystes cassivelaunus* and *Liocarcinus depurator*) and hermit crabs. A single specimen of common shrimp (*Crangon crangon*) was observed at station R2_014. The area coverage was low (<1-5% in GA and <1-3% in CC) likely due to an increasing dynamic seabed closer to the west coast of Denmark.

The observed sandy-bottom epifauna community is very common in the North Sea and similar communities and taxa are observed both close to the coast in the nearby sandbank areas of Natura 2000 site no. 220 (Naturstyrelsen, 2013a), in the nearby sites for Vesterhav Nord OWF (MariLim, 2015) and Vesterhav Syd OWF (MariLim, 2015), and further from the coast at and around Jyske Rev (Orbicon, 2019; Orbicon, 2018a; Orbicon, 2018b) (see section 5.5.1.2).

Hard bottom community
The hard bottom community was observed on sediment type 3 – mixed substrate 10-25% rocks and sediment type 4 – stone reef >25% rocks. These sediment types are collectively termed stone reefs (when observed together) and had the highest number of epifauna species of all sediment types. The hard-bottom community was dominated by epifauna attached to the larger stones (>10 cm).

THOR_WP-E_ROV_STILL_OWF_014_03



THOR_WP-E_ROV_STILL_OWF_014_07

THOR_WP-E_ROV_STILL_CC_R3_03

THOR_WP-E_ROV_STILL_CC_R2_13

THOR_WP-E_ROV_STILL_OWF_034_09

THOR_WP-E_ROV_STILL_OWF_119_05

Figure 5-26. Examples of the hard-bottom epifauna community, with some of the dominating species. A: white lime tube worms, leafy bryozoans and sea anemones (red arrow). B: marine reddish fungus (red arrow) and dead man´s fingers (*Alcyonium digitatum*). C: sea anemones on large stone. D: brown crabs (*Cancer pagurus*) and common sea urchins (*Echinus esculentus*). E: spiny starfish (*Marthasterias glacialis*) (red arrow). F: hydroids in front and dead man´s fingers.

The hard bottom community was observed mainly on sediment type 3 and 4 corresponding to local stony-reef areas with high rock coverage >10%. The epifauna community was dominated by lime tube worms (*Pomatoceros triqueter* and *Spirorbis tridentatus*), hydroids, leafy bryozoans (*Flustra foliacea*), dead man´s fingers (*Alcyonium digitatum*), anthozoans and a few sea urchin (See full species list in Table 5-10). The area coverage was varying and generally low, likely due to the dynamic conditions and sand scrubbing of the stones (<1-50% in GA and <1-70% in CC).

The observed hard-bottom epifauna community is very common in the North Sea and similar communities and taxa are observed both closer to the coast in the nearby stone reef areas of Natura 2000 site no. 247 (Naturstyrelsen, 2013b), in the nearby sites for Vesterhav Nord OWF (MariLim, 2015) and Vesterhav Syd OWF (MariLim, 2015), and further from the coast at and around Jyske Rev (Orbicon, 2019; Orbicon, 2018a; Orbicon, 2018b) (see section 5.5.1.2).

Mixed bottom community

The mixed bottom community was observed on sediment type 2a – gravel and 2b – mixed substrate 1-10% rocks. Sediment type 2a - gravel had the lowest number of epifauna species of all sediment types.

The mixed-bottom epifauna community contained a mix of sandy-bottom species and hard-bottom species as previously described. The area coverage of epifauna varied and was generally low, likely due to the dynamic conditions and sand scrubbing of the stones (<1-30% in GA and <1-5% in CC).

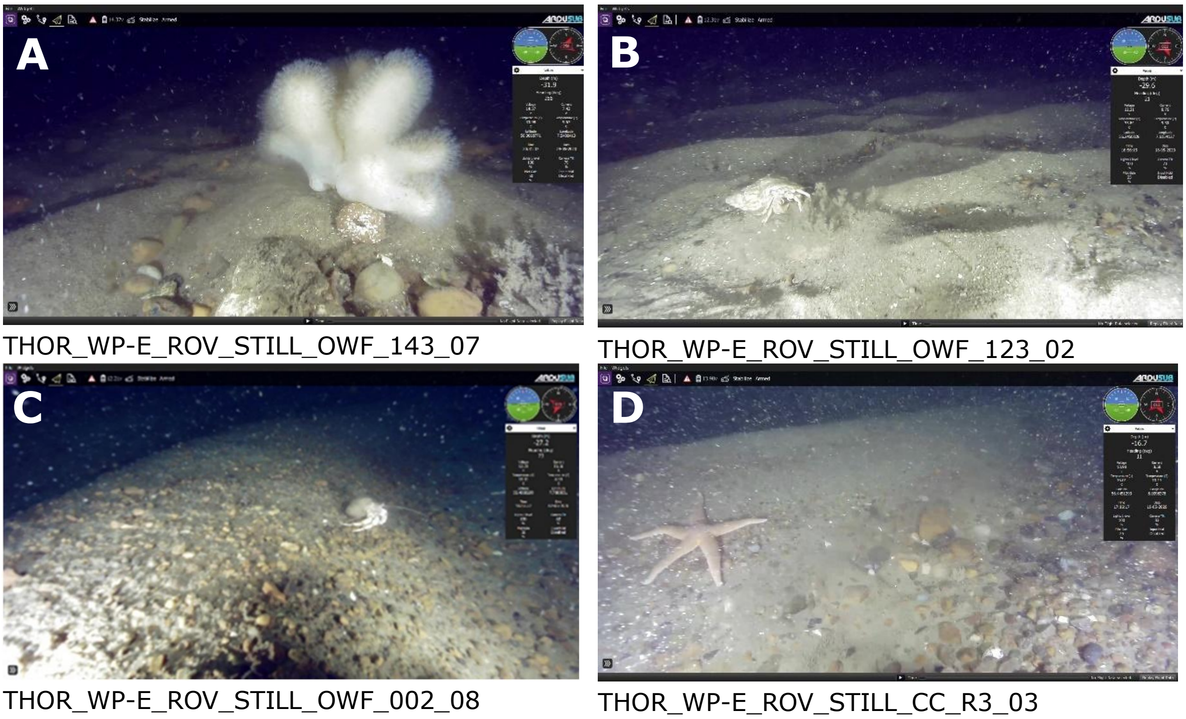


Figure 5-27. Examples of the mixed-bottom epifauna community, with some of the dominating species. A: stone with dead man´s finger and a sea anemone. B: hermit crab (*Pangurus bernhardus*). C: gravel on sand ripple with hermit crab. D: starfish (*Asterias rubens*).

The observed mixed-bottom epifauna community is very common in the North Sea and similar communities and taxa are observed closer to the coast in the nearby sites for Vesterhav Nord OWF (MariLim, 2015) and Vesterhav Syd OWF (MariLim, 2015), and further from the coast at and around Jyske Rev (Orbicon, 2019; Orbicon, 2018a; Orbicon, 2018b) (see section 5.5.1.2).

5.5.2.2 Gross area for Thor OWF

In total 33 epifauna taxa/species were observed in the gross area for Thor OWF, which is normal for the North Sea area compared with similar ROV-video investigations at similar depths in the Jyske Rev area (Orbicon, 2019; Orbicon, 2018a; Orbicon, 2018b) and in the nearby sites for Vesterhav Nord (Vattenfall, 2020a) and Syd (Vattenfall, 2020b) OWFS and CCs (see section 5.5.1.2).

The gross area for Thor OWF was dominated by sandy-bottom (75% area coverage) and mixed-bottom epifauna communities (21% area coverage)(Table 5-11, Figure 5-24). Hard-bottom community on larger rocks had the lowest coverage of 4% area coverage.

The overall substrate specific coverage of epifauna was low in the gross area for Thor OWF and concentrated in the rocky areas (sediment type 3 and 4) (<1-50%), where the hard bottom community dominated. The mixed community on mixed substrate had medium coverage <1-30% and the sandy-bottom community had the lowest area coverage of <1-5% for epifauna.

5.5.2.3 Cable corridors (CC)

In total 24 and 19 epifauna taxa/species were observed in the northern cable corridor (R2) and in the southern cable corridor (R3), respectively. A lower number of epifauna species in the cable corridors is expected, due to an increase in wave and current dynamics closer to the coast compared with the deeper gross area for Thor OWF.

The CC area (41% area coverage) generally had more mixed-bottom epifauna community compared to the gross area for Thor OWF (21% area coverage)(Table 5-11, Figure 5-24). The two cable corridors are slightly different with approximately 11% more mixed substrate in R2 (46% area coverage) compared to R3 (35% area coverage)(Table 5-11, Figure 5-24). Both corridors are dominated by sandy-bottom epifauna communities and have nearly the same % hard bottom community (3% and 2%)(see Table 5-12, Figure 5-24).

The overall substrate specific coverage of epifauna was low in both cable corridors and as seen for the gross area for Thor OWF concentrated in the rocky areas (sediment type 3 + 4), where the substrate specific coverage of epifauna was 20% and 1-70% for R2 an R3, respectively (Table 5-12). The mixed community and the sandy bottom community had comparable coverages of <1% to 5%.

Table 5-12 Substrate specific % coverage range of epifauna on the 3 epifauna communities in the cable corridors – the northern cable corridor (R2) and the southern cable corridor (R3). Brackets indicate how many stations were monitored with the community type in either cable corridor.

Epifauna community	Northern corridor - R2	Southern corridor - R3
Sandy bottom community	<1% (13 st)	<1-3% (16 st)
Mixed bottom community	<1-5% (5 st)	<1% (1 st)
Hard bottom community	20% (2 st)	1-70% (2 st)

In conclusion, the cable corridors had similar epifauna communities, with 11% more mixed-bottom community in the northern corridor (R2) compared to the southern corridor (R3), which likely accounts for a slightly higher number of epifauna species in the northern corridor (R2 =24 species/taxa) compared to the southern corridor (R3 = 19 species/taxa).

Thus, a difference between the two cable corridors is based on a difference in the area coverage of the sediment types and not in the existence of any particular distribution patterns or permanent local patches of populations.

5.5.3 Infauna in the gross area for Thor OWF and cable corridors

Method for infauna sampling and analysis in the gross area for Thor OWF and the cable corridors is described in detail in section 4.1.3.4. Data are presented in Appendix 6 – Infauna data. The statistical analysis for infauna is presented in more details in Appendix 8 – Statistical analysis for infauna and shortened below.

5.5.3.1 Infauna species and communities

The number of species, abundance and biomass observed in the gross area for Thor OWF (GA) and the two cable corridors (CC) are presented in Table 5-13. Species number is given as a total for all samples in the different areas (GA, CC, R2 and R3), whereas abundance and biomass are shown per m^2.

Table 5-13 Number of species, individuals, and biomass expressed as wet weight and dry weight in the gross area for Thor OWF (Gross area) and cable corridors (CC): R2 – northern cable corridor and R3 – southern cable corridor.

	Gross area	R2	R3	CC (R2 + R3)
No. of species	81	43	46	63
No. of individuals pr. m^2	2342	1352	2369	1877
Wet weight pr. m^2 (g)	170	93	210	153
Dry weight pr. m^2 (g)	90	42	106	75

Species number: Infauna was found on 148 stations of the total 150 stations sampled – 119 in GA, 15 in R2 and 16 in R3 (see Table 4-1). No infauna was found at two stations (OWF_044 and OWF_067). Species lists for all stations, are shown in Appendix 6.

A total of 81 species were identified in the gross area for Thor OWF, 43 species in the northern (R2) and 46 species in the southern (R3) cable corridor.

The number of species per sample varied between 0-14 in the gross area for Thor OWF (average 5.7 species pr. sample), 4-11 in the northern corridor (R2) (average 6.3 species pr. sample) and 1-17 in the southern corridor (R3) (average 6.6 species pr. sample). Figure 5-28 illustrates the number of species per sample for all stations. Species numbers varied between samples within the gross area for Thor OWF and the two cable corridors. The only clear pattern is a more species rich area in the southwestern part of gross area for Thor OWF, where the sediment has the highest silt and clay content (see section 5.3.5.1).

The gross area for Thor OWF was dominated by the horseshoe worm *Phoronis* sp. (73%), the two bristle worms *Spiophanes bombyx* (5%), *Magelona mirabilis* (4%) and the sea urchin (*Echinocyamus pusillus*, 2%) (Numbers are given as the % contributed by this species out of the total number of individuals in the area).

The southern cable corridor (R3) was also dominated by horseshoe worm (*Phoronis* sp., 58%), the two bristle worms *Magelona mirabilis* (18%), *Spiophanes bombyx* (3%), and the mussel bean-like Tellina (*Fabulina fabula, 2%*).

The northern cable corridor (R2) was, however, dominated by several bristle worms including *Magelona mirabilis* (32%), *Protodorvillea kefersteini (20%), Spiophanes bombyx* (12%), ribbon worms Nemertini (4%), pea urchin (*Echinocyamus pusillus*, 2%), the marine amphipod *Urothoe poseidonis* (2%), and the mussel bean-like Tellina (*Fabulina fabula, 2%*).

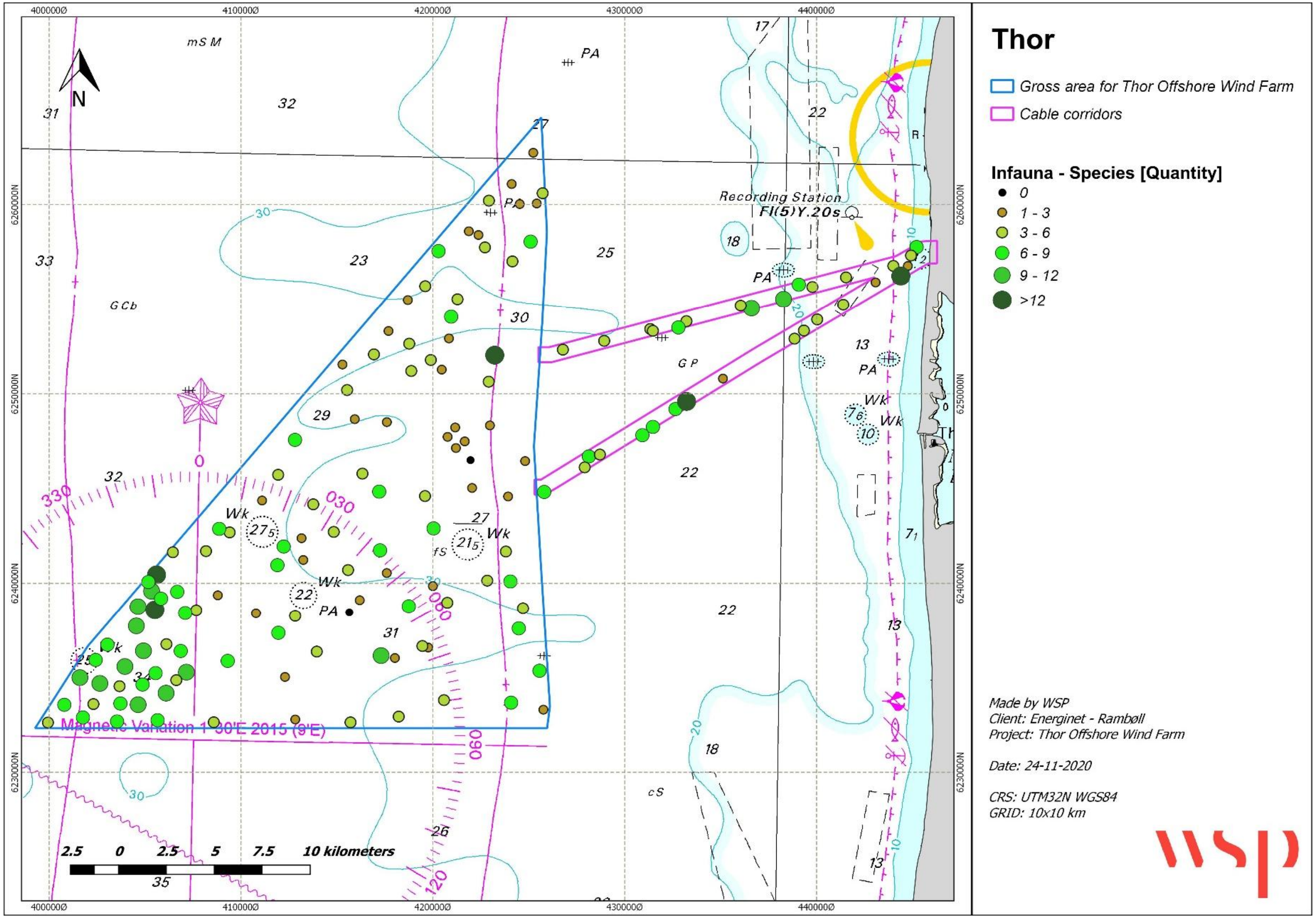


Figure 5-28 Number of infauna species at sampled stations.

Thus, many of the dominating species were observed in both the gross area for Thor OWF and the two cable corridors. The gross area for Thor OWF and the southern corridor were most alike and dominated by *Phoronis* sp. The northern cable corridor differed by being dominated by bristle worms and having a larger variety of dominating species contributing more than 1% of the total number of individuals in this cable corridor (R2).

The dominating species in the three areas are all common in the North Sea and generally adapted to dynamic areas as listed in Table 5-14 below.

Table 5-14 Description of the dominating infauna species in the gross area for Thor OWF and the two cable corridors (R2 and R3).

General information /description of dominating species in the OWF area, R2 and R3
It has not been possible to identify species within the genus **Phoronida**, which is always the chase with species within this genus. *Phoronis* sp. are worms which filters and absorb food through a so called lophophore, which is an extension of the coelum in the form of a tentacle crown. They live in the seabed in coastal areas and down to 400 m depth and is widespread almost all over the world (Ruppert, E.E., Fox, R.S., and Barnes, R.D., 2004; Emig, C.C, 1982).
Spiophanes bombyx primary lives on sandy sediment in the eulittoral zone down to 1000 m depth. It lives in Y-shaped tubes, encrusted with sand and are common in the North Sea (Kirkegaard J. B, 1992).
Magelona mirabilis feeds on detritus, microalgae and smaller animals found on the surface of the sediment. *M. mirabilis* is thought to be a food source for juvenile flatfish and typically lives buried in fine sand. It is typically found from 0-32 m depth. It is widely distributed in the North Sea and is adapted to unstable areas with strong currents, wave activity and mobile sediment. *Magelona mirabilis* can be found in high abundance where the environment allows it (Rayment, W.J., 2007).
Fabulina fabula is widespread in the North Sea i.a. in the Skagerrak and along the west coast of Jutland. *F. fabula* is both capable of filtering the water for microalgae and detritus as well as feeding on sediment. It lives buried in fine and silted to coarse sand and filters through its siphon at the surface. It is typically found at depths of 0-55 m and is adapted to unstable areas with strong currents, wave activity and mobile sediment (Rayment, W.J., 2008).
Protodorvillea kefersteini occurs along open coasts in depths of 10 to 30 m and is common in the North Sea (Kirkegaard J. B, 1992).

Abundance: A total of 3986 individuals were identified in the 119 samples collected in the gross area for Thor OWF, which corresponds to 2342 individuals per m^2. A total of 290 individuals were identified in the 15 samples collected in the northern cable corridor (R2) corresponding to 1352 individuals per m^2, whereas 542 individuals were identified in the 16 samples collected in the southern cable corridor (R3) corresponding to 2369 individuals per m^2.

The abundance (ind./m^2) for all stations sampled varied between 0-16,730 ind./m^2 in the gross area for Thor OWF (average 2345 ind./m^2), 350-3430 ind./m^2 in the R2 (average 1353 ind./m^2) and 70-9380 ind./m^2 in the R3 (average 2371 ind./m^2) (see Figure 5-30).

The only clear pattern is again a tendency to a higher abundance in the most southwestern part of the gross area for Thor OWF with highest depth and finest sediment.

The abundance was on average higher in the southern corridor (R3) compared to the northern cable corridor (R2).

Figure 5-29 shows infauna abundance separated into the dominating infauna classes for the gross area for Thor OWF, R2 and R3. The horseshoe worm *Phoronis* sp. dominates the abundance in both the gross area for Thor OWF and the southern cable corridor (R3), whereas species within the class polychaeta dominates the northern cable corridor (R2).

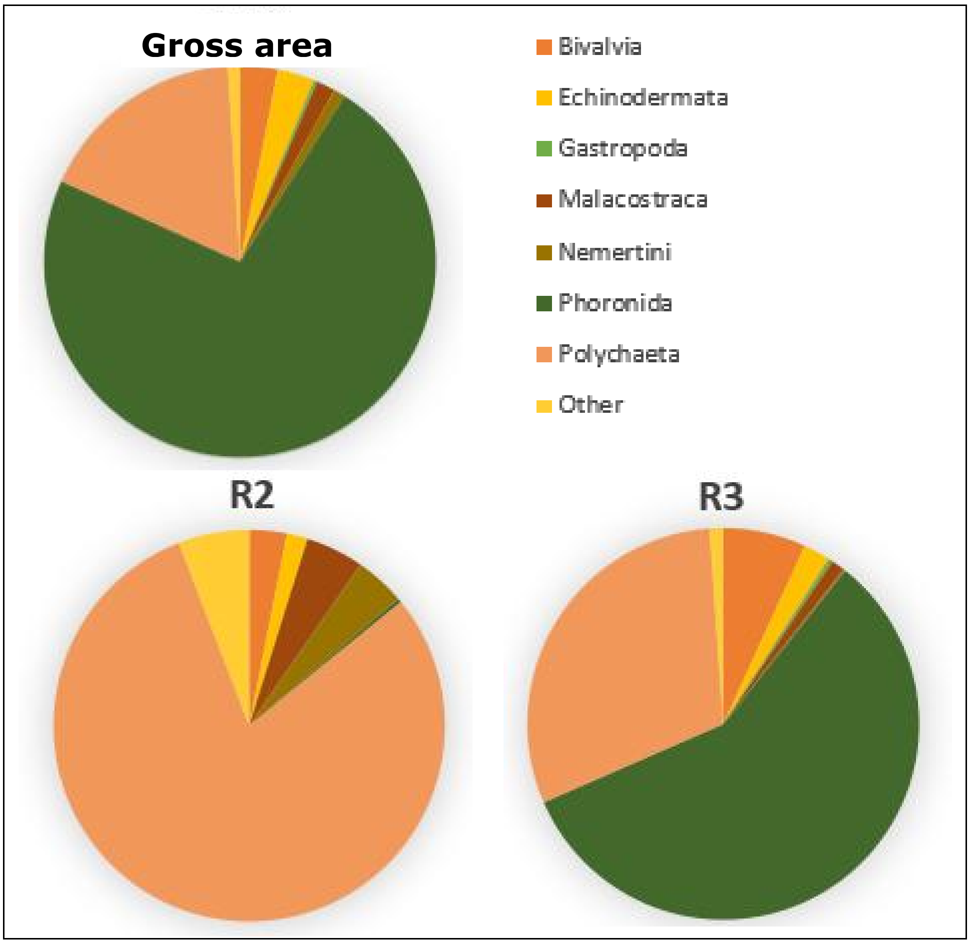


Figure 5-29 Infauna abundance separated into the dominating infauna classes in percentage. Gross area = the gross area for Thor OWF. R2 = Northern cable corridor. R3 = Southern cable corridor.

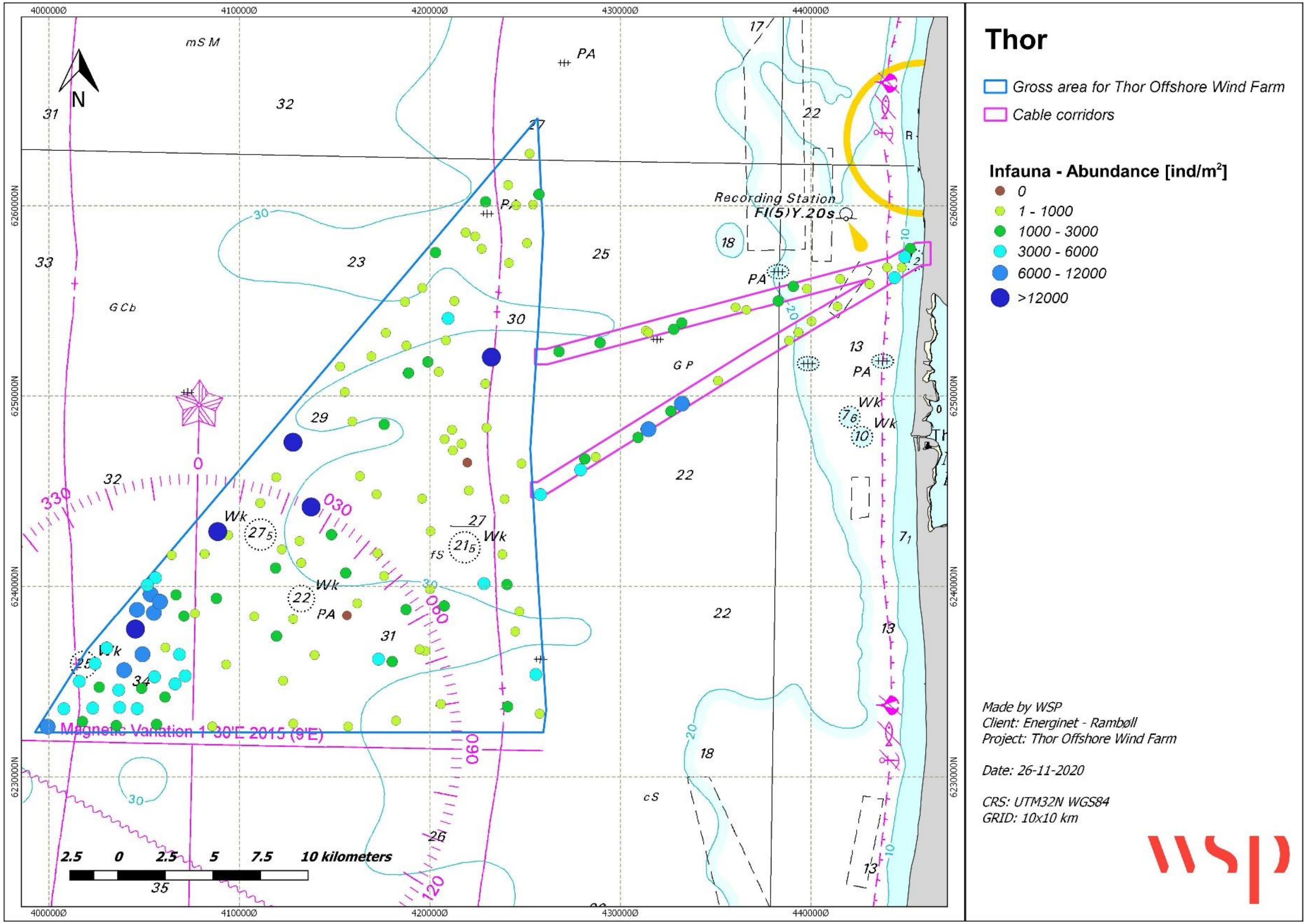


Figure 5-30 Abundance (ind./m²) of infauna at sampled stations.

Biomass: The biomass is measured as dry weight, and is shown in Table 5-13 for the gross area for Thor OWF, the two cable corridors (CC=R2+R3), the northern - (R2) and southern cable corridor (R3).

The biomass for all sampled stations varied between 0-1127 g DW/m^2 in the gross area for Thor OWF (average 90 g DW/m^2), 0.8-390.7 g DW/m^2 in R2 (average 42 g DW/m^2) and <0.1-458 g DW/m^2 in R3 area (106 average g DW/m^2).

Figure 5-32 below illustrates the biomass (g DW/m^2) for all sampled stations. Biomass is highly variable in the gross area for Thor OWF and in the two cable corridors. There is however a tendency, as seen for species number and abundance, for on average higher biomasses in the southwestern part of the gross area for Thor OWF, and a higher biomass in the southern cable corridor (R3) compared to the northern cable corridor (R2).

Figure 5-31 shows the biomass separated into the dominating infauna classes in the gross area for Thor OWF and cable corridors. The class echinodermata dominates the biomass in both the gross area for Thor OWF and the southern cable corridor (R3), whereas species within the class bivalvia dominate the biomass in the northern cable corridor (R2).

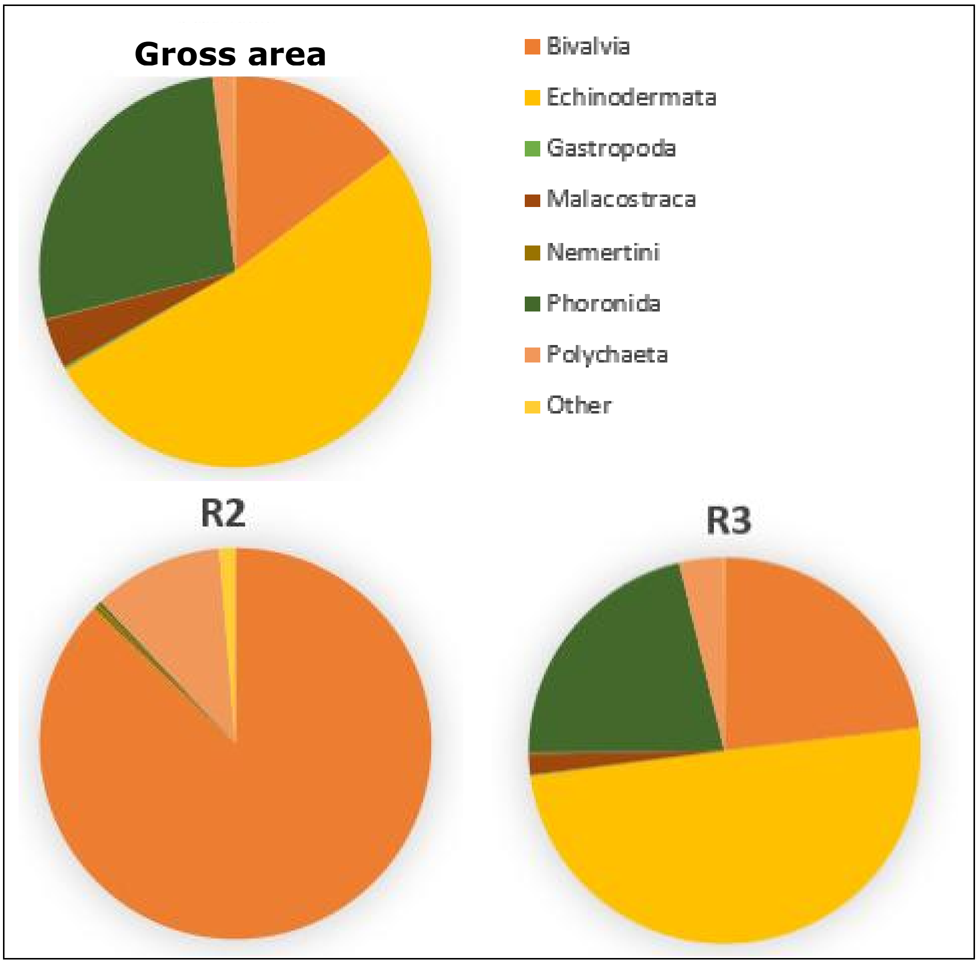


Figure 5-31 Biomass separated into the dominating infauna classes in percentages. Gross area = the gross area for Thor OWF. R2 = Northern cable corridor. R3 = Southern cable corridor.

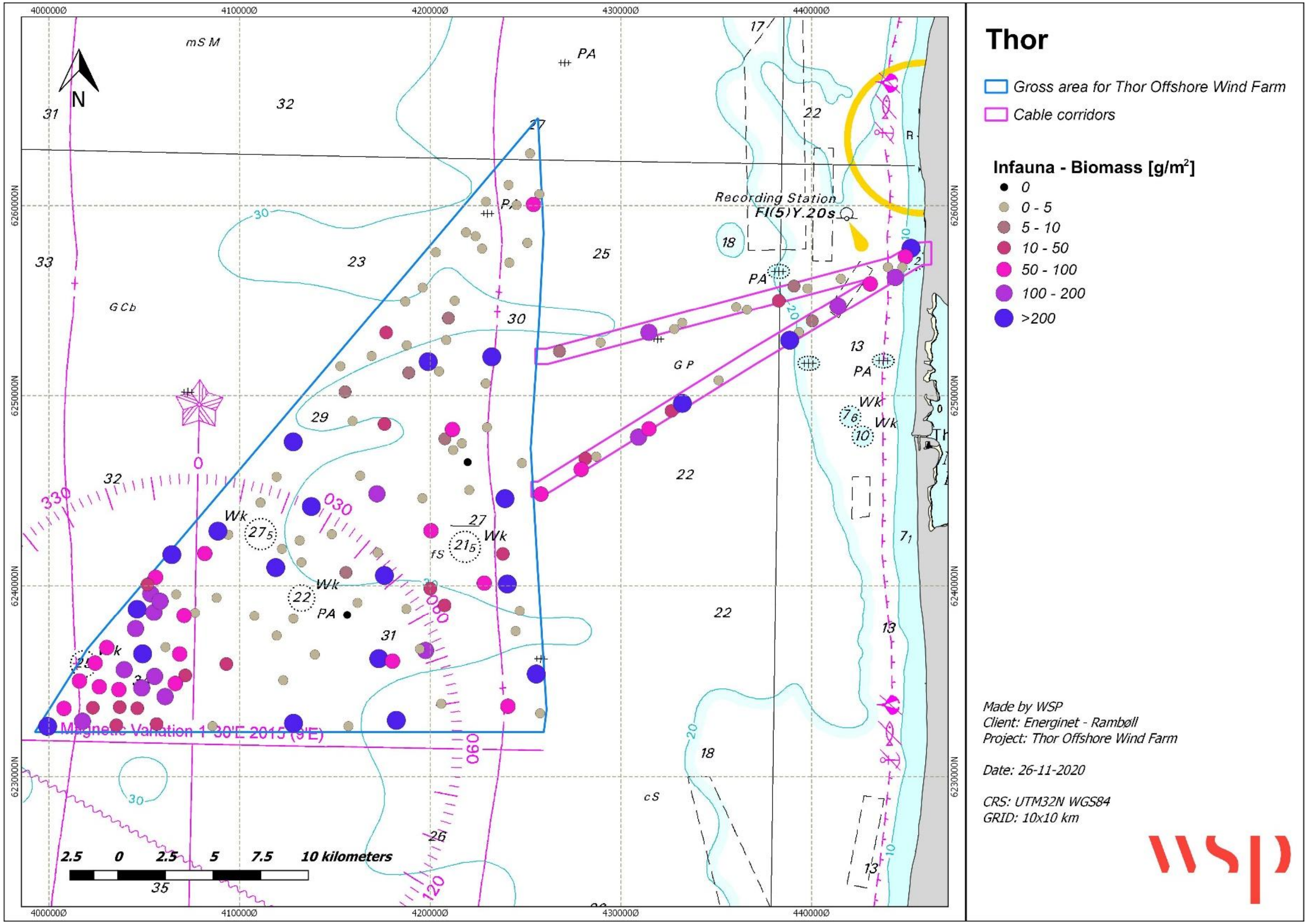


Figure 5-32 Biomass of infauna species at sampled stations in g DW/m²

5.5.3.2 Infauna diversity and ecological indexes

Different infauna indexes can be used to describe the infauna communities in Danish waters, including the species diversity index Shannon Wiener diversity index (H') and Pilou´s Evenness index, and the ecological indexes AMBI- and DKI-index. In-depth method descriptions are given in Appendix 8.

The results for the indexes are shown in Table 5-15 below. Assumptions for the calculations and interpretation of data are described in Appendix 8.

Table 5-15 Overview of the results of the Shannon-Wiener diversity index (H'), Pielou´s Evenness index (J'), AMBI and DKI index in the gross area for Thor OWF (Gross area) and cable corridors (CC): R2 – northern cable corridor and R3 – southern cable corridor.

	GA	R2	R3	CC (R2 + R3)
Shannon-Wiener diversity(H')	1.00	1.40	1.13	1.26
Pielou´s Evenness index (J')	0.69	0.78	0.71	0.74
AMBI	1.57	1.62	1.14	1.33
DKI	0.78	0.81	0.83	0.82

Species diversity indexes

The species diversity in the three areas given by the Shannon Wiener diversity index shows that the diversity found in both the gross area for Thor OWF and the two cable corridors is lower than the normal range for Danish waters, which is typically 1.5-4 (Pedersen & Deding, 2017). Note that the index score can only be used to compare within the same area or between areas, where the physical and environmental parameters are similar. E.g. comparison cannot be done between the gross area for Thor OWF, R2 and R3 but can be used to follow a development between years in the same area.

Pielou´s Evenness index (J') refers to how similar in abundance (individuals pr. m^2) each species is to the other species found at the station. The value of this index ranges between 0 and 1 - the greater the value the greater the evenness in species abundance and numbers between species. The evenness is between 0.69-0.78 for the gross area for Thor OWF and the two corridors R2 and R3. Shannon-Wiener index (H') and Pielou´s Evenness (J') index show the same pattern with a more even distribution of species and abundance in the northern cable corridor (R2) than in the two other areas. This is caused by a more equal number of individuals between the species in R2 compared to a more unbalanced major dominance of the horseshoe worm (*Phoronis* sp.) in the gross area for Thor OWF (78% of all individuals) and the southern cable corridor (R3, 58% of all individuals).

The ecological indexes

The AMBI-index is a marine index used to evaluate the effect of eutrophication on infauna in European Fjords, coastal areas and sea areas (Borja et al, 2000). The index is evaluated from the abundance of individuals in five ecological groups (GI-GV, se Appendix 8, Figure 1-2), which are classified according to their sensitivity/tolerance to environmental stressors. The AMBI-index shows the relation between sensitive species and robust species in the area and uses this relation to classify how disturbed an area is and to describe the condition of the infauna community. As for the diversity indexes you can only compare within the same area and between areas, where the physical and environmental parameters are similar. The index ranges between 0-6 (undisturbed to extremely disturbed).

The AMBI value is between 1.2 < and ≤ 3.3 in the gross area and R2, thus they are in the same category, whereas R3 falls in the category 0,2-1,2, however in the high end of the range (Table 5-15). The category 0,2-1,2 indicates infauna communities that are impoverished, and that the area classification is undisturbed, whereas the category 0,2-1,2 indicates infauna communities that are unbalanced and that the area classification is lightly disturbed. The dominating ecological group is I in the cable corridor R3; which include specialist carnivores and some deposit feeding tubicolous polychaetes, whereas the gross area and the cable corridor R2 is dominated but the dominating ecological group III; which are generalists living under a wide range of environmental conditions including the very dynamic conditions along the west coast of Denmark. The dominance of these species is, thus, caused by the species being robust generalists, which are able to tolerate the changing and dynamic conditions along the west coast of Denmark.

The Danish quality index (DKI) has been developed to assess the condition of a water area in accordance with the EU Water Framework Directive. The ecological state of an area can be expressed by the DKI index. The index ranges between 0-1 (bad to high ecological status). The ecological status is good for the gross area for Thor OWF and high in the two cable corridors according to the DKI values (see Table 5-15, Appendix 8).

In conclusion, the indexes illustrate an infauna community with lower than normal species diversity: The gross area and the northern cable corridor (R2) are dominated by robust generalists and classified by the AMBI index as an unbalanced infauna community. The Southern cable corridor (R3) has a few more specialist carnivores and some deposit feeding polychaetes resulting in the area categorized as undisturbed. The Danish quality index (DKI), which is a supporting parameter for the evaluation of the ecological status in the Water Framework Directive, scores the gross area as having good ecological status, whereas the ecological status in the two cable corridors was high. The indexes are, thus, indicative of a dynamic environment determining the composition and condition of the infauna community in both the gross area for Thor OWF and the two cable corridors.

5.5.3.3 Statistical analysis of infauna composition and distribution

Statistical analysis was used to investigate the species composition and distribution within the gross area for Thor OWF and the two cable corridors.

Infauna species composition

Statistical analysis (multivariate statistical analysis) of the difference in species composition between infauna samples collected at each station was conducted to clarify if different infauna communities could be identified in the three areas investigated (Gross area, R2 and R3). Different infauna communities are identified as separate groupings when plotted in a graph (MDS plot). The results of the multivariate analysis (Bray Curtis similarity matrix) are shown in Figure 5-33 below.

The MDS plot shows no clearly separate infauna communities in the gross area for Thor OWF or in the two cable corridors. The results therefore show that it is in general the same infauna community/the same species composition that is observed in all three areas (GA, R2 and R3). However, there is a tendency that the infauna composition is more similar for the gross area for Thor OWF and the southern cable corridor (R3) than for the northern corridor (R2) (Figure 5-33). This was also observed in section 5.5.3.1 by more equal abundances between species in the northern cable corridor, compared to the horseshoe worm (*Phoronis* sp.) dominating both R3 and the gross area for Thor OWF.

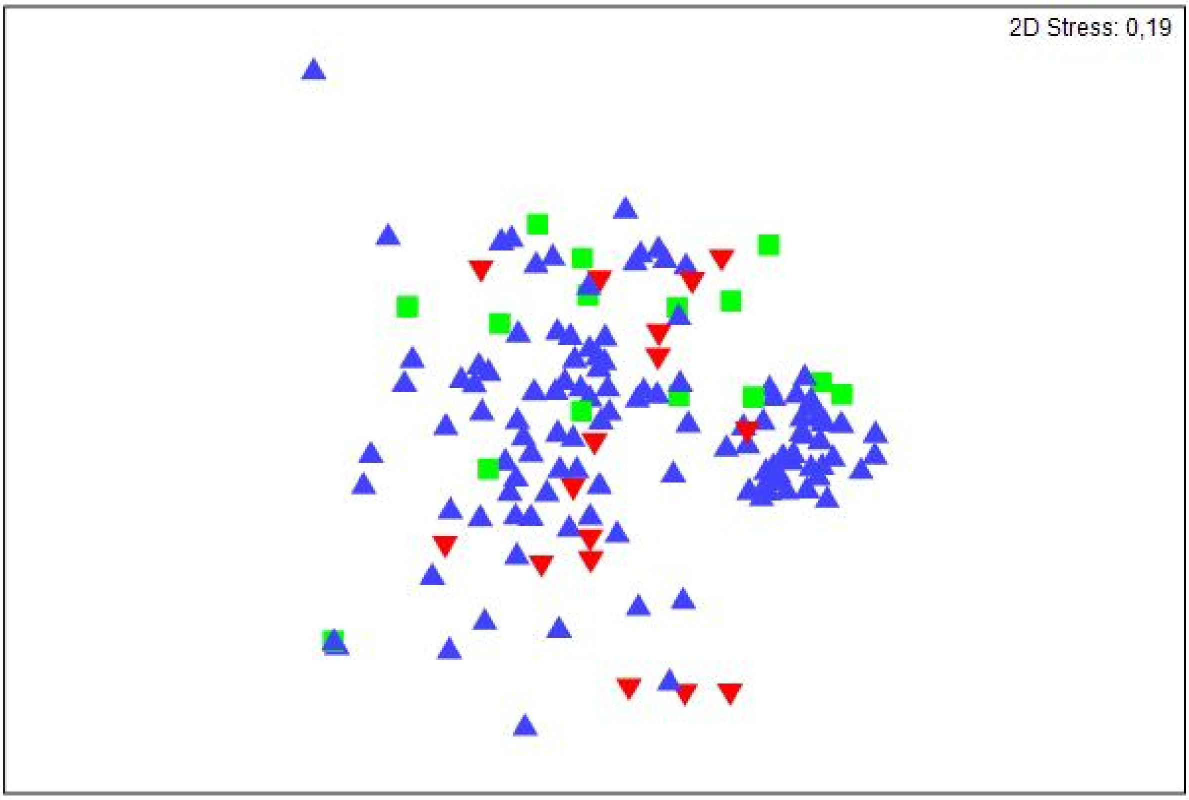


Figure 5-33 The difference in species composition between stations. The MDS Plot provides a visual presentation of the differences between station (grouped by area) displaying the calculated Bray-Curtis similarity matrix. Blue triangles are stations from the gross area for Thor OWF, Red triangles are stations from the northern cable corridor (R2) and Green squares are stations from the southern corridor (R3).

Analysis of the controlling abiotic parameters for infauna composition
An analysis was conducted to investigate if the observed infauna species composition at the stations could be explained by differences in the abiotic parameters in the three areas (GA, R2 and R3). Important abiotic parameters affecting the infauna species composition is oxygen availability, salinity, sediment characteristics and water depth. This analysis was conducted pooling all data from the gross area for Thor OWF and the cable corridors.

The oxygen availability and salinity concentrations were very similar at all stations (Table 5-1), which was also expected in this very dynamic part of the North Sea, where the water column is generally well mixed (see section 5.2.2). Oxygen and salinity were therefore not included in the analysis.

Thus, only four parameters were analysed to describe the variation in infauna composition:

- Water depth (in meters)
- Silt & clay fraction (d10), indicating the fine sediment fraction
- Median grain size (d50), indicating the average grain size of the sediment
- Coefficient of uniformity (d60/d10), indicating the uniformity of grain size in the samples

The statistical analysis (DistLM = Distance based linear model) showed that water depth explained most of the variation in the infauna community across all stations (6.8%, $p<0.01$). The fine sediment fraction (d10, silt and clay fraction) was the sediment variable, which explaining most of the variation in the infauna community across all stations (2.7%, P<0,01). Together the 2 variables explained 9.3% (p<0.01) of the variation in the infauna community across all stations.

Variation in infauna species composition with depth

As water depth was the variable that explained infauna composition at the stations best, a further analysis of the infauna composition with increasing water depth from the shallowest to the deepest samples was conducted.

The results of the analysis (Bray Curtis similarity matrix) are shown in Figure 5-34 below.

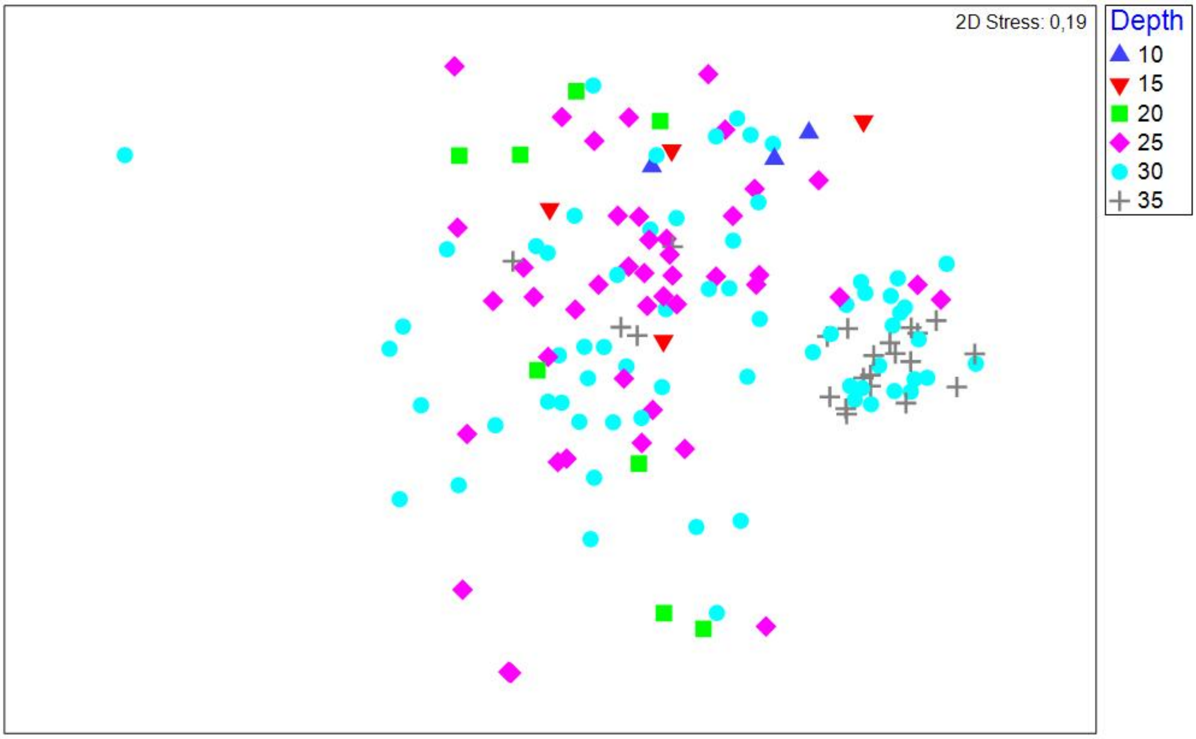


Figure 5-34 Differences between species composition with water depth. The MDS Plot provides a visual presentation of the differences between all stations (grouped by water depth intervals of 5 meters) displaying the calculated Bray-Curtis similarity matrix. All stations are included e.g. from both cable corridors and the gross area for Thor OWF. Each symbol in the MDS-plot is one station. The stations have been grouped in the water depth intervals to illustrate similarities and differences in the taxon composition between the individual samples. The depth intervals chosen to illustrate the effect of depth on the community structure: dark blue triangles = 7.5-12.5 m, red triangles = 12.5-17.5 m, green squares = 17.5-22.5 m, pink = 22.5-27.5 m, light blue circles = 27.5-32.5 m and grey crosses = 32.5-37.5 m.

Figure 5-34 Illustrates how community structure changes with depth. There is some separation in the community structure for the deepest stations (grouping of grey + symbols and to some degree light blue circles – to the right) and in the shallowest stations (dark blue triangles and to some degree red triangles). However, there is also a large degree of overlap in the community structure at stations across water depth, which explains why depth was only able to explain 6.8% of the variation in infauna species composition between stations. E.g. there are some differences in infauna composition with water depth but generally a large overlap in species composition between water depths. Which again confirms that the infauna community in the gross area for Thor OWF and the cable corridors is generally the same – that is one community with large variance.

This is supported by another study conducted in the shallow coastal area along the west coast of Denmark in connection with the EIA for sand nourishment along the coast (0-8 m depth) (Rambøll, 2020a). This study similarly concluded that the benthic fauna along the coast is part of a single community, which stretches along the west coast of Denmark, the larvae being spread and distributed in the entire area by the strong currents (Rambøll, 2020a).

In conclusion, the statistical analyses show that the infauna species in the gross area for Thor OWF and the two cable corridors are dominated by robust generalists, generally belonging to one infauna community, with generally the same species composition in the three areas (gross area, R2 and R3) as well as overlapping species composition with water depth.

5.5.3.4 Comparison between infauna observed in Thor OWF and other areas

This section compares infauna data from the gross area for Thor OWF with similar data from projects in areas comparable to the gross area for Thor OWF (see section 5.5.1.3 – existing data for infauna). This is done to clarify if the collected Thor infauna data can be considered normal, high or low for the region in general.

The number of observed infauna species was similar in the gross area for Thor OWF and the OWF area in Vesterhav Nord and was based on a similar investigated surface area (total sampled area 1.7 and 1.8 m^2, respectively) (see section 5.5.1.3 – existing data for infauna). The number of species was higher for both cable corridors in the investigated area of Thor OWF than what was observed in the Vesterhav Nord even though a higher surface area was investigated for the cable corridor at Vesterhav Nord (0.2 m^2 for R2 and R3 and 0.3 m^2 at Vesterhav Nord) (see Table 5-16 below). More species were observed in both the gross area for Thor OWF and Vesterhav Nord compared to the sand extraction site at Jyske Rev (562-QA). Looking at both the abundance per m^2 and the biomass per m^2 higher values are seen in the gross area for Thor OWF with four-times higher abundance in the gross area for Thor OWF than in Vesterhav Nord and with six times higher abundance than in the sand extraction site (562-QA). The Southern cable corridor (R3) had approximately six-times more individuals than what was observed in the Vesterhav Nord and in the sand extraction site (562-QA), whereas the abundance in the northern corridor (R2) was four-times higher than what was observed in the cable corridor of Vesterhav Nord and the sand extraction site (562-QA). The same pattern applied for the biomass measurements (Table 5-16).

Though, abundance and biomass were higher in the gross area for Thor OWF and the cable corridors, than what was observed in the Vesterhav Nord OWF and cable corridors and the sand extraction site (562-QA), they are well within values observed in other studies in Tannis Bugten (GEUS and Orbicon, 2018) and less or much less than the abundance and biomass observed in Kattegat (Pedersen, H.B and Deding, H. , 2017).

The diversity patterns reveal that the infauna community in the northern cable corridor (R2) and especially the gross area for Thor OWF was more unbalanced and disturbed than what was observed in the sand extraction site 562-QA and in the Vesterhav Nord investigation area. With higher dominance of individual species, and uneven number of individuals for each species. Whereas the Southern cable corridor was classified as undisturbed as for the sand extraction site 562-QA.

In, conclusion infauna species diversity in the gross area for Thor OWF and cable corridors was comparable to other infauna studies in the area. However, the abundance and biomass of infauna in the investigated area were generally high compared to similar infauna studies in the nearby area.

Table 5-16. Comparison of parameters between the infauna data from the gross area for Thor OWF and cable corridors (CC): R2 – northern cable corridor and R3 – southern cable corridor; the sand extraction site 562-QA and in the area investigated for Vesterhav Nord OWF. * indicates samples collected with a grab sampler (0.1 m^2 each). All other samples are collected with a HAPS sampler (0.0143 m^2 each).

	No. of species (samples)	No. of individuals pr. m^2	Wet weight pr. m^2 (g)	Dry weight pr. m^2 (g)	Shannon Wiener (H´)	AMBI
THOR						
Gross area	81 (119)	2342	170	90	1.00	1.57
R2	43 (15)	1352	93	42	1.40	1.62
R3	46 (16)	2369	210	106	1.13	1.14
CC (R2 + R3)	63 (31)	1877	153	75	1.26	1.33
Extraction site						
562-QA	37 (25)	364	54	30	3.1	1.18
Ref. site (562-QA)	35 (25)	392	36	20	3.0	1.44
Vesterhav Nord						
OWF	81 (18)*	698	47		3.0 (1.6-3.8)	
CC	15 (3)*	373	4		2.0 (0-3)	

5.6 Benthic Habitats

This section presents the combined results for infauna and epifauna communities to present a cumulated map of benthic habitats in the investigated area (se Figure 5-35).

General

Benthic habitats in the gross area for Thor OWF and the two alternative cable corridors were mainly characterized by infaunal benthic communities. In sandy-bottom areas different infauna species dominated, whereas in mixed bottom areas and hard bottom areas where stones were available epifauna such as tube worms (*Pomatoceros triqueter* and *Spirorbis tridentatus*), hydroids, leafy bryozoans (*Flustra foliacea*), dead man´s fingers (*Alcyonium digitatum*) and anthozoans dominated (See full species list in Table 5-10). Epifauna coverage in hard bottom areas decreases with dynamic and water depth of the seabed.

The registered benthic fauna species are robust due to their adaptation to the dynamic conditions along the exposed coast of Denmark with strong wave action during stormy weather events and periodic occurrence of large amounts of resuspended material in the water column, which result in frequent scrubbing of the stones and covering of fauna with sand (Rambøll, 2020a; Vattenfall, 2020a; Vattenfall, 2020b).

The different communities observed are presented in Figure 5-35 below.

Infauna distribution

The largest part of the gross area for Thor OWF is characterized by sandy bottom with horseshoe worm (*Phoronis* sp.). Abundance and biomass varied strongly with the deepest, southwestern part having the highest numbers of species, abundance and biomass. The same species dominated but more species were found as well as higher abundance and biomass in general in this area. In general, Phoronids sp. dominated the abundance and Echinodermata dominated the biomass in the gross area for Thor OWF.

The lower part of the cable corridors (7.5-17.5 m) (See Appendix 8) was dominated by sandy bottom with *Magelona mirabilis* and bean-like Tellina (*Fabulina fabula* = synonym *Tellina fabula*), followed by *Spiohanes bombyx* and *Protodorvillea kefersteini* (12.5-27.5 m) (see Appendix 8), and also had a high percentage of mixed sediment with few epifauna. Abundance was dominated by brittle worms in the northern cable corridor (R2) and *Phoronis* sp. in southern corridor (R3). Biomass was dominated by bivalves in R2 and Echinodermata in R3.

Stone reef habitats were located in small patches and constituted 2-4 % of the gross area for Thor OWF and each cable corridor.

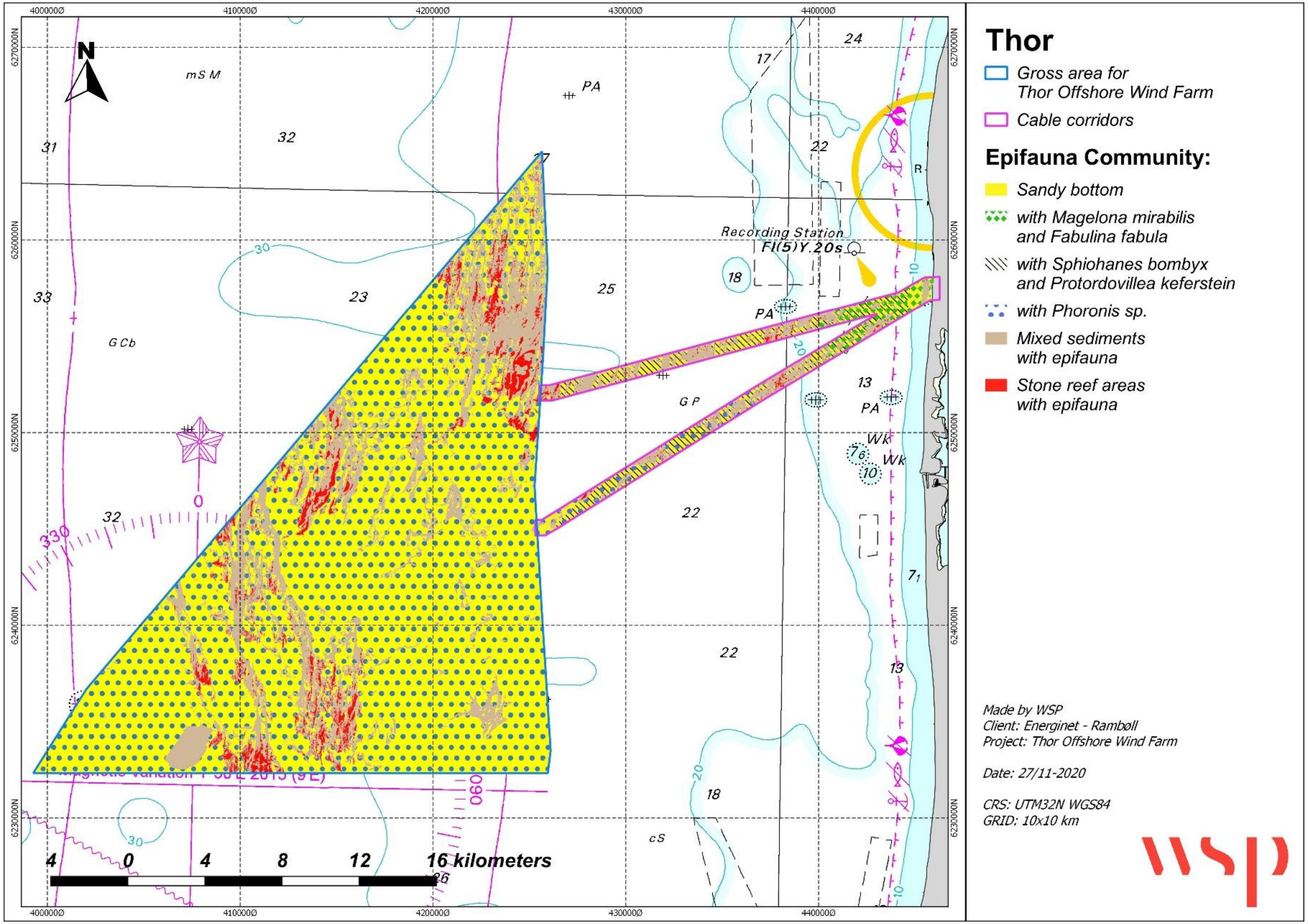


Figure 5-35. Map of benthic habitats in the gross area for Thor OWF and the cable corridors. Note overlap between sandy-bottom communities in the cable corridors.

6. SENSITIVITY ANALYSIS AND POTENTIAL IMPACTS

In the following potential impacts of the planned Thor OWF and cable corridors for benthic fauna and flora are listed and irrelevant subjects are scoped out. A sensitivity analysis of benthic infauna and epifauna is included and finally potential impacts are assessed.

6.1 Potential impacts

Identification and assessment of potential impacts of benthic fauna is carried out on the basis of the activities defined in the plan for Thor OWF (see chapter 3).

Environmental assessment is not conducted for benthic flora, since this is generally not present in the investigated area due to a highly dynamic seabed in the lower parts of cable corridors and the gross area for Thor OWF and light limitation at greater water depth (see section 5.4).

The possible impacts on benthic fauna and flora of the planned Thor OWF and the relevant project phases for the impact are listed below.

Permanent impacts (operation phase):

- Permanent footprint from foundations and cable protections

Temporary impacts (construction phase):

- Temporary footprint from cable installation
- Increased concentrations of suspended sediments in the water column
- Sediment deposition on the seabed
- Release of nutrients and toxic substances from suspended sediment
- Heat development around the cables

6.1.1 Not assessed - Irrelevant potential impacts

In the following is given a short description of potential impacts that are **not assessed** and why these are not deemed potentially significant.

6.1.1.1 Nutrients

As an indirect effect of sediment spill by e.g. dredging or digging activities, nutrients buried in the sediment can be released into the water column and increase the nutrient concentration in the water.

In relation to total nitrogen (TN) the measured concentrations varied between below detection limit (300 mg/kg DW) and 570 mg/kg DW. In relation to total phosphorus (TP) the measured concentrations varied between below detection limit (50 mg/kg DW) and 210 mg/kg DW. Both nutrient concentrations are low compared to natural concentrations of TN and TP in marine sediments.

Nutrient concentrations and organic content measured at the stations in the gross area for Thor OWF and cable corridors varied and were generally low and within natural background concentrations for the North Sea region (Seiter et al., 2004) (see section 5.3.5.2).

Experiences from Horns Rev III show that nutrient concentrations in the water column from such organic-poor sediments (released from digging or grudging) are very low or even below the detection limit. Consequently, this potential environmental impact is not considered further (Orbicon, 2014).

6.1.1.2 Toxic substances

Toxic substances can either be released from the seafloor sediment during e.g. dredging and digging activities and thus have an effect on benthic organisms (indirect impact), or they can be part of the treatment of project structures as paint, grout or other substances and be dissolved into the seawater thus affecting benthic organisms (direct impact).

In general, the chemical analyses at all stations in this study showed chemical concentrations below the Lower Action Level in the Danish guideline for disposal of dredged material (Miljøstyrelsen, 2005), indicating background levels of all chemical substances in the sediment, natural for the this part of the North Sea region.

Exceedance was observed in only two samples (ENV_R2_019 = 25 mg/kg DW and ENV_R3_020 = 21 mg/kg DW) with cobber concentrations (Cu) above the Lower Action Level (2 mg/kg DW) but not above the Upper Action Level (90 mg/kg DW), indicating above natural concentrations. Both samples were taken at stations in the western part of the cable corridors (see Figure 4-3). The exceedances are low, and dilution occurs rapidly in the dynamic waters along the West coast of Denmark. Effects on the benthic fauna and flora is therefore not expected and is not assessed any further.

6.2 Sensitivity analysis of benthic fauna species

The sensitivity of the benthic fauna species is determined from the species ability to recover and re-establish themselves in an impacted area and the time this takes.

The benthic fauna species along the west coast of Denmark are very robust and able to handle regular displacement, burial and high sediment concentrations in the water, which are a natural condition in this part of the North Sea region due to a very dynamic seabed and large sand transport along the coast (Culter and Mahadevan, 1982; Nelson, 1993; DONG Energy, Vattenfall, The Danish Energy Authority and the Danis Forest and Nature Agency, 2006; Rambøll, 2020a).

Furthermore, the benthic fauna reproduces through larvae, which are transported and distributed with the current along the coast. The benthic fauna along the coast is therefore part of a single community (Rambøll, 2020a) and has a high recovery potential from the surrounding seabed, which stretches along the entire west coast of Denmark. This makes the benthic fauna along this coast very robust (Vattenfall, 2020a; Vattenfall, 2020b; Orbicon, 2014) and able to handle large disturbances. Their sensitivity is accordingly low compared to species with more patchy distribution in the inner, less dynamic Danish waters.

6.2.1 Sensitivity of infauna species

Studies of recovery time of benthic communities along the west coast of Denmark and the shallower part of the North Sea corresponding to the conditions in the gross area for Thor OWF and cable corridors has mainly been conducted in connection with beach or coastal nourishment for different coastal protection projects (see below). However, the species present in these projects are the same as observed in the investigated areas and these studies are therefore also relevant here.

DFU's studies of beach nourishment (rainbowing) at Agger Tange and reef feeding at Fjaltring (2002, 2003, 2004) have both shown significant effects on benthic fauna, especially in the form of reduced incidence of bristle worms. DFU (DTU Aqua) found that the recovery time of the benthic fauna after coastal nourishment (rainbowing) at Agger Tange was >1 year despite low numbers of individuals (249 ind. / m^2) and a dominance of opportunistic species with high reproductive potential (DFU, 2005). Other studies show recovery times of approx. one year for the benthic fauna in shallow water and up to 5 years for more long-lived species.

Studies from US have shown rapid recovery time for benthic fauna (<1 year), due to the fact that the existing coastal benthic fauna communities are adapted to disturbance from very mobile sediment (Nelson, 1993; Culter and Mahadevan, 1982). The more diverse and species-rich benthic communities further from land (deeper than 3 m), live in a relatively more stable environment - these communities may take longer to re-establish a coastal sandy community (Nelson, 1993; Rakocinski et al, 1993; Culter and Mahadevan, 1982). Essink et al (1997) report from the RIACON study from beach nourishment experiments in several North Sea countries that most benthic fauna species were largely re-established 1 year after beach feeding (1-3 m thickness) (Essink et al, 1997). Brittle stars have been observed to recover within 1-2 years after trawling (FAO.org, 2020). The more long-lived species such as mussels (e.g. *Fabulina fabula and Abra alba*) and sea urchins (*Echinocardium cordatum*) re-established more slowly. For these species, which do not have successful reproduction every year, the recovery of total biomass and normal age structure is expected to take 2-5 years (Essink et al, 1997).

The gross area for Thor OWF was generally dominated by *Phoronis* sp. and bristle worms (Polychaeta) including *Magelona mirabilis, Spiophanes bombyx, Scoloplos armiger, Nepthtys cirrosa and Lanice; and also Echinocardium cordatum,* which dominated infauna abundance and biomass.

The cable corridors were also dominated by *Magelona mirabilis, Spiophanes bombyx and* bean-like Tellina (*Fabulina Fabula*, old name *Tellina fabula*). The sea potato *Echinocardium cordatum* dominated in the southern corridor (R3) and *Echinocyamus pusillus* dominated in the northern cable corridor (R2). The northern cable corridor (R2) was also dominated by the amphipod *Urothoe poseidonis.* The southern cable corridor (R3) was dominated by the mussel *Abra Alba* and the brittle star *Amphiura chiajei.*

Many bristle worms can handle coverage of larger deposits of sediment (Essink, 1999; Essink et al, 1997). The bristle worms *Nepthys hombergii* can handle approx. 90 cm coverage with sand and more than 17 cm continuous deposition per month, *Capitella capitata* can handle approx. 90 cm coverage and approx. 5 cm per month, and *Scoloplos armiger* can handle approx. 50 cm coverage and 10 cm per month (Essink, 1999). The robust seaweed flea species in the cable corridors (*Urothoe poseidonis and Bathyporeia elegans*) are generally good diggers and are very mobile both in the seabed and in the water phase (DFU, 2005). The dominant mussel species bean-like Tellina (*Fabulina fabula*) and white furrow shell (*Abra albra*) are also robust species adapted to the exposed and highly dynamic near-coastal zone in the North Sea and Kattegat (Jensen & Sprärck, 1934; WORMS Registrer, 2020).

Statistical analysis of the species composition of infauna in both the gross area for Thor OWF and cable corridors shows the same – e.g. that robust generalist species dominate the investigated areas, and that it is generally the same infauna community that is present, resulting in a good recovery potential in impacted areas from the surrounding, similar infauna community (see section 5.5.3.3 – Statistical analysis of infauna composition and distribution). Furthermore, due to the similarity of the infauna composition within the gross area for Thor OWF, the sensitivity is also the same no matter where the future OWF is placed within the gross area for Thor OWF.

6.2.2 Sensitivity of epifauna

Epifauna in areas with larger stones (>10 cm sediment type 2b, 3 and 4) in both the gross area for Thor OWF and the cable corridors was dominated by tube worms, hydroids, leafy bryozoans

(*Flustra foliacea*), dead man´s fingers (*Alcyonium digitatum*) and anthozoans. These species have recovery times similar to the infauna of 1-5 years. Recovery time is approximately 5 years for hydrozoans and leafy bryozoan (MarLIN, 2020). It takes dead man´s fingers approximately 3 years to reach maturity (MarLIN, 2020), anthozoans likely reaches breeding age at minimum 1.5 years (MarLin, 2020) and the common (edible) sea urchin reaches maturity after approximately 1-3 years (MarLin, 2020).

Comparison with similar ROV-investigations from comparable areas according to sediment type and depth shows that the epifauna species in both the gross area for Thor OWF and the cable corridors are very common in the area. The epifauna therefore have a high recovery potential in impacted areas from the surrounding epifauna populations.

6.2.3 Conclusion

The benthic fauna communities of infauna and epifauna present in the gross area for Thor OWF and the two cable corridors are therefore assessed to be very robust and with recovery times of 1-5 years after removal from temporary footprint activities e.g. cable flushing or digging. Also, both the epifauna and infauna community are very common and widespread in this part of the North Sea region with a high recovery potential in impacted areas from the surrounding, similar communities.

6.3 Assessment of potential impacts

In the following potential impacts of the planned Thor OWF and cable corridors for benthic fauna are assessed.

6.3.1 Footprint

6.3.1.1 General

All solid structural elements of a project placed on the seafloor are footprints and these typically destroy the benthic flora and fauna beneath. When the footprint is temporary, e.g. cable trenches, the benthic community can recover and re-establish after the impact has ceased (construction phase). In the case of permanent footprint (operation phase), i.e. for the wind turbine foundations, the benthic communities are permanently lost.

The immediate impact is typically the death of the organisms directly under the footprint area. However, during dredging, digging or jetting/flushing activities, benthic organisms can survive when displacement is done without direct physical destruction and does not include deep burial.

The benthic communities observed in the gross area for Thor OWF and cable corridors are common in the North Sea and with a good recovery potential from the surrounding populations and generally low recruitment times. No red-list species, protected species or habitat types were observed in the gross area for Thor OWF or the two cable corridors. Furthermore, the registered benthic fauna species are generally robust due to their adaptation to the dynamic conditions along the exposed west coast of Denmark with strong wave action during stormy weather events and periodic occurrence of large amounts of resuspended material in the water column, which result in frequent scrubbing of the stones and covering of the species with sand (Rambøll, 2020a; Vattenfall, 2020a; Vattenfall, 2020b). The sensitivity of the benthic communities in both the gross area for Thor OWF and the two cable corridors is therefore generally assessed as low in relation to impacts from the planned Thor OWF (see section 6.2 for further detail).

6.3.1.2 Gross area for Thor OWF

Permanent footprint

The permanent footprint of the foundations has been loosely estimated from the planned number of wind turbines and approximate diameters of erosion protection used for nearby wind farm projects (se section 3.2).

With an erosion protection around each foundation of in total 20 m in diameter, the total footprint of the 125 8 MW turbines is estimated to 0.039 km^2 and 0.021 km^2 for the 67 15 MW turbines. The gross area for Thor OWF is 440 km^2, however, the final area for Thor OWF will be 50% of this, e.g. 220 km^2*.*The footprint is therefore maximally 0.2 ‰ to 0.1 ‰ of the future Thor OWF area of 220 km^2. This is a rough estimate used for impact assessment of the plan.

The foundations have a small footprint of less than 1 ‰ of the future Thor OWF area (220 km^2) for the estimated 125 8 MW turbines and 67 15 MW turbines even if taking into account potential erosion protection around the foundation of the turbines. It has, however, not been clarified whether erosion protection will be used or not. Erosion protection in a diameter of approximately 20 meters around the foundations is included to establish that the foundations even including possible erosion protection will take up very little area in the future Thor OWF. It is therefore not necessary to distinguish between different foundation types as these will have a much smaller footprint resulting in much less impact on benthic fauna than estimated for foundations with erosion protection in this section.

The benthic communities under the foundations and erosion protection are expected to be permanently removed. However, hard bottom fauna, which is naturally present in smaller parts of the gross area for Thor OWF will likely re-settle this hard substrate – this is discussed in section 6.3.2 below. The increase in hard substrate from the footprint in the area is less than 1% of the existing hard bottom sediment (=sediment type 4) for both wind turbine scenarios. The increase in hard bottom sediment in the area is therefore not significant. The biggest change in benthic community will be if the turbines are placed on sand and very little change will result from placing the turbines on hard substrates. This can be specifically assessed in the EIA, when the position of the wind turbines is known.

The areas permanently impacted by the footprint of the turbines is smallest for the 67 15 MW turbines. However, the footprint of both turbine types constitutes a small part of the planned Thor OWF area (220 km^2) (<1‰) and of the west coast of Denmark. A general change in the benthic community in the future Thor OWF area is therefore not expected. The benthic community has a low sensitivity for disturbance and a high recovery potential in the area. Only *minor negative impacts* can therefore be expected on benthic fauna in the future Thor OWF area from the permanent footprint of the foundations no matter where these are placed within the investigated area.

It is difficult to assess whether one placement of the wind turbines and foundations within the gross area for Thor OWF is better for the benthic communities than others, since different placement benefits either the sandy bottom or the hard bottom community (Figure 6-1). E.g. the impact on infauna will be lowest if the turbines are placed on hard substrate, whereas the impact on epifauna is lowest if the turbines are placed on sandy bottom.

Mixed bottom with gravel has the lowest species numbers and placement of the turbines here might impact the benthic community the least.

Another way to assess placement could be that for infauna highest species numbers, abundances and biomasses are observed in the sandy (sediment type 1b) area in the southwestern part of the gross area for Thor OWF. Lowest numbers of infauna in general are found in the eastern most sandy part (sediment type 1b) of the gross area for Thor OWF (see Figure 6-1).

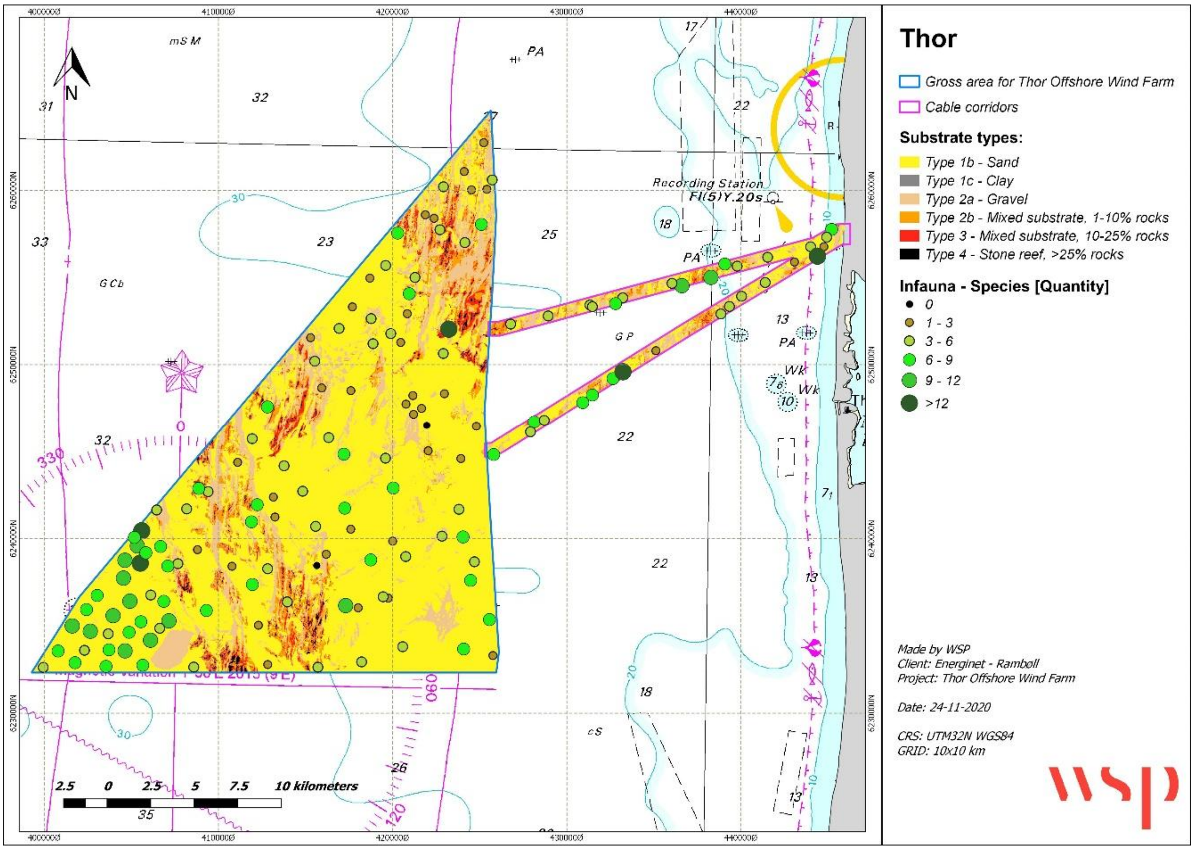


Figure 6-1 Number of infauna species at the sampled stations.

However, the main point is that no matter where the turbines are placed the impacts on the benthic communities will be only *minor*. This is assessed since only a small area is impacted by the footprint, and thus also only a small part of the benthic community consisting of common, robust species is impacted by the footprint.

Temporary footprints

Temporary footprints within the gross area for Thor OWF will originate mainly from inter-array cables between the turbines and bottom-impacting machines. Cable trenches leave temporary footprints, and the benthic community can recover and re-establish after the impact has ceased. The footprint will affect an insignificantly small part of the seabed along the west coast of Denmark. The observed species are common in the North Sea region with high recovery potential from the surrounding populations and a low sensitivity to disturbance. Recovery time for the benthic community in the investigated area is assessed to 1-5 years and the existing benthic communities are expected to recover fully in the investigated area. Only *minor negative impacts* can therefore be expected on benthic fauna from the footprint of inter-array cables and other bottom-impacting machines in the gross area for Thor OWF.

6.3.1.3 Cable corridors

Cable trenches in the two cable corridors leave temporary footprints and the benthic community can recover and re-establish after the impact has ceased. The footprint will affect an insignificantly small part of the seabed along the west coast of Denmark (one or both cable corridors). The observed species are common in this part of the North Sea region. Recovery time for the benthic community in the investigated area is assessed to 1-5 years and is therefore of short to medium duration and the existing benthic communities are expected to recover fully in the investigated area. The benthic communities in the cable corridors are robust with high recovery potential from the surrounding populations and a low sensitivity to disturbance. Only *minor negative impacts* can therefore be expected on benthic fauna using one or two cable corridors (R2, R3, or R2+R3).

The cable corridors have small differences such as more epifauna species in the northern corridor (R2) (23 versus 18 species) and more infauna species in the southern corridor (R3) (46 versus 43 species). This difference is likely due to 11% more mixed sediment types such as gravel and sand with few large rocks (<10%) in the northern corridor and relatively more sandy sediment in the southern corridor.

The small difference in the benthic communities between the two cable corridors is not great enough to qualify that one cable corridor will result in less impact on the benthic community. The impact on the benthic fauna communities will be only *minor* in both cable corridors.

6.3.2 Introduction of new habitats

The introduction of permanent new hard-substrate habitats in the form of foundations, and possibly cable protection and erosion protection around each foundation base in the form of larger stones, potentially increases the hard bottom area within the gross area for Thor OWF and the cable corridor. It is not yet known whether erosion protection or cable protection will be used in the project.

Taking into account the estimated footprint of the foundations plus erosion protection and assuming that the footprint is only placed in the sand area, then the area increase of hard bottom in the gross area for Thor OWF is estimated to be less than 1% (when adding the foundations to the existing sediment type 4). It should be noted that hard bottom substrate is already present in local patches in the gross area for Thor OWF (sediment type 3+4 = stone reef areas) constituting <4% of the area. Such a small increase of less than one percent of the hard bottom area in the gross area for Thor OWF will not change the distribution of sediment types or benthic fauna communities in the area significantly.

In the two cable corridors the hard bottom area may increase if cable protection in the form of placement of larger rocks on top of the cable trace are used, but likely not more than seen for the gross area for Thor OWF (<1%).

These are only loose estimates since the size of the foundations, erosion protection, cable protection is not specified at this stage.

A positive impact of the introduction of more, hard substrate from foundations, erosion protection and cable protection is, that the new hard structures can function as artificial reefs, which again serve as substrate for macroalga, blue mussels and other epifauna. This way valuable new stone reef habitats are created. Experience from Horns Rev and Nysted OWFs showed that addition of hard bottom structures from foundations increased heterogeneity and changed the benthic communities from infauna to epifauna communities (DONG Energy, Vattenfall, The Danish Energy

Authority and the Danis Forest and Nature Agency, 2006). Abundance and biomass of the benthic communities increased, including an increase in biomass of 50-150 times, most of this as available food for fish and seabirds (DONG Energy, Vattenfall, The Danish Energy Authority and the Danis Forest and Nature Agency, 2006).

An increase in the hard bottom area within the gross area for Thor OWF and cable corridors of less than 1% is permanent but will not change the benthic communities in the areas, since hard bottom is already a natural part of the area. No impacts can therefore be expected on benthic fauna in the gross area for Thor OWF and cable corridors (R2 and R3) as a result of such a small increase in hard bottom area.

6.3.3 Increased suspended sediments and sedimentation

Sediment spillage results in increased suspended sediment concentrations and sediment deposition locally around the excavation and cable flushing activities. Sediment spillage in the water column results from cable flushing and potential digging activities for foundations.

Results from sediment modelling at Vesterhav Nord and Syd OWFs showed that increased suspended sediment and deposition from cable flushing and instalment of foundations are low and within the large natural variation in suspended sediment seen along the highly dynamic west coast of Denmark (Vattenfall, 2020a; Vattenfall, 2020b). Furthermore, activities that results in sediment spillage are short-term (<2 months) and progresses spatially e.g. does not occur in the entire area at the same time at Vesterhav Nord and Syd OWFs (Vattenfall, 2020a). The sediment spillage in the Thor OWF is expected to be comparable to that found in the Vesterhav Syd and Nord OWFs, which are located within 13-14 km of the gross area for Thor OWF. The duration of the sediment spilling activities will most likely be longer, since the number of turbines planned for the Thor OWF (67 or 125) is so far between 3 to 6.5 times larger than for Vesterhav Nord and Syd OWFs (21-20 turbines).

Benthic fauna filter feeders can potentially be affected by high concentrations of suspended sediment in the water column, which can clog their gill apparatus and reduce food intake. However, the benthic fauna on the west coast of Denmark is adapted to highly variating and high concentrations of suspended sediment in the water column, as the natural mean and maximum concentrations are very high just above the seabed (Vattenfall, 2020a; Rambøll, 2020a). For example, at times there may be extremely high concentrations of suspended sediment in the water column (up to 185 mg/l) (Rambøll, 2020a), while the natural concentration of suspended sediment (background concentration) on the west coast of Denmark is estimated to be approx. 0-7 mg/l (Rambøll, 2020a).

Likewise, the modelled sedimentation in Vesterhav Nord and Syd OWFs is estimated to result in depositions locally in the order of a few millimeters, which is very low compared to the natural sediment transport on the very dynamic west coast of Denmark, where more than 1 m of sand can be removed or applied during severe storms (COWI, 2015), and where the sand transport along the coast is very high e.g. approx. 1.4 million m^3 per year towards south from Thorsminde and up to 1 million m^3 per year in a northerly direction towards Thyborøn (Kystdirektoratet, 2001; Vattenfall, 2020a).

The benthic fauna species along the west coast of Denmark are very robust and able to handle regular displacement, burial and high sediment concentrations, which are a natural condition in the area due to a very dynamic seabed and heavy sand transport along the coast (see section 6.2). The communities are assessed to be robust and have a low sensitivity to impact. Sediment spillage is local around the spillage point and moves from foundation to foundation or from start to end of the cable corridor, exposing the local areas to increased concentrations in a few days to months at the most. Increased concentrations of suspended sediment and increased deposition due to sediment spillage from the Thor project are likely within the natural variation regardless of location in the investigated area or two instead of one cable corridor and are, thus, assessed to result in potential impacts of *none to minor* for benthic fauna and flora in the area.

6.3.4 Heat development around the cables

The electric current in the inter-array cables and export cables generates electromagnetic fields (EMF) and heat.

It is assumed that the submarine cables for the Thor project will be designed to shield the surroundings from the electric field (E-field) that arises during the operation of the wind turbines. Due to the difference in current strengths, the field strengths over the inter-array cables connecting the turbines will be significantly less than over the transport cable from the gross area for Thor OWF to landfall (Vattenfall, 2020a). The electromagnetic field can cause increases in temperature in the sediment just around the cable.

There are few studies of benthic tolerance limits for magnetic fields and temperature rises. The vulnerability of some of the most common benthic species along Denmark's west coast was assessed in connection with the EIA for Horns Rev III (Energinet, 2014). The benthic animals were assessed as generally not vulnerable to EMF or to temperature rises. Only common starfish (*Asteria rubens*) are registered as being medium sensitive to a temperature rise in the sediment. Common starfish, however, is a mobile surface-living species that is able to leave the affected area. The sensitivity of the benthic fauna in the investigated area in general is therefore assessed as low and the impact is, thus, assessed as *none to minor* for benthic animals regardless of location of the cable in the gross area for Thor OWF and in two the cable corridors, and regardless of use of one or two cable corridors

7. CUMULATIVE EFFECTS

Cumulative effects can be the result of cumulated impacts from the plan, i.e. construction of an offshore wind farm and grid connection in the gross area for Thor OWF within the planned period of establishment, compared with other contemporary known plans, programs or specific projects in the surrounding parts of the North Sea region.

Potential cumulative effects for benthic fauna and flora are mainly related to sediment spillage in the construction phase, which originate mainly from cable flushing and possibly establishment of foundations depending on method used. Sediment spillage in the water column causes increased suspended sediment concentrations in the water column and subsequent increased sediment deposition on the seabed and associated organisms.

The following projects are considered relevant in relation to the cumulative effects for benthic fauna (see Figure 7-1):

- Vesterhav Nord OWF
- Vesterhav Syd OWF
- Coastal nourishment and beach nourishment along the west coast of Denmark
- Resource extraction sites

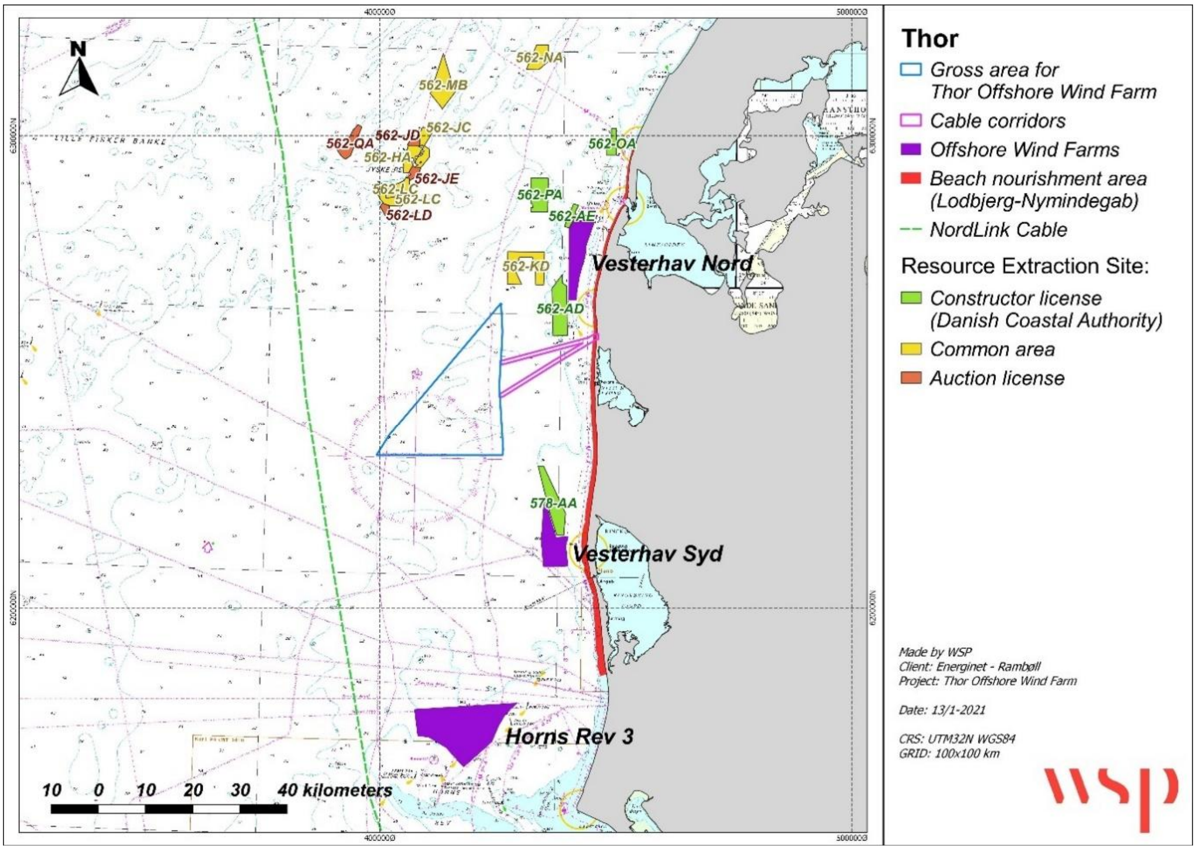


Figure 7-1. Overview of planned and operative projects in the surrounding part of the North Sea.

It is expected that construction of the Thor OWF can begin in 2024 and run until 2027. It is likely that the offshore wind farm can be put into operation at an ongoing basis from 2025 and be fully developed in 2027 (Rambøll, 2020b).

The offshore wind farms Vesterhav Nord and Vesterhav Syd are expected to be constructed during 2023 with full commissioning at the end of 2023 (Rambøll, 2020b).

Regarding coastal nourishment, there is a joint agreement for the Lodbjerg-Nymindegab section, where in the period 2020 – 2024, coastal protection can take place in the form of coastal nourishment in selected sections of the coast. The purpose is to ensure that the dunes on the west coast are ready to withstand erosion and associated dune breakthroughs during a 100-year storm event at the start of each winter season. Consequently, the dunes must have a certain minimum height and a minimum width (Rambøll, 2020b).

Along the west coast of Denmark a number of resource extraction sites are placed – primarily in regard to nourishment of the beaches for coastal protection. As part of specific EIAs for these raw material sites, there has been performed modelling of sediment spreading from the extraction activity. These models show that sediment spreading occurs within the resource extractions sites (including a 500 m protection zone). It is therefore assessed that the extraction sites and the construction of Thor OWF will have no cumulative impact on Benthic fauna and flora.

Specification of overlapping time periods (Rambøll, 2020b)**:**

- Based on schedules for the establishment of Thor OWF in relation to the Vesterhav Nord and Vesterhav Syd OWFs, no cumulative impacts are expected, as construction of Thor will not take place until 2024, after Vesterhav Nord and Vesterhav Syd OWFs are supposed to be fully commissioned.
- There can potentially be a cumulative effect in the form of sediment spillage from the construction of Thor and co-occurring sediment spillage from the coastal nourishment project along the west coast of Denmark, which takes place every year and is planned in the period (2020 - 2024). The area where the cables form Thor OWF is landed is one of the coastal sections for coastal feeding.

Results from sediment modelling at Vesterhav Nord and Syd OWFs show that increased suspended sediment and deposition from cable flushing and instalment of foundations are low and within the large natural variation in suspended sediment seen along the highly dynamic west coast of Denmark (Vattenfall, 2020a; Vattenfall, 2020b). The sediment spillage from Thor is expected to be comparable to that found in the Vesterhav Syd and Nord OWFs, which are located within 13-14 km of Thor OWF.

Coastal nourishment along sections of the coast is done within 0-8 meters depth and is expected to have potential cumulative effects only with cable flushing activities along one or both export cable corridors from the gross area for Thor OWF to landfall.

Sediment modelling from the EIA of coastal nourishment from Lodbjerg to Nymindegab (Rambøll, 2020a), for a normal and extreme nourishment scenario also shows increased suspended sediment and sedimentation generally within the large natural variation along the very dynamic shore. The benthic fauna community along the section Lodbjerg - Nymindegab is dominated by a few species with a relatively high individual abundance, while the rest of the species were relatively few. However, the species found are generally robust species that survive in highly wave-exposed habitats, which are characterized by unstable areas with strong currents, mobile sediment and high levels of suspended sediment. The impact of increased suspended sediment and sedimentation from the Shore nourishment project is assessed as insignificant (which is lower than minor) for benthic fauna and flora.

Since the increase in suspended sediment is likely within the natural variation in the gross area for Thor OWF and one or two cable corridors, and since the same is the case for the shore nourishment project, the cumulated effects from these two projects are also expected to be none to maximally *minor impacts*.

8. NATURA 2000

The project occupies or crosses no Natura 2000 sites directly, but one Natura 2000 site is located approximately 300 m south of the southern cable corridor (R3) and 13 km east of the gross area for Thor OWF: Natura 2000 site no. 220 (DK00VA341) *Sandbanker ud for Thorsminde* – designated for 1110 Sandbanks. Local Natura 2000 sites are shown in Figure 4-1.

Natura 2000 area no. 247 (DK00VA348) *Thyborøn Stenvolde* is located approximately 12 km north of the gross area for Thor OWF designated for the habitat type 1170 reefs. All other Natura 2000 sites are more than 21 km away from the gross area for Thor OWF and cable corridors and designated for the habitat type 1170 stone reef. Bird protection areas (SPAs) under the Bird directive are not present (see Figure 4-1).

The planned Thor OWF can potentially impact only the closest Natura 2000 site via sediment spillage and related increases in sediment concentration and sedimentation. However, sediment modelling in the nearby Vesterhav Syd and Nord OWF showed sediment spillage resulting in increased sediment concentrations, which were within the natural variation in this dynamic area off the west cost of Denmark. Significant impacts of sediment spillage are therefore not expected from the current existing knowledge from the area.

9. MITIGATION MEASURES

No mitigation measures are necessary since no significant impacts are expected from the project plan of Thor Offshore Wind Farm on benthic fauna and flora.

10. KNOWLEDGE GAPS

Existing data in combination with the comprehensive field sampling of both geophysical and biological parameters in the gross area for Thor Offshore Wind Farm and the two cable corridors ensures a solid and sufficient base for the baseline mapping and the environmental assessment of benthic fauna and flora.

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