

BOOSTING STONY REEFS IN BORKUM STONES

*A NATURE-INCLUSIVE APPROACH FOR
SCOUR PROTECTION*



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**BOOSTING STONY REEFS IN BORKUM STONES:
A NATURE-INCLUSIVE APPROACH FOR SCOUR PROTECTION**

Minor Project Report

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Abstract

This report evaluates the potential for enhancing nature inclusivity within the GEMS project, in alignment with ONE-Dyas' commitment to positive regional impact. The focus is on developing nature-inclusive designs for scour protection around the platform, drawing inspiration from the habitat commonly present in Borkum Stones. The proposed designs aim to replicate the natural stony reef formations and enhance connectivity with surrounding hard substrates to support habitat development, biodiversity, and ecosystem resilience.

Extensive surveys over the past five years by various organizations, including GEOxyz and MarineSpace commissioned by ONE-Dyas, have mapped the Borkum Stones area in detail. This region, with its rich history of rocky reefs and oyster beds, once supported rich marine habitats that have since diminished due to anthropogenic impacts. The historical records of these reefs underscore the ecological importance of reinvesting in similar habitats, as restoring these features could help reestablish critical marine ecosystems and support a diverse array of marine life. The presence of significant hard substrates, such as large boulders and biogenic reefs formed by the sand mason worm *Lanice conchilega*, further highlights the area's potential for ecological restoration.

The proposed designs seek to enhance connectivity between the scour protection and adjacent boulder clusters, addressing potential ecological impacts and future decommissioning effects. The integration of the proposed nature inclusive designs could facilitate hard substrate expansion and enhance local connectivity. This potentially benefits reef-typical species, supporting higher richness, diversity and abundance. By focusing on the expansion and connectivity, the design also considers future decommissioning, aiming to maintain habitat integrity after the completion of the production phase.

The report suggests using 2"-8" granite rocks for their efficiency and suitability in establishing rocky reef communities. The design proposals include improvement of the scour protection around the legs of the platform and two possible trajectories toward nearby boulder clusters. By enlarging the local rock dump and creating a transition zone, leading to higher habitat complexity and diversity, the area will attract a higher variety of species. The trajectories toward boulder clusters will further enlarge hard substrate surface and enhance connectivity between different hard substrate areas.

However, successful implementation requires addressing several uncertainties: confirmation of rock dumping methods, optimal rock coverage balancing efficiency with habitat development, and the need for further investigation into potential ecological impacts in the trajectories towards boulder clusters. Additionally, the current data gaps regarding the presence of smaller cobbles, gravel beds, and *Lanice conchilega* fields highlight the need for further surveys and analysis.

In conclusion, while the nature-inclusive designs present significant potential for ecological enhancement within the GEMS project, further research and monitoring are necessary to refine the implementation strategies and ensure alignment with the Borkum Stones habitat.

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Abbreviations

Abbreviation	Meaning
BfN	Bundesamt für Naturschutz – the German Federal Agency for Nature Conservation
BOD	Basis Of Design
BRUV	Baited Remote Underwater Video
DCP	Dutch Continental Plat
DDC	Drop Down Camera
DVV	Dual Van Veen Grab
eDNA	Environmental DNA
GCP	German Continental Plat
GEMS	Gateway to the Ems
H1170	“Reef”, a specific habitat with code 1170, based on the Habitats Directive
HSM	Hollandsche Staalbouw Maatschappij
MBES	Multibeam Echo Sounder
MER	Milieu Effect Rapportage; Environmental Impact Analysis
NID	Nature Inclusive Design
NNMI	Normally Not Manned Installation
OWZ	Offshore Wind Zone
ROV	Remotely Operated Vehicle
SSS	Side Scan Sonar
UNESCO	United Nations Educational, Scientific and Cultural Organization
VVG	Van Veen Grab
WWF	World Wide Fund for Nature

Introduction

Over the past few decades, the once biodiverse, fruitful North Sea has seen some drastic changes in biodiversity, population densities, and a decline in overall health. Ecosystems are under extreme pressure due to factors such as exploitation, pollution, overfishing, climate change, and the introduction of invasive species (European Marine Board, 2013; Selim et al., 2016; Van Der Veer et al., 2015). As a result, entire populations are vanishing from the North Sea (Lindeboom, 1995). Examples are the disappearance of large oyster banks, shifts in plankton communities, and declining fish populations (Lindeboom, 1995; Olsen, 1883; Peperzak, 2005). Next to the almost complete extirpation of herring, severe depletion has also been observed for species like mackerel and cod (Lindeboom, 1995). Furthermore, large predators that used to be common in the North Sea, like the thornback ray and spurdog, almost completely vanished from the region (Heessen, 2010). Besides the negative impact overfishing has on fish stock, the fishing techniques used greatly impact sea life. For example, the intensified bottom trawling and dredging activities have resulted in irreversible changes to the seabed and the benthic community (Bremner et al., 2003; Clare et al., 2015).

Simultaneously, the North Sea has seen an increase in energy extraction activities. As the world is in the midst of an energy transition, opportunities for green energy sources as well as local extraction of fossil fuels are being explored. Though it is important to invest in renewable energy sources to promote the energy transition, the demand for fossil fuels cannot be ignored. The fact remains that about 85% of the current energy supply in the Netherlands comes from fossil fuels (CBS, 2023). This is also acknowledged by the Dutch Government, which states that natural gas will continue to play an important role (CBS, 2017; Ministry of Economic Affairs of the Netherlands, 2016; ONE-Dyas, 2024; Wiebes, 2018). Over the recent decades, the Netherlands has explored both land and sea to find suitable areas for wind farming and gas extraction. Both these developments further impact the marine ecosystem. Examples of such impacts are damage to the seabed during construction, the introduction of foreign materials and maintenance activities around these structures. This results in an alteration of the local habitats and shifts in the local ecosystem (European Marine Board, 2013; Selim et al., 2016).

On the other hand, these offshore projects offer new opportunities for marine life. For example, the wind farms and oil platforms will create 'safe havens' as the surrounding area will be closed-off for fishing activities. Next to that, offshore installations increase the presence of hard substrates in the region. Lastly, they provide room for (more) regenerative interventions and nature restoration projects. This has led to a boost in research- and restoration projects and a growing interest in nature inclusive innovations. For instance, the possibilities of oyster restoration programs within offshore windfarms are being explored (Bos et al., 2023; Bureau Waardenburg, 2021, 2022; De Rijke Noordzee, 2022). Additionally, several organizations executed monitoring expeditions to study the benthic development on offshore foundations and their scour protection (Bos et al., 2023; Bouma & Lengkeek, 2009, 2013; Coolen et al., 2022; Kingma et al., 2023). The Dutch oil and gas company ONE-Dyas has also expressed their interests in sustainable and regenerative initiatives for their new offshore project 'GEMS'. For example, the company is committed to reducing their carbon emissions by connecting their gas platform to a

nearby windfarm. This makes it the first offshore platform to fully operate on wind energy (ONE-Dyas, n.d.). Furthermore, ONE-Dyas is exploring the possibilities to minimize environmental impact and the opportunities to enhance marine life (ONE-Dyas, n.d.)

The GEMS project is located in Borkum Stones, an ecologically valuable region north of the Wadden Sea. The area covers part of the Dutch and German continental shelf and is surrounded by multiple protected areas, including Natura 2000 and UNESCO sites and the WWF Oyster Pilot. In addition, studies have shown presence of biogenic reefs created by the sand mason worm, *Lanice conchilega*, as well as permanent flooded sandbanks and reefs. Furthermore, it is believed that the Borkum Stones are part of the area that used to contain large oyster beds (Olsen, 1883; Sander et al., 2021). Additional evidence of oyster grounds in this region is provided by fishery data, as reviewed by Berghahn & Ruth (2005). Next to the biogenic reefs, the area is partly covered with stony reef habitat. These stony reefs have advantages over sandy bottom habitats, as they increase surface complexity, create shelter and nursery areas, and provide hard substrates to settle on (Coolen, 2017). It is believed that parts of the stony reefs, have vanished over time due to various disturbances, including human activities such as overfishing (Álvarez et al., 2019; Coolen, 2017; Van Duren et al., 2017).

Altogether, Borkum Stones offers an interesting site for nature restoration and conservation. Incorporating this in the GEMS project reveals great opportunities for ONE-Dyas to reach their personal objectives and create a more restorative GEMS project. For this, the “RE-GEMS” project was established in collaboration with BlueLinked. The RE-GEMS project will focus on three opportunities within GEMS, namely the reintroduction of the oyster, monitoring of *Lanice conchilega*, and boosting stony reef habitats. This paper will concentrate exclusively on leveraging this third opportunity, with the primary objective of integrating a Nature-Inclusive Design (NID) for the scour protection rock dumps. In this project, the scour protection surrounding the N05-A platform is considered a prime candidate for integrating this NID, given its proximity to hard substrate areas and the 500m safety zone. The design aims to mimic the natural stony reef formations found in the Borkum Stones area, thereby enhancing connectivity with nearby hard substrate habitats and attracting species that thrive in such environments. This approach supports habitat development, increased biodiversity, and ecosystem resilience. Additionally, the design will utilize materials readily available within the GEMS project to minimize costs and efforts, aiming for a high-yield, low-input outcome.

The goal of this paper is to develop a nature-inclusive design proposal for the platform scour protection, starting with the basis of design (BOD). The BOD will include a description of the GEMS project, details on the platform and scour protection, and some background information on the Borkum Stones. The second chapter will discuss natural stony reef definitions and criteria, previous NIDs, and relevant biological models. These benchmarks will help identify key criteria for the NID. The third chapter will focus on the actual design. This will include a few possible scenarios, describing the most suitable options for a more nature inclusive rock dump. This chapter will also discuss any challenges, uncertainties, and considerations for the NID. For example, the effects of decommissioning. Lastly, Chapter 4 will contain a long-term monitoring proposal that will support the validation of the NID in the future.

1. Basis of Design

To develop a suitable nature-inclusive scour protection design, a basis of design needs to be established. In this case, the basis of design includes all information on the platform and the surrounding area. First, a general description of the GEMS project will be given, followed by technical and practical details of the platform. Next, the geographical, environmental, and hydrodynamical conditions of the area will be included in the general description of Borkum Stones. Lastly, special attention will be devoted to the surveys conducted in Borkum Stones and the valuable lessons that can be derived from them.

1.1 The GEMS project and activities

1.1.1 Project description

GEMS, which stands for ‘Gateway to the Ems’, is a project situated at the mouth of the Ems estuary. Currently, the project is focused on the N05-A field, located in the North Sea on the border between the Netherlands and Germany (Figure 1). The GEMS project includes a production platform, a power cable route, and a gas pipeline (ONE-Dyas, 2020a). The 8.7km long cable route will connect the platform to the German Windfarm Riffgat, located about 5km East of the platform (Figure 2) (ONE-Dyas, 2020a; Schubert et al., 2023). This will allow the platform to operate fully on wind-generated electricity. Scour protection will be installed where the cable route crosses the Powercable Nordnet. To transport the treated natural gas, a 14.7km pipeline will be installed to connect the platform to NGT's existing natural gas pipeline (ONE-Dyas, 2020a). The new pipeline will cross two power cables, Buitengaats and Zee-energie, that connect offshore windfarm Gemini to the Eemshaven. The two crossings will be combined into one larger crossing area that also includes a scour protection rock dump.

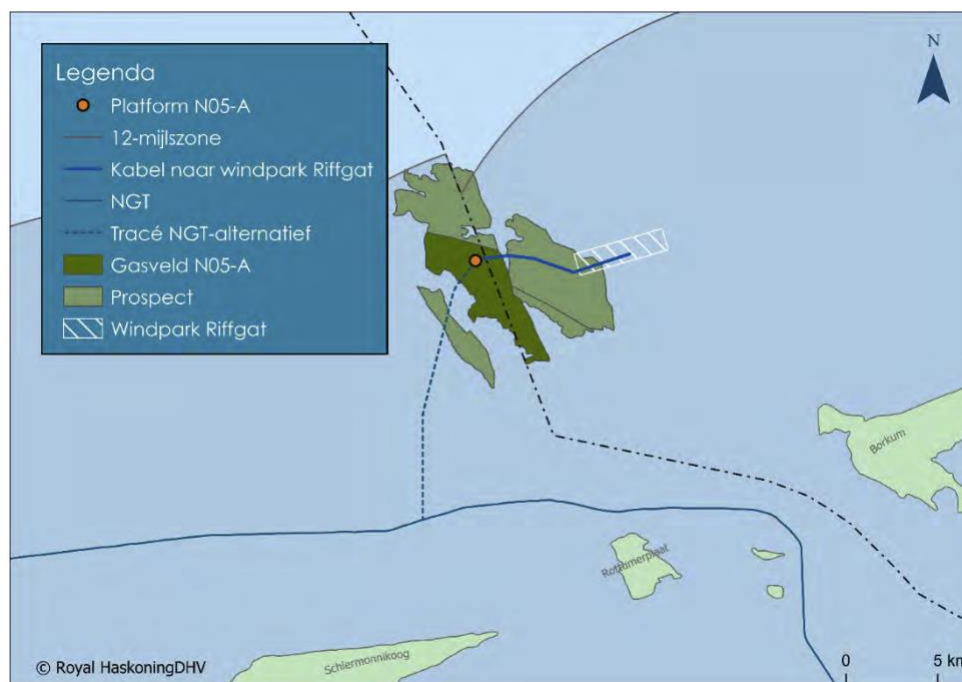


Figure 1. Map of the GEMS area including the N05-A platform location, gas fields and prospects, pipelines and cable routes. Retrieved from Royal HaskoningDHV (2020a).

1.1.2 Environmental impact

Connecting the platform to the wind farm is part of the GEMS objective to reduce environmental impact. Next to this, ONE-Dyas has incorporated new techniques and systems to support green hydrogen production and CO₂ capture and storage in the future. They have also executed a thorough environmental impact analysis, to measure the projects' influence on the surrounding marine environment.

According to ONE-Dyas' environmental impact analysis (MER), no negative impact is expected during the drilling and production phase or the transport phase (Royal HaskoningDHV, 2020a, 2021). This is because there will be no discharge of drill cuttings, and the effects of production or transport are expected to be minimal. Nevertheless, the construction and decommissioning phases are expected to cause disturbances and negatively impact the environment. During construction, it is estimated that an area of 32.8 hectares will be disturbed (Royal HaskoningDHV, 2020a). Construction activities include the installation of the platform, the pipeline, and drilling activities (ONE-Dyas, 2020b). This is without the sediment discharge of the drill cuttings, as these cuttings will be transported to shore (Royal HaskoningDHV, 2020a, 2021). The effects of decommissioning are so far in the future that they have not yet been assessed (ONE-Dyas, 2020b).

1.2 Platform N05-A

1.2.1 General details of the platform

The construction of the N05-A offshore platform started in 2022 at HSM Offshore Energy in Schiedam. The platform will be installed on the Dutch Continental Plat (DCP) about 20km off the coast from Schiermonnikoog and 1.5km from the German border (Offshore Technology, 2021; Royal HaskoningDHV, 2020c). From this location, up to twelve wells will be drilled to reach the surrounding gas reserves. The platform will include an area that will be designed as a permanent manned installation. However, the platform will operate as a Normally Not Manned Installation (NNMI) (HSM Offshore Energy, n.d.).



Figure 2. Visualization of the GEMS project showing the N05-A platform location and Riffgat Windfarm including the pipeline and cable route. Retrieved from HSM Offshore Energy (n.d.).



Figure 3. Visualization of the N05-A platform. Retrieved from Royal HaskoningDHV (2020b)

1.2.2 Technical details platform

The platform features a topside, a skirt pile jacket, and 10 well slots; 8 for production and 2 spare slots (see Figure 3). The production capacity is 6 MNm³/day, including an allowance for an additional 2.5 MNm³/day (HSM Offshore Energy, n.d.). The dimensions of the platform will be about 61.5m by 34m (see Figure 4). The structure is 15m in height and includes 2 main levels and a helicopter platform (HSM Offshore Energy, n.d.). The steel support structure is a 40m by 20m, 6-legged jacket that sits on the ocean floor (HSM Offshore Energy, n.d.). The piles have a leg spacing of 17mx34m (see Figure 4 and Figure 5) (ONE-Dyas, 2020a).

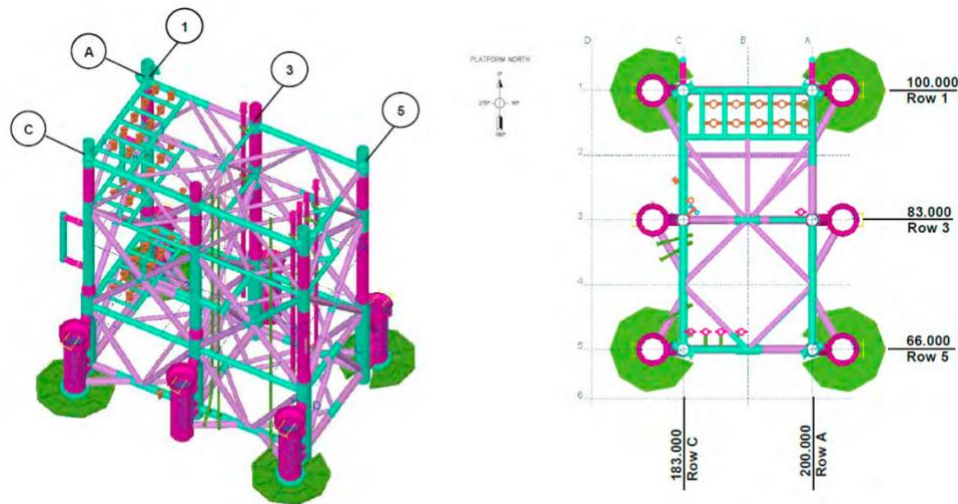


Figure 4. Technical drawing the N05-A platform. The pink and turquoise structures represent the skirt construction, the green parts are the mud mats. Adapted from ONE-Dyas (2020a).

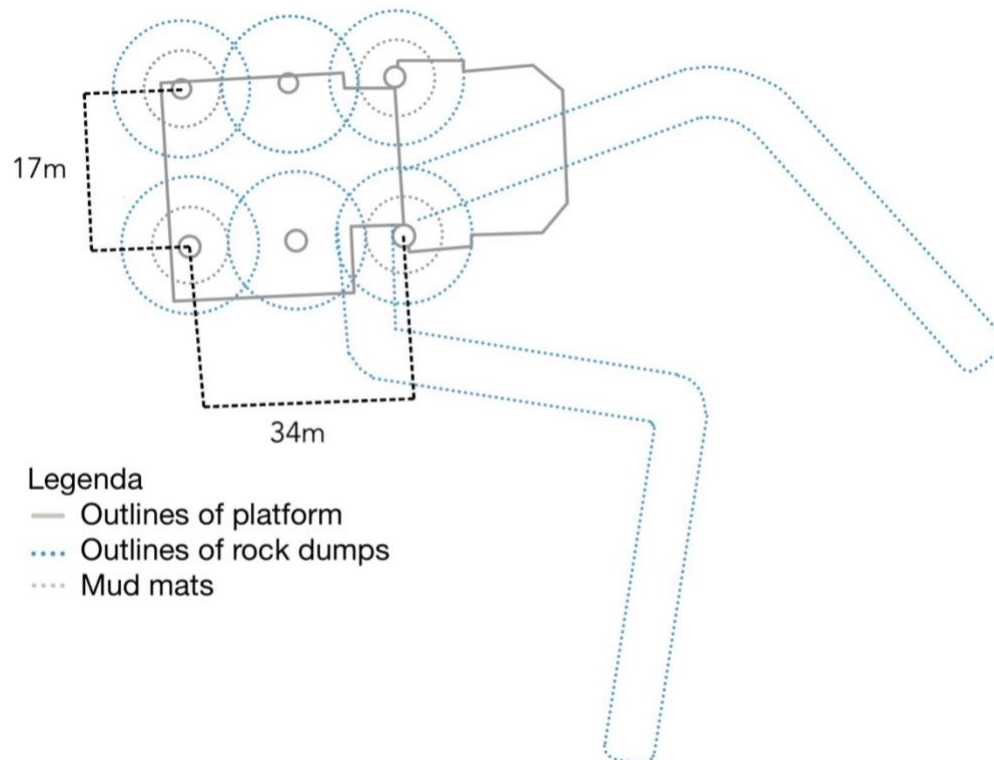


Figure 5. Illustration of the N05-A platform and the scour protection, including the pipeline and cable. Based on "N05A-7-50-0-72051-01" (n.d.) (see Appendix B)

1.2.3 Technical details scour protection

The platform pile foundations are susceptible to scouring of the surrounding soil, threatening safe operation. Placing a layer of rocks on the seafloor around the legs prevents the sand from scouring. This layer of rocks is referred to as scour protection. In the North Sea, scour protections often consist of two layers: (1) the filter layer and (2) the armor layer (Emmanouil et al., 2023; Tangaroa Consult & N-Sea, 2023). Sometimes a third, sprinkle layer is added on top of the armor layer (Tangaroa Consult & N-Sea, 2023).

The platform will have about 9m of rock dump extending from the legs, reaching a diameter of 21.6m hard substrate in total (see Figure 6) (Tangaroa Consult & N-Sea, 2023). The hard surface area around each pile is about 366m². Around the four outer piles, a mud mat is included in the construction, covering a part of the seafloor as well (ONE-Dyas, 2020a). The scour protection will be applied around the edges of the mud mats. As the scour protection around the piles are close to each other and the rocks will be dumped in a scattered and loosely organized manner, there will be overlap between the rock dumps. This results in a large rock cluster covering an area of about 2000m². The scour protection rises to about 1.6m above the seafloor, with 1.3m of 1-3" rocks and 0.3m of 2-8" rocks on top (Tangaroa Consult & N-Sea, 2023). The total volume of rocks needed is 1500m³ for the filter layer (1"-3") and 600m³ for the armor layer (2"-8") (see Table 1). The slope between the seafloor and the maximum height of the scour protection will cover about 4.56m. Based on these estimations, the slope will be about 19° degrees. This slope is considered quite steep, and it covers the seabed completely, leaving no room for a mosaic including soft-sediment patches.

Table 1. Scour protection volumes on the legs of the platform (without sprinkle layer) and the pipeline and cable exits.

ROCK DUMP VOLUME			
	LAYER 1 (1"-3")	LAYER 2 (2"-8")	LAYER 3 (1"-3")
LEGS	1500 m3	600 m3	-
PIPELINE	650 m3	375 m3	225 m3
CABLE	300 m3	250 m3	150 m3

Table adapted from "N05A-7-50-0-72051-01" (n.d.) and "N05A-7-50-0-72051-03 (n.d.). (see Figure D2 in Appendix D)

Additional scour protection will be added to the outgoing pipeline and power cable as well. Based on the technical drawings, the total length of the pipeline rock dump will be about 128m and the power cable rock dump is an estimated 100m ("N05A-7-50-0-72051-01", n.d., see Figure D1 in Appendix D). The rock dumps are 11m and 9m in width and rise to 1.51m and 1.16m above the seafloor. The total volume of rocks needed is 1325m³ for the filter layer (1"-3") and 625m³ for the armor layer (2"-8") (see Table 1).

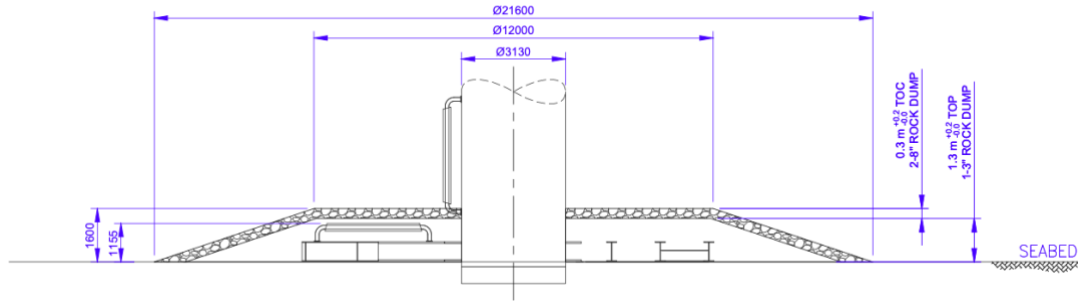


Figure 6. Visualization of the scour protection rock dump around a pile of the platform without a mud mat. Retrieved from “N05A-7-50-0-72051-03” (n.d.) (see Figure D2 in Appendix D).

To further protect the platform, there will be a 500m safety zone around the platform. This will be 500m measured from each point of the outer edge of the offshore platform in accordance with international law (Kruidhof, 2023).

The rock dump will likely be installed using a fallpipe vessel. Often, a remotely operated vehicle (ROV) is used to help bring the fallpipe into position (Emmanouil et al., 2023). With the ROV, accurate rock installation is possible (Emmanouil et al., 2023). However, according to colleagues from HSM, due to the inherent difficulty in achieving precise placement, the rocks will be dumped in a scattered and loosely organized manner. This means rock dumping around the platform will be less specific compared to the technical design proposals.

1.3 Borkum Stones

Over the past five years, the GEMS area has been surveyed quite extensively by multiple surveying companies. The area around the N05-A platform, the pipeline connection to the NGT, and multiple different possible cable routes to the Riffgat Windfarm were included in the surveys commissioned by ONE-Dyas. Both surveys included highly detailed sediment classifications and habitat assessments (GEOxyz, 2019b; MarineSpace Ltd, 2022b). Other surveys and expeditions within the region have been performed as well, for example by Oceana (Álvarez et al., 2019), WUR (Bos et al., 2014; Bos & Paijmans, 2012; Coolen, 2017; Witbaard et al., 2008) and BioConsult (Bildstein et al., 2023; Schubert et al., 2023).

1.3.1 Introduction to Borkum Stones

The GEMS project is located within Borkum Stones, a relatively shallow area within the North Sea, stretching across the Dutch-German border (see Figure 7). It's surrounded by several Natura 2000 areas, such as the North Sea Coastal zone of the Netherlands and the German Borkum Riff, a bird-directive habitat closer to the German coast (Álvarez et al., 2019). Another area close to Borkum Stones is the Wadden Sea area, comprising of a Dutch and German part, also classified as Natura 2000 area and part of the World Heritage UNESCO list (Álvarez et al., 2019). Lastly, there is a WWF oyster restoration project situated north of the N05-A platform (Didden et al., 2020).

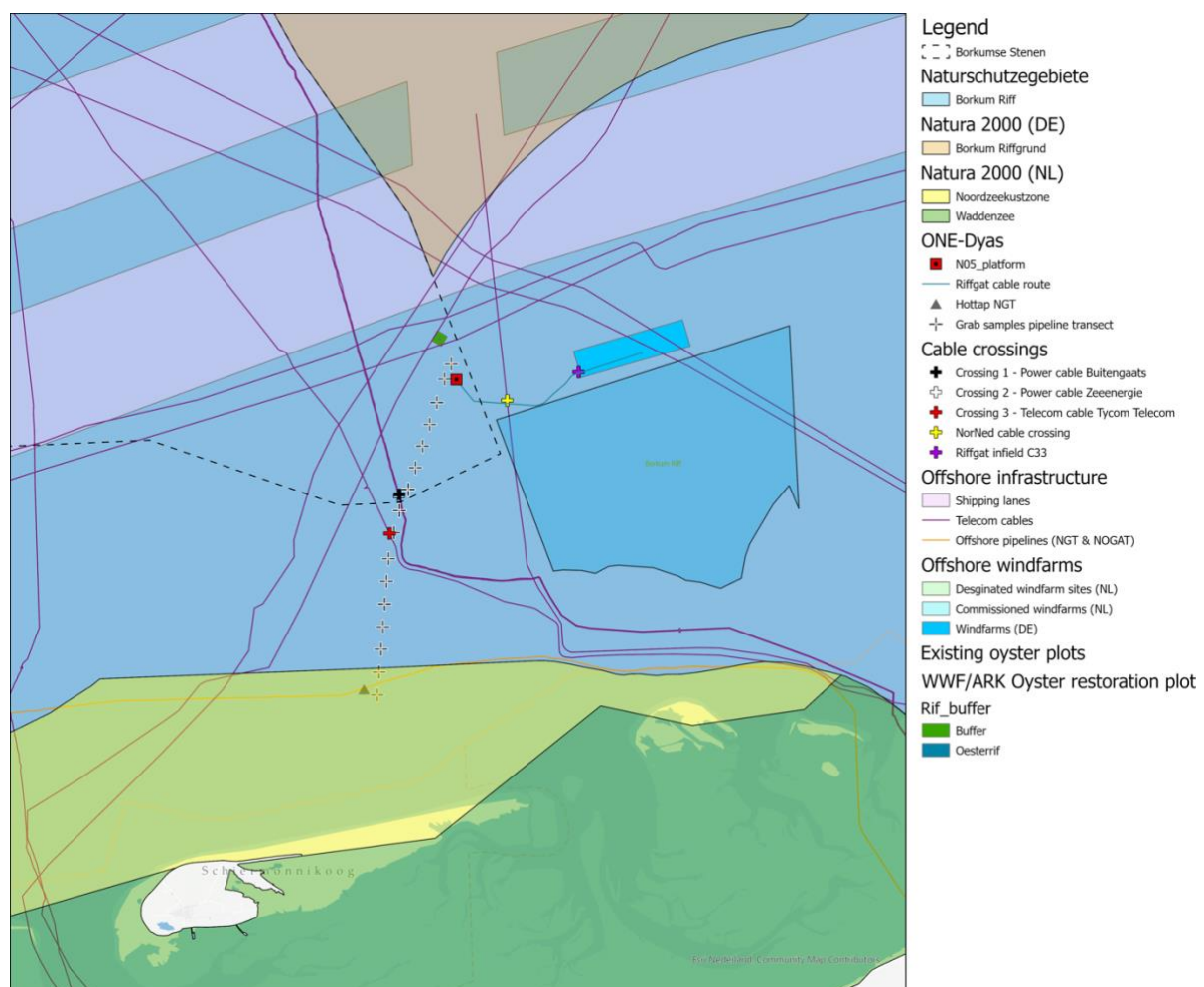


Figure 7. The GEMS area and nearby zones, designated for specific purposes. Large shipping lanes are shown, as well as sand-winning fields, windfarms, protected Natura2000 areas, and the WWF oyster restoration.

Within the southern North Sea, Borkum Stones is among the areas with the highest biodiversity and ecological values (Lindeboom et al., 2005), and is considered one of the few remaining natural geogenic reef areas (Álvarez et al., 2019). Consequently, the German side of Borkum Stones (Borkum Riffgrund in German) has already been classified as a Natura 2000 area. This is because this area contains sandbanks (H1110) and reefs (H1170), which are both listed under Annex I of the EU Habitats Directive (2013). Due to its geographical location and diverse habitat types, the Dutch Borkum Stones has also been designated as a potentially protected area. Up to this day, the southern part of Borkum Stones has been exposed to high-intensity bottom trawling fishing, targeting benthic species (see Figure 8) (Ovens, 2016). These fishing techniques are known to disrupt the seabed and the benthic ecosystems, as they destroy habitats and increase mortality. Unlike the German side, where bottom trawling is forbidden, the Dutch part of Borkum Stones is not protected yet. But, as the Dutch Borkum Stones is included in the Marine Strategy 2022-2027, the area will likely be included in the list of marine protected areas and seabed-disturbing activities such as bottom trawling will be prohibited (Rijksoverheid, 2022b, 2022a).

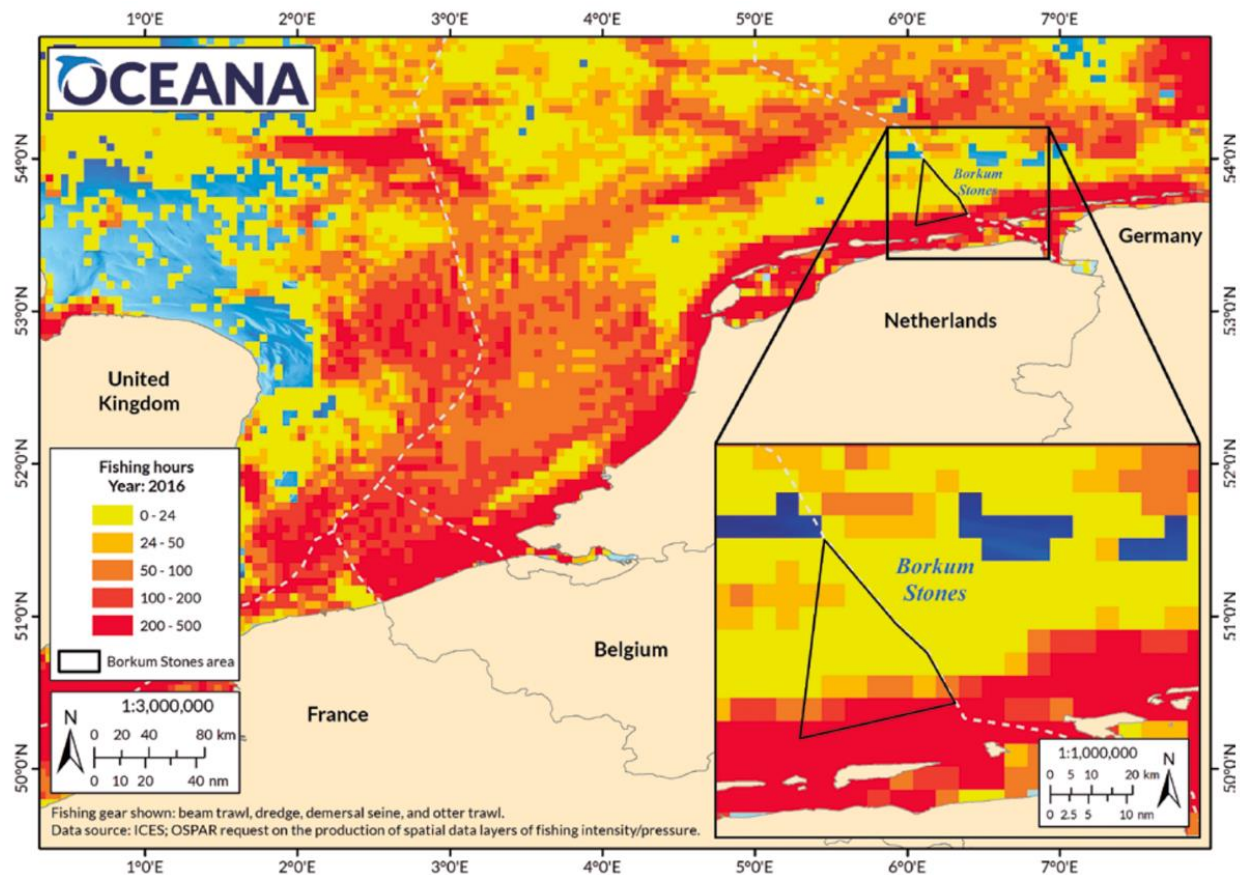


Figure 8. Total fishing hours in the Dutch North Sea in 2016. Retrieved from Álvarez et al. (2019).

1.3.2 Geographical conditions

The Borkum Stones is a shallow region located in the southern North Sea, encompassing approximately 653 km² on the Dutch side and 625 km² in German waters (Álvarez et al., 2019; Kruidhof, 2023). The area is situated near the Dutch Wadden Islands and Borkum Island in Germany and varies in minimal depth: starting from 8 meters (Dutch waters) or 18 meters

(German waters), with a maximum depth reaching 33 meters (Álvarez et al., 2019). The average depth around the GEMS project lies between 20 and 33 m (Royal HaskoningDHV, 2022).

The seabed of the Borkum Stones is heterogeneous, featuring a mix of substrates and seabed characteristics shaped by glacial deposits (Álvarez et al., 2019). As the current North Sea bed is predominantly composed of sand and mud, the presence of hard substrates holds ecological significance for this area (Álvarez et al., 2019). Where hard substrates used to cover large areas of the North Sea in the past, many have been removed over time by anthropogenic interventions (Álvarez et al., 2019; Bildstein et al., 2023; Coolen, 2017; Witbaard et al., 2008). As a result, the Borkum Stones, together with the Cleaver Bank, are the only remaining hard substrate areas in the Dutch North Sea (Álvarez et al., 2019).

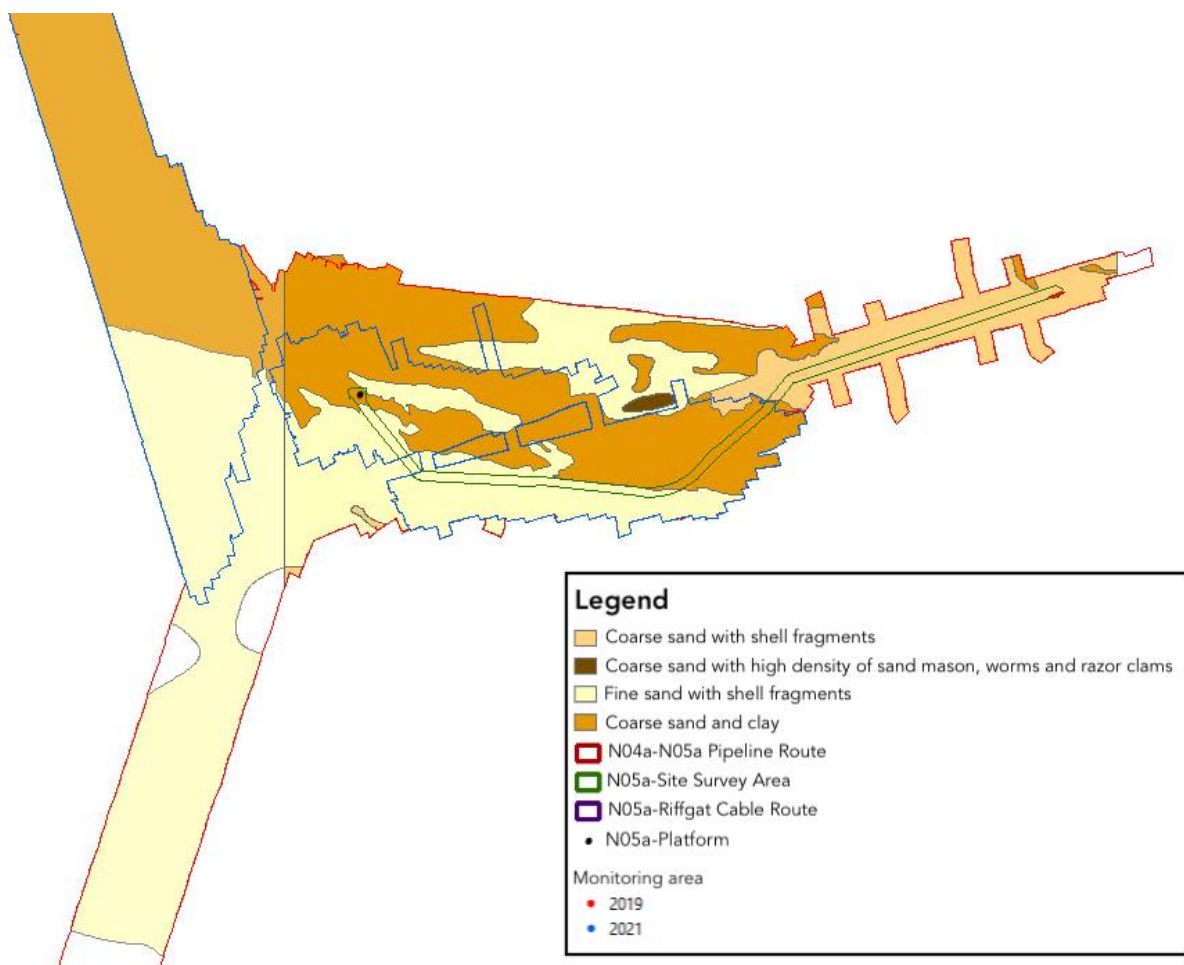


Figure 9. Sediment mapping of part of the GEMS project, including the area around the platform, parts of the pipeline routes (to NGT and to N04a) and the cable route to the windfarm (located on the right side).

1.3.3 Biogenic and geogenic substrates

As already mentioned, Borkum Stones contains areas with mixed hard substrates, such as rocks and cobbles, as well as sandy and gravelly substrates. Higher coverage of these hard substrates gives rise to stony reef habitats. Based on the geological evolution of the North Sea, the glacial deposits coming from Northern Europe have given shape to the seabed and the stony reef habitats found in the German and Dutch waters (Houziaux et al., 2011; Laban, 1999; Schwarzer et al., 2019). These glacial erratic boulders include granite and limestones, mainly from glacial deposits of the Saale glaciation during the Pleistocene period (Jak et al., 2009; Schwarzer et al.,

2019; Schwarzer & Diesing, 2006). Depending on rock coverage and reef size, stony areas can be classified as H1170 habitat and gain a protective status (Habitats Directive, 2013; Natura 2000, 2014). The Dutch side of the Borkum Stones has not received any classification or habitat type affirmation thus far, this will be discussed further in Chapter 2. Stony reefs are very diverse habitats and can support higher biodiversity compared to nearby sandy bottom regions, making them a valuable part of the Borkum Stones (Álvarez et al., 2019; Coolen, 2017). Various marine creatures, including fish, anemones, sponges, and crabs, find refuge and suitable living conditions amidst the larger rocks and gravel.

Additionally, Borkum Stones houses biogenic reefs created by the sand mason worm, *Lanice conchilega*. By creating tubular structures ensconced with shells and sand, these biogenic reefs provide a fertile substrate that fosters a remarkable diversity of species (Álvarez et al., 2019; Coolen et al., 2015; Rabaut et al., 2007). Dense *Lanice conchilega* reefs are characterized by a population density exceeding 1500 individuals per m² (Coolen et al., 2015). Together, they encompass a substantial 74km² in the southern region of the Dutch Borkum Stones (Coolen et al., 2015). Because of the variety in soft and hard substrates, *L. conchilega* supports sediment burrowing species as well as species that require hard substrates (Álvarez et al., 2019; Coolen et al., 2015; Rabaut et al., 2007). The biota present in these biogenic reefs can even exceed the biodiversity of rocky reefs (Coolen et al., 2015; Rabaut et al., 2007). Additionally, *L. conchilega* reefs serve as a corridor for species that are challenged to travel across extensive sandy sediments (Rabaut et al., 2007). Their steppingstone function could also contribute to higher success rates in reef restoration and reintroduction projects (Coolen et al., 2015). The biogenic reefs are not part of the H1170 definition within the Netherlands, but their presence will be considered in the design part of this research.

The GEMS area

In the surveys commissioned by ONE-Dyas, it was found that the project lies close to densely populated *L. conchilega* areas as well as large boulders (see Figure 9)(GEOxyz, 2019b; MarineSpace Ltd, 2022b). During both surveys, side scan sonar (SSS) and multibeam echosounder (MBES) were used to collect information on the seabed. Presence of *L. conchilega* was detected by means of high reflectivity and boulders of >0,3m could be mapped based on reflectivity and shadows in the SSS data, revealing low- and high-density boulder areas. Due to the high concentration of boulders and dense sand mason worm aggregations around and north of the proposed N05-A location, the platform was relocated to a sand dominated area, about 300m to the east and 800m to the south. Large boulders were also found along the cable route to the Riffgat Windfarm, often within areas also containing pebbles and cobbles.

Similar findings have been reported by other studies, identifying hard substrate areas such as boulders and biogenic reefs (Bildstein et al., 2023; Bos et al., 2014; Schubert et al., 2023). These studies used similar approaches, collecting data from sonar scans in combination with ground truthing. Bos et al. (2014) discovered both hard substrates (H1170) and *Lanice conchilega* in the Dutch Borkum Stones. This finding partially confirmed earlier assumptions made by Bos and Pajmans (2012) regarding the presence of hard substrates. For instance, after comparing data with the 2019 and 2021 surveys, Bildstein et al. (2023) detected several additional boulders within the GEMS project area. Additional diving expeditions further acknowledged three boulder fields around the N05-A platform and cable route (Schubert et al., 2023).

The large hard substrate areas showing higher reflection on the SSS data were often additionally surveyed using video recordings and stills. In the 2019 survey, Grab_C3_2 is mentioned as potential stony reef, as it showed a high proportion of boulders and cobbles (see Appendix B) (GEOxyz, 2019b). This was followed by a stony reef assessment based on the additional footage, determining coverage and density of rocks and cobbles. Due to insufficient cover and elevation, the area was not considered a potential stony habitat, but was later classified as a high-density *L. conchilega* patch (see Figure 9, dark brown area) (GEOxyz, 2019b). Several high reflectivity areas revealed additional dense *L. conchilega* areas in the northern part of the GEMS project after ground truthing the SSS data (GEOxyz, 2019b). The MarineSpace Ltd (2022a, 2022b) survey also performed additional video transects for high reflectivity areas, recording stony patches and associated epifaunal species at several stations (ENV_20, 28-30, 33-34, 36-37, 39, 41, 43-44; see Appendix C). No additional surveying was performed for the highly dense *L. conchilega* patches in 2021 (MarineSpace Ltd, 2022b).

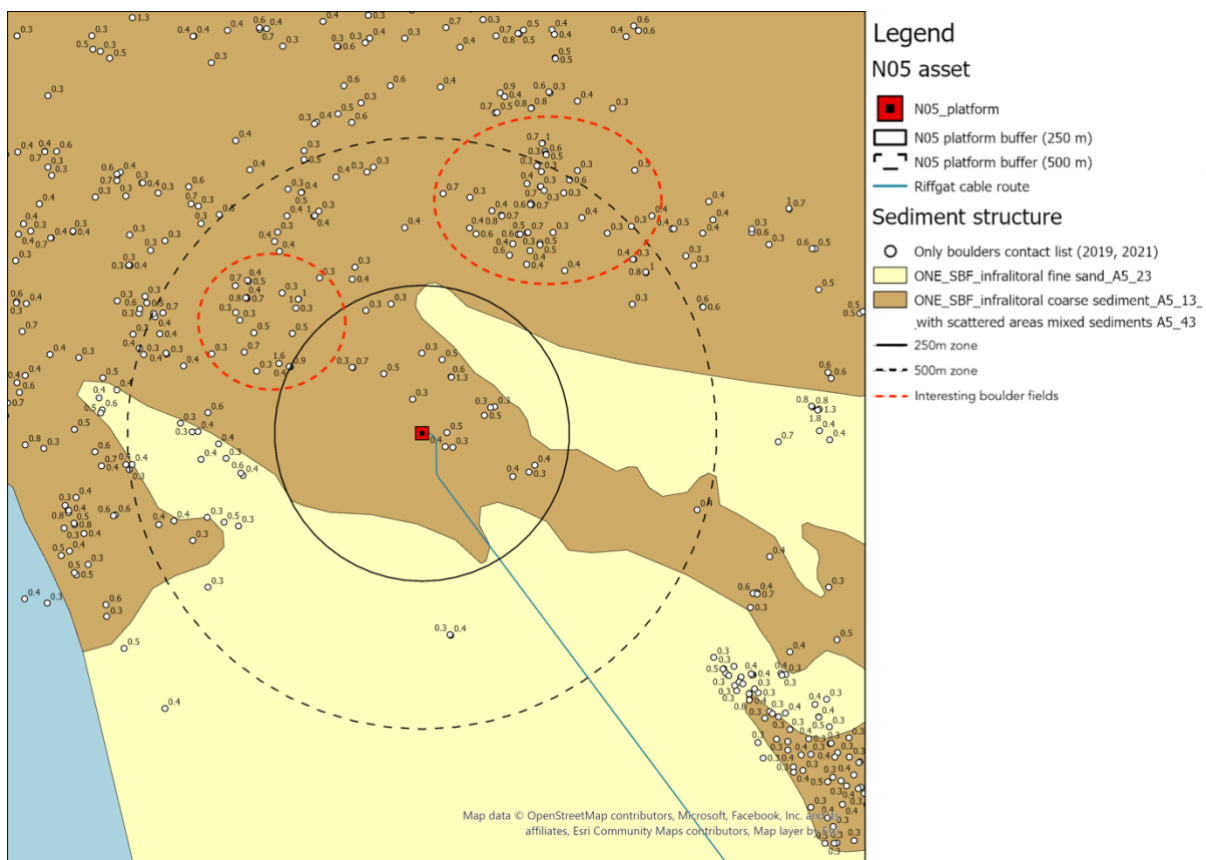


Figure 10. Mapping of sediment and boulders and magnetic anomalies within the N05-A platform area. A 250m radius and 500m radius around the platform illustrate the connectedness to boulders within the area. Additional red circles are added to interesting boulder areas, for expansion and connection to potential H1170 reefs.

The area around the platform

In the northern part of the GEMS project, including the platform area, multiple studies have confirmed presence of large boulders (>0.3m). Several boulders can be found near the platform, and within a 500-meter radius, there are some potentially interesting boulder fields (see Figure 10). It can be assumed that areas with several large boulders (>0.3m) likely contain smaller boulders and cobbles as well. However, these have not been mapped in detail. Based on grab sampling, cobbles only showed up in Grab P_1 (see Appendix B) (GEOxyz, 2019b).

Furthermore, the area surrounding the platform consists of mainly coarse sediments including shell fragments and several infaunal species, like polychaetes and burrowing anemones (GEOxyz, 2019b). The sand mason worm *Lanice conchilega* was found at all five survey stations that lie within 1km of the new platform location (Grab P_0 and 1, Grab C_3, ENV_26 and 27; see Figure 11). Since *L. conchilega* is classified under the H1170 habitat according to European guidelines, it can provide a suitable environment for rocky reef biota, making it a valuable and contributing element. Considering the combination of boulder fields with the dense *L. conchilega* patches within this region, this will further support the development of a diverse environment for both infaunal and epifaunal species to settle.

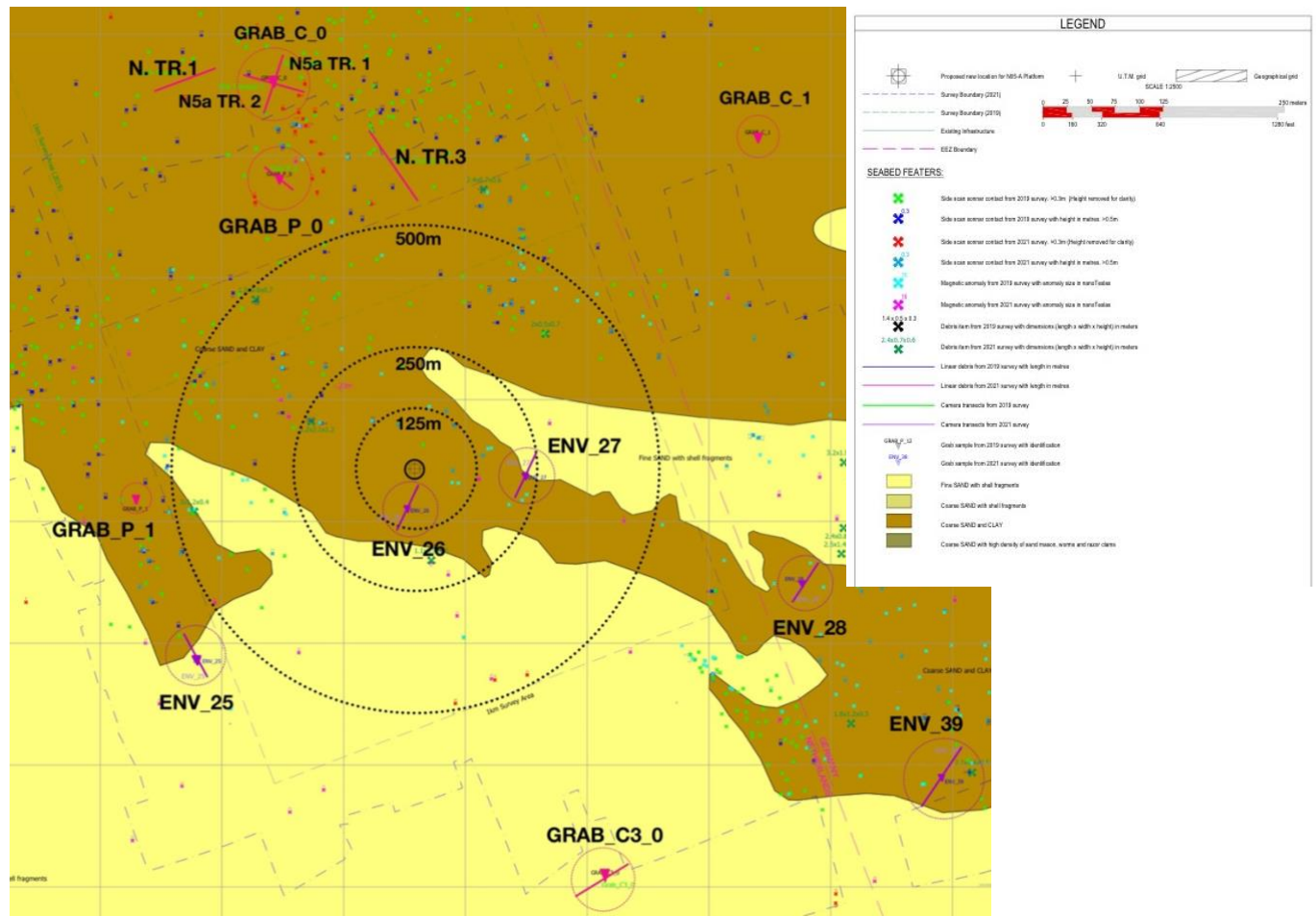


Figure 11. Sediment map of the platform area including nearby grab and transect locations. Adapted from MarineSpace Ltd (2022b)

2. Benchmarks of the Design

After establishing the basis of the design, the benchmarks and baselines for natural rocky reefs have to be determined. In this report, the main criteria will be based on the Dutch definition of H1170, as written in the Habitats Directive, and the definition presented by Irving (2009). Both definitions have also been used by MarineSpace Ltd (2022a, 2022b) and GEOxyz (2019a, 2019b) in their habitat assessments. Aside from these definitions, inspiration for the design will be drawn from biological models and theories. Therefore, various interesting principles from nature will be discussed.

2.1 Rocky Reef definitions

Rocky reefs, often surrounded by sand, enlarge the presence of hard surfaces to settle on as well as the ability for organisms to find hiding spots and shelter. The diverse sizes and randomly distributed rocks and cobbles, combined with gravelly and sandy areas, create a highly diverse landscape and substrate, attracting various species. Compared to the surrounding sandy bottom, a rocky reef can increase the local biodiversity by two-fold (Coolen, 2017).

2.1.1 The H1170 definition by the Habitats Directive

Rocky reefs are classified habitats (H1170) listed in Annex I of the Habitats Directive. The most recent Dutch version on this Habitats Directive document is provided by the Ministry of Agriculture, Nature and Food Quality (MANFQ) under the European Natura 2000 network, referred to as Natura 2000 (2014). The H1170 habitat is referred to as “Reefs of the open sea”. This habitat definition is based on a few criteria, leaving some room for interpretation. An illustrated interpretation of this document can be seen in Figure 12. An important criterium is the presence of hard substrates that rise above the sediment surface, see Figure 12A (Natura 2000, 2014). This is further translated into the need for large sized boulders, rocks and coarse gravel (>64mm) to be present in an area. Especially large boulders (>0.3m) can be detected using sonar scans, but there are no described requirements for minimal coverage. However, there are some general guidelines for identifying potential rocky areas based on sonar scans. For example, Rijkswaterstaat maintains the rule of thumb that there need to be at least 50 boulders within a km² area to comply with the H1170 classification (Wijnhoven, 2022a).

Areas that contain smaller sized rocks and gravel (between 8-64mm), are only considered H1170 if sessile organisms that specifically depend on hard substrates are attached (Natura 2000, 2014). Another exception can be made for even smaller sediment types, which are only considered part of an H1170 reef when present in some mosaic pattern, alternating with rocks, boulders and gravel (Natura 2000, 2014). Deviating from the European definition, biogenic reefs like *L. conchilega* fields and oyster banks are not considered H1170 reef features according to the Dutch H1170 criteria (Natura 2000, 2014). These biogenic structures are included in habitat types H1110 and H1140 (Natura 2000, 2014).

Besides the presence of hard substrates, the H1170 reefs are also recognizable for their species composition. The rocky substrates may contain bottom-dwelling communities, though this is not part of the minimum requirement (see Figure 12). It only indicates the quality of a reef; without these communities, a reef is considered poor quality (Natura 2000, 2014). Present sessile epibenthos also assist in recognizing and locating reefs, especially when rocks are covered by seasonal sedimentation. According to Bos et al. (2014), the stony reefs in the Borkum Stones can be identified based on the presence of several hard substrate species (see Figure 13). Primary indicators are the dead man's fingers (*Alcyonium digitatum*), jewel anemone (*Corynactis viridis*), structure-forming sponges (e.g. *Haliclona oculata*) and hydroid polyps (Bos et al., 2014). Secondary indicators are for example slugs and the spider crab (*Macropodia* sp.). Lastly, registration types for this habitat are the tubeworm (*Spirobranchus triqueter*) and the seasnail (*Liparis liparis liparis*) (Bos et al., 2014). Adding to this, the red algae (*Lithothamnion sonderi*), sea anemones (*Urticina* sp.) and several mollusks (e.g. *Aequipecten opercularis* and *Acropagia crassa*) are considered typical H1170 species (Natura 2000, 2014).

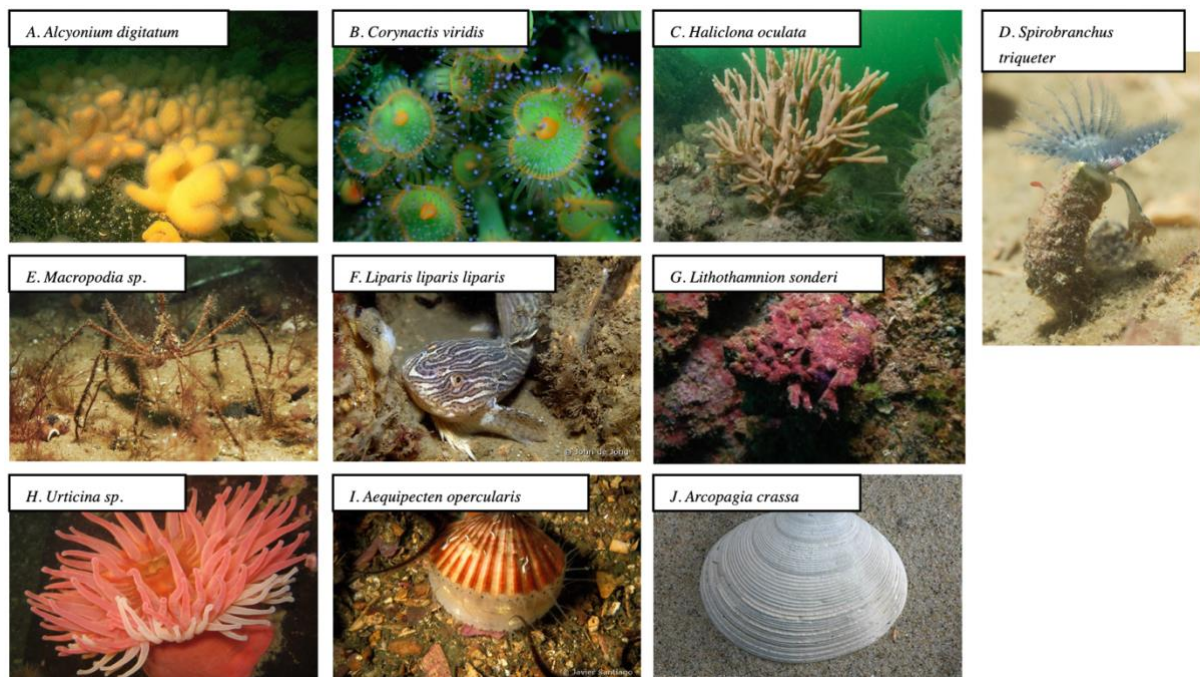


Figure 13. Examples of species typical for a stony reef habitat within Borkum Stones. Based on Natura2000 (2014) and Bos et al. (2014). Image sources are listed under References.

2.1.2 The stony reef definition of Irving (2009)

Another definition for rocky reefs, which is also been referred to in the GEOxyz surveys (2019a, 2019b), is from Irving (2009). In this document, Irving (2009) discusses and describes the 2007 version of the Habitats Directive definition of H1170 reefs, also including a more detailed UK interpretation and the interpretation manual from 2007 (Irving, 2009). Although this definition has not explicitly been approved by the Dutch authorities, it is a useful and more detailed tool for the assessment of potential stony reefs compared to the H1170 directive.

The definition of Irving (2009) is based on the extent, composition, elevation, and the biota of an area (see Table 2). Areas that can be described as small (<25m²), with little cobbles (<10%), no elevation, and dominated by infauna are considered not a reef (Irving, 2009). This scenario is shown on the left in Table 2. When the size of the area is larger than 25m², with a composition of 10%-40% cobbles and boulders, creating some elevation (<64mm) on the seabed, the area is identified as "Low reefiness" (Irving, 2009). For rocks to be included in the composition (%), they need to be at least 64mm in diameter. Furthermore, the composition (%) relates to the minimal area size (>25m²) but also considers the patchiness of an area. This means that patchy areas, showing large variation in sandy sediments and rocky areas, can still be considered a stony reef. When the area shows higher composition (>40%) and elevation (>64mm), together with a high presence of epifaunal species, it is classified as having a higher reefiness (Irving, 2009). In this case, the rocks are often clast supported, which means the rocks are in contact with each other and create a self-supporting framework. In contrast, matrix-supported rocks have clasts that are not in direct contact with each other; instead, they are surrounded by a matrix of finer-grained material like sand and silt that support the rock.

Table 2. The main characterizing features of a stony reef according to Irving (2009).

Characteristic	Not a 'stony reef'	'Resemblance' to being a 'stony reef'		
		Low ²	Medium	High
Composition:	<10%	10-40% Matrix supported	40-95%	>95% Clast supported
<i>Notes: Diameter of cobbles / boulders being greater than 64mm. Percentage cover relates to a minimum area of 25m². This 'composition' characteristic also includes 'patchiness'.</i>				
Elevation:	Flat seabed	<64mm	64mm-5m	>5m
<i>Notes: Minimum height (64mm) relates to minimum size of constituent cobbles. This characteristic could also include 'distinctness' from the surrounding seabed. Note that two units (mm and m) are used here.</i>				
Extent:	<25m ²	← ————— >25m ² ————— →		
Biota:	Dominated by infaunal species			>80% of species present composed of epifaunal species

2.1.3 The rocky reef definition by BfN (2018)

The German Federal Agency for Nature Conservation (BfN) has also worked on a monitoring manual for H1170 Reefs. The recording of a rock field/boulder field according to the German guidelines as presented in BfN (2018) includes several criteria and parameters. These are mainly based on the hydroacoustic methods and ground truthing results. For these purposes they have used the SSS, in combination with ground-truthing using video analysis and grab sampling. BfN (2018) have included images representing some of the criteria in their appendix. A few of these examples are shown in Figure 14.

The BfN (2018) paper includes several criteria to recognize and classify a reef. When evaluating side-scan sonar data in the frequency range ≥ 300 kHz, stone sizes of approximately 30 to 50cm can be recognized. Because this is the minimal detection size for the SSS data, such individual stones or blocks are surrounded by buffer areas with a radius of 75m (BfN, 2018). Secondly, if the distance between adjacent individual stones ($\geq 30 - 50$ cm) is less than 20m, the stones are grouped and considered as a cohesive reef structure. If a group of boulders contains at least 21 rocks, it is considered a reef regardless of its size (BfN, 2018). For a biologically characterized geogenic reef, at least 3 reef-typical taxa must be present in the video material of the selected region. The present community must be dominated by epibenthic sessile species and cover at least 5% of the seafloor. Reef-typical taxa include specific species or groups of organisms commonly associated with reef habitats, such as certain types of algae, sponges, bryozoans, or other sessile (non-moving) marine life (BfN, 2018). Lastly, there must be at least 50% coverage of structural organisms on at least three visible stones or blocks within the selected region. These are organisms that contribute to the physical structure of the reef, such as large sponges, corals, or dense mats of algae.

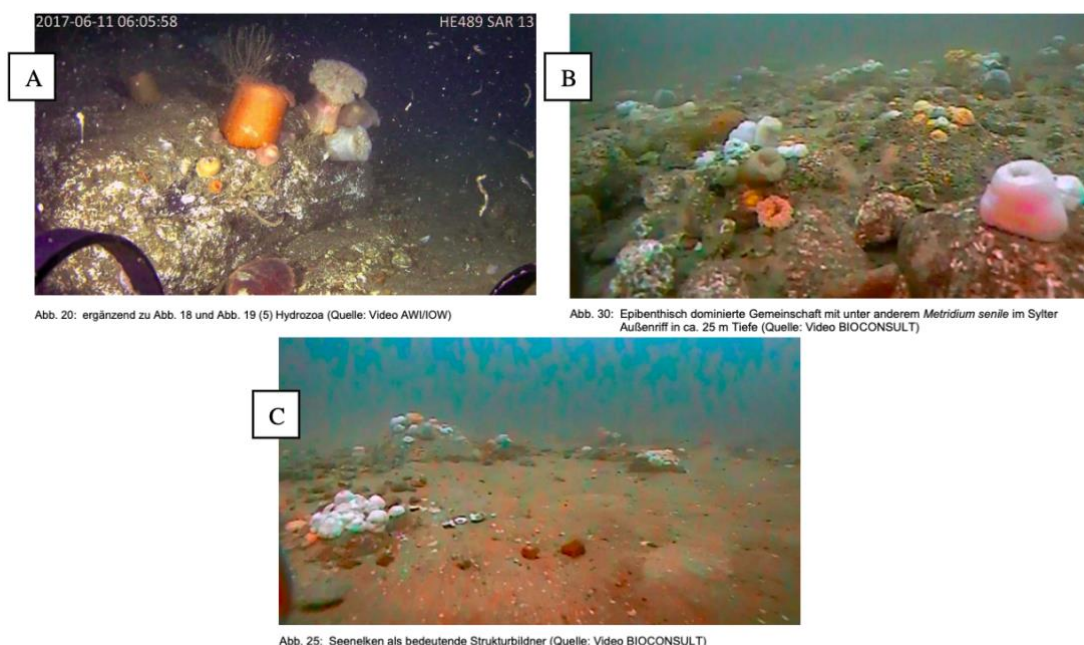


Figure 14. Examples of the biodiversity criteria for rocky reef classification according to the German guidelines. (A) shows an example of reef-typical species that must be present, (B) shows an epibenthic dominated community and (C) shows stones that are >50% covered by species. Images retrieved from BfN (2018).

2.1.4 Take-away criteria

The NID will be designed to mimic the natural rocky reef habitat that is present in the Borkum Stones region. Therefore, careful consideration of the different definitions is necessary. Although the stony reef definitions differ in their exact criteria, they show similarities in the need for large rocks and boulders and their criteria for coverage and presence of reef-specific species. For the NID, the following criteria will be considered in the design:

- Area needs rocks that are >64mm
- The minimal coverage of rocks should be $\geq 10\%$
- The area should be at least 100m² (one large patch or sum of smaller patches)
- The distance between different hard substrate patches should be <20m

Furthermore, the development of stony reef habitat is considered successful when:

- There is colonization of stones, cobbles and gravel with reef-typical species
- Minimum of 3 reef-typical species need to be present on video recordings
- The present community is dominated by epibenthic sessile species
- More coverage and more structural organisms mean higher quality reef

Aside from these criteria, the NID will draw inspiration from biological models to create a more optimized design. Nature's way to create connections and infrastructures will help find the most efficient way of connection between the hard substrates present. The next part of this Chapter will discuss several natural concepts, biological models and the lessons that can be drawn.

2.2 Biological Models and theories

2.2.1 Natural concepts and models

1. Diversity

Diversity is a concept that describes the variety and variability of life forms within a given ecosystem, region, or the entire planet. It is a fundamental element in many biological and ecological models. For example, higher diversity in species supports a more stable ecosystem. The reason for this lies in the variety of functions that each organism has within the ecosystem. A high diversity of species with complementary functions creates a very stable environment that is more redundant and resilient to disturbances (Allan et al., 2011). Furthermore, landscapes with diverse topography and habitat types increase general population stability (Oliver et al., 2010). This is evident in butterfly populations as well as other insects, such as bees and bugs (Diekötter et al., 2008; Oliver et al., 2010). This is also suggested by Stachowicz, Bruno and Duffy (2007), presenting evidence that higher biodiversity, particularly in marine ecosystems, contributes to greater stability in several ways. A visualization with the different aspects of biodiversity in a marine ecosystem is given in Figure 15. The richness of sessile taxa consistently decreases variability in community properties, which implies greater stability in the ecosystem. Furthermore, increased biodiversity enhances the resistance to and recovery from disturbances or invasions, further supporting the idea that more diverse ecosystems are more stable (Stachowicz et al., 2007).

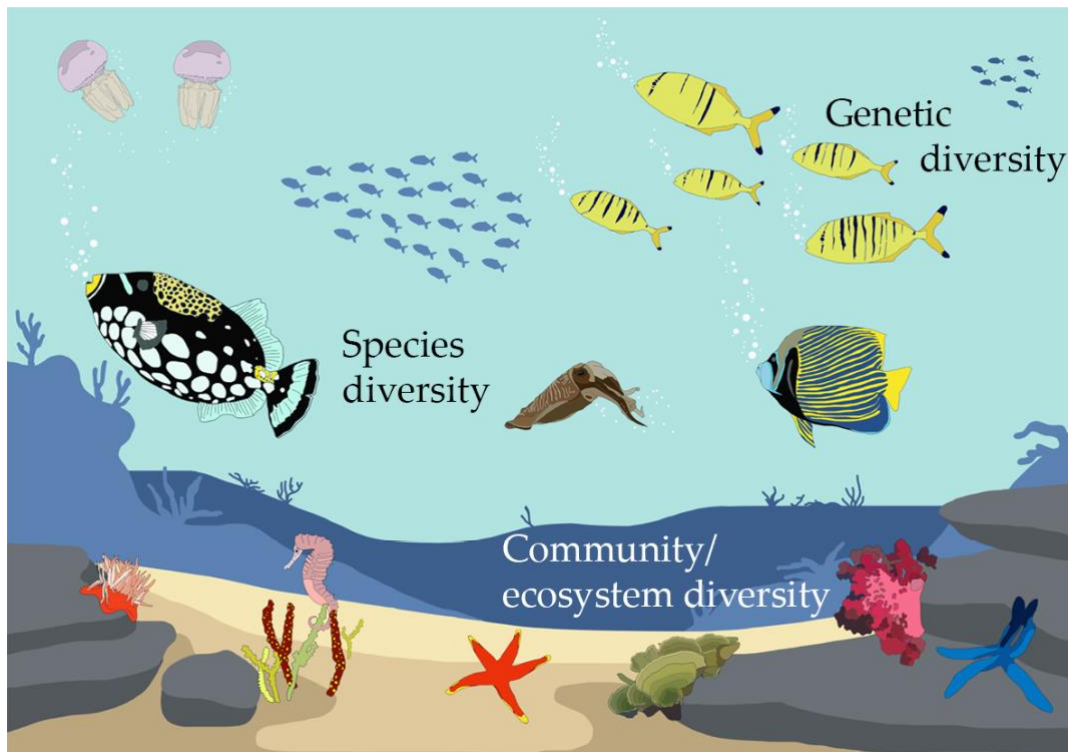


Figure 15. Visualization of a biodiverse marine ecosystem that includes the species diversity (all species), genetic diversity (the range of a species' genetic variation), and the ecosystem diversity (the variety of communities and ecosystems). Retrieved from Wilson & Primack (2019).

2. Connectivity

Another natural concept is connectivity. It is a key concept that underpins many ecological and biological models, helping to explain and predict patterns of biodiversity, species distribution, and ecosystem function. For example, landscape connectivity is an important factor that influences species richness, next to habitat heterogeneity (differences within habitat) and variability (habitat changes over time) (Diekötter et al., 2008). Connectivity among habitat patches is crucial for maintaining species diversity and ecosystem health (Haddad et al., 2015). Adding corridors and creating connected landscapes will allow for greater gene flow, species migration, and recolonization, which enhance resilience to environmental changes and disturbances (Damschen et al., 2006; Haddad et al., 2015). Increasing connectivity of habitat patches will support the goal of increasing local biodiversity (Diekötter et al., 2008; Haddad et al., 2015). Natural patterns of connectivity between landscapes are stepping stones, riparian corridors, wildlife migration routes, and biogeographic transition zones.

3. Stepping stones

A form of connectivity can be reached through stepping stones. Stepping stones can connect larger habitat areas, enabling species to move across landscapes that would otherwise be impassable (Taylor et al., 1993). This is crucial for animals with limited dispersal abilities (Moilanen & Hanski, 2001). There are a variety of natural stepping stones, such as forest patches, ponds, wetlands, hedgerows, and marine reef habitats (Bennett, 2003). For example, small forested areas within a largely deforested region can serve as stepping stones for woodland species (Bennett, 2003). In the marine environment, networks of protected areas can function as stepping stones for fish and other marine life, aiding their movement across otherwise inhospitable ocean stretches (Opdam & Wascher, 2004). Protected marine reserves, including

Borkum Riffgrund, are also considered important stepping stones (Rachor & Günther, 2001). Additionally, structures like sunken ships or purpose-built reef modules can act as artificial stepping stones, enhancing connectivity between natural reef areas (Beier & Noss, 1998). Other geogenic structures, like seamounts and underwater ridges, can also host diverse reef communities and serve as important stepping stones for deep-sea species (Roberts, 2000). Offshore windfarms have also proven to play a role in providing stepping stones, increasing pelagic connectivity (see Figure 16) (Adams et al., 2014). This approach of using man-made structures to provide more stepping stones in impassable areas, is already being integrated in restoration projects within the North Sea (Degraer et al., 2020; Ter Hofstede et al., 2023).

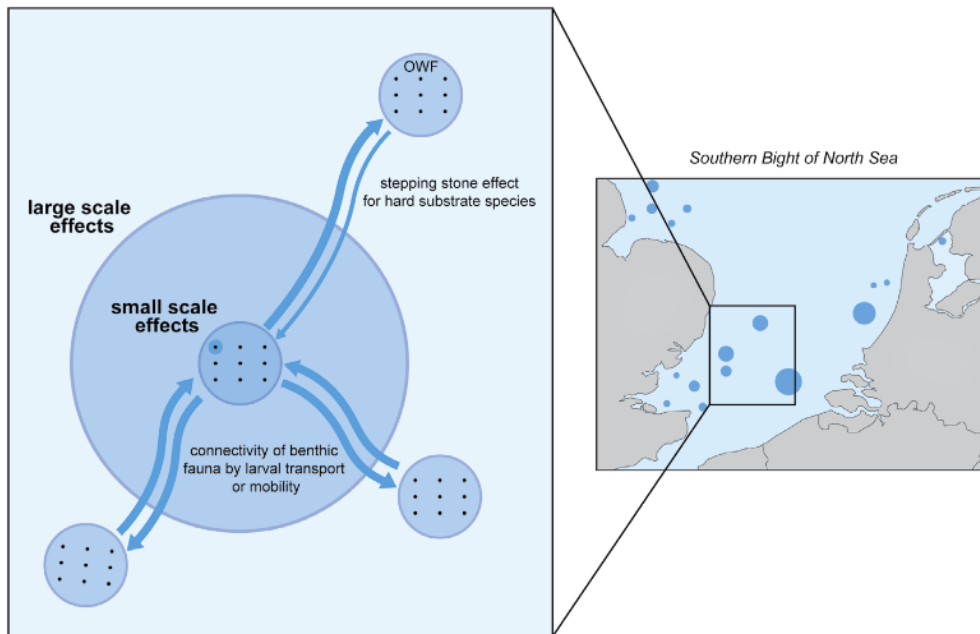


Figure 16. Visualization of the stepping stone effect of OWFs and the connectivity. Illustration by Hendrik Gheerardyn, retrieved from Degraer et al. (2020)

4. Mosaic and habitat heterogeneity

The term "mosaic" refers to the spatial arrangement of different habitat types within a landscape. It is not a biological model but rather a concept used to describe the patchwork of habitats that make up an ecosystem. Mosaic patterns can be found in various environments, for example different habitat types, like rocky reefs, biogenic reefs and soft bottom areas, together shaping one landscape. It can also be on a smaller scale, for example, several patches of rocky substrates within a sandy environment. The mosaic pattern is also referred to as the habitat heterogeneity, which can be considered on a large and small scale depending on the habitat type and fauna of interest (micro, meio, macro or mega)(Pittman, 2017). The value of mosaic patterns is that they support higher species diversity, because they offer a variety of habitats that can support different species with varying ecological requirements (Chesson & Rosenzweig, 1991; Downes et al., 1998; Mestdagh et al., 2020; Pickett & Cadenasso, 1995; Sebens, 1991).

5. The “edge effect”

Furthermore, the boundaries or edges between different habitat patches (e.g., the edge of a reef or a forest) can create unique ecological conditions that affect species behavior, population dynamics, and interactions (Laurance & Yensen, 1991; Murcia, 1995; Sambrook et al., 2016). These are also referred to as ‘transition zones’. In the marine ecosystem, habitat transitions of

biogenic origin have shown to increase habitat complexity, which in turn enhances biodiversity (Fagan et al., 1999; Lohrer et al., 2013; Sambrook et al., 2016). Even though these “edge effects” in marine habitats like rocky reefs have not been studied extensively, higher species diversity is commonly associated with habitat edges (Sambrook et al., 2016). Complex habitats provide more niches and resources, supporting a greater variety of species. They also facilitate interactions among species. For instance, the presence of certain burrowing organisms can improve sediment aeration, benefiting other species that require oxygenated environments. Lastly, they contribute to key ecosystem functions, such as nutrient cycling and sediment stability. These transitions help maintain the overall health and resilience of the marine ecosystem (Lohrer et al., 2013).

2.2.2 Natures Unifying Patterns

As the design strives to be nature-inclusive, it is valuable to consider lessons from nature in the design. The Biomimicry Toolbox, from the Biomimicry Institute, listed lessons from nature as “Nature’s unifying patterns” (*Nature’s Unifying Patterns - Biomimicry Toolbox*, n.d.). It is an attempt to show the 10 most essential patterns in nature, found across the world (*Nature’s Unifying Patterns - Biomimicry Toolbox*, n.d.). These lessons can be used as a guideline when designing nature-inspired solutions. A few important lessons for this project will be explained shortly.

Nature prioritizes optimizing systems

In nature, systems are optimized rather than maximized. In this way, nature seeks efficiency and balance in its designs, with the goal of minimizing energy and material resources (*Nature’s Unifying Patterns - Biomimicry Toolbox*, n.d.). The biological concepts branching, and mosaic patterns are great examples of this.

Nature is responsive and attuned

All things in nature are designed to be finely tuned to the local conditions and respond to cues from the surrounding environment (*Nature’s Unifying Patterns - Biomimicry Toolbox*, n.d.). This makes it more robust to withstand changes and disruptions. This can be seen in the adaptiveness of species and the changes within habitats.

Nature connects shape to function

Different shapes have different functionalities and different costs. The shapes that are present in nature are always focused on meeting the functional requirements and use a minimum of resources (*Nature’s Unifying Patterns - Biomimicry Toolbox*, n.d.). For example, the different shapes of rocks within a reef fulfill different functions within the habitat.

Nature prioritizes using available resources

Nature primarily uses abundant resources. This simply means that highly available materials are preferred over other rare materials (*Nature’s Unifying Patterns - Biomimicry Toolbox*, n.d.). An example is the use of common resources like carbon and calcium to shape the harder structures of marine organisms.

2.3 Reviewing artificial man-made reefs

2.3.1 Artificial substrates

Previous research has shown that offshore structures such as old oil rigs, monopile foundations, and shipwrecks can facilitate the colonization and formation of ecologically valuable artificial reefs (Frumkes, 2002; Kaiser & Pulsipher, 2005; Sammarco et al., 2014; Van Elden et al., 2019). However, these artificial reefs have been found to represent only a subset of the hard substrate biota and can allow the settlement of invasive species (Bouma & Lengkeek, 2009, 2013; De Mesel et al., 2015; Gates et al., 2019, p. 20; O'Shaughnessy et al., 2020; Van Elden et al., 2019). On the other hand, the scour protection around the piles of offshore structures showed to create successful, naturally occurring hard substrate habitats (Glarou & Zrust, 2020; Ter Hofstede et al., 2022). Therefore, several artificial reef structure designs have focused on conventional scour protection, and how to make it even more nature inclusive (e.g. Emmanouil et al., 2023 & Lengkeek et al., 2017). Examples of such artificial substrates are shown in Figure 17, and include reef balls, reef mats, large rock clusters and pipes (Emmanouil et al., 2023; Lengkeek et al., 2017). Although these nature inclusive designs (NIDs) can support colonization of hard substrate biota, most of these designs do not resemble the surrounding, natural hard substrates in the North Sea. Neither do they mimic the natural materials, as they are often made of concrete or other complex, chemical substrates like plastics. These chemical substrates are considered undesirable because they can pollute their environment (Davies et al., 2010; Grella et al., 2016; Tippler et al., 2014; Wright et al., 2011). In addition, these NIDs would require additional labor, production and investments.



Figure 17. Materials used for scour protection. Blue is conventional scour protection material, green represents large structures that provide holes, purple shows smaller structures to increase complexity, orange shows natural substrates, and red is materials made of plastics. Adapted from Lengkeek et al. (2017).

Other studies focusing on mitigating rocky habitat loss through artificial reefs, have demonstrated successful habitat development using rocks and boulders (Abelson & Shlesinger, 2002; Hueckel et al., 1989; Schwarzer et al., 2014). For example, Hueckel et al. (1989) recommends using materials that are available in large quantities and are non-deteriorating. Quarry rock is highly recommended, as this is also considered suitable for establishing rocky reef communities (Hueckel et al., 1989). Besides that, this type of rock is quite similar to the glacial deposits of granite that are already present in the North Sea (Schwarzer et al., 2019). Several studies have already pointed out the importance for reef mitigation projects to aim for mimicking boulder habitat (Coolen, 2017; Liversage & Chapman, 2018). They argue the artificial reef design should closely resemble natural habitats rather than only partially mimicking them. Unlike natural habitats, these semi-natural habitats did not show to support certain unique boulder-specific species (Liversage & Chapman, 2018). Furthermore, using rocks of various sizes and stacking them creates diverse crevices, which is essential for attracting and supporting reef-associated organisms (Abelson & Shlesinger, 2002; Emmanouil et al., 2023; Hueckel & Buckley, 1987). This includes sea anemones, amphipods and the European flat oyster (*Ostrea edulis*) (Emmanouil et al., 2023). Aside from supporting epibenthic sessile species, Liversage & Chapman (2018) also highlight the importance of such boulder habitat for fisheries, as some juvenile fish species need these boulders and crevices to hide from predators. The addition of larger rock structures can also support adult Atlantic cod and the European lobster (Emmanouil et al., 2023).

Even though studies often discuss the possible influences that structures and materials have on species settlement, there seems to be no general preference in substrate types. For example, Kingma et al. (2023) compared granite, concrete and marble and their influence on taxonomic richness. There were no significant effects for substrate type, but there was a positive correlation between total surface and taxonomic richness (Kingma et al., 2023). This corresponds with the findings of e.g. Hueckel and Buckley (1987) and Abelson and Shlesinger (2002). Although some studies mention the ecological benefits of other materials, these are often targeting really specific species (Emmanouil et al., 2023). For example, application of calcareous limestone and loose shells can have a positive effect on larvae settlement of the European flat oyster (Emmanouil et al., 2023).

3. Nature Inclusive Design for Scour Protection

The proposed nature inclusive design consists of a two-step approach. The first part of the design considers the scour protection around the piles of the platform and includes the application of a transition zone between the rock dump and the surrounding sandy seabed. The second part of the design considers connecting this newly introduced rocky area to already present hard substrates within the area. There are several possibilities to enlarge the hard substrate surface in the area and to connect to nearby boulder clusters. As previously present rocky reefs have disappeared, there is much value in restoring this specific habitat type.

3.1 Material and design considerations

3.1.1 Material of choice

Within the GEMS project, 1"-3" (25.4-76.2mm) and 2"-8" (50.8-208.2mm) granite rocks are used for the rock dump. The availability of the material and the possibilities to adjust the volume of rock that is ordered, make the granite rocks a favorable option. Adding to that, the natural stony reef habitats found in the North Sea include granite glacial deposits from Northern Europe based on the geological evolution of the North Sea (Houziaux et al., 2011; Laban, 1999; Schwarzer et al., 2019). The preference for granite rocks is further supported by the results of reef mitigation and restoration research (see Chapter 2), showing no strong preference for proposed alternatives. Nevertheless, it would be interesting if it were possible to combine the rock dump with some other materials as well. Great examples are shells or calcareous materials like limestones, as they are naturally present within the area.

3.1.2 Design outline

To make the scour protection more nature inclusive, inspiration is drawn from the natural rocky reefs present in Borkum Stones. Furthermore, previous studies on mitigating rocky reef habitats and restoration give valuable insights and reveal interesting approaches. The design features have been determined based on all gathered information and are listed under Chapter 2.1.4 Take-away criteria. The main design will incorporate the armor layer granite rocks (2"-8"), as this includes >64mm rocks and includes a larger grading range. The variety in rock grading results in crevices of smaller and bigger size, supporting many species and their different life stages (Lengkeek et al., 2017). For example, the queen scallop and the seasnail show affinity with large structures as well as gravel beds (Lengkeek et al., 2017). Other reef-typical species, such as the Mermaids glove (*Haliclona oculata*) and dead man's fingers (*Alyconium digitatum*) prefer rocky substrata and can be attached to a variety of stones (Budd, 2008; Mayhew, 2006; Readman et al., 2023). The rock coverage will aim for 10% over at least 100m², preferably even 40% or higher to reach a level of "medium reefiness" as defined by Irving (2009). Due to limitations within the project, larger rocks (>208.2mm) and large rock piles are not a possibility and will not be included in this NID.

The design will consist of a two-step approach. The first goal is to increase the transition zone around the scour protection rock dump and the seabed sediments. The second aim is to enhance connectivity between hard substrates in the region by investing in a larger area beyond just the platform.

3.2 Nature inclusive design proposals

The NIDs depend on the permitting possibilities and the volume of additional rocks that can be added in addition to the planned rock dumps. In this chapter, different scenarios are visualized in tables. These tables show an indication of the additional rock volume (m³) that will be needed as well as the added surface area (m²). It also considers the coverage (percentage of area that is covered with rocks) and the thickness of the rock layer (see column armor layer (m)). Lastly, it shows the relative volume compared to the total rock volume that is necessary for the armor layer of the scour protection around the platform. This is 600m³ for the scour protection around the piles and 625m³ for the pipeline and cable exits. It is important to note that the values given in the tables should be considered as crude estimations and are used to illustrate a variety of possible NIDs.

3.2.1 Enlarging the transition zone of the platform

The design

We would propose a transition zone with a minimum of 10m (width), and a coverage between 40% and 80% (see Figure 18B). These parameters can be adjusted based on technical feasibility as well. In this design, the scour protection would be expanded by 10m (see Figure 18A, orange dotted line). For the convenience of calculations, we consider the average thickness of the rock grading (0.127m). For this scenario, between 113 and 226m³ of additional rocks would be needed (see Table 3).

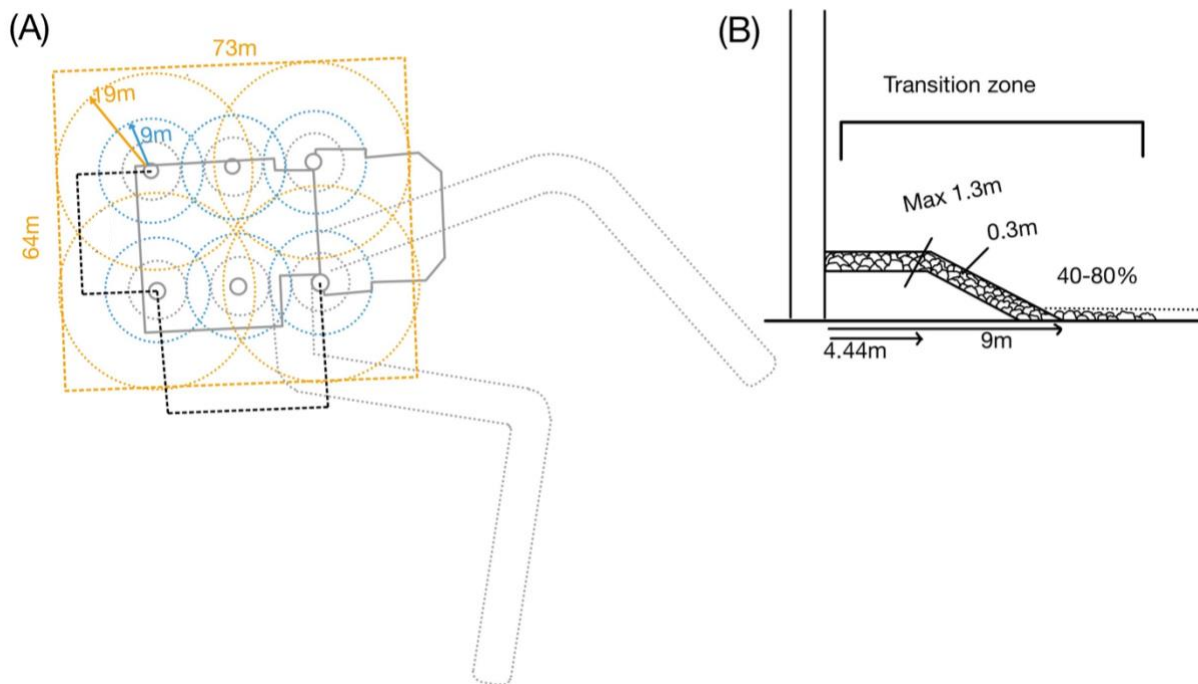


Figure 18. Illustrations of a possible 10m transition zone around the platform. (A) Shows the top view, including the platform (grey line), the planned rock dumps of the pipeline and cable exits (dotted grey line), the rock dump around the leg piles (dotted blue line) and the transition zone (dotted orange line). (B) shows a side view from one of the piles with a transition zone, including the dimensions of the scour protection.

Table 3. Rock volumes and surface coverages illustrating a couple of transition zone designs.

Opt.	Description	Change	Total surface (m ²)	Added surface (m ²)	Coverage (%)	Thickness rock layer (m)	Rock volume (m ³)	Relative to total volume (%)
0	Regular rock dump	no	2000	0	100%	0.3	600	-
1	Rock dump expansion	adding 10m*	4672	2672	80%	0.127	226	22%
2	Rock dump expansion	adding 10m*	4672	2672	60%	0.127	170	17%
3	Rock dump expansion	adding 10m*	4672	2672	40%	0.127	113	11%

* Adding 10m to the radius, resulting in a radius of 20.8m of hard substrate around the pile.

The expectations

Enlarging the rock dump around the platform is considered one of the most straight-forward adaptations possible for the project. The addition of 10m rocks to the conventional rock dump is inspired by previous research and proposals on eco-friendly scour protection (Lengkeek et al., 2017). This NID is considered a minimal adaptation, because it only increases local hard substrate with 10m, and the effect will be relatively small on an ecosystem scale. Furthermore, this adaptation of the scour protection does not increase connectivity.

By creating an additional single layer of rocks of the same rock grading, with a lower coverage percentage, a more subtle transition from rock dump to seabed can be created. Simultaneously, a larger hard substrate area is created. These transition zones in naturally occurring reefs are generally considered the most biodiverse, because this habitat suits both epifaunal and infaunal species. Especially when the hard substrate coverage is slowly thinning out to the outer parts of the transition zone, a mosaic between rocks of various sizes and sand patches can be formed. This allows for biogenic reef building species like *Lanice conchilega* to co-exist next to sessile rocky reef species, such as *Alcyonium digitatum*. Furthermore, increased reef complexity and a larger variety in height and coverage attracts a higher number of fish species and other megafauna.

3.2.2 Trajectories to Boulder Clusters

As previously mentioned, several boulder clusters are within a 500m radius from the platform (see Figure 10). Connecting these boulder areas to the platform's rock dump can further boost the local rocky reef habitat. The focus here lies on increasing the ecological value of the region by connecting hard substrate areas, expanding from the platform but working within the boundaries of the permits. Depending on the permits within this area, we seek to expand the rock dump towards the boulder clusters and connecting the different areas. There are two boulder clusters that will be considered in this NID, referred to as boulder cluster A and B (see Figure 19).

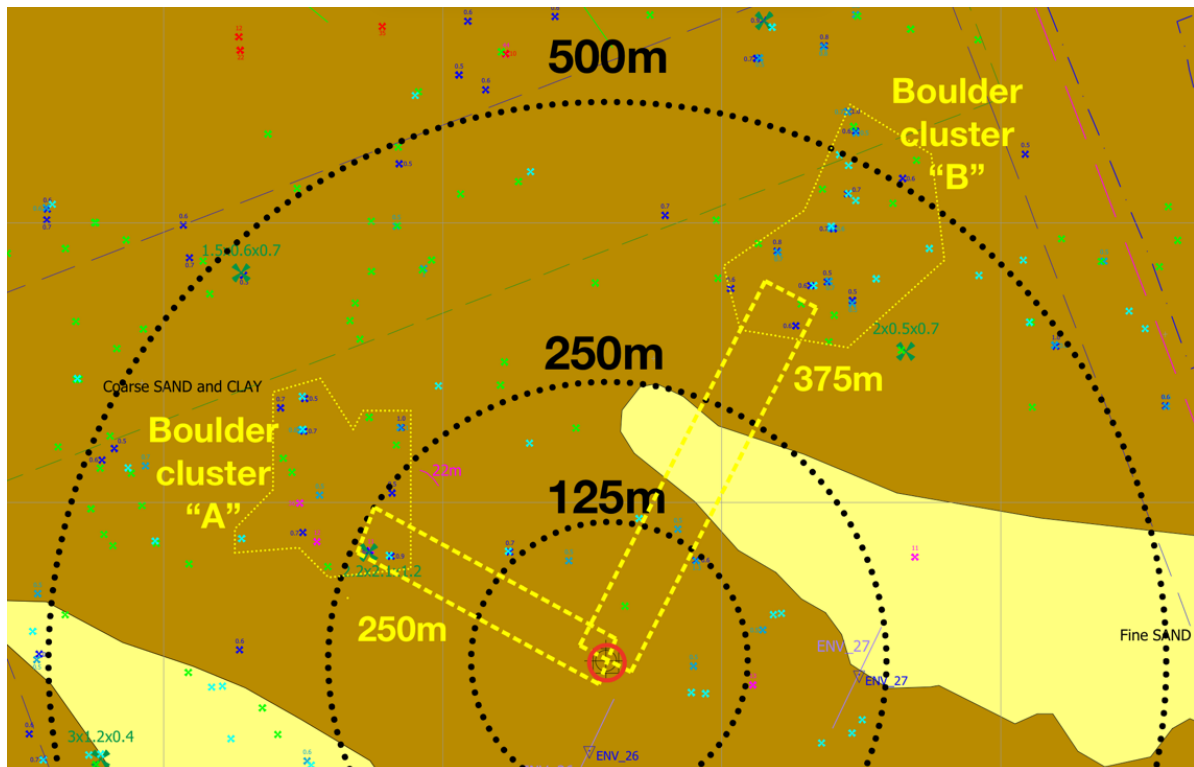


Figure 19. Map showing the platform (red circle) and the two possible trajectories towards boulder clusters "A" and "B". The trajectories are $\pm 50\text{m}$ wide and 250m and 375m long.

Trajectory A

In this scenario, the scour protection would be expanded in one particular direction, towards one of the two nearby boulder areas, labeled boulder cluster "A" (see Figure 19). It will span a distance of about 250m and will be about 50m wide. The coverage will lie between 10% and 40%. For the convenience of calculations, we consider the average thickness of the rock grading (0.127m).

There are several possibilities to increase connectivity between the boulder field and the platform, using trajectory A. The four different options are shown in Table 4 and are illustrated in Figure 21. The first option is just one straight line towards the boulder fields, with a coverage of 15%. The second and third include a patch design, consisting of 10x50m hard substrate patches separated by 15m of sand (see Figure 20). These patches are covered for 15% or 30% with rock dump. The fourth option includes a similar patched trajectory, with rock coverage thinning out from 40% to 10% (see Table 4).

For these trajectory designs, between 95 and 238m³ of additional rocks would be needed.

Table 4. Rock volumes and surface coverages illustrating a couple of trajectory designs.

Opt.	Description	Change	Total surface (m ²)	Added surface (m ²)	Coverage (%)	Thickness rock layer (m)	Rock volume (m ³)	Relative to total volume (%)
0	Regular rock dump	no	2000	0	100%	0.3	600	-
1	250m x 50m		14500	12500	15%	0.127	238	19%
2	250m x 50m including patches of 15m		7000	5000	15%	0.127	95	8%
3	250m x 50m including patches of 15m		7000	5000	30%	0.127	191	16%
4	250m x 50m including patches (15m)	1st 75m	3500	1500	40%	0.127	76.2	6%
		2nd 75m	5000	1500	20%	0.127	38.2	3%
		3rd 100m	7000	2000	10%	0.127	25.4	2%
		total	added: 250m	7000	5000		139.7	11%

Trajectory B

In this scenario, the scour protection would be expanded in another direction, towards the nearby boulder cluster B (see Figure 19). It will span a distance of about 375m and will be about 50m wide. The coverage will lie between 10% and 40% and will have an average thickness of 0.127m.

For the trajectory towards boulder cluster B, the same four design options are considered (see Figure 21). These are shown in Table 5. The first option is just one straight line towards the boulder fields, with a coverage of 15%. The second and third include a patch design, consisting of 10x50m hard substrate patches separated by 15m of sand (see Figure 20). These patches are covered for 15% or 30% with rock dump. The fourth option includes a similar patched trajectory, with rock coverage thinning out from 40% to 10% (see Table 5).

For these trajectory designs, between 143 and 357m³ of additional rocks would be needed.

Table 5. Rock volumes and surface coverages illustrating a couple of trajectory designs.

Opt.	Description	Change	Total surface (m ²)	Added surface (m ²)	Coverage (%)	Thickness rock layer (m)	Rock volume (m ³)	Relative to total volume (%)
0	Regular rock dump	no	2000	0	100%	0.3	600	-
1	375m x 50m		20750	18750	15%	0.127	357	29%
2	375m x 50m including patches of 15m		9500	7500	15%	0.127	143	12%
3	375m x 50m including patches of 15m		9500	7500	30%	0.127	286	23%
4	375m x 50m including patches (15m)	1st 125m	4500	2500	40%	0.127	127	10%
		2nd 125m	7000	2500	20%	0.127	64	5%
		3rd 125m	9500	2500	10%	0.127	32	3%
		total	added: 375m	9500	7500		223	18%

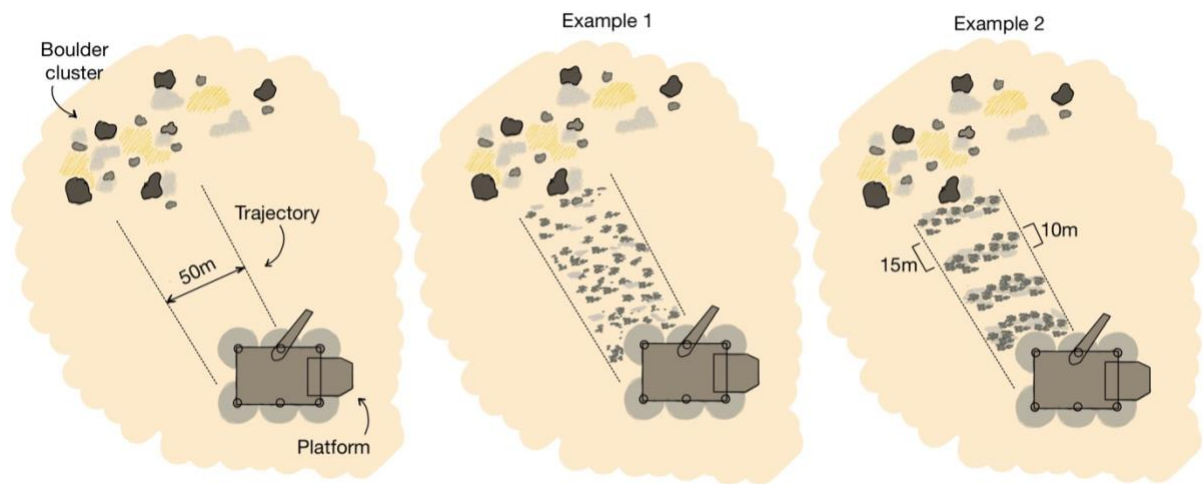


Figure 20. Illustration of a possible trajectory towards a boulder cluster with two examples of coverage: Example 1 showing coverage in the full length of the trajectory and Example 2 illustrates patched coverage with hard substrate patches of 10x50m.

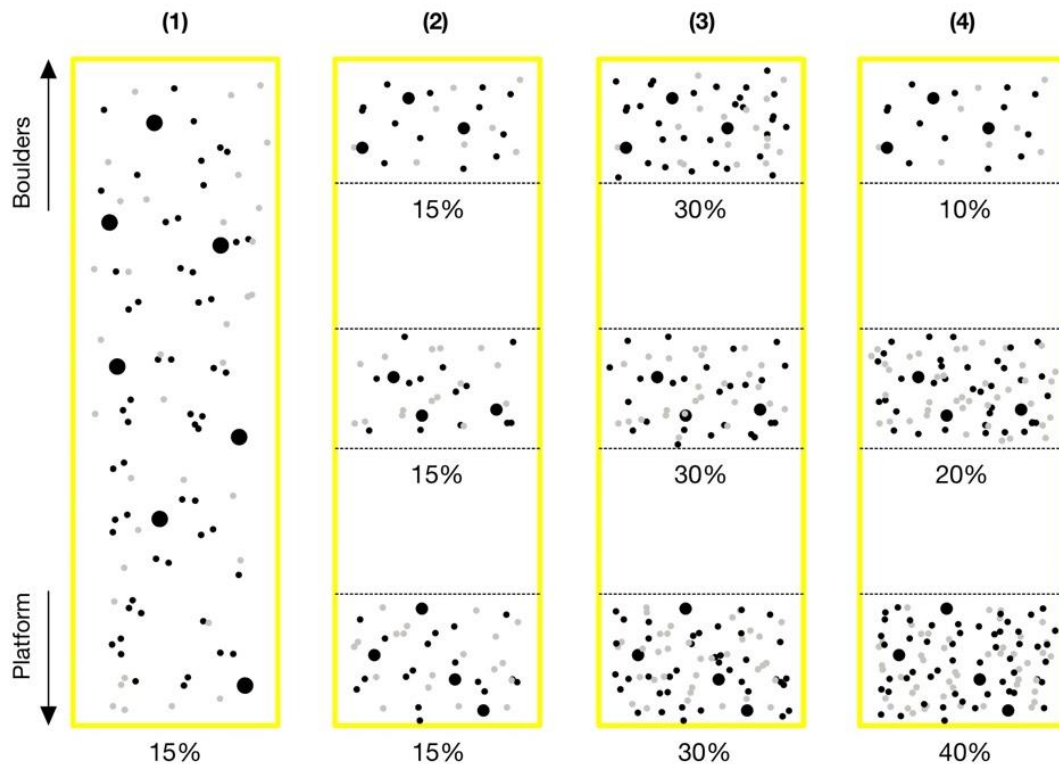


Figure 21. Illustrations of the different trajectory options (shown in Tables 4 and 5) to connect the platform to nearby boulders.

The expectations

These scenarios are specifically designed to connect to the nearby boulder fields (Boulder Cluster A and B) according to the survey data from the area (GEOxyz, 2019b; MarineSpace Ltd, 2022b). The scenarios all create a variety of transition zones between the sand (0% coverage) and the rock coverages. The areas that have lower coverage of rocks also create a more gradual slope towards the high coverage small area around the platform. Especially when combined with the transition zone design as presented above.

4. Monitoring the Design

The NID is designed to mimic the stony reefs in Borkum Stones. Therefore, several criteria need to be met. These criteria are based on three stony reef definitions (Natura2000, Irving and BfN) and are summarized in Chapter 2.1.4 Take-away criteria. To show the NID meets these criteria and prove successful installment of the rocks and development of reef-like habitat, the area needs to be monitored. The main questions for the monitoring plan are:

- **How does the area fit the geogenic criteria of a stony reef after an x amount of time?**
The criteria being as discussed in Chapter 2.1.4 Take-away criteria and “x” is related to the different monitoring moments and how the area develops over time (x can be: 1yr, 2yrs, 5yrs etc.).
- **How does the habitat develop over time and in what way does the species composition of the area match the stony reef community after an x amount of time?**
The species composition and coverage are discussed in Chapter 2 and the most important criteria are listed in Chapter 2.1.4 Take-away criteria. In this case, comparison to other stony reefs could also be interesting.
- **What are the differences in habitat development among Trajectory A, Trajectory B, and the platform?**
Comparisons between the newly introduced hard substrate areas provide a good insight in the optimal balance between coverage (%) and habitat development, making it the most efficient design, aiming for “low input, maximal output”.

In this chapter the relevant monitoring techniques will be discussed as well as a suggested monitoring plan. The monitoring plan will give an insight in the most important parameters to consider and the possible monitoring over time. This can be used as an advisory document for future monitoring activities. Precise use of instruments and planning will depend on the executing marine survey company.

4.1 Overview of relevant monitoring techniques

The NID introduces two main subjects that are important to include in the monitoring plan. Firstly, the addition of rocks will alter the geogenic landscape by increasing the hard substrate. Secondly, these rocks will facilitate the formation of rocky reef habitats and the associated biota. Therefore, this chapter focuses on monitoring techniques that will show the development of the hard substrate, considering 1) coverage and 2) biodiversity. This chapter is based on a thorough analysis of current surveys and methods, mainly executed in the North Sea. A summary excel sheet is included in Appendix E.

4.1.1 Monitoring techniques for hard substrate coverage

To determine hard substrates on the seabed, there are two preferred scanning techniques: the multibeam echosounder (MBES) and the side scan sonar (SSS). These techniques, in combination with some ground truthing, can provide different sets of information and provide data the mapping of hard substrates. Using the data from the scanners, maps are created that can show presence of hard substrates, like reefs, boulders or *L. conchilega* fields, based on reflectivity. Aside from boulder detection, these techniques can also determine sediment type.

This can be valuable, as presence of smaller rocks, gravel and shells support some hard substrate species as well and are considered part of a rocky reef when covered with reef-typical species (Natura 2000, 2014).

Using the Multibeam Echosounder

The multibeam echosounder can provide a bathymetry mapping of the seabed, but also records backscatter data to identify structures like shipwrecks (Fugro Survey B.V., 2015; GEOxyz, 2019a). The advantage of the multibeam echosounder is that the bathymetry data and backscatter data can be compared to improve mapping of objects (Mascioli, 2024) and that it can be done at a reasonable cost (Amiri-Simkooei et al., 2019). A disadvantage of MBES is the angle of coverage, which can get very narrow in shallow waters, and overcleaning of the data can delete important datapoints (UK Hydrographic Office, 2020). Furthermore, the analysis of MBES data can be quite time consuming and error-prone (Feldens et al., 2021).

Boulder detection

Most studies and surveys used the multibeam echosounder (MBES) to study the topography and morphology of the seabed (Álvarez et al., 2019; Damveld et al., 2018; Fugro Survey B.V., 2015; GEOxyz, 2019a; Koop et al., 2019, 2020, 2021; MarineSpace Ltd, 2022a; Mestdagh et al., 2020; Neil et al., 2016; Van Der Reijden et al., 2019). Using MBES data, some studies have succeeded in mapping hard substrates like boulders and cobbles (Feldens et al., 2021; Mestdagh et al., 2023). According to Feldens et al. (2021), the data on depth and backscattering is able to facilitate boulder detection. They suggest creating multi-band images, including calibrated backscatter data (Feldens et al., 2021). In the assessment written for ONE-Dyas, Mascioli (2024) suggested mapping rocks and boulders with a multibeam echosounder, using the bathymetry data as well as the backscatter data to improve mapping of point objects. A MBES with a high resolution of 0.25x0.25m (the surveys commissioned by ONE-Dyas used a 1x1m resolution) should be sufficient to analyze rocks and boulders of sizes less than 2-3m (Mascioli, 2024).

Sediment identification

Using MBES backscatter data, the sediment type can also be identified (Fugro Survey B.V., 2015; Koop et al., 2019, 2020, 2021; Mestdagh et al., 2020; Snellen et al., 2019; Van Der Reijden et al., 2019). It can determine the Folk classification of the sediment, although the data would need additional ground truthing to confirm this (Amiri-Simkooei et al., 2019; Snellen et al., 2019).

Using the Side scan sonar

A side-scan sonar creates a black-and-white image of the seabed based on the reflectiveness of the sediment and existing structures, like shipwrecks (Fugro Survey B.V., 2015; GEOxyz, 2019a; MarineSpace Ltd, 2022a). The advantage of SSS is that they are high resolution systems and can generate detailed images of small topographic features (Limpenny et al., 2010). The operation of SSS is also easy over large scales (Feldens et al., 2021). The downside of this technique is that it needs careful interpretation, and only leads to successful identification of certain seabed features when they are really distinct from each other (Limpenny et al., 2010).

Boulder detection

Several studies have used a side scan sonar for the characterization of the seabed (Bildstein et al., 2023; Coolen et al., 2015; Tiano et al., 2020). The analysis and application of SSS has been

broadly investigated in the past few years, showing promising results. For example, larger shapes like sand ripples and waves, have been successfully mapped using SSS (Fugro Survey B.V., 2015; GEOxyz, 2019a; MarineSpace Ltd, 2022a). Furthermore, different studies were able to identify hard substrates like boulders and cobbles, thanks to the high-resolution images (Coolen et al., 2015; Feldens et al., 2021; Limpenny et al., 2010). According to Feldens et al. (2021), the towing of the SSS further supports the detection of small objects and helps visualize boulders and their acoustic shadows, which can be used to determine the boulder size. They concluded that boulder identification with SSS backscatter mosaics was very reliable, but also mention that smaller boulders can be more difficult to interpret, and artefacts might lead to misidentification (Feldens et al., 2021).

Sediment identification

In the survey done by GEOxyz (2019a, 2019b), the sediment type was determined using side scan sonar bathymetric data. Other examples of studies that used this technique are Berthold et al. (2017) and Smith et al. (2023). High-frequency side scan sonar showed trends between the backscatter data and sediment properties, as well as soil strength (Berthold et al., 2017; Smith et al., 2023). Smith et al. (2023) also suggest the high-frequency SSS would further improve seabed characterization. It is also possible to determine the Folk Classification based on the SSS data, although additional ground truthing is needed to confirm this.

Combining techniques and ground truthing

Some studies use both MBES and SSS and compare them to increase the chances of correctly identifying seabed morphology (Gilliard et al., 2012; Hoffmann et al., 2022). In a comparison analysis of MBES versus SSS in detecting boulders, it was suggested to use a combination of the two (Feldens et al., 2021). Furthermore, MBES or SSS data are often used in combination with some form of ground truthing, like image analysis or grab sampling (Coolen et al., 2015; Heinrich et al., 2016). Using a form of ground truthing as a supplementary technique helps to confirm the presence of rocky reefs and distinguish them from *L. conchilega* reefs.

In the case of sediment classification, sediment grabs followed by particle size analysis would be most effective. For grab sampling, box corers are predominantly used, as they have an efficient closure and can take undisturbed sediment samples (Amiri-Simkooei et al., 2019; Bos et al., 2014; Coolen, 2017; Koop et al., 2019; Leewis et al., 2018; Mestdagh et al., 2020). Box corers are also preferred by MWTL during monitoring projects in the North Sea (Coolen et al., 2022). Another grab that is frequently used is the Van Veen Grab (VVG), which is quick and takes a lot of volume (Bos et al., 2014; Coolen, 2017; Craeymeersch & Hamer, 2023; Eggleton et al., 2016; GEOxyz, 2019a; MarineSpace Ltd, 2022a; Schröder et al., 2008; Snellen et al., 2019; Van Der Reijden et al., 2019).

Additional visual sampling is preferred to determine the coverage (%) and height of hard substrates. Video and image recordings are especially valuable in areas with smaller rocks and cobbles, which are more difficult to analyze with MBES or SSS. Several studies have identified hard substrata characteristics using video transects from a Hopper Camera, Drop Down Camera, or Towed Camera (Álvarez et al., 2019; Amiri-Simkooei et al., 2019; Coolen, 2017; Damveld et al., 2018; Didden et al., 2020; GEOxyz, 2019a; Koop et al., 2019; MarineSpace Ltd, 2022a; Mestdagh et al., 2020; Schubert et al., 2023; Tiano et al., 2020; Van Der Reijden et al.,

2019, 2021). The videos can also be used to confirm the presence of rocky reefs and distinguish them from *L. conchilega* beds on the seafloor.

In conclusion, using MBES and SSS data in combination with ground truthing would be advised based on this analysis. Video and image analysis would be the least invasive approach, as they do not disturb the habitat. A downside of this approach is the fact that some rocks cannot be recognized as they are covered by species or sediment. In that perspective, grab sampling can be considered more effective and complete in some cases. To realize a final monitoring plan, careful consideration of above-mentioned monitoring techniques and the surveying possibilities within the project is advised.

4.1.2 Monitoring techniques to measure biodiversity

A proper insight in the biodiversity within the rocky reef habitat can be assessed by a combination of different sampling techniques and data. The most suitable techniques to collect data on biodiversity are grab and visual sampling. First of all, visual sampling can be done using Drop Down Camera's (DDC), Remotely Operated Vehicles (ROV) or other waterproof cameras, like the Hopper Camera. The cameras can be used for video transects, imaging, and baited remote underwater videos (BRUV). Grab sampling can be done using box corers, Hamon hoppers or Van Veen grabs. New developments have also proven it is possible to show certain species are present using environmental DNA (eDNA) (Stat et al., 2017; Van Bleijswijk et al., 2020).

Different organism groups

To effectively monitor biodiversity, it is crucial to account for various organism groups that require distinct monitoring methods. Therefore, the monitoring techniques for epibenthos, endobenthos, fish, and other vagile megafauna are considered separately.

Epibenthos

Epibenthos can be sampled using visual sampling and grab sampling. Visual sampling is preferred as this is a less invasive technique. Epibenthos can be detected using video recordings and images that have been taken. Based on our analysis, popular techniques are video transects and video recordings taken by a scuba-diver, drop down camera or ROV (see Appendix E). Especially epibenthic species on artificial substrata are often recorded using these techniques (Bouma & Lengkeek, 2013; Coolen, 2017; Schröder et al., 2008; Vanagt & Faasse, 2014). Interesting species are the different mollusks, cnidaria and sponges that thrive in stony reef habitats.

Endobenthos

Endobenthos can be easily sampled using grab sample techniques, like the Dual Van Veen grab and Box Corer. Using different types of mesh sieves, the different sizes endobenthos can be separated into macro (1mm) and meio (0.5mm). Analyzing the grab samples and doing taxonomic identification helps determining different species. Interesting species are the different bristle worms, annelids, mollusks, and in specific the sand mason worm *Lanice conchilega*.

Fish and other vagile megafauna

Fish and vagile megafauna can be observed in video and image recordings. During drop down video recordings and scuba excursions, a variety of species can be recorded.

However, the movement of the diver and camera may cause the fish to startle, hide or swim away. Using a baited remote underwater video prevents this, attracts fish to come close to the camera, and is able to record for a longer period of time (Griffin et al., 2016; Lengkeek et al., 2017). During the monitoring of vagile species, the different swimming habits and habitat preferences need to be taken into account. For example, benthic fish prefer to stay close to the seabed, while pelagic fish prefer the open water column. Interesting species are angler fish (*Lophius piscatorius*), two-spotted clingfish (*Diplecogaster bimaculate*) and the squat lobster (*Galathea intermedia*). In addition, presence of shark and ray species also give a good indication of the health of the reef (Aburto-Oropeza et al., 2015).

Representations of biodiversity

To study the development of the hard substrate community, several indices are used (see Table 6). These are statistical representations of biodiversity in different aspects: density, diversity, and richness. Furthermore, abundance and evenness are also included. These will give a good impression of the biodiversity within the area and its development over time. For example, higher species density means more species present within a defined area (m²) or volume (m³). Furthermore, higher richness indicates a larger number of different species, while higher diversity shows that the area is richer, and species are more abundant. Evenness provides insight into how species are distributed across an area, helping to identify both highly abundant and rare species. An increase in total abundance also indicates the development of the habitat.

Table 6. Overview of factors that are representative for biodiversity.

<i>Index</i>	<i>Description</i>	<i>High when there are</i>
General density	The number of individuals per unit area or volume.	<i>More individuals within e.g. 1m²</i>
Species density	The number of species per unit area or volume.	<i>More species within e.g. 1m²</i>
Species diversity	The number and relative abundance of species within a community.	<i>More species, that are also abundant</i>
Species richness	The number species within a community.	<i>More species</i>
Total abundance	The number of individuals of a given species within a community.	<i>More individuals of a species</i>
Evenness	The distribution of different species over a community (evenly or not).	<i>Equal amounts of individuals for all species</i>

4.2 Suggestion monitoring plan

4.2.1 Monitoring of the hard substrate

To study the hard substrates and their influence on the environment and biodiversity, two main characteristics are considered: coverage (%) and height. Assessing the coverage includes four different substrate types: boulders, rocks, gravel, and soft sediments. See Table 7 for an overview of what needs to be measured and why.

Table 7. Topics of interest for hard substrate monitoring.

Measure	Unit	Explanation
Coverage of boulders (>256mm)	%	These boulders were already present. Their presence within the region influences the development of the rock dump.
Coverage of cobbles (>64mm)	%	The coverage of cobbles will probably mainly include the 2"-8" rock grading that will be dumped according to the NID.
Coverage of pebbles (2-64mm)	%	Coverage of pebbles includes part of the 2"-8" rock grading and smaller pebbles that were already present.
Coverage of soft sediment (<2mm)	%	The coverage of all three hard substrates together with the soft sediments will give a good overview on the area and will help assess if the desired coverage is reached.
Height of hard substrate	m	The height of the rock dump influences species interaction with the hard substrates and is therefore important to include in the monitoring.

4.2.2 Monitoring of biodiversity

To study the development of the hard substrate community, several indicators are used: density, diversity, richness, abundance and evenness. Additionally, special attention is given to the presence of specific organisms, for example predators, typical H1170 species or non-native species. Predators can reflect ecosystem balance and biodiversity, while H1170 typical species reveal habitat quality and specific environmental conditions. On the other hand, non-native species often highlight ecosystem disturbances or changes.

To provide estimations for these indicators, we need to measure three distinct factors during the monitoring process. See Table 8 for an overview of these factors and what can be determined using this data.

Table 8. Topics of interest for biodiversity and community composition

Measure	Unit	Determines
(A) Total number of species	<i>X species per Y</i>	• Species diversity • Species richness • Presence of apex/predator species • Presence of typical H1170 species (Ch 2.2) • Presence of exotic and non-native species
(B) Total number of individuals	<i>X individuals per Y</i>	• General density • Benthic coverage
(C) Number of individuals per species	<i>X individuals per Y species</i>	• Species density • Abundance of species • Evenness

4.2.3 Long term plan

Monitoring should consist of regular survey expeditions to assess the state, health and development of the H117 NID. It is recommended that the initial measurements (T0) be conducted after the rock dump is installed. The next measurement (T1) can be done after 1 year of installation, followed by monitoring regularly (e.g. each 5 years), until decommissioning (Hermans et al., 2020). A visualization of the monitoring timeline is shown in Figure 22.

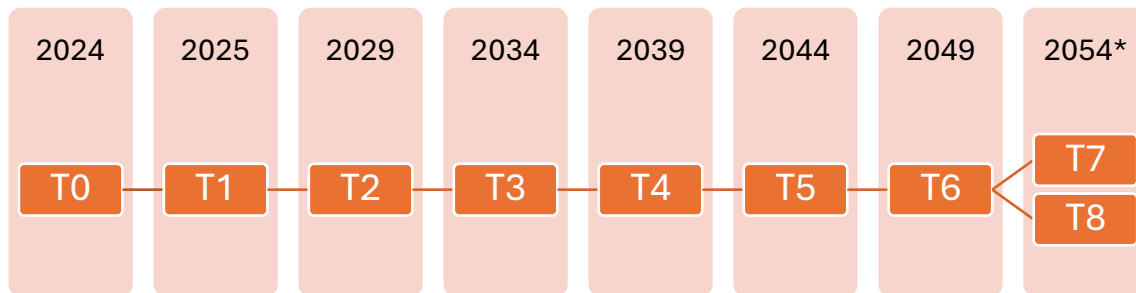


Figure 22. Schematic visualization of a long-term monitoring plan. *Decommission year if the production period is indeed 30 years as expected.

Repeated monitoring surveys

It is recommended that the second survey is done in the early phases of development, to monitor the ecological success of the NID (Hermans et al., 2020). After the second monitoring survey, a regular monitoring plan needs to cover the production period of the N05-A platform. This period is estimated to be between 25 and 30 years (ONE-Dyas, n.d.).

Monitoring regularly is important to create a good impression of the habitat development over time. Based on previous monitoring campaigns, surveys can be executed each year or every three years (Wijnhoven, 2022b; Wijnhoven et al., 2022). According to Van Hoey et al. (2019), monitoring should be done at least every 6 years.

After the production period, the N05-A platform and associated structures are decommissioned. Before decommissioning, a final survey should be done to create the final results of the NID habitat development. After decommissioning, an additional final monitoring survey will show the final state of the area and will also show the impact of decommissioning on the NID.

Timing of the monitoring surveys

Based on monitoring guidelines provided by Noble-James et al. (2018), monitoring of benthic habitats is best during spring or summer, as there is a lower chance of bad weather conditions. It is also advised to do repeated surveys in the same season, to prevent seasonal variation between surveys (Noble-James et al., 2018).

Discussion

The goal of this report was to give an insight in the opportunities of the GEMS project to become more nature inclusive, aligning with ONE-Dyas' goal to invest in biodiversity and to leave a positive impact on the region. More specifically, the focus of this report was on the development of a nature-inclusive design for the platform scour protection. Based on the areas' history, the Borkum Stones offers an interesting site for nature restoration and conservation of these hard substrates. Looking at the historical recordings of abundant rocky reefs and oyster beds in the North Sea, reinvesting in this specific habitat type is considered valuable, as it fits within the previous and current environment. After a thorough analysis of the area, the GEMS project and the stony reef criteria, several nature inclusive scour protection designs have been developed. All in all, this report has shown the rock dump around the platform offers a great opportunity for hard substrate expansion and connection to other surrounding hard substrates, such as nearby boulder clusters.

The designs that are proposed in this report, aim to mimic the natural stony reef formations found in the Borkum Stones area. The trajectory designs further aim to enhance the connectivity with nearby hard substrate habitats and attract species that thrive in such environments. This approach supports habitat development, increased biodiversity, and ecosystem resilience. Higher connectivity will also be of interest when considering possible decommissioning of the platform in the future. Removal of the platform structures might influence the stony substrates that are in vicinity of the platform. However, research has shown the robustness of a habitat also depends on size and coverage. By expanding the hard substrate towards the naturally occurring boulder areas, these trajectories can increase local connectivity, enhancing species richness and abundance. Therefore, this approach ensures that a significant portion of the rocky reef habitat will remain intact after the platform is decommissioned. Altogether, the improved scour protection design is expected to integrate seamlessly with the existing Borkum Stones ecosystem and strives to enhance the area's ecological value.

However, to ensure successful installment and development, some additional information needs to be gathered. First, the exact dumping of the rocks is expected to be done using a fall pipe vessel, as this is the most common practice. This has not been confirmed by ONE-Dyas, which means it remains unclear whether the different rock dump designs and their corresponding coverage (%) can be achieved or not. Secondly, there is a delicate balance between optimal rock coverage (%), efficiency (including time, materials and costs), and good habitat development. This optimal balance needs to be proven and developed by further research and monitoring of these NIDs. Third, it is important that the trajectory between the platform and the boulder clusters is checked for other areas of interest, such as cobbles, gravel or *Lanice conchilega* fields. The stony reef definitions as discussed in Chapter 2, expressed the importance of >64mm sized cobbles, but the current surveys have focused on boulders of > 300mm (2021) and >500mm (2019). This means that the potential hard substrate of interest, such as cobbles with a size between 64 and 300 mm, have not been mapped. Gravel beds and *L. conchilega* fields can also be considered of ecological value, and knowing whether this is present in the trajectories towards the boulder clusters is therefore of importance. However, grab

sampling and transects have been executed mostly south of the platform, or >600m north of the platform. This excludes the potential trajectory areas, and results in the lack of crucial information like hard substrate presence. Adding additional rocks as proposed in this NID might disturb valuable gravel and cobble areas that are present but have not been mapped. Therefore, it is important that SSS or MBES backscatter data is closely reviewed before finalizing this NID. Unfortunately, this data was not made available yet and could therefore not be incorporated in this report.

The choice of material within the project was based on efficiency, availability and was substantiated by several studies. Eventually, the 2"-8" granite rocks used for the scour protection armor layers within the GEMS project seemed most convenient. Granite is available in large quantities, non-deteriorating and is a highly recommended substrate, considered suitable for establishing rocky reef communities (e.g. Hueckel et al., 1989). Besides that, granite and limestone are part of the glacial deposits that are already present in the North Sea. Several studies have also shown the positive influences of larger structures, or a combination of large and small rocks, on stony reef habitat. However, due to limitations within the project, larger rocks (>208.2mm) and large rock piles were not included in the designs. Finally, it is important to note that there is no indication yet of the costs for additional rock transport. It also remains unclear whether the sprinkle layer will be added to the scour protection of the cable and pipeline exits or not, as this is within the 500m safety zone of the platform where fishing will be prohibited. If the sprinkle layer will not be installed, this might create some options for the additional 2"-8" rock transport. Either way, the 2"-8" rocks are still considered the best choice to keep costs and efforts as low as possible, aiming for a high-yield, low-input outcome.

Lastly, the monitoring plan as proposed in this report has some limitations and is mainly giving advice on the techniques that have been used in previous studies. It also includes the most important parameters that should be considered in the final monitoring plan, divided into the main topics of hard substrate and biodiversity. It is also important to note that the monitoring survey will be executed by an external party. Therefore, the exact monitoring timeline and techniques will depend on the input of ONE-Dyas, other external parties and of course the commissioned marine survey company. Furthermore, it would be interesting if the NID could be compared to a stony reef habitat nearby. This will help determine if the area aligns with the Borkum Stones environment. But, based on the GEOxyz and MarineSpace surveys, there is no area in proximity of the platform that meets the criteria of a stony reef. This is contradicted by other research, for example Bildstein (2022), who claims presence of H1170 "Reef" around the platform and along the cable route. Therefore, additional monitoring around the platform is recommended. In the case of absent stony reef, it is advised to use stony reef definitions and relevant studies to determine whether the NID suits this habitat type. This report used the stony reef definitions from Natura2000 (2014), Irving (2009) and BfN (2018), as these have been used by the rocky reef surveys (Bildstein et al., 2023; GEOxyz, 2019a; MarineSpace Ltd, 2022a; Schubert et al., 2023).

For future developments, it might also be interesting to consider another material, namely the drill cuttings of the project which contain clay and chalk. These cuttings can be recycled and incorporated to produce reef blocks and other structures that attract certain species. This was not considered for the purpose of the stony reef NID, but it might be incorporated into a new NID

in the future, for example in the BlueLinked ReefBooster project. This also creates a more sustainable way of producing reef structures, as the process will be more circular.

Another recommendation for future NIDs would be to consider an additional biological model: branching. This model has not been used for the stony reef NIDs, although it might be interesting to consider in the future, when implementing ReefBoosters for example. This biological model is related to connectivity and is mainly about the spreading of networks, displaying short connections and main routes, reducing energetic costs. It allows species to cover a larger area, without unnecessarily high costs. Next to the branching of trees, this strategy can also be seen for ant species, slime mold as well as fungi (Nakagaki et al., 2004; Reid & Beekman, 2013; Reid et al., 2011). An interesting example is the slime mold *Physarum plasmodium*, which network type closely resembles the mathematically shortest route (Nakagaki et al., 2004). Branching patterns have not been found when it comes to stony reef habitats, although the idea of enabling species to find the most direct route or connection to another reef nearby is interesting to consider.

Summarizing, the nature inclusive designs as presented in this report show great possibilities for nature enhancement within the area. Incorporating the designs in the GEMS project also aids ONE-Dyas in reaching their personal objectives and to create a more restorative GEMS project. Even though there are still some remarks and uncertainties about the execution of the project and the monitoring, this report reveals some promising ideas that will support hard substrate habitats and increased connectivity.

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Appendix

List of Appendixes:

- (A) Interview with Sander van Wijnhoven (in Dutch)
- (B) Map of the GEOxyz survey locations
- (C) Map of the MarineSpace survey locations
- (D) Technical drawings of the platform from ONE-Dyas
- (E) Overview of existing techniques
- (F) Overview of existing surveys

A. Interview with Sander van Wijnhoven

Interview with Sander van Wijnhoven (in Dutch) 17-06-2024

Introductie rondje

Vraag: De definitie van H1170 is voor mij nog erg onduidelijk, en ik had een artikel van u gelezen waarin dingen werden genoemd die mij nog niet bekend waren. Ter voorbeeld: de eis voor 50 stenen in een 1 km² gebied. Ook is het mij nog steeds erg onduidelijk of het minimum oppervlak 25m² of 100m² is voor een H1170 definitie volgens de Nederlandse richtlijnen en welke invloed organismen hebben op classificatie. Weet u hier meer over en kunt u dit toelichten?

Sander: De definitie staat nog erg open voor discussie, het gaat vooral echt over oppervlak en connectiviteit. Momenteel werkt de WUR aan een nieuw document hiervoor, Oscar Bos is hier volgens mij mee bezig. Dus ik zou vooral even contact opnemen met hem als je hier meer over wilt weten. Daarnaast, die 50 stenen per km² eis, is meer een richtlijn voor Rijkswaterstaat. Het wordt dus wel gebruikt maar is niet een harde officiële eis voor H1170 gebied. Het werd door Rijkswaterstaat bijvoorbeeld gebruikt tijdens het monitoring programma op de Klaverbank, om te kijken naar het effect van de gesloten gebieden op dit habitat. Daarnaast heb je ook eisen zoals de aanwezige biota. Daarvoor geldt vooral, sessiele organismen zijn meer een kwaliteitskenmerk. Die geven aan dat er hard substraat is.

Vraag: Oke helder, dankjewel. Voor mij is het vooral belangrijk om te begrijpen wat H1170 inhoudt voor mijn project. Met een natuur inclusief design, willen we namelijk rocky reef zoals aanwezig in Borkumse Stenen nabootsen. Dus de man-made structuren in en rondom Borkumse Stenen willen we voorzien van zulke designs, om deze op deze manier “te upgraden” en waardevoller te maken.

Mening van Sander hierover: Leuk project, ik denk ook heel erg waardevol. Wat je nu al ziet is dat schelpen fracties en oesterriffen ook interessant zijn voor zulke projecten. Wat we zien bij het WNF-project, is dat de oesterriffen nu al vissen aantrekken! Heel gaaf om te zien. Daarbij zou ik me niet te veel vasthouden aan de H1170 eisen voor je design. De H1170 definitie is niet per se van belang hier, maar de waarde natuurlijk wel!

Vraag: En als we zoiets uitvoeren, moeten we ook nadenken over het monitoren en tracken van het effect van zo’n NID. Wij dachten zelf aan SSS & MBES technieken gebruiken, in combinatie met video & foto transecten en evt extra bemonstering. Wat is jouw ervaring op dit gebied en weet je meer over andere monitoring projecten?

Sander: Ja, volgens mij is Borkumse Stenen ook een Habitat richtlijn gebied volgens KRM. Het ingewikkelde aan Borkumse Stenen is dat het wel wordt beschouwd als H1170 habitat, maar wordt niet geclassificeerd als H1170 beschermd gebied. Maar ik denk dat Borkumse Stenen wel een geschikt gebied is voor deze NID! Daarnaast weet ik dat de Borkumse Stenen onderdeel gaat worden van een expeditie van MONS. Dit voorstel ligt klaar, maar er is nog geen groen licht en het zal worden gefinancierd door de overheid. Voor deze monitoring zullen SSS en MBES beide gebruikt worden en komen er videobeelden van de bodem en waar nodig ook bemonstering met behulp van een bodem happer. Daarna volgt er een monitorings programma – hierbij gaat het echt om kwaliteit en niet om omvang. Vooralsnog is het niet helemaal beschermd, maar visserij en zandwinning mag in principe dus niet meer in Borkumse Stenen. Maar dat sluit niet uit dat er nog wel eens wordt gevist helaas.

B. Map of the GEOxyz survey locations

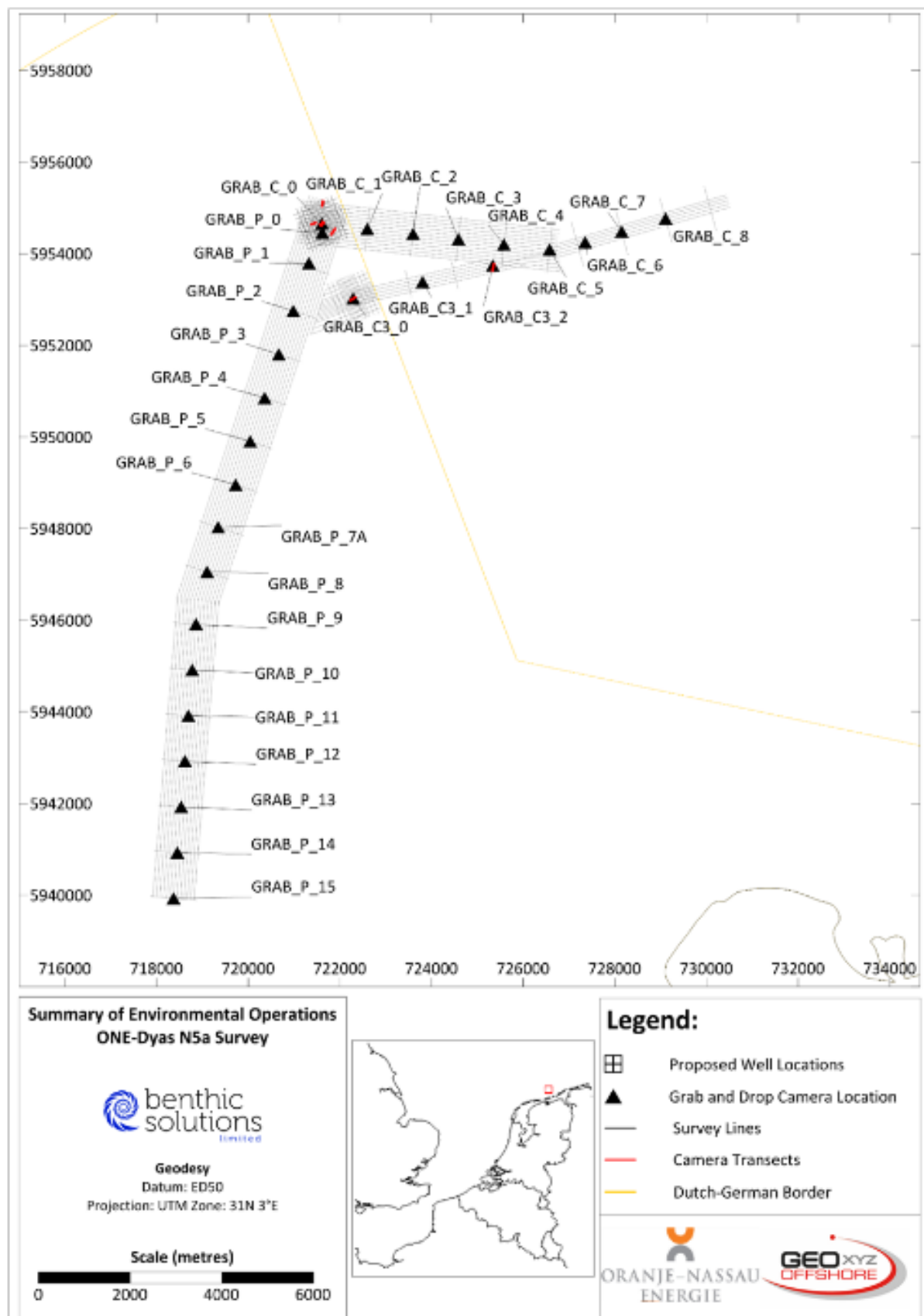


Figure B1. Mapping of the GEOxyz (2019) survey area including the platform, cable route and area between the platform and the Riffgat windfarm. Retrieved from GEOxyz (2019a)

C. Map of the MarineSpace survey locations

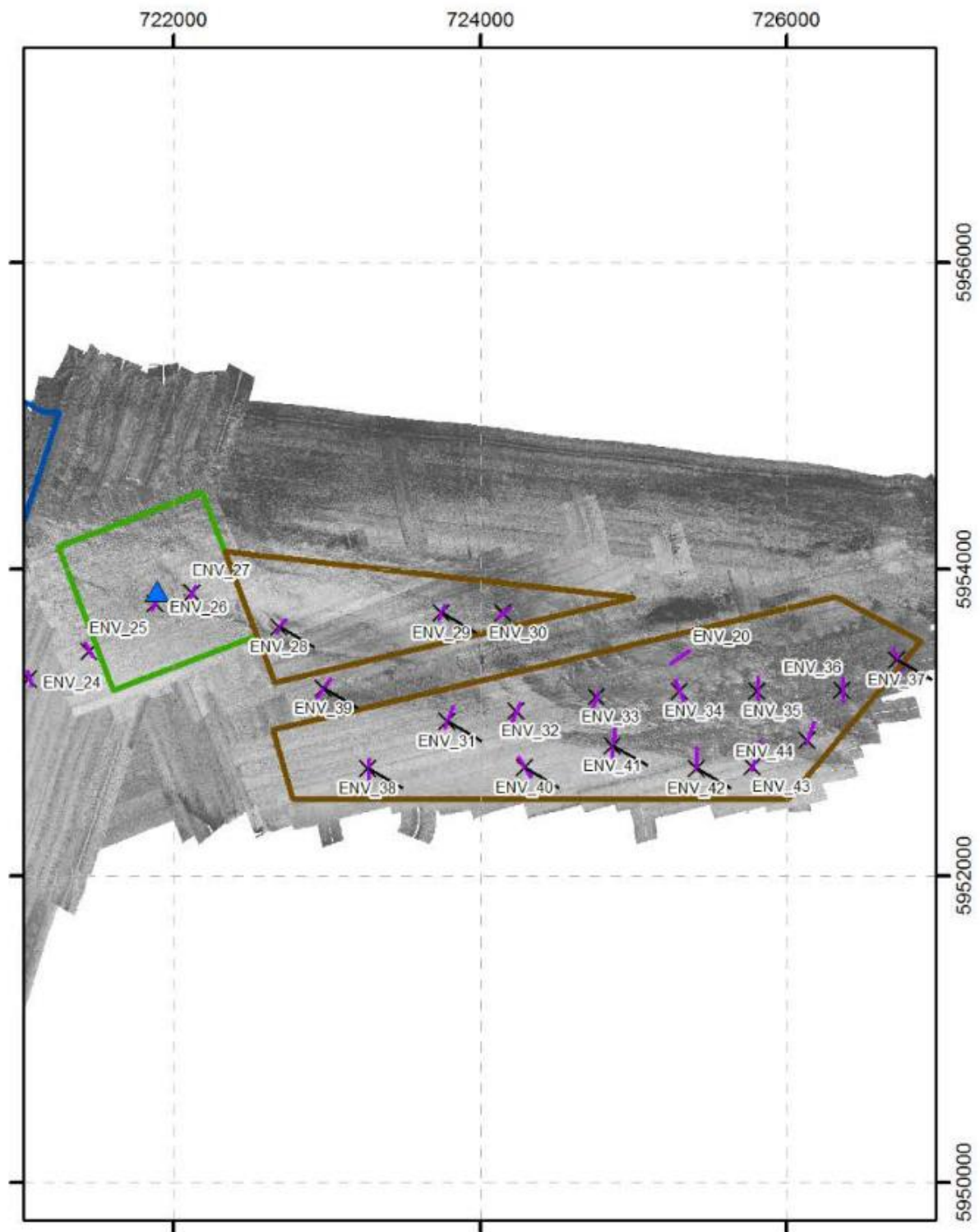


Figure C1. Mapping of part of the MarineSpace Ltd (2022) survey area including the platform and area between the platform and the Riffgat windfarm. Retrieved from MarineSpace Ltd (2022a)

D. Technical drawings of the platform from ONE-Dyas

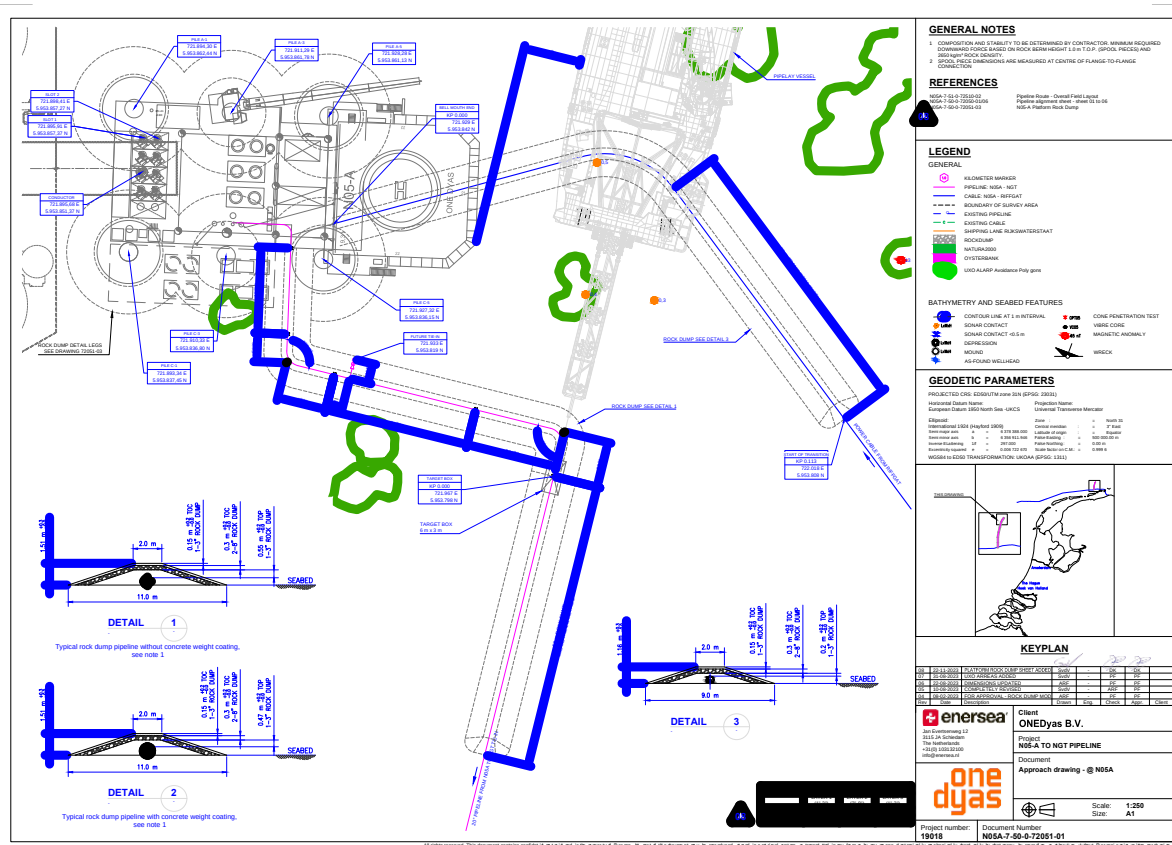


Figure D1. Document NR. N05A-7-50-0-72051-01

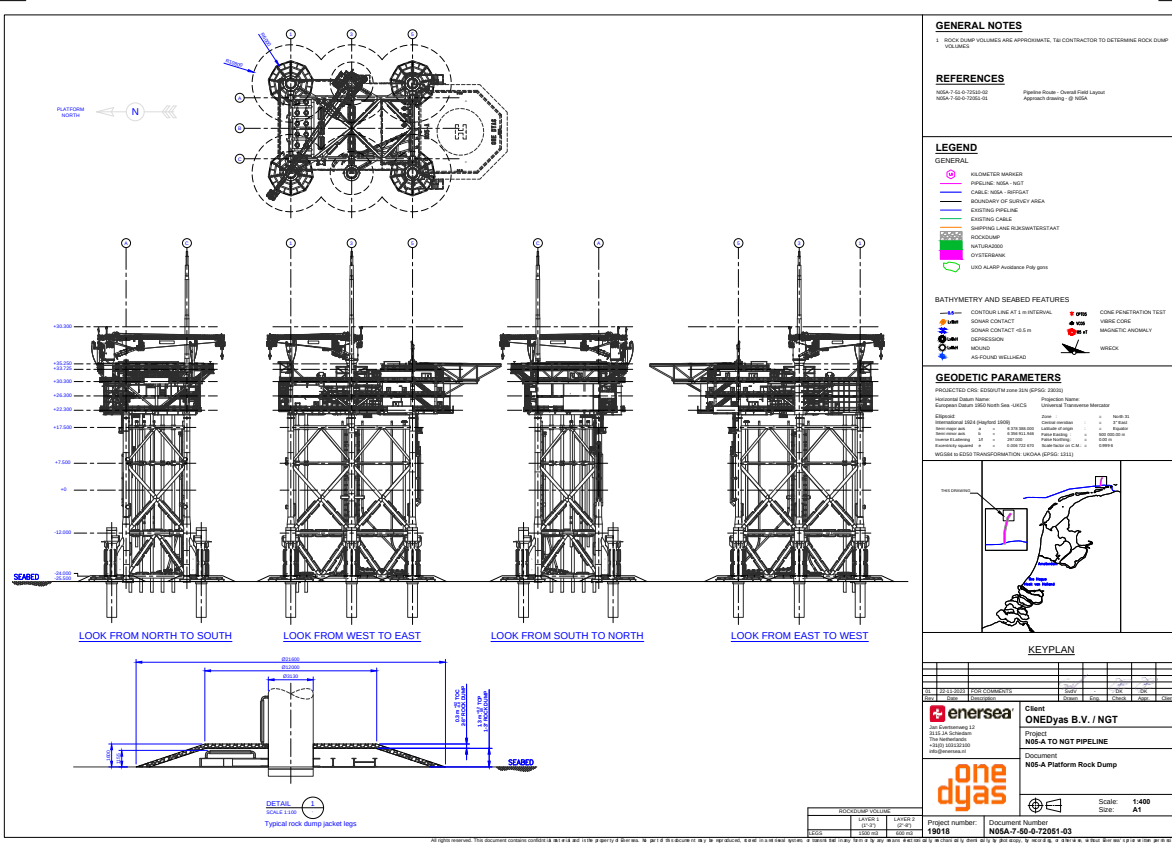


Figure D2. Document NR. N05A-7-50-0-72051-03

E. Overview of existing techniques

Sampling type	Sampling technique type	Sampling technique type abbreviation	Analysis	Analysis abbreviation	Purpose	Parameter	Parameter abbreviation	Source	Notes
Correction measurements	Global positioning system	GPS			abiotic characterisation	Location		12,24,25,26	
Correction measurements	Motion reference unit	MRU			abiotic characterisation	Motion		24,25,26	
Environmental data	Automatic Identification System	AIS			abiotic characterisation	Noise		33	
Environmental data	Wave buoy				abiotic characterisation	Waves		36	
Fauna sampling	Airlift sampler Self Contained Underwater Breathing Apparatus		Microscopic analysis		taxonomic identification	Epibenthos; on hard substrata		6	
Fauna sampling	Airlift sampler Surface Supplied Diving		Microscopic analysis		taxonomic identification	Epibenthos; on artificial substrata*		11	*steel from offshore platforms
Fauna sampling	Beam trawl				taxonomic identification	Benthic fish		31	
Fauna sampling	Beam trawl				taxonomic identification	Benthopelagic fish		31	
Fauna sampling	Beam trawl				taxonomic identification	Epibenthos		31	
Fauna sampling	Benthic dredge				taxonomic identification	Benthic fish		40	
Fauna sampling	Benthic dredge				taxonomic identification	Benthopelagic fish		40	
Fauna sampling	Benthic dredge				taxonomic identification	Epibenthos		40	
Fauna sampling	Benthic dredge (Bodemschaaf?)				taxonomic identification	Epibenthos		30	
Fauna sampling	Bottom trawl / Grande Ouverture Verticale / Otter trawl				taxonomic identification	Benthic fish		33	
Fauna sampling	Bottom trawl / Grande Ouverture Verticale / Otter trawl				taxonomic identification	Benthopelagic fish		33	
Fauna sampling	Bottom trawl / Grande Ouverture Verticale / Otter trawl				taxonomic identification	Epibenthos; Macrobenthos		33	
Fauna sampling	Bottom trawl / Grande Ouverture Verticale / Otter trawl				taxonomic identification	Pelagic fish		33	
Fauna sampling	Kieler Kinderwagen	KK			taxonomic identification	Epibenthos		30	no fish or shrimps
Fauna sampling	Ring trawl (Method Isaad Kidd)	MIK			taxonomic identification	Fish larvae		33	
Fauna sampling	Surface supplied diving	SSE	Microscopic analysis		taxonomic identification	Epibenthos; on hard substrata*		11	*gravel and rocks
Fauna sampling	Triple-D dredge / Deep Digging Dredge	DDD			taxonomic identification	Benthic fish		15	
Fauna sampling	Triple-D dredge / Deep Digging Dredge	DDD			taxonomic identification	Benthopelagic fish		15	
Fauna sampling	Triple-D dredge / Deep Digging Dredge	DDD			taxonomic identification	Endobethos		15	
Fauna sampling	Triple-D dredge / Deep Digging Dredge	DDD			taxonomic identification	Epibenthos		15	
Fauna sampling	WP2 plankton net*	WP2	Image analysis		taxonomic identification	Zooplankton		12,33,36	*using ZooScan, ImageJ, ZooProcess and Plankton Identifier Software
Geophysical data	2D Ultra High Resolution	2D UHR			sediment identification	Shallow subsurface soil stratigraphy		1,44	
Geophysical data	Drift-experiment				hazardous substances reach	Location		4	
Geophysical data	Magnetometer	MAG			seabed identification	Ferrous metal objects		1,44	
Geophysical data	Multibeam echosounder	MBES	Combined with image analysis		habitat identification*	Habitat type		21	*proven to support habitat identification of Sabellaria spinulosa
Geophysical data	Multibeam echosounder	MBES	Backscatter data analysis		seabed identification	Artificial substrata*		44,45	*wrecks
Geophysical data	Multibeam echosounder	MBES	Bathymetric data analysis		seabed identification	Bathymetric Position Indices	BPI	21,23	

Geophysical data	Multibeam echosounder	MBES	Bathymetric and Backscatter data analysis	seabed identification	Sand ripples & sand waves		25,28,44	
Geophysical data	Multibeam echosounder	MBES	Combined with image analysis	seabed identification	Sand ripples & sand waves		25	
Geophysical data	Multibeam echosounder	MBES	Bathymetric data analysis	seabed identification	Seabed characteristics		1,2,18,20,23,25	topography & morphology
Geophysical data	Multibeam echosounder	MBES	Ground truthing with grabs	sediment identification	Folk Classification		24,27	
Geophysical data	Multibeam echosounder	MBES	Backscatter data analysis	sediment identification	Sediment type		18,20,23,25,26,27,44	
Geophysical data	Sediment profile Imagery	SPI		seabed identification	Endobenthos		22	
Geophysical data	Sediment profile Imagery	SPI		seabed identification	Sand ripples & sand waves		22	
Geophysical data	Sediment profile Imagery	SPI		seabed identification	Seabed characteristics		22,23	
Geophysical data	Sediment profile Imagery	SPI	Image analysis	sediment identification	Sediment type		22,23	
Geophysical data	Side Scan Sonar	SSS	Combined with image analysis	habitat identification*	Habitat type		6	*proven to support habitat identification of Lanice conchilega & Sabellaria spinulosa
Geophysical data	Side Scan Sonar	SSS	Backscatter data analysis	seabed identification	Artificial substrata*		1,44,45	*wrecks
Geophysical data	Side Scan Sonar	SSS	Bathymetric data analysis	seabed identification	Sand ripples & sand waves		1	
Geophysical data	Side Scan Sonar	SSS	Bathymetric data analysis	seabed identification	Seabed characteristics		4,6,22,43	
Geophysical data	Side Scan Sonar	SSS	Bathymetric data analysis	sediment identification	Sediment type		45	
Geophysical data	Singlebeam echosounder	SBES	Bathymetric data analysis	seabed identification	Seabed characteristics		43	
Geophysical data	Sub-bottom profiler (pinger)	SBP	Pinger data analysis	seabed identification	Seabed characteristics		1,43,45	shallow and deeper geology
Geophysical data	Sub-bottom profiler (pinger)	SBP		sediment identification	Shallow subsurface soil stratigraphy		1,44,45	
Geophysical data	Ultra Short BaseLine	USBL		abiotic characterisation	Location		43	
Grab sampling	Borehole			sediment identification	Sediment type		1,45	
Grab sampling	Box corer	BC	Spectrophotometry	biotic characterisation	Chlorophyll-a	Chl-a	23	
Grab sampling	Box corer	BC	Particle Size Analysis	PSA	Folk Classification		24	
Grab sampling	Box corer	BC	Particle Size Analysis	PSA	Grain size		6,23,24,25,32,40,32	23 tm 25: mesh sieves (4,2&1mm) & laser diffraction
Grab sampling	Box corer	BC	Mesh sieve; 2 mm	sediment identification	Sediment type		6,40	
Grab sampling	Box corer	BC	Particle Size Analysis	PSA	Silt %		6	
Grab sampling	Box corer	BC	Dynamic flash combustion	sediment identification	Total Nitrogen	TN	23	
Grab sampling	Box corer	BC	Dynamic flash combustion	sediment identification	Total Organic Carbon	TOC	23	
Grab sampling	Box corer	BC	Loss on Ignition analysis	LOI	Total Organic Matter	TOM	23,40	
Grab sampling	Box corer	BC	1 mm mesh sieve	taxonomic identification	Endobenthos; Macrobenthos		6,21,22,32*,40	*density, species richness, DNA
Grab sampling	Box corer	BC	0.5 mm mesh sieve	taxonomic identification	Endobenthos; Meiobenthos		6*,21,23	*only top 2.5cm
Grab sampling	Box corer	BC	1 mm mesh sieve	taxonomic identification	Epibenthos; Macrobenthos		6,21,22,32*,40	*density, species richness, DNA
Grab sampling	Box corer	BC	0.5 mm mesh sieve	taxonomic identification	Epibenthos; Meiobenthos		6*,21,23	*only top 2.5cm
Grab sampling	Dual Van Veen grab	DVV	Inductively coupled mass spectrometry	ICP-MS	Alumenium	Al	45	
Grab sampling	Dual Van Veen grab	DVV	Inductively coupled mass spectrometry	ICP-MS	Arsenic	As	1,45	
Grab sampling	Dual Van Veen grab	DVV	GC mass spectrometry	GC-MS	Barium	Ba	45	

Grab sampling	Dual Van Veen grab	DVV	GC mass spectrometry	GC-MS	abiotic characterisation	Benzoanthracene / chrysene		1,45
Grab sampling	Dual Van Veen grab	DVV	GC mass spectrometry	GC-MS	abiotic characterisation	Benzo(a)fluoranthenes / benzopyrenes		1,45
Grab sampling	Dual Van Veen grab	DVV	Inductively coupled mass spectrometry	ICP-MS	abiotic characterisation	Cadmium	Cd	1,45
Grab sampling	Dual Van Veen grab	DVV	Inductively coupled mass spectrometry	ICP-MS	abiotic characterisation	Chromium	Cr	1,45
Grab sampling	Dual Van Veen grab	DVV	Inductively coupled mass spectrometry	ICP-MS	abiotic characterisation	Copper	Cu	1,45
Grab sampling	Dual Van Veen grab	DVV	GC mass spectrometry	GC-MS	abiotic characterisation	Dibenzoanthracene / indenopyrene / benzoperylene		1,45
Grab sampling	Dual Van Veen grab	DVV	GC mass spectrometry	GC-MS	abiotic characterisation	Dibenzothiophene		1,45
Grab sampling	Dual Van Veen grab	DVV	GC mass spectrometry	GC-MS	abiotic characterisation	Fluoranthene / pyrene		1,45
Grab sampling	Dual Van Veen grab	DVV	Inductively coupled mass spectrometry	ICP-MS	abiotic characterisation	Iron	Fe	45
Grab sampling	Dual Van Veen grab	DVV	Inductively coupled mass spectrometry	ICP-MS	abiotic characterisation	Lead	Pb	1,45
Grab sampling	Dual Van Veen grab	DVV	Inductively coupled mass spectrometry	ICP-MS	abiotic characterisation	Mercury	Hg	1,45
Grab sampling	Dual Van Veen grab	DVV			abiotic characterisation	Moisture content		1,45
Grab sampling	Dual Van Veen grab	DVV	Gas chromatography	GC	abiotic characterisation	N-alkanes		1,45
Grab sampling	Dual Van Veen grab	DVV	GC mass spectrometry	GC-MS	abiotic characterisation	Naphthalene		1,45
Grab sampling	Dual Van Veen grab	DVV	Inductively coupled mass spectrometry	ICP-MS	abiotic characterisation	Nickel	Ni	1,45
Grab sampling	Dual Van Veen grab	DVV	GC mass spectrometry	GC-MS	abiotic characterisation	Phenanthrene / anthracene		1,45
Grab sampling	Dual Van Veen grab	DVV	GC mass spectrometry	GC-MS	abiotic characterisation	Phytane	Ph	1,45
Grab sampling	Dual Van Veen grab	DVV	GC mass spectrometry	GC-MS	abiotic characterisation	Pristane	Pr	1,45
Grab sampling	Dual Van Veen grab	DVV	Inductively coupled mass spectrometry	ICP-MS	abiotic characterisation	Tin	Sn	45
Grab sampling	Dual Van Veen grab	DVV	Gas chromatography flame ionisation detection	GC-FID	abiotic characterisation	Total Hydrocarbon Content	THC	1,45
Grab sampling	Dual Van Veen grab	DVV	Induction furnace following carbonate removal		abiotic characterisation	Total Organic Carbon	TOC	1,45
Grab sampling	Dual Van Veen grab	DVV	Loss on Ignition analysis	LOI	abiotic characterisation	Total Organic Matter	TOM	1,45
Grab sampling	Dual Van Veen grab	DVV	Gas Chromatography	GC	abiotic characterisation	Unresolved complex mixture	UCM	1,45
Grab sampling	Dual Van Veen grab	DVV	Inductively coupled mass spectrometry	ICP-MS	abiotic characterisation	Vanadium	V	45
Grab sampling	Dual Van Veen grab	DVV	Inductively coupled mass spectrometry	ICP-MS	abiotic characterisation	Zinc	Zn	1,45
Grab sampling	Dual Van Veen grab	DVV	Particle Size Analysis	PSA	sediment identification	Fines %		1,45
Grab sampling	Dual Van Veen grab	DVV	Particle Size Analysis	PSA	sediment identification	Folk Classification		1,45
Grab sampling	Dual Van Veen grab	DVV	Particle Size Analysis	PSA	sediment identification	Grain size		1,45
Grab sampling	Dual Van Veen grab	DVV	Particle Size Analysis	PSA	sediment identification	Gravel %		1,45
Grab sampling	Dual Van Veen grab	DVV	Particle Size Analysis	PSA	sediment identification	Sand %		1,45
Grab sampling	Dual Van Veen grab	DVV	Particle Size Analysis	PSA	sediment identification	Sediment boundary		1
Grab sampling	Dual Van Veen grab	DVV	Particle Size Analysis	PSA	sediment identification	Wentworth Classification		1,45
Grab sampling	Dual Van Veen grab	DVV	0.5mm mesh sieve		taxonomic identification	Endobenthos; Macrobenthos		1,45
Grab sampling	Dual Van Veen grab	DVV	0.5mm mesh sieve		taxonomic identification	Endobenthos; Meiobenthos		1,45
Grab sampling	Dual Van Veen grab	DVV	0.5mm mesh sieve		taxonomic identification	Epibenthos; Macrobenthos		1,45
Grab sampling	Dual Van Veen grab	DVV	0.5mm mesh sieve		taxonomic identification	Epibenthos; Meiobenthos		1,45

Grab sampling	Hamon happer	HH	Particle Size Analysis	PSA	sediment identification	Folk Classification	27	
Grab sampling	Hamon happer	HH	Particle Size Analysis	PSA	sediment identification	Grain size	27,31	
Grab sampling	Hamon happer	HH	Mesh sieve		sediment identification	Sediment type	27,31	
Grab sampling	Hamon happer	HH	1 mm mesh sieve		taxonomic identification	Endobenthos; Macrobenthos	31	
Grab sampling	Self Contained Underwater Breathing Apparatus	SCUBA	Mesh sieve; 2 mm*		sediment identification	Sediment type	2, 3, 6	*only specified in source nr. 6
Grab sampling	Surface supplied diving	SSE			habitat identification	Hard substrata	11	
Grab sampling	Van Veen grab	VVG	Particle Size Analysis	PSA	sediment identification	Folk Classification	27,31	
Grab sampling	Van Veen grab	VVG	Particle Size Analysis	PSA	sediment identification	Grain size	6,26*,27,30,31, 32,36	*1mm mesh sieve
Grab sampling	Van Veen grab	VVG	Mesh sieve; 2 mm		sediment identification	Sediment type	6,27,30,36	
Grab sampling	Van Veen grab	VVG	Particle Size Analysis	PSA	sediment identification	Silt %	6,30,36	
Grab sampling	Van Veen grab	VVG	Dry combustion analysis		sediment identification	Total Carbon	Ctot	36
Grab sampling	Van Veen grab	VVG	Dry combustion analysis		sediment identification	Total Inorganic Carbon	TIC	36
Grab sampling	Van Veen grab	VVG	Dry combustion analysis		sediment identification	Total Nitrogen	TN	26,36
Grab sampling	Van Veen grab	VVG	Induction furnace following carbonate removal		sediment identification	Total Organic Carbon	TOC	26,36
Grab sampling	Van Veen grab	VVG	1 mm mesh sieve		taxonomic identification	Endobenthos; Macrobenthos	2,30,31,36	
Grab sampling	Van Veen grab	VVG	0.5 mm mesh sieve		taxonomic identification	Endobenthos; Meiobenthos	2	
Grab sampling	Vibrocore	VC			sediment identification	Sediment type	1,45	
Scratch sampling	Self Contained Underwater Breathing Apparatus	SCUBA	Microscopic analysis		taxonomic identification	Epibenthos	3, 5, 8	
Scratch sampling	Self Contained Underwater Breathing Apparatus	SCUBA	Microscopic analysis		taxonomic identification	Epibenthos	3	
Scratch sampling	Self Contained Underwater Breathing Apparatus	SCUBA	Microscopic analysis		taxonomic identification	Epibenthos	32	
Scratch sampling	Surface supplied diving	SSE	Microscopic analysis		taxonomic identification	Epibenthos on artificial substrata	17,37,39,41,42	
Visual sampling	Baited Remote Underwater Video	BRUV	Image analysis		taxonomic identification	Benthic fish	49,50	
Visual sampling	Baited Remote Underwater Video	BRUV	Image analysis		taxonomic identification	Benthopelagic fish	49,50	
Visual sampling	Baited Remote Underwater Video	BRUV	Image analysis		taxonomic identification	Hyperbenthos	49,50	
Visual sampling	Baited Remote Underwater Video	BRUV	Image analysis		taxonomic identification	Pelagic fish	49,50	
Visual sampling	Drop Down Video	DDV	Image analysis		habitat identification	Habitat type	1,6,21,45	*EUNIS habitat type
Visual sampling	Drop Down Video	DDV	Image analysis		seabed identification	Seabed characteristics	1,6,21,45	
Visual sampling	Drop Down Video	DDV	Image analysis		sediment identification	Sediment type	1,45	
Visual sampling	Drop Down Video	DDV	Image analysis		taxonomic identification	Benthic fish	1	
Visual sampling	Drop Down Video	DDV	Image analysis		taxonomic identification	Benthopelagic fish	1	
Visual sampling	Drop Down Video	DDV	Image analysis		taxonomic identification	Epibenthos	1,32,45	
Visual sampling	Drop Down Video	DDV	Image analysis		taxonomic identification	Epibenthos on artificial substrata*	36,42	
Visual sampling	Drop Down Video	DDV	Image analysis		taxonomic identification	Pelagic fish	1	
Visual sampling	Drop Down Video	DDV	Image analysis		taxonomic identification	Vagile megafauna	1	
Visual sampling	Hopper Camera		Image analysis		seabed identification	Sand ripples & sand waves	20	
Visual sampling	Hopper Camera		Image analysis		seabed identification	Seabed characteristics	20,21,22,28	
Visual sampling	Hopper Camera		Image analysis		taxonomic identification	Epibenthos	36	
Visual sampling	Remotely Operated Towed Vehicle	ROTV	Image analysis		seabed identification	Seabed characteristics	21	

Visual sampling	Remotely Operated Vehicle	ROV	Transect video analysis		abiotic characterisation	Artificial substrata*	2	*wrecks and fishing nets
Visual sampling	Remotely Operated Vehicle	ROV	Image analysis		seabed identification	Seabed characteristics	2,26	
Visual sampling	Remotely Operated Vehicle	ROV	Image analysis		sediment identification	Sediment type	2	
Visual sampling	Remotely Operated Vehicle	ROV	Transect video analysis		taxonomic identification	Benthic fish	2,26	
Visual sampling	Remotely Operated Vehicle	ROV	Transect video analysis		taxonomic identification	Benthopelagic fish	2,26	
Visual sampling	Remotely Operated Vehicle	ROV	Transect video analysis		taxonomic identification	Epibenthos	2,26	
Visual sampling	Remotely Operated Vehicle	ROV	Close Visual Inspection	CVI	taxonomic identification	Epibenthos on artificial substrata*	7	*offshore objects
Visual sampling	Remotely Operated Vehicle	ROV	General Visual Inspection	GVI	taxonomic identification	Epibenthos on artificial substrata*	7	*offshore objects
Visual sampling	Self Contained Underwater Breathing Apparatus	SCUBA	Visual biodiversity inventory		taxonomic identification	Epibenthos on artificial substrata*	8	*ship wreck
Visual sampling	Splitbeam echosounder (EK60 & EK80)		LSSS/Echoview		biotic characterisation	Fish stock	34	
Visual sampling	Surface supplied diving	SSE	Image analysis		taxonomic identification	Epibenthos on artificial substrata*	41	*offshore monopiles
Visual sampling	Video Plankton Recorder	VPR	Image analysis		taxonomic identification	Phytoplankton	12	
Visual sampling	Video Plankton Recorder	VPR	Image analysis		taxonomic identification	Zooplankton	12	
Visual sampling	Video transect Surface supplied diving		Image analysis		taxonomic identification	Epibenthos on artificial substrata*	17	
Visual sampling	Video transect Towed Camera		Image analysis		seabed identification	Sand ripples & sand waves	23,24,25	
Visual sampling	Video transect Towed Camera		Image analysis		seabed identification	Seabed characteristics	23,24,25	
Visual sampling	Video transect Towed Camera		Image analysis		taxonomic identification	Epibenthos	22,23,31	
Visual sampling	Video transect and frame photos Self Contained Underwater Breathing Apparatus		Image analysis		habitat identification	Habitat type	3	
Visual sampling	Video transect and frame photos Self Contained Underwater Breathing Apparatus		Image analysis		seabed identification	Artificial substrata	2, 8	
Visual sampling	Video transect and frame photos Self Contained Underwater Breathing Apparatus		Image analysis		seabed identification	Hard substrata	3, 5, 8	
Visual sampling	Video transect and frame photos Self Contained Underwater Breathing Apparatus		Image analysis		sediment identification	Sediment type	2, 3, 5	
Visual sampling	Video transect and frame photos Self Contained Underwater Breathing Apparatus		Image analysis		taxonomic identification	Benthic fish	6, 8, 14	
Visual sampling	Video transect and frame photos Self Contained Underwater Breathing Apparatus		Image analysis		taxonomic identification	Benthopelagic fish	6, 8, 14	
Visual sampling	Video transect and frame photos Self Contained Underwater Breathing Apparatus		Image analysis		taxonomic identification	Epibenthos	3, 5, 8, 14	
Visual sampling	Video transect and frame photos Self Contained Underwater Breathing Apparatus		Image analysis		taxonomic identification	Vagile megafauna	2, 3, 5, 8, 14	
Water sampling	Acoustic Doppler Current Profiler	ADCP			abiotic characterisation	Current direction	36	
Water sampling	Acoustic Doppler Current Profiler	ADCP			abiotic characterisation	Current velocity	36	
Water sampling	Bottle (sterilized)				taxonomic identification	environmental DNA	eDNA	46
Water sampling	Bucket (sterilized)				taxonomic identification	environmental DNA	eDNA	47
Water sampling	Conductivity sensor				abiotic characterisation	Conductivity	Con	36

Water sampling	Conductivity, Temperature, and Depth measuring device	CTD		abiotic characterisation	Conductivity	Con	2,12,20,32,33,43
Water sampling	Conductivity, Temperature, and Depth measuring device	CTD		abiotic characterisation	Depth	Dep	2,12,20,32,33,43
Water sampling	Conductivity, Temperature, and Depth measuring device	CTD		abiotic characterisation	Salinity	Sal	33
Water sampling	Conductivity, Temperature, and Depth measuring device	CTD		abiotic characterisation	Temperature	Temp	2,12,20,32,33,43
Water sampling	Continuous Underway Fish Egg Sampler	CUFES	Zoocam	taxonomic identification	Fish eggs		33
Water sampling	Cytocence		In-situ fluorometry	biotic characterisation	Chlorophyll-a	Chl-a	33
Water sampling	Cytocence		Image analysis	taxonomic identification	Phytoplankton		33
Water sampling	Cytocence		Image analysis	taxonomic identification	Zooplankton		33
Water sampling	Fluorescence sensors	TAL		abiotic characterisation	Phycocyanin		12
Water sampling	Fluorescence sensors	TAL		abiotic characterisation	Phycocerythrin		12
Water sampling	Fluorescence sensors		In-situ fluorometry	biotic characterisation	Chlorophyll-a	Chl-a	12,33
Water sampling	Freeflow carousel water sampler		Analytical Autoanalyser	AA	Ammonium	NH4	12
Water sampling	Freeflow carousel water sampler		Analytical Autoanalyser	AA	Nitrate	NO3	12
Water sampling	Freeflow carousel water sampler		Analytical Autoanalyser	AA	Nitric oxide	NO	12
Water sampling	Freeflow carousel water sampler		Analytical Autoanalyser	AA	Nitrite	NO2	12
Water sampling	Freeflow carousel water sampler		Analytical Autoanalyser	AA	Phosphate	PO4	12
Water sampling	Freeflow carousel water sampler		Analytical Autoanalyser	AA	Silicon	Si	12
Water sampling	Irradiance sensor			biotic characterisation	Photosynthetically Active Radiation	PAR	12
Water sampling	Laser Optical Plankton Counter	LOPC	Image analysis	taxonomic identification	Zooplankton		12
Water sampling	Manta net			abiotic characterisation	Microplastics	MP	33
Water sampling	Niskin bottle			abiotic characterisation	Dissolved Inorganic Carbon	DIC	33
Water sampling	Niskin bottle			abiotic characterisation	Dissolved Organic Carbon	DOC	33
Water sampling	Niskin bottle			abiotic characterisation	Nitrate	NO3	33
Water sampling	Niskin bottle			abiotic characterisation	Nitrite	NO2	33
Water sampling	Niskin bottle			abiotic characterisation	Oxygen	O	33
Water sampling	Niskin bottle			abiotic characterisation	Phosphate	PO4	33
Water sampling	Niskin bottle			abiotic characterisation	Total Organic Matter	TOM	33
Water sampling	Niskin bottle		In-situ fluorometry	biotic characterisation	Chlorophyll-a	Chl-a	33
Water sampling	Niskin bottle			taxonomic identification	environmental DNA	eDNA	48
Water sampling	Oxygen Sensor			abiotic characterisation	Oxygen	O	12,36
Water sampling	Secondday standard pyranometer			abiotic characterisation	Global radiation	GR	12
Water sampling	Temperature sensor			abiotic characterisation	Temperature	Temp	5,36

F. Overview of existing surveys

Source nr.	Name	Project type	Document name	Commissioner	Executer	General Location	Exact location	Start date (sampling)	End date (sampling)	Season	Notes
1	GEMS	Commissioned Survey	Anlage-12_Marine-Space-Ltd-2022_Bewertungsbericht-Lebensraume-All-Areas	ONE-Dyas	Marine Space	Borkum Stones	GEMS project	21-okt-21	16-nov-21	autumn	
2	Oceana	Commissioned Survey	PROTECTING THE NORTH SEA: BORKUM STONES		Oceana	Borkum Stones	Dutch Part	29-jul-17	7-aug-17	summer	
3	Greenpeace	Commissioned Survey	OASES OF BIODIVERSITY Dive investigations of reef structures on the Borkum reef bottom in April 2023	Greenpeace	Submaris & Bioconsult	Borkum Stones	Similar locations as the GEMS project	1-apr-23	17-apr-23	spring	
4	Greenpeace	Commissioned Survey	WORTHY OF PROTECTION, EXPLORING THE HIDDEN STONY REEFS OF BORKUM	Greenpeace	Bioconsult & Geo Ingenieurservice Nord-West	Borkum Stones	Similar locations as the GEMS project	1-aug-23	1-sep-23	summer	
5	WWF	Commissioned Survey	Active restoration of native oysters in the North Sea	WWF	Bureau Waardenburg	Borkum Stones	Borkum Reef Grounds	9-sep-19	11-sep-19	summer	
6	J.W.P. Coolen	PhD	Reefs, sand, and reef-like sand: a comparison of the benthic biodiversity of habitats in the dutch borkum reef grounds			Borkum Stones	Borkum Reef Grounds	17-Sep-09	22-sep-09	summer/autumn	
7	J.W.P. Coolen	PhD	Marine fouling assemblages on offshore gas platforms in the southern north sea: effects of depth and distance from shore on biodiversity			North Sea	5 offshore platforms in the southern North Sea	unknown			
8	J.W.P. Coolen	PhD	Artificial reefs influence species distribution (part 1)			North Sea	Dutch and British parts of Southern North Sea & the Dogger Bank	4-sep-14	13-sep-14	autumn	
9	J.W.P. Coolen	PhD	Artificial reefs influence species distribution (part 2)			North Sea	Dutch EEZ & British EEZ	year 2013	year 2015	NA	no sampling information, using from other research
10	J.W.P. Coolen	PhD	Marine Stepping Stones: Water flow drives mytilus edulis population connectivity between offshore energy installations			North Sea	27 locations in the North Sea	Apr-14	Jan-16	winter/spring	no sampling information, using from other research
11	J.W.P. Coolen	PhD	Benthic biodiversity on old platforms, young wind farms and rocky reefs			North Sea	Dutch continental shelf (natural and artificial reefs)	year 2014		NA	
12	Floeter et al.	Independent Research	Pelagic effects of offshore wind farm foundations in the stratified North Sea			North Sea	Two OWFs in Germany	19-jul-14	24-Jul-14	summer	
13	Lunt et al.	Independent Research	Wave energy and flow reduce the abundance and size of benthic species on oyster reefs			U.S.	St Charles and Aransas Bays, Texas	1 wk in May 2013		spring	not useful sampling
14	Schrieken et al.	Independent Research	Marine fauna of hard substrata of the cleaver bank and dogger bank			North Sea	Cleaver bank & Dogger bank	? june 2011		summer	
15	NIOZ	IMIS	Atlas of the megabenthos (incl. small fish) on the Dutch continental shelf of the North Sea			North Sea	Dutch continental shelf	year 2006	year 2011	NA	
16	van Loon et al.	MWTL	A regional benthic fauna assessment method for the Southern North Sea using Margalef diversity and reference value modelling	Rijkswaterstaat & Ministry of Infrastructure and the Environment	WUR	North Sea	Southern North Sea	year 2010	year 2015	NA	not useful sampling
17	eCOAST	Commissioned Survey	Development of hard substratum fauna in the Princess Amalia Wind Farm. Monitoring six years after construction	Prinses Amaliawindpark	eCOAST	North Sea	Prinses Amaliawindpark	28-10-2011	23-07-2013	NA	
18	Koop et al.	DISCLOSE	An Object-Based Image Analysis Approach Using Bathymetry and Bathymetric Derivatives to Classify the Seafloor	DISCLOSE	TU Delft, NIOZ, RUG, Stichting Noordzee	North Sea	Borkumer Stones and Røstbanken	8-jul-05		summer	
19	van der Reijden et al.	DISCLOSE	Beyond connecting the dots: A multi-scale, multi-resolution approach to marine habitat mapping	DISCLOSE	TU Delft, NIOZ, RUG, Stichting Noordzee	North Sea	Central and Southern North Sea	1986, 2003-2004, 2008-2015		NA	different data from different other surveys
20	Koop et al.	DISCLOSE	Measuring Centimeter-Scale Sand Ripples Using Multibeam Echosounder Backscatter Data from the Brown Bank Area of the Dutch Continental Shelf	DISCLOSE	TU Delft, NIOZ, RUG, Stichting Noordzee	North Sea	Bruine Bank	1-mei-19		spring	
21	van der Reijden et al.	DISCLOSE	Conservation Implications of Sabellaria spinulosa Reef Patches in a Dynamic Sandy-Bottom Environment	DISCLOSE	TU Delft, NIOZ, RUG, Stichting Noordzee	North Sea	Bruine Bank	oct-nov 2017	1-mei-19	NA	
22	Tiano et al.	DISCLOSE	Experimental bottom trawling finds resilience in large-bodied infauna but vulnerability for epifauna and juveniles in the Frisian Front	DISCLOSE	TU Delft, NIOZ, RUG, Stichting Noordzee	North Sea	Frisian Front	1-jun-17		summer	
23	Mestdagh et al.	DISCLOSE	Linking the morphology and ecology of subtidal soft-bottom marine benthic habitats: A novel multiscale approach	DISCLOSE	TU Delft, NIOZ, RUG, Stichting Noordzee	North Sea	Bruine Bank	26-okt-17	5-nov-17	autumn	
24	Amiri-Simkoei et al.	DISCLOSE	Seafloor Characterization Using Multibeam Echosounder Backscatter Data: Methodology and Results in the North Sea	DISCLOSE	TU Delft, NIOZ, RUG, Stichting Noordzee	North Sea	Bruine Bank	27-okt-17	3-nov-17	autumn	
25	Koop et al.	DISCLOSE	Seafloor Classification in a Sand Wave Environment on the Dutch Continental Shelf Using Multibeam Echosounder Backscatter Data	DISCLOSE	TU Delft, NIOZ, RUG, Stichting Noordzee	North Sea	Bruine Bank	27-okt-17	3-nov-17	autumn	same data as row 25, different research question
26	van der Reijden et al.	DISCLOSE	Discovery of Sabellaria spinulosa reefs in an intensively fished area of the Dutch Continental Shelf, North Sea	DISCLOSE	TU Delft, NIOZ, RUG, Stichting Noordzee	North Sea	Bruine Bank	1-aug-17		summer	
27	Snellen et al.	DISCLOSE	Performance of Multibeam Echosounder Backscatter-Based Classification for Monitoring Sediment Distributions Using Multitemporal Large-Scale Ocean Data Sets	DISCLOSE	TU Delft, NIOZ, RUG, Stichting Noordzee	North Sea	Cleaver Bank	1-nov-13	1-feb-15	NA	
28	Damveld et al.	DISCLOSE	Video Transects Reveal That Tidal Sand Waves Affect the Spatial Distribution of Benthic Organisms and Sand Ripples	DISCLOSE	TU Delft, NIOZ, RUG, Stichting Noordzee	North Sea	Texel offshore	1-jun-17		summer	
29	van der Reijden et al.	DISCLOSE	North Sea demersal fisheries prefer specific benthic habitats	DISCLOSE	TU Delft, NIOZ, RUG, Stichting Noordzee	North Sea	Dutch EEZ	1-jan-08	31-dec-15	NA	not a survey
30	Craeymeersch et al.	Commissioned Survey	Biologische monitoring PO: Eems Tussenrapportage data voor-en najaar 2020, 2021, en 2022	RWS (NH)	WMR	North Sea	Eems	19-mei-20	20-mei-20	spring	
31	Eggleton et al.	Commissioned Survey	Dogger Bank SCI 2014 Monitoring R&D Report	UK Marine Biodiversity Monitoring R&D Programme	Cefas and JNCC	North Sea	Dogger Bank	17-mei-14	6-jun-14	spring	
32	Bos et al.	Commissioned Survey	Natuurwaarden Borkumse Stenen: project aanvullende beschermde gebieden	Ministerie EZ	IMARES, buwa	Borkum Stones	Borkum Stones	11-aug-13	16-aug-13	summer	same data as Coolen
33	Ifremer	Commissioned Survey	International Bottom Trawl Survey (NS-IBTS2023-Q1)	International Council for the Exploration of the Sea	Ifremer	North Sea	North Sea	20-Jan-23	28-feb-23	winter	

34	ICES WGIPS	Survey	The 2022 ICES Coordinated Acoustic Survey in the Skagerrak and Kattegat, the North Sea, West of Scotland and the Malin Shelf area	ICES WGIPS	North Sea	Most of the continental shelf in the North Sea, West of Scotland and the Malin Shelf	22-jun-22	25-jul-22	summer	
35	Deltares	Commissioned Survey	Rich Reefs in the North Sea	Ministry of Economic Affairs	Deltares	Dutch Continental Shelf				not a survey?
36	BeoFINO II	Commissioned Survey	Benthosökologische Auswirkungen von Offshore-Windenergieparks in der Nordsee	Bundesministeriums für Umwelt, Naturschutz und Reaktorsicherheit	BeoFINO II	FINO 1	1-mrt-05	1-okt-07	NA	
37	Krone e.a.	?	Epifauna dynamics at an offshore foundation – Implications of future wind power farming in the North Sea			FINO 1	1-mrt-05	1-okt-07	NA	
38	German Federal Ministries	RAVE (Research at alpha ventus)	Ecological Research at the Offshore Windfarm alpha ventus: Challenges, Results and Perspectives	Federal Ministry for Environment, Nature Conservation and Nuclear Safety & Federal Maritime and Hydrographic Agency		Alpha Ventus	NA	NA	NA	book with multiple articles
39	Mesel et al.	Commissioned Survey	Succession and seasonal dynamics of the epifauna community on offshore wind farm foundations and their role as stepping stones for non-indigenous species	C. Power*	Operational Directorate Natural Environment, Royal Belgian Institute of Natural Sciences,	Windturbines at Thorntonbank, Belgian Part of the North Sea	autumn 2008	summer 2012	NA	*not indicated, but the owner of the windpark
40	Eurofins	Commissioned Survey	Benthic development in and around offshore wind farm Prinses Amalia Wind Park near the Dutch coastal zone before and after construction (2003-2017)	Rijkswaterstaat	Eurofins	Prinses Amaliawindpark	19-mrt-17	1-apr-17	spring	document has partly the same data as eCoast
41	Bouma & Lengkeek	Commissioned Survey	Development of underwater flora- and fauna communities on hard substrates of the offshore wind farm Egmond aan Zee (OWEZ)	Noordzeewind, NUON & Shell	Bureau Waardenburg	Offshore Windfarm Egmond aan Zee	Feb & Sept 2008		winter and summer	
42	Bouma & Lengkeek	Commissioned Survey	Benthic communities on hard substrates of the offshore wind farm Egmond aan Zee (OWEZ)	Noordzeewind, NUON & Shell	Bureau Waardenburg	Offshore Windfarm Egmond aan Zee	Feb & Sep 2011		winter and summer	
43	FOREWIND LIMITED	Commissioned Survey	DOGGER BANK TRANCHE A ACOUSTIC AND GEOPHYSICAL SURVEY	Forewind Limited	GEMS group	Dogger Bank	28-jun-10	27-dec-10		
44	FUGRO	Commissioned Survey	GEOPHYSICAL SITE INVESTIGATION SURVEY, BORSSELE WIND FARM SITE III	Rijksdienst voor Ondernemend Nederland	FUGRO	Borsele				
45	GEMS	Commissioned Survey	N05A Development Environmental Baseline Survey Report	ONE-Dyas	GEOxyz	GEMS project	1-mei-19	15-mei-19	spring	pipeline included
46	Stat et al.	Independent Research	Ecosystem biomonitoring with eDNA: metabarcoding across the tree of life in a tropical marine environment			Coral Bay	17th of March 2015	18th of March 2015	spring	research
47	NIOZ	?	Analysis of a coastal North Sea fish community: Comparison of aquatic environmental DNA concentrations to fish catches		NIOZ	Wadden Sea				
48	Westgaard et al	Independent Research	Towards eDNA informed biodiversity studies – Comparing water derived molecular taxa with traditional survey methods		Noorse Zee / Barents Zee	Svalbard & Barents Sea	May & September 2015		spring	
49	Bureau Waardenburg	Commissioned Survey	Eco-friendly design of scour protection: potential enhancement of ecological functioning in offshore wind farms	Ministry of Economic Affairs	Bureau Waardenburg	Windfarms	NA			