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Work plan towards an offshore wind farm hard substrate sampling & monitoring programme in the Netherlands [MONS-project ID46]

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Wageningen University & Research report C003/22

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Summary

In The Netherlands, the first offshore wind farm (OWF) became fully operational in 2007. This OWF was followed by several others. The establishment of wind farms is accompanied by a rapid colonisation by fouling species, which attach on the newly introduced hard substrates. Monitoring programmes of the communities on wind turbine foundations in the Netherlands have not yet been conducted on a long-term basis (>5 years) after construction. The 'Monitoring and Research, Nature Enhancement and Species Protection' (MONS) aims, among many other things, to monitor hard substrate communities in OWFs during the next 10 years. The focus is on differences in succession in OWFs with different characteristics in the various habitats and monitoring long term succession of benthic communities on the turbine foundations and scour protection layer (SPL).

Since the execution of hard substrate sampling campaigns in OWFs is challenging and costly, an advice was requested on how to come to a feasible monitoring programme in MONS. For this purpose, the available and to-be-developed sampling methods and legal & safety requirements were evaluated.

Multiple methods are available that are or may become suitable but no single method meets all criteria. On the very short term, the only fully suitable method to obtain samples from the turbine foundations, is collection by divers using manual scraping tools and sample nets as has been performed in past research in OWFs and on other offshore installations. However, OWF operators prefer to replace diving work with remotely operated vehicles (ROVs) wherever possible, as part of their legal obligations to minimise health and safety risks. In the next 2 years, an ROV mounted sampling tool in development by Bluestream and Wageningen Marine Research may become a suitable replacement for diver sampling. To collect small rocks from the scour protection layer, multiple methods exist, but for some of the options may not be accepted by OWF operators. The single method likely to be accepted is to make use of ROV mounted manipulator arms, collecting the rocks and depositing them in baskets. This has been applied in the past and the use of ROV tools increases health & safety, which is why this method is likely to be preferred by offshore windfarm operators.

The following table summarises all aspects that were considered and values them on availability, acceptability and an indication of costs in a qualitative manner.

Diver / ROV \ surface lift	**Method**	**Quantitative**	**Practically feasible**	**Legally feasible**	**Preferred by scientists**	**Acceptable to operators**	**Available**	**Budget impact**
Diving	Scuba	Yes	Yes	No	Yes	No	Yes	Low
Diving	SSE DP vessel	Yes	Yes	Yes	Yes	Maybe	Yes	High
Diving	SSE moored vessel	Yes	Yes	Maybe	Yes	Maybe	Yes	Medium
Diving	SSE RIB with standby	Yes	Yes	Maybe	Yes	Maybe	Yes	Medium
ROV	Scrape-net	Maybe	No	Yes	No	Yes	Yes	Medium
ROV	Suction tool	No	Yes	Yes	No	Yes	Yes	Medium
ROV	Vortex	No	Yes	Yes	No	Yes	Yes	Medium
ROV	Bluestream WMR tool single sample	Yes	Yes	Yes	Yes	Yes	Maybe	Medium
ROV	Bluestream WMR tool multiple samples	Yes	Yes	Yes	Yes	Yes	Maybe	Low
ROV	Manipulator take SPL rocks	Yes	Yes	Yes	Yes	Yes	Yes	Medium
ROV	Seabed scoop take SPL rocks	Yes	Yes	Yes	Yes	Yes	No	Medium
SL	Hamon grab take SPL rocks	Yes	Yes	Yes	Yes	Maybe	Yes	Low
SL	Orange-peel grab take SPL rocks	Yes	Yes	Yes	Yes	Maybe	Yes	Low

1 Introduction

Offshore wind farms (OWFs) are continuously being planned, licenced and constructed in the North Sea (de Vrees, 2019). In The Netherlands, the first OWF (Egmond aan Zee - OWEZ) was commissioned in 2005, built in 2006 and became fully operational in 2007 (Lindeboom et al., 2011). The introduction of this OWF was followed by many others. The establishment of OWFs is accompanied by a rapid colonisation by fouling species, which attach on the newly introduced hard substrates. In two Dutch OWFs (OWEZ & Princess Amalia WF), short-term (up to 5 years) inventories have been conducted to assess the succession of fouling communities on the structures (Bouma and Lengkeek, 2013; Vanagt and Faasse, 2014). These and other studies from neighbouring countries (De Mesel et al., 2015; Kerckhof et al., 2019; Krone et al., 2013b; Leonhard and Frederiksen, 2006) or on similar installations [i.e. oil and gas platforms (Coolen et al., 2020c, 2020a)] have indicated that the introduction of OWFs increases the local biodiversity, species richness and densities of benthic organisms. Current related research projects focus on the creation of nature inclusive designs (NID) to promote the attachment and/or presence of specific species of interest, such as flat oysters (*Ostrea edulis*) and other reef forming species [examples of projects: BENSO (Bureau Waardenburg BV, 2019), KOBINE (Wageningen Marine Research, 2021a), ECO-FRIEND (Wageningen Marine Research, 2018), Ecoscour (Van Oord, 2020)], while others are mainly focusing on the effects that fouling species have on the environment and their functions [examples of projects: ASSESS (Wageningen Marine Research, 2021b), NWA-2 wind farms & ecosystem (NWO, 2020)]. However, monitoring programmes of the communities on wind turbine foundations in the Netherlands have not yet been conducted on a long-term basis (>5 years) after construction. International data are available in a shared database (Coolen et al., 2021) but this lacks data on communities >12 years after construction since wind farms of this age have not yet been monitored.

1.1 MONS

The knowledge gap in monitoring data of OWF in the Netherlands was recognised in the 'Monitoring and Research, Nature Enhancement and Species Protection' [in Dutch: *Monitoring en Onderzoek Natuurversterking en Soortenbescherming*, MONS (Asjes et al., 2021)]. MONS aims at assessing how the multi-use program for the North Sea will fit within the ecological carrying capacity of the North Sea. To address this question an integral and systematic monitoring programme is planned that focuses on the physical, chemical and biological parameters for the functioning of the ecosystem and the variation of species distribution, including birds, mammals, invertebrate benthic organisms and fish (Asjes et al., 2021). One of the foreseen elements in MONS is the monitoring of communities present on wind turbine foundations, surrounding scour protection layers (SPL) and NID structures on the seabed which, in part, is a continuation of the Dutch governmental offshore wind ecological programme (WOZEP). In MONS, it was also recognised that monitoring these communities is challenging, as methods applied in the past, such as mooring vessels on turbine foundations during sampling by divers, may not be accepted by wind farm operators anymore. Therefore, as a first step, MONS aims to inventory and evaluate potential methods to monitor the hard substrate communities in OWFs.

1.2 Potential monitoring methods

In the past in the Netherlands and in most surrounding countries, monitoring methods varied slightly between projects but always aimed to collect quantitative data on the epifauna communities present on the wind turbine foundations. Species were scraped off from an area of known size on the foundation and collected, conserved and later identified and counted in the laboratory.

1.2.1 Previously applied methods: diving

The most applied method has been diving, often carried out by commercial surface supplied or scientific scuba divers collecting samples using putty knives, scraping the fauna from the structure and collecting it in nets. This has been applied in the Netherlands (Bouma and Lengkeek, 2012; Vanagt and Faasse, 2014), Belgium (De Mesel et al., 2015), Germany (Krone et al., 2013b), the UK (Bessell, 2008) and Denmark (Leonhard and Frederiksen, 2006) and on offshore oil and gas platforms in Dutch waters (Coolen et al., 2020c, 2020a) as well as on rocky reefs and shipwrecks (Coolen et al., 2016, 2015a; Lengkeek et al., 2013b).

Recent attempts, however, to apply diving methods again in Dutch OWFs, were unsuccessful as more stringent regulations are currently applied by the OWF operators and as a result much larger and more expensive vessels are needed for the execution of sampling campaigns that require diving activities. In addition, operators only allow diving if no other method is capable of attaining the same results. This change in policy has resulted in the cancellation of the year 10 hard substrate monitoring campaign in the first two Dutch OWFs which was planned to be executed as part of WoZEP (Joop Coolen, personal observation). To plan a hard substrate monitoring programme in which scrape samples can be collected from wind turbine foundations, the feasibility of diving campaigns needs to be reconsidered.

1.2.2 Novel methods: Remotely operated vehicles

For the collection of detailed information on the communities, similar to the diver collected scrape samples, there are novel alternatives on the horizon. Robotic methods are evolving and are being applied in offshore industry as much as possible, increasingly replacing diving methods (Joop Coolen, personal observation). Therefore, the use of remotely operated vehicles (ROVs) with specialised robotic tools to scrape and collect fauna from the turbine foundations, is being considered for MONS. Although video methods have successfully been used to detect the presence of large invertebrates on offshore structures (Karlsson et al., 2021; Schutter et al., 2019; van der Stap et al., 2016), these methods cannot quantify nor identify the benthic community in high detail since most species remain unseen as they are too small to be detected on video or are present out of camera view covered by other species. Scraping and/or suction tools for ROVs are available on the market, e.g. the ROV Suction Sampler (Cellula Robotics, 2021) and Marine Growth Tool (Vortex Subsea Solutions, 2021a) but their effectiveness to meet MONS requirements needs to be considered.

2 Assignment

2.1 Background aims of hard substrate monitoring MONS

Among the long-term MONS research objectives is the aim to provide data on which indigenous and non-indigenous species inhabit the hard substrate in offshore wind farms and monitor the local succession. Additional MONS aims related to this subject are to gain insight into:

1) The factors that play a role in the occurrence of species and the development of communities on a small scale (within the wind farm) and large scale (connectivity of wind farms);
2) The significance of the hard substrate and wind farm related communities for the development of communities elsewhere in the (Dutch) North Sea;
3) The significance of communities for the food web and ecological processes in general;
4) How the specific design of wind farms can contribute to the settlement and development of communities with specific values with regards to nature compensation (e.g. positive effects on protected species) and how to manage the decommissioning and removal of wind farms.

2.2 Knowledge questions

To be able to address the MONS offshore wind hard substrate related questions, the Dutch Ministry of Infrastructure and Water Management requested a work plan in which available and potential methods for obtaining scrape samples of known surface area from offshore turbine foundations and the surrounding scour protection layer (SPL) are evaluated.

Therefore, this report aims to answer the following questions:

1) Which detailed data are needed on offshore wind hard substrate communities?
2) What methods are available to collect samples from wind turbine foundations and the scour protection layer?
3) What methods could be developed to collect quantitative samples from wind turbine foundations and the scour protection layer?

In the next phase, the MONS OWF hard substrate monitoring programme can be set up, and, this information can then be used to describe, select and possibly develop the most appropriate method.

2.3 Aim & approach

This report aims to describe and evaluate the available and potential methods for obtaining scrape samples of known surface area from offshore turbine foundations and the surrounding scour protection layer (SPL). This has been carried out by collecting information on the following topics:

1) Which detailed data are needed in MONS, including an evaluation of all OWF hard substrate related chapters in the MONS report of 4 October 2021 (Asjes et al., 2021);
2) How samples have been collected in the past in previous hard substrate monitoring programmes in OWF and similar structures in the North Sea;
3) What methods are available to collect samples from wind turbine foundations and the scour protection layer (SPL) with an evaluation of the feasibility to apply these methods in Dutch wind farms as part of MONS;
4) What methods could be developed that would be feasible and able to collect quantitative samples from wind turbine foundations and SPL with an evaluation of the feasibility to apply these methods in Dutch wind farms as part of MONS;
5) A plan on how to select and apply the best method or, if needed, develop this in an (international) cooperation between MONS, WOZEP, scientists and industry (operators as well as contractors), and how to develop a monitoring plan in which this method is applied in Dutch wind farms as part of MONS.

3 Methods

To collect the information required to evaluate the best way forward, a desk study was performed, to assess the MONS requirements, evaluate available methods applied in previous projects, legal aspects of these methods and interviews were conducted with experts from the industry to evaluate working regulations and expected feasibility of methods.

The following activities were carried out:

- The content of the most recent version of the MONS report (Asjes et al., 2021) was assessed to extract the basic monitoring data needs for the monitoring of hard substrate species in OWFs and extract (potential) data needs from other MONS topics, where relevant to hard substrates in OWFs.
- Literature research was conducted to define additional data needs for this type of monitoring based on international experience, such as those described by the ICES Working Group on Marine Benthal and Renewable Energy Devices (Coolen et al., 2021).
- An inventory of the potential field work methods for scrape sampling (e.g. industry way of SSE diving / scientific way of SSE diving / ROV operated scrape sampler) was made.
- An inventory of the current relevant Health, Safety, Quality and Environment (HSQE) regulations in the wind industry was made, among others via meetings with an Operations & Maintenance (O&M) manager of an OWF operator in Dutch waters.
- The Dutch Working Conditions Catalogue relevant to diving work was assessed, together with additional international standards, to form a complete overview of all requirements, by law and within the operational regulations in OWF.
- Based on the MONS data needs and the HSQE and other regulations overview, the feasibility of each potential method was assessed. The aim was to select a method as most suitable and feasible that meets as much as possible the MONS requirements and all the HSQE and other regulations. The latter is essential, as methods that do not meet all these regulations will be refused by OWF operators.
- The description of the most suitable method was reviewed by experts at OWF operators, an ROV and diving company and others, as part of a wider review of an earlier version of this report.

4 MONS data needs

The MONS report describes a total of 141 research aims. Some of these aims depend on the delivery of data from the hard substrate monitoring programme. To allow these other aims to be facilitated by the hard substrate monitoring, the content of the MONS report was assessed to create an inventory of all possible data requests. This inventory is given below, starting with the hard substrate specific aims and then adding all other sections and their potential data needs. Then, a more generic set of requirements is provided, based on (international) experience with monitoring of artificial structures in the North Sea and the wish to collect additional important data that may not be included in MONS but would improve the scientific output of the MONS programme.

In summary, the hard substrate monitoring programme should aim at providing data based on quantitative samples as well as quantitative video analysis, collected in a systematic manner. All species in the samples should be identified, counted and weighed. All species visible in the video should be identified and counted. It is likely that additional samples of fresh or even live specimens will need to be provided to the other research sections of MONS.

4.1 Hard substrate specific aims (MONS §4.4.2.2.)

The MONS report describes the aims of the monitoring of hard substrates on wind turbine foundations in paragraph 4.4.2.2. Therein links with other MONS components are given, and the monitoring programme should provide insight in the changes in the benthos community, what the effects are of changes in the food web and whether changes fit in the carrying capacity of the North Sea (paragraph 4.1 MONS). The programme should support questions on mitigation measures as well as nature inclusive design (NID) and decommissioning. Most MONS topics involve modelling of effects. Therefore, monitoring programmes should aim to provide data that can effectively be used in these models.

The following hard substrate related questions were formulated in MONS:

1. Which species will colonise hard substrates in offshore windfarms and surrounding soft sediments?
2. What drives succession of the community on hard substrates in offshore windfarms?
3. Does this succession depend on the presence of multiple wind farms (e.g. by functioning as stepping stones) and on the possible increased species pool?

In the work plan proposed here, the focus is on hard substrate communities in OWFs. The surrounding soft sediment will be monitored in other sections of MONS and/or WOZEP.
Question 1 will need to be addressed by the collection of physical scraped samples from small patches at different depths on the turbine foundations, on the scour protection layer (SLP) and on the NID structures in the wind farms. Furthermore, there will be a collection of video footage of the same structures to assess the presence of large and less abundant or mobile species that are not collected in the physical samples. The scraped samples should be of known size to allow extrapolation of densities and weights. Ideally all samples within the scrape sample programme should be of identical size, e.g. the sample size as used in the study of the hard substrate communities in the Princess Amalia wind farm (0.056 m^2; Vanagt and Faasse 2014, Coolen et al. 2020b).
To address question 2, repeated samples should be taken in different years (long term succession) as well as different seasons (short term variation in communities), since both parameters (in particular seasonality) are of importance to succession in benthic communities in OWF (Coolen et al., 2022). To further assess geographic variation in space and time, existing data from monitoring programmes in neighbouring countries will need to be included, e.g. via the Working Group on Marine Benthal and Renewable Energy Devices, in which the joint international database has been setup (Coolen et al., 2021) as part of the CRITTERBASE developed by the Alfred Wegener Institute (Kloss et al., 2021).

For question 3 additional work is likely needed, e.g. using oceanographic models and molecular tools. Only the potential need for additional samples to carry out molecular analysis (e.g. genetic connectivity) is noted, no further description of this research is given here. The OWF hard substrate specific data needs are summarised in table 4.1.

Table 4.1 Basic data needs of the MONS hard substrate monitoring programme.

Data required	**Scrape results**	**Video results**
Species names	All species as present in samples.	All species >20 mm as visible on video, present in the visible top layer of the community.
Abundance	Abundance of individuals as present in samples. Known sampled area can be converted to individuals per m^2.	Abundance of individuals >20 mm present in the visible top layer of the community. Visible area can be estimated and can be converted to individuals per m^2.
Weight	Weight of individuals as present in samples. Known sampled area can be converted to individuals per m^2.	Not possible (unless in combination with physical sampling or reference to a size-weight regression database).
Additional samples	Additional samples of the community can be taken if needed, e.g. for molecular analysis.	Not possible.

4.2 MONS sections that may use hard substrate activities & results

In addition to the specific aims and questions in paragraph 4.4.2.2. of MONS, other sections in MONS are expected to make use of the hard substrate activities, e.g. by acquisition of additional samples or by using the resulting data or data on species that are not the primary aim of the hard substrate monitoring, but may be incidentally observed (e.g. fish). Therefore, the other sections in the MONS report were reviewed and relevant subjects with their specific data needs are given below.

It should be noted that this section does not intend to replace any detailed research on fish abundances, behaviour or otherwise, or perform any valuation of effects on the species considered in other MONS sections. It merely aims to identify potential data needs and possible requests from other MONS sections such as the acquisition of additional samples.

4.2.1 Basis of the food web (MONS §4.1)

For the basis of the food web sections, feeding strategies and functioning of the benthic communities on the hard substrates (turbine foundations as well as nature inclusive designed structures) will be studied in relation to the carrying capacity of the North Sea. This section will likely make use of taxonomic information as well as densities and weights of the communities on the hard substrates. Additional sample acquisition during hard substrate monitoring campaigns can be expected, e.g. to collect specimens for stable isotope analysis, energy content or to perform *ex situ* experiments.

Table 4.2. Data needs of the MONS food web programme.

Data required	Scrape results	Video results
Species names	All species as present in samples.	All species >20 mm as visible on video, present in the visible top layer of the community.
Abundance	Abundance of individuals as present in samples. Known sampled area can be converted to individuals per m^2.	Abundance of individuals >20 mm present in the visible top layer of the community. Visible area can be estimated and can be converted to individuals per m^2.
Weight	Weight of individuals as present in samples. Known sampled area can be converted to individuals per m^2.	Not possible (unless in combination with physical sampling or reference to a size-weight regression database).
Additional samples	Additional samples of the community can be taken. It is likely that live specimens can be collected.	Not possible.

4.2.2 Zooplankton (MONS §4.2)

The MONS zooplankton section shortly notes the presence of wind farms and nature inclusive designed structures in relation to the increase of filter feeding organisms on the artificial hard substrates which may feed on zooplankton. This section will likely make use of taxonomic information and densities of the benthic community on the turbine foundations. Furthermore, information on feeding type (e.g. passive filter feeder, active filter feeder, deposit feeder) will be required, and also possibly information on dietary preferences of the species occurring on the hard substrates. The latter is not of direct influence on the sample programme of hard substrates.

Table 4.3. Data needs of the MONS zooplankton programme.

Data required	Scrape results	Video results
Species names	All species as present in samples.	All species >20 mm as visible on video, present in the visible top layer of the community.
Abundance	Abundance of individuals as present in samples. Known sampled area can be converted to individuals per m^2.	Abundance of individuals >20 mm present in the visible top layer of the community. Visible area can be estimated and can be converted to individuals per m^2.
Additional samples	Additional samples of the community can be taken. It is likely that live specimens can be collected.	Not possible.
Feeding traits	Can be generated based on species names. Additional experiments using live specimens may be needed.	Can be generated based on species names as observed on video, when present in the visible top layer of the community but with less detail than the scrape samples.

4.2.3 Fish (MONS §4.3)

The MONS fish section aims to study the function of OWF related hard substrates for hard substrate associated fish. Questions include how the presence of OWF influences behaviour, growth, distribution, abundance and species composition. It is known that some fish species associate almost exclusively with hard substrates. Others are not exclusive but extensively feed there or make use of the habitat for other purposes. Although the hard substrate monitoring will not target fish species per se, it is possible that a variety of fish species will be observed during the video surveys. To facilitate the MONS fish research, it is, therefore, advised to also register the species, size and number of observed fish

during the survey. Scrape sampling will only provide information on small fish species or small specimens (larvae, juveniles, possibly eggs of certain species) specifically those living and/or hiding in and among hard substrate communities. To a large extent this also accounts for video observations on hard substrates (although larvae and small specimens can likely not be determined to species, genus or even family level). It can however be expected that fish species that are typically residing near hard structures (e.g. for foraging purposes, 'hiding' in the shade of light or currents, or schooling around objects), are occasionally recorded as well. With video these species and specimens might typically measure in the range of 5-20 cm of length. Smaller-sized species and specimens will be hard to detect or recognize whereas larger-sized species and specimens will probably only appear irregularly on the recording and might tend to stay out of sight (keep a distance from the moving object). Video recording might therefore provide some qualitative information (presence) on fish species living in the water column, but hardly any quantitative information on the role of wind parks in attracting larger-sized, pelagic and/or commercial fish-species.
Furthermore, fish models may make use of species names, abundance and weights of the benthic community, in combination with of the stomach content analysis of fish, to compare what is available as food with wat is eaten by the fish.

Table 4.4. Data needs of the MONS fish programme.

Data required	**Scrape results**	**Video results**
Species names (of hard substrate benthic species)	All species as present in samples.	All species >20 mm as visible on video, present in the visible top layer of the community.
Incidental observations on fish	Not possible.	Fish will be observed during video analysis.
Abundance (of hard substrate benthic species)	Abundance of individuals as present in samples. Known sampled area can be converted to individuals per m^2.	Abundance of individuals >20 mm present in the visible top layer of the community. Visible area can be estimated and can be converted to individuals per m^2.
Weight (of hard substrate benthic species)	Weight of individuals as present in samples. Known sampled area can be converted to individuals per m^2.	Not possible (unless in combination with physical sampling or reference to a size-weight regression database).
Additional samples (of hard substrate benthic species)	Additional samples of the community can be taken. It is likely that live specimens can be collected.	Not possible.

4.2.4 Benthos and benthic habitats (MONS §4.4)

Within the benthos section of MONS, the sections on Nature inclusive design of constructions (MONS §4.4.3.2.), Decommissioning of offshore wind farms (MONS §4.4.3.3.) and Protection of reef forming species (MONS §4.4.3.4.) may all require data from the hard substrate monitoring activities.
The Nature inclusive design (NID) section aims to optimise the designs while accounting for the presence of species of interest (e.g. oysters) and how these species develop in wind farms. NID structures will need to be studied using similar methods as applied to the wind turbine foundations, to estimate the added value and the influence of the use of different materials, habitat complexity, etc. The hard substrate monitoring in OWFs, therefore, will need to include the NID structures from the start, including the observations of fish, since some NID structures aim to facilitate fish populations, by functioning as refuges or nursery grounds.
At the end-of-life of an offshore wind farm, all structures that were introduced will need to be removed during the decommissioning phase, including NID structures. It is expected that the data generated on the epifauna communities on the NID structures will be included in the evaluation of the impact of this removal.
For the protection of species and nature restoration planning, information is needed on the potential of various sites/regions for restoration of biogenic reefs. In particular, the identification of tube worm reefs (*Sabellaria* spp. and *Lanice conchilega*) distribution is essential, but other reef builders such as

European flat oysters (*Ostrea edulis*) and horse mussels (*Modiolus modiolus*) are mentioned as well. Some of these species will likely be observed in the hard substrate monitoring. Possible additional attention is needed for these species, e.g. by acquiring extra samples for the purpose of identification of the most suitable substrates and creating shapes/contours of potential suitable substrates or communities present.

Table 4.5. Data needs of the MONS benthos and benthic habitats programme, excluding targeted monitoring of hard substrates.

Data required	**Scrape results**	**Video results**
Species names (of hard substrate benthic species)	All species as present in samples.	All species >20 mm as visible on video, present in the visible top layer of the community.
Incidental observations on fish	Not possible.	Fish will be observed during video analysis.
Abundance (of hard substrate benthic species)	Abundance of individuals as present in samples. Known sampled area can be converted to individuals per m^2.	Abundance of individuals >20 mm present in the visible top layer of the community. Visible area can be estimated and can be converted to individuals per m^2.
Weight (of hard substrate benthic species)	Weight of individuals as present in samples. Known sampled area can be converted to individuals per m^2.	Not possible (unless in combination with physical sampling or reference to a size-weight regression database).
Additional samples (of hard substrate benthic species)	Additional samples of the community can be taken. It is likely that live specimens can be collected.	Not possible.

4.2.5 Birds (MONS §4.5)

Bird research aims to study, *i.a.*, the attraction of birds to OWF. Research questions include whether reasons can be identified for any attraction of birds to OWF. This includes analysis of food availability. It is likely that data on epifauna species will be used for this, e.g. to assess the availability of shellfish on the turbine foundations or fish near the structures as a food resource to birds.

Table 4.6. Data needs of the birds programme.

Data required	**Scrape results**	**Video results**
Species names (of hard substrate benthic species)	All species as present in samples.	All species >20 mm as visible on video, present in the visible top layer of the community.
Incidental observations on fish	Not possible.	Fish will be observed during video analysis.
Abundance (of hard substrate benthic species)	Abundance of individuals as present in samples. Known sampled area can be converted to individuals per m^2.	Abundance of individuals >20 mm present in the visible top layer of the community. Visible area can be estimated and can be converted to individuals per m^2.
Weight (of hard substrate benthic species)	Weight of individuals as present in samples. Known sampled area can be converted to individuals per m^2.	Not possible (unless in combination with physical sampling or reference to a size-weight regression database).

4.3 Generic monitoring requirements

Based on previous international experience comparing and jointly analysing data from the epifauna communities in OWFs (Coolen et al., 2022, 2021; Dannheim et al., 2018), it is necessary to define a set of generic requirements. These requirements preferably should be included in a new 'Rijkswaterstaat voorschrift' (RWSV) or similar protocol, such as available for the collection of Hamon Grabs and other seabed samplers (Rijkswaterstaat, 2021a) and for the fresh or brackish shallow water macrozoobenthic suction sampler (Rijkswaterstaat, 2021b).

4.3.1 Sample quality

To guarantee a minimum quality of the data and allow international exchange and reuse of the data, the following aspects are considered essential:

- **Known size of sampled area**
  The area sampled should be registered, to allow extrapolation of data, e.g. to individuals per m^2, per turbine, per wind farm. For MONS, the sampled area should be identical to the previous Dutch OWF monitoring campaigns, in which 0.056 m^2 was sampled.
- **Limited damage to sampled organisms**
  Any method should attempt to limit the damage to organisms as much as reasonably possible, to prevent issues with later identification, e.g. due to missing parts. Damage may cause misidentification and introduce differences with previous monitoring results.
- **Near-all organisms removed from substrate**
  Within the sampled area, (nearly) all or nearly all macrofauna should be removed. Any novel method used should be able to sample ca. 100% of the fauna, in a similar manner as with previous methods when divers collected the samples.
- **Sieved mesh size 1 mm**
  Organisms should be collected using nets, containers or sieves with a mesh size of 1 mm, as it was used in the previous monitoring analyses.

4.3.2 Data requirements

4.3.2.1 Environmental data

The following environmental data should be measured and registered on the level of each sample:

- **Depth**
  Depth at which the sample was taken in meters of seawater (msw) with a known accuracy, e.g. ±0.1 m, against a reference water level, such as lowest astronomical tide (LAT).
- **Elevation above seabed**
  The depth of the seabed against LAT can be used to calculate the height of each sample above the seabed, which is registered with a known accuracy, e.g. ±0.1 m.
- **Orientation**
  Orientation of the substrate which was sampled. Some parts of turbine foundations and scour protection have a non-vertical orientation, and the wind direction of the sample combined with the direction of the prevailing current may vary between locations and between samples within a location. Orientation is known to cause variation in epifauna communities (Coolen et al., 2020c). Therefore, it is essential to register the orientation of the substrate, even when all samples were taken in the same orientation. Orientation should be registered in two values in degrees with a known accuracy, e.g. ± 10 degrees, in the direction perpendicular to the average of the plane of the sampled substrate. The first value indicates orientation in a horizonal plane (i.e. wind direction), the second the orientation in a vertical plane (i.e. if the substrate was oriented sideways, upward, etc.), where upward oriented samples score 0º, vertical samples 90º and downward oriented samples 180º. For example. a sample taken on the vertical structure of the monopile on the north-west side of the pile, is given a value of 315º (NW) for the horizonal plane and a value of 90º for the vertical plane.
- **Distance from structure**
  For samples taken on the scour protection or from NID structures, the distance from the nearest turbine foundation in meters is registered.
- **Exposure level**

The level to which a sampled substrates is exposed to the surrounding seawater and its inhabitants may influence the community and should be registered, most likely in a semi quantitative manner, e.g. 100% for the outside surface of turbine foundations, 0% for enclosed spaces with no or extremely limited water exchange (e.g. inside monopiles), 50% in between rocks of the SPL. This should be very well defined to allow systematic scoring between sampling campaigns over multiple years.

- **Salinity**
  Although not expected of much influence in Dutch offshore waters, salinity may play a role on the international scale of wind farm impacts. It can be easily measured during sampling and, therefore, is recommended to be included.
  Temperature
  This is an important factor related to seasonality and succession of the community (Coolen et al., 2022), can easily be measured during sampling and, therefore, is recommended to be included.
- **Substrate material**
  The sampled material may be of importance for the development of the community, with rock in the SPL attracting different species than the steel of the turbine foundation. Therefore, it is recommended to be included.
- **Substrate rugosity**
  The complexity of substrates is known to influence invertebrate community composition (Fuchs, 2013). Therefore the rugosity should be registered, most likely in a semi-quantitative manner, e.g. 0% for surfaces that are completely flat (without any curving), 10% for surfaces flat in one direction but slightly curved in the other direction, e.g. monopile foundations, 50% for surfaces with multiple small diameter curving or rough surfaces such as >0.5 m sized rocks and 100% for highly complex surfaces such as a large number of pebbles or gravel in a single sample. This should be very well defined to allow systematic scoring between sampling campaigns over multiple years.

4.3.2.2 Meta-data

Some data on the turbine or wind farm level should be registered to allow later assessment of high-level effects, e.g. between types of turbine foundation or scour protection:

- **Sampling date and time**
  The date is relevant for later analysis of temporal (e.g. seasonal) patterns, the time is relevant for calculations of LAT vs sampled depth.
- **Geographical coordinates**
  The position of each sampled turbine foundation or NID structure should be registered.
- **Structure type**
  This should include information that it is a wind farm, and which type of foundation this has, e.g. monopile (diameter xx m), gravity-based foundation, tripod, jacket, floating, etc.
- **Substructure type**
  Was the sample taken from a certain part of the foundation, e.g. from the SPL
- **SPL grading**
  What is the size of the rocks in the SPL in general? Often a median diameter of the rocks is provided and should be registered. This is essential information to inform future nature inclusive design of SPL.
- **SPL material**
  What material was used for the SPL in general, e.g. granite, sand stone, marble, etc. Were other materials included, such as shells, oysters, concrete, etc. This is essential information to inform future nature inclusive design of SPL.
- **SPL height above seabed**
  The maximum height of the SPL rocks above the seabed, is registered with a known accuracy, e.g. ±0.1 m.
- **NID material**
  The material used in a NID structure that is samples, should be described in general, to reflect whether the material described for each sample is identical or different from other parts of the structure.

4.4 Expected species

In most monitoring programmes carried out in the southern North Sea, communities were dominated by three species groups, in a depth related pattern (Figure 4.1). Although some variation has been observed between countries and age of the installations (Coolen et al., 2022; Degraer et al., 2020), in all cases, the blue mussel (*Mytilus edulis*) was the dominant species in the intertidal zone and first 5 to 10 meters of the subtidal zone. Then, in most cases, a mixture of hydroids, mostly the oaten pipes hydroid (*Tubularia indivisa*) covered with large numbers of amphipods, mostly *Jassa herdmani*, was present between 5 to 15 meters water depth. Finally, the deeper parts of foundations and SPL are dominated by anemones, mostly the plumose anemone (*Metridium senile*).

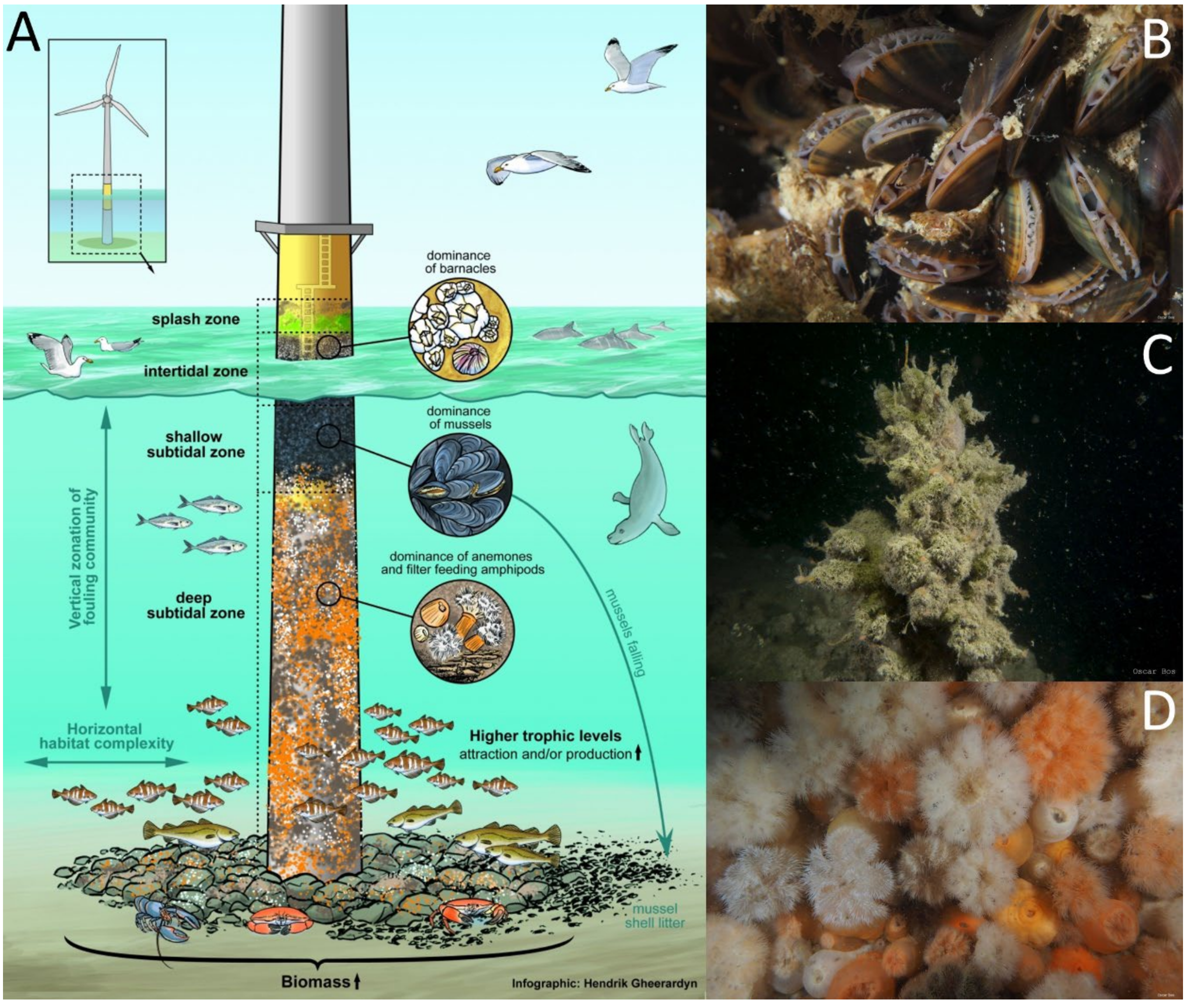

Figure 4.1 *A: Depth related patterns on wind turbine foundations* (Degraer et al., 2020)*, B: blue mussels, C: oaten pipes hydroids covered by amphipods, D: plumose anemones, photos by Oscar Bos (WMR).*

However, in the near future, OWFs in the Netherlands will be developed farther offshore than the current installations. This will likely result in additional common species (Figure 4.2), such as colonies of the soft coral dead man's fingers (*Alcyonium digitatum*) mixed in the deeper zone with plumose anemones and large sponges, as observed on offshore platforms and shipwrecks (Schrieken et al., 2013; Schutter et al., 2019; van der Stap et al., 2016). Furthermore, encrusting tube worms such as *Spirobranchus* spp. and Ross worm (*Sabellaria spinulosa*) become more abundant, in particular on far offshore sites in the direction of UK waters (Coolen et al., 2020c).

In addition to the dominant species, a long list of benthic species can be expected. The ICES Working Group on Marine Benthal and Renewable Energy Devices (WGMBRED) collected data from research around offshore installations in Belgium, the Netherlands, Germany and Denmark, including seven OWFs and nine oil and gas platforms (Coolen et al., 2021). This dataset contains about 700 hard substrate associated species.

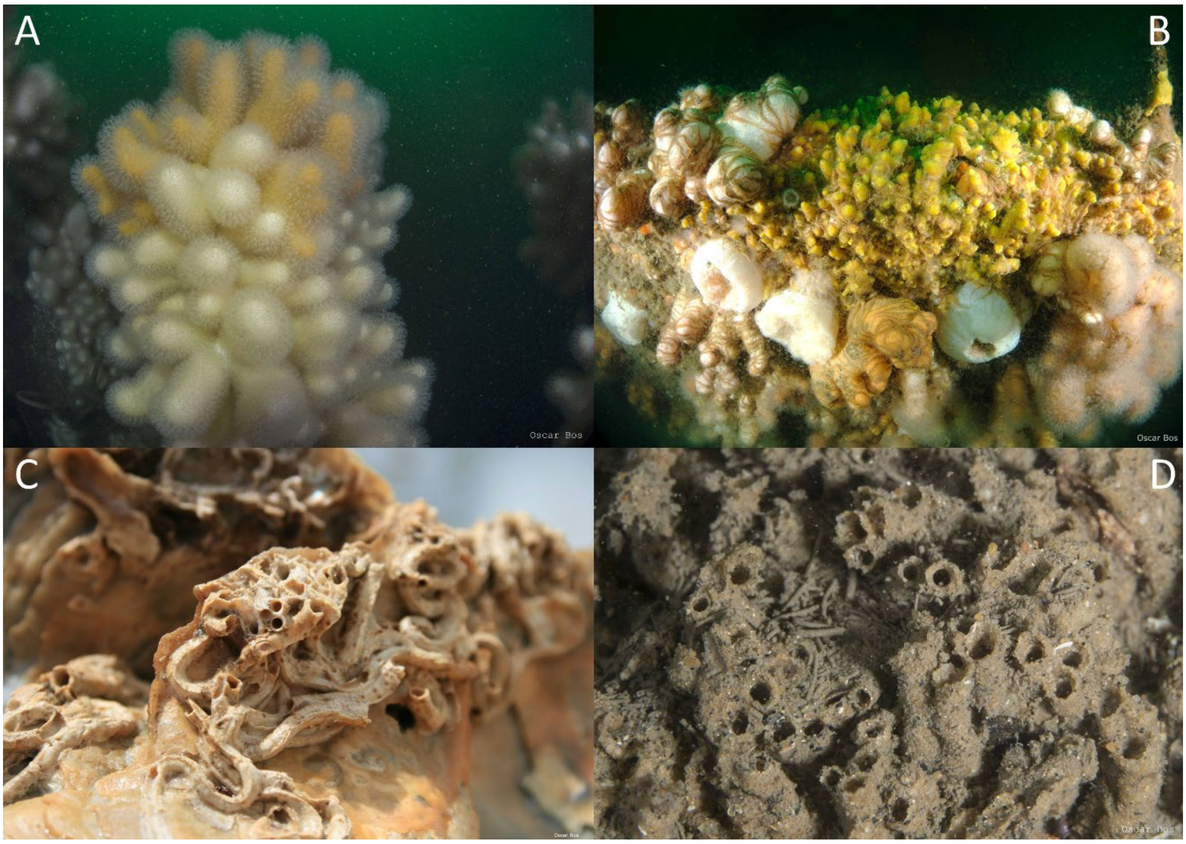

Figure 4.2 *Species that can be expected on far offshore locations. A: dead man's finger, B: large sponges, C: calcareous tube worms, D: Ross worm. Photos by Oscar Bos (WMR).*

4.5 Location planning

For the MONS hard substrate video monitoring plan, an analysis has been made of the locations that could be included (Wijnhoven et al., 2022). Since video analysis is less time consuming than scrape sample analysis, it is expected that a lower number of OWFs can be studied for the scrape sampling monitoring. However, this can only be evaluated once the scrape sample acquisition method is known and can be compared to the MONS budget, as the total budget available for the monitoring may limit the number of sites, depending on the cost of the method. Therefore, no location planning is included in this report. It is suggested to align with the proposed monitoring design of Wijnhoven et al. (2022) regarding the selection of specific wind turbines and wind parks, although the number of monitoring sites and variables to be compared (and the proposed number of samples to allow the detection of differences between different situations) might deviate.

5 Methods to study hard substrate communities in OWF

Methods that have been applied in reef research in the south eastern North Sea were inventoried. Experience from offshore wind farms, offshore oil and gas platforms, shipwrecks and geogenic reefs (see Table 5.1), was included. Since novel methods may be needed to improve safety and cost efficiency of sample acquisition, a set of methods with which there is no or very limited prior experience in OWFs in the Netherlands as well as methods that are under development, have been included as well.

Table 5.1. Overview of hard substrate studies per reef type

Reef type	Reference
Offshore wind farms	Bouma and Lengkeek, 2013; De Mesel et al., 2015; Krone et al., 2013b; Mavraki et al., 2021; Vanagt and Faasse, 2014
Oil and gas platforms	Coolen et al., 2020c, 2020a, 2020b; Luttikhuizen et al., 2019; Schutter et al., 2019; van der Stap et al., 2016
Shipwrecks	Coolen et al., 2016; Krone and Schröder, 2011; Lengkeek et al., 2013b, 2013a; Schrieken et al., 2013
Geogenic reefs	Coolen et al., 2015a; Lengkeek et al., 2017; Schrieken et al., 2013

The MONS OWF scrape monitoring programme aims to collect quantitative data on the complete epifauna community, including small species, and provide weights and counts of all species. Video monitoring will not be able to provide the needed data, since significant taxonomic detail is often lacking and many species are not visible on video (van der Stap et al., 2016). For completeness, however, a few available video methods are shortly described at the start of this chapter. The focus of the following sections, however, will be on (innovative) methods capable of collecting physical samples from the hard substrates in OWFs.

It should be noted that no single method can provide a complete inventory of all epifauna and attracted larger, mobile species. Small scrape samples are ideal for the detection of small species (1 to 50 mm) and allow detailed quantification, in particular of weights and abundances, but lack the ability to study the community on scales above a few m^2 per turbine foundation, since the acquisition and processing of the samples is very labour intensive. Video surveys on the other hand are ideal for the inventory of species across large areas, e.g. covering thousands of m^2 in a single survey within a day, but they lack the ability to identify small species (e.g. below 20 mm) or species occurring underneath thick epifauna communities. However, the combination of such techniques may be able to provide the best possible inventory within the limited timeline or available budget of programmes such as MONS.

5.1 Video

Video analysis has a long history of application in offshore industry and is suitable to collect images on the large (>20 mm) species in the top layer of the epifauna community (Schutter et al., 2019; van der Stap et al., 2016). In recent years it has also been applied in targeted monitoring programmes of geogenic reefs, either by drop cam (Coolen et al., 2015a) or by video cameras mounted on ROVs (Bureau Waardenburg et al., 2020). Drop cam video is ideal for fast and cost-efficient inventory of bottom fauna but is less suitable to collect high quality footage in the vertical plane, along the turbine foundation. ROV mounted video analysis has already been identified within MONS as a suitable method to study the epifauna communities on the turbine foundation scale. ROV mounted cameras are capable of filming in all directions where both ROV and camera can move. Fibre optic lines available on

ROVs allow for extremely high data through-put and can be fitted with high-end resolution cameras (e.g. 4K; personal communication Jan-Jelle Huizinga, Bluestream Offshore b.v.).
Software optimised for the quantification of species on the video is available on the market and has been applied in monitoring and research in the Netherlands. Further details on video monitoring in OWF as part of MONS can be found in the MONS video monitoring plan (Wijnhoven et al., 2022).

5.2 Diving

To date, physical sample acquisition from the epifauna communities in OWFs has been exclusively carried out by divers. In the Netherlands, in the OWEZ and Princess Amalia OWF, commercial surface supplied divers have sampled the turbine foundations by scraping the fauna and collecting it in a macrofauna net. The SPL was sampled by picking rocks and transporting these to the surface (Bouma and Lengkeek, 2012; Vanagt and Faasse, 2014).
Similar methods were applied in Belgium, although there, scientific scuba divers collected the samples (De Mesel et al., 2015). Recently in Germany, samples were taken by scientific divers using surface supplied equipment from a small rigid-hull inflatable boat (RIB; personal communication by Roland Krone, Krone-Projekte). Similar methods have been applied in Germany to perform visual counts by divers (Krone et al., 2017, 2013a). In the Danish Horns Rev wind farm, samples were collected by scuba divers, scraping both the turbine foundation and the large rocks of the SPL (Leonhard and Frederiksen, 2006). Diving methods in Dutch North Sea conditions can be divided roughly into two types, scuba diving and surface supplied diving (SSE). Since both methods are commonly used in OWF in the international North Sea, they will both be evaluated here. One specialism of SSE diving is dry bell / saturation diving. Since at this point the expected depths of OWFs in the Netherlands do not require this type of diving, saturation diving is not further considered in this report.

Both methods are suitable from a scientific sample collection and quality point of view. Divers can quantitatively scrape and collect the fauna from turbine foundations, NID structures and very large rocks in the SPL, or collect small to medium sized rocks from SPL and place them in nets in lifting baskets that can be taken on board by lifting from deck. Since these methods have been applied many times before, no further detail is given below and focus will be on the feasibility of the diving itself.

5.2.1 SCUBA diving

Scuba is an acronym of Self Contained Underwater Breathing Apparatus. This means that the breathing equipment used by the diver operates without the need of external sources of breathing gas. The breathing gas can be air or a mix of air with additional oxygen and/or helium. This breathing gas is carried on the diver’s back in a pressurised tank. Depending on depth, tank size and activity, a diver can remain under water for hours, but in the North Sea diving times of maximum 1 hour are common (personal observations Joop W.P. Coolen). Scuba is the most used method in the recreational diving industry as well as in scientific diving around the world. Many different organisations provide scuba diving training. When following the Dutch requirements for diving at work (see §6.2 on diving regulations), a formal commercial scuba training should be followed, and exams carried out following the certifying institutes criteria. Commercial scuba divers in the Netherlands can carry out diving operations to a depth of maximum 30 meters. For deeper diving additional training is required. Scuba divers can make use of wireless or wired voice communication when using full face masks outfitted with a communication box that is connected to a communication set on the surface. Communication is possible among divers and between the diver(s) and the surface unit.

Hard substrate monitoring in OWFs has been carried out by scuba divers in Belgium (De Mesel et al., 2015), Denmark (Leonhard and Frederiksen, 2006) and the United Kingdom (Bessell, 2008), but not in the Netherlands, where surface supplied diving was used (Bouma and Lengkeek, 2012; Vanagt and Faasse, 2014). However, various non OWF related hard substrate research projects have been carried out successfully in the Dutch part of the North Sea using scuba methods. Recent projects include:

- An inventory of the epifauna community on the Halfweg concrete gravity based foundation in the Netherlands after removal of the gas platform that was present on top of this foundation (Coolen et al., 2020a).

- Inventories around biogenic reefs, such as the mixed shellfish reef in the Voordelta (Christianen et al., 2018; Sas et al., 2018, 2016).
- Inventory of the epifauna community on an experimental concrete anchor placed for the slow mill wave energy generator (unpublished work by Rob Witbaard, NIOZ).
- Inventory of epifauna communities on shipwrecks, as part as an assessment of the need to protect shipwrecks as reef habitat (Lengkeek et al., 2013b) and as part of multiple scientific research projects (Beermann et al., 2020; Coolen, 2017; Coolen et al., 2016, 2015b; Luttikhuizen et al., 2019; van Walraven et al., 2016).

This shows that scuba methods are suitable to study hard substrate communities around artificial structures using methods that are accepted in the scientific community.

However, in the Working Conditions Catalogue: Working under Hyperbaric Conditions (WCC; §6.2) diving work using scuba equipment around offshore energy installations, is excluded. Since the Dutch offshore industry strictly follows the WCC rules and for monitoring work in OWF, permission from the operator is mandatory, it is unlikely that scuba diving methods will be allowed in Dutch offshore wind farms.

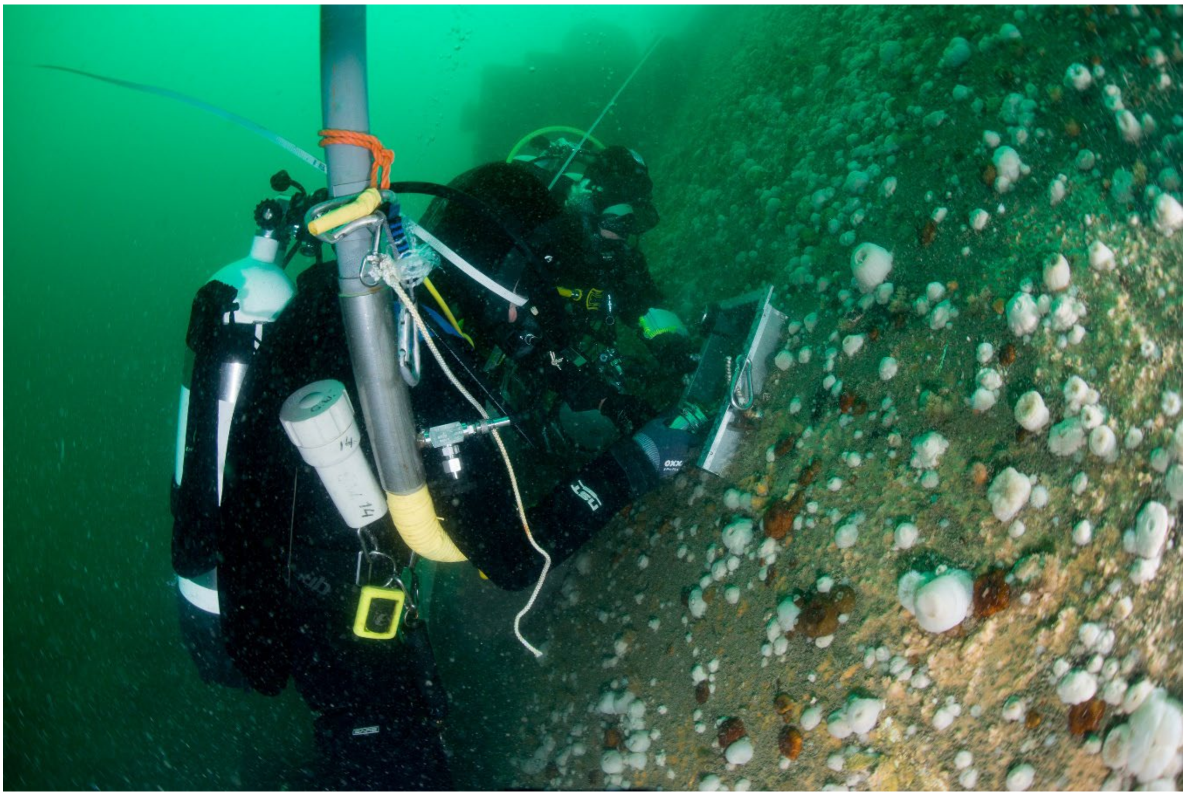

Figure 5.1 *Commercial scientific scuba divers collecting epifauna samples from the vertical walls of the Halfweg gravity based foundation using an airlift sampler and sampling frame. Photo by Udo van Dongen, Bureau Waardenburg b.v..*

5.2.2 Surface supplied diving

Surface supplied equipment (SSE, Figure 5.2) diving is a method in which the diver receives breathing gas from the surface via an umbilical (air hose). The divers are fitted with a helmet or large band mask, which is outfitted with a breathing system, voice communication and optional camera system. A backup air supply is present in a small tank on the divers back. Often offshore divers also carry a positioning beacon, allowing a surface support team to monitor the position of the divers in 3 dimensions. When no beacon is carried, the surface team can also register the diver’s depth via the pneumo hose in the umbilical. The main difference between scuba and SSE is the practically unlimited supply of air available to the diver, significantly increasing safety, which is considered very important in offshore industry (personal communication Mark Waltman, Bluestream Offshore b.v.). Other standard facilities present in SSE diving, such as the live video feed, are not common in scuba diving but are possible when the scuba diver is wired to the surface.

Figure 5.2 *Scientific SSE diver Joop Coolen (WMR) ready to enter the water to sample an offshore installation. Photos by Ulf Sjoqvist (Neptune Energy).*

SSE diving is the standard in the offshore industry and has been used in the past in multiple monitoring and scientific campaigns. Internationally, SSE divers sampled wind turbine foundations in Germany (Krone et al., 2017) and the United Kingdom (Emu Limited, 2008).
Various OWF and non-OWF related hard substrate research projects have been carried out successfully in the Dutch part of the North Sea using SSE diving methods. These projects include:

- Monitoring of the epifauna communities in the Offshore Windfarm Egmond aan Zee in multiple years after construction (Bouma and Lengkeek, 2012, 2008).
- Monitoring of the epifauna communities in the Princess Amalia Wind Farm in multiple years after construction (Coolen et al., 2020c; Vanagt et al., 2013; Vanagt and Faasse, 2014).
- Scientific research on oil and gas platform foundations operated by Neptune Energy (GDF Suez / Engie at the time), including the L10-A complex, L15-A, Q13-A, K9-A, D15-A platforms and several others (Bos et al., 2019; Coolen et al., 2020c, 2020b, 2016).
- Scientific research on gas platform foundations operated by Petrogas, on the A12-CPP and Q1 Haven platforms (unpublished work by Joop W.P. Coolen).

This shows that SSE diving is suitable to study hard substrate communities around artificial structures, including offshore wind farms, using methods that are accepted in the scientific community.

For the evaluation of the feasibility of SSE diving for the MONS hard substrate monitoring, much more detail is necessary to be included. For example, the type of vessel has much influence on the project costs, diving work is weather dependent and different regulations between operators can be expected. In the past, diving vessels have moored to the OWF foundation, allowing the shutdown of all moving parts in the water, making diving operations relatively easy and cost-efficient as compared to diving from dynamic positioning (DP) vessels. At this point, it is uncertain whether OWF operators might allow this mooring to the turbine foundations again. This needs to be discussed on a case-by-case basis with vessel operators, diving companies, OWF operators and the relevant authorities. It highly depends on the material stress caused to the turbine foundation by the vessel tugging continuously on the mooring ropes, in particular in poor weather conditions (personal communication Rob Tegel, Vattenfall). It is likely that smaller vessels will easier receive permission to moor to the foundation than larger ones. Additional considerations include the need to stop the wind turbine generator (WTG) from moving (personal communication Mark Waltman, Bluestream Offshore b.v.). If this is needed during diving operations the operator may incur significant costs as no energy can be produced at that time.

Alternative methods could be considered, e.g. by SSE diving from a very small vessel, such as a large RIB, outfitted with a simple SSE system and operating together with a larger vessel that is standby near the turbine foundation, but at a safe distance from the diver and without collision risk to the foundation. The large vessel can house all the larger safety requirements, such as the compression chamber, and house the dive team when standby. The small vessel is likely to be accepted for mooring on turbine foundations. This method is likely to be more cost-efficient than working from DP vessels and may be better accepted from the viewpoint of risk to the turbine foundation. It is, however, more weather dependent and could be considered less safe, since safety systems are on standby at some distance from the dive team, in contrast to diving directly from a large vessel on which these are present around the dive team. This method was proposed by a consortium of Bureau Waardenburg and Wageningen Marine Research as a safe hybrid method suitable for scientific SSE diving around offshore energy structures but was never discussed with industry as a result of the COVID-19 pandemic. Since it is a non-standard way of diving, the feasibility needs to be further discussed with diving companies and OWF operators. Bluestream offshore (personal communication Mark Waltman) indicated that this way of working would be stand-alone and cannot be combined with work at other sites that do apply standard methods of SSE diving. It is unclear at this time whether this proposed method indeed would be more cost efficient than diving methods applied during previous campaigns.

Since SSE diving is accepted in industry, proposing a monitoring of OWF foundations by SSE diving is an option in MONS. However, the industry only accepts diving as a method if no other safer and suitable methods are available. Therefore, the use of remotely operated vehicles needs to be considered as an alternative method to SSE diving.

5.3 Remotely operated vehicles

ROVs are tethered drone-like robots built for underwater operations. Many models are available on the market, but the models commonly used in the Dutch offshore industry and by Rijkswaterstaat are the small observation class ROVs and observation class with light intervention tools, such as manipulator arms, or the slightly larger light work-class type. Observation class ROVs are optimised to collect video footage during inspections and perform simple measurements and other tasks, e.g. grabbing light equipment and cutting ropes. In the Netherlands, models that are in use include the Saab Seaeye Tiger (Figure 5.3) which is used mostly for video inspection and measurements with sensors, and the Saab Seaeye Panther-XT Plus (Figure 5.4) which is in use in offshore industry as well as by Rijkswaterstaat. The common tooling on an ROV can include a camera, video lights, depth sensor, sonar imaging, positioning beacon and manipulator arms (Figure 5.5). The acquisition of samples using an ROV can likely be combined with video monitoring at the sampled sites to acquire larger scale images of the fouling communities, as described in the MONS video monitoring programme report (Wijnhoven et al., 2022). Further specialised but still common tooling include systems to remove epifauna from structures, such as high pressure guns or high speed spinning flaps similar to grass trimmer wire. However, to acquire quantitative samples from a wind turbine foundation, additional (innovative) tools are needed. The sampling process with an ROV would consist of multiple steps when scraping samples:

1. The ROV system is prepared and deployed, most likely using a launch and recovery system (LARS).
2. The ROV approaches the turbine foundation and site to be sampled and docks the sampling tool.
3. The epifauna is scraped from the structure, making it available to be collected.
4. During the scraping, the loosened epifauna is collected and stored.
5. Once the required surface area has been cleaned of epifauna and all fauna is collected and stored, the ROV will detach the sampling tool from the turbine foundation.

   a. In case multiple samples can be stored independently with the ROV, steps 2-5 will be repeated and then the sampling ends for this deployment.
   b. In case a single sample can be stored with the ROV, sampling now ends for this deployment.
6. The ROV navigates back to the tether management system (TMS) for recovery.
7. The ROV is recovered on deck.
8. On deck, the samples are removed from the storage and will be processed, conserved and stored.
9. In case additional samples are needed, steps 1-8 are repeated.

The following considerations should be noted about this process:
- The position of the scraping tool should remain stable during the sampling process to prevent loss of sample and to attain a known sampled area.
- The loosened fauna should remain mostly intact on an individual level, during scraping and then during collection, and storage inside the sampling tool, i.e. not be chopped in many small pieces since it will need to be identified in the laboratory later on.
- Any mesh used to store the fauna should meet the maximum mesh size requirements, e.g. maximum mesh hole size of 1x1 mm.
- The sample should be kept inside the sampling tool storage and protected from being washed out. Even negatively buoyant organism such as mussels can be expected to wash out with movement of the ROV in waves and current.
- In case multiple samples are stored in the sampling tool, any mixing between samples should be prevented, i.e. each sample should be isolated from all the others.

At this point, no tool exists that can complete all the steps given the considerations above. Some tools exist that can accomplish part of the steps. Furthermore, a tool is currently being developed by WMR and Bluestream offshore b.v., which may in the future be able to complete all the steps while meeting the considerations. The available tools and tool under development are described in the next sections.

With regards to the collection of rocks from the SPL, different tools are available on the market, e.g. using ROV manipulator arms to grab rocks and place them in nets in baskets, like divers have done in the past, or use a scoop or grab. These potential tools are described in the next section as well.

Figure 5.3 *Older model Saab Seaeye Tiger ROV, as used in offshore industry for video inspections and small sensor measurements. Photo: Joop W.P. Coolen.*

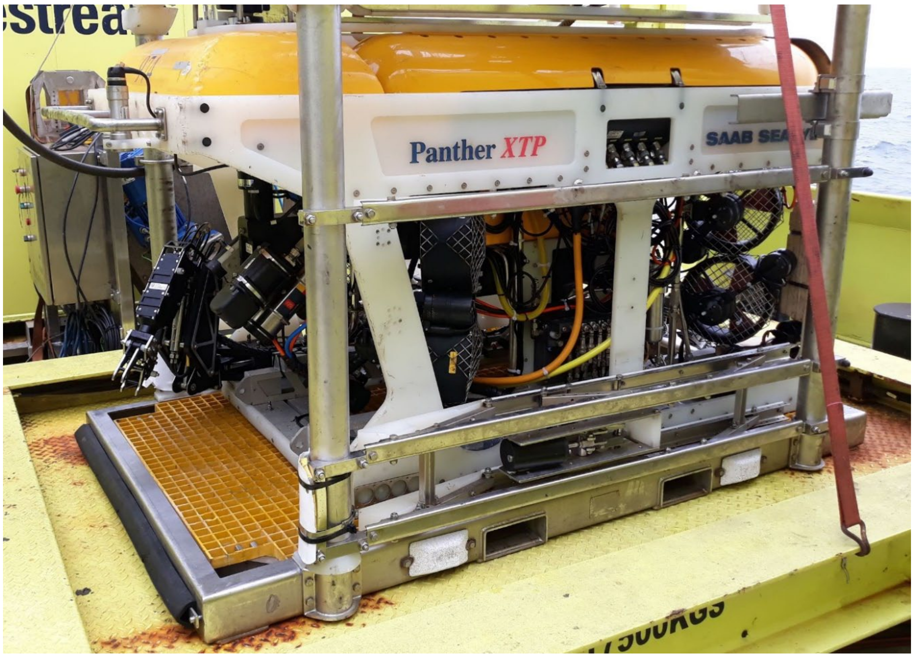

Figure 5.4 *Saab Seaeye Panther-XT Plus ROV in use by Rijkswaterstaat. Here visible inside the launch and recovery systems (LARS), a metal garage-like frame used to safely deploy and recover the ROV. Photo: Joop W.P. Coolen.*

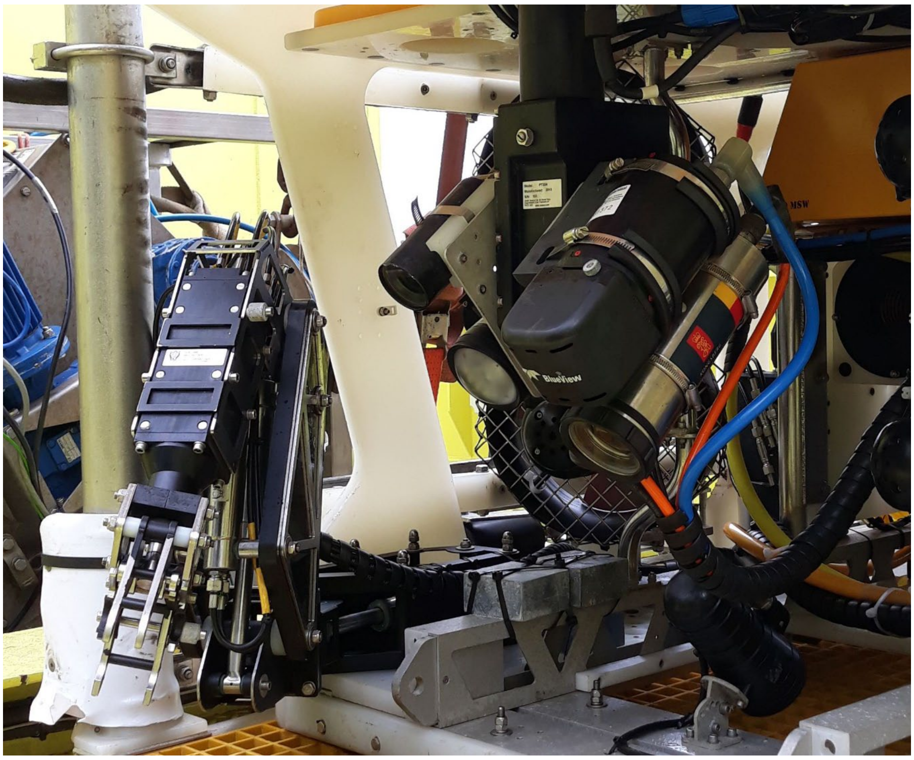

Figure 5.5 *Manipulator arm (left) and 4K camera system with video light (right) as present on the Saab Seaeye Panther-XT Plus ROV in use by Rijkswaterstaat. Photo: Joop W.P. Coolen.*

5.3.1 Currently available methods

Various methods are available on the market, that are able to scrape and/or collect epifauna from artificial structures. Here an exhaustive list is given of the methods that are deemed compatible with the ROVs described in the previous section.

5.3.1.1 Manipulator arms with putty knife and macrofauna net

Commonly used tools on ROVs include the manipulator arms as described in the previous section. Manipulator arms are capable of movement in various dimensions, similar to a human arm. In perfect conditions, an ROV could probably obtain a sample from a vertical structure, by placing a putty knife in one manipulator and a macrofauna net to collect the fauna in the second manipulator. With the putty knife the fauna can be scraped off after which it falls into the net. However, in the North Sea, conditions are almost never perfect. The ROV is moved in different directions by the water current and waves, which requires continuous positioning. Since there is a lag between the movement of the ROV and correction by the ROV pilot, this will likely result in many missed attempts to scrape and collect fauna. Any quantitative sampling is near-impossible using this method. Therefore, this method is regarded as unsuitable for the purpose of the MONS hard substrate monitoring.

5.3.1.2 ROV suction samplers

Suction samplers are available on the market from different producers. In general, they contain a hose capable of sucking in organisms, which are then transported to one of the multiple storage containers or nets. The water is then sieved and the organisms remain stored in the containers. A revolving rosette is then used to switch between the filled container with an empty one, after which a new independent sample can be taken. This storage of multiple samples is important as it saves time. The recovery of the ROV between each sample is more time consuming than recovery between sets of multiple samples. The following products are available:

Cellula Robotics ROV Suction Sampler

The Suction Sampler (Cellula Robotics, 2021) is a system with eight revolving two litre containers in a rosette. The bottom of the containers is fitted with a sieve with 1.5 or 3 mm holes, to which a suction pump is connected. Fauna is sucked into the inlet hose, then transported to the container and separated from the water, which passes through the sieve into the pump. After sampling the rosette turns 1/8, sealing off the first container and making an empty one available to be filled. The ROV Suction Sampler requires two proportional hydraulic valves on the ROV to operate the turning of the rosette and to drive the pump.

The system does not include a scraping device nor a method to guarantee a known area is sampled in a repeatable manner. It is possible to customise the system on request and it may be possible to add a scraping system and larger sample containers.

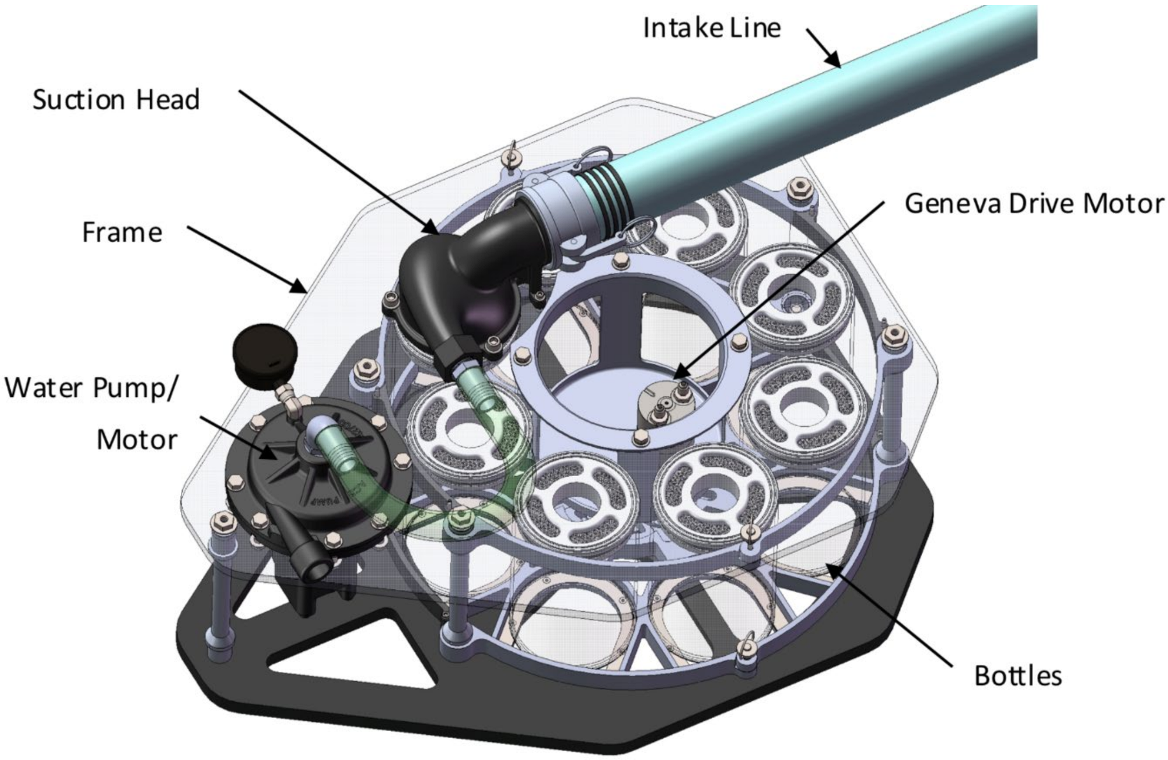

Figure 5.6 *Cellula Robotics ROV Suction Sampler. Image by Cellula Robotics* (Cellula Robotics, 2021).

Global Foundation for Ocean Exploration suction sampler

This suction sampler (Cantwell et al., 2019; McLetchie and Dunn, 2019) is very similar to the Cellula version, but with six containers each of 2.7 litres. Other features are similar to the Cellula version. The system does not include a scraping device nor a method to guarantee a known area is sampled in a repeatable manner. Furthermore, the system appears custom-built for the United States National Oceanic and Atmospheric Administration (NOAA) and is not advertised for purchase, which is the case for the Cellula version.

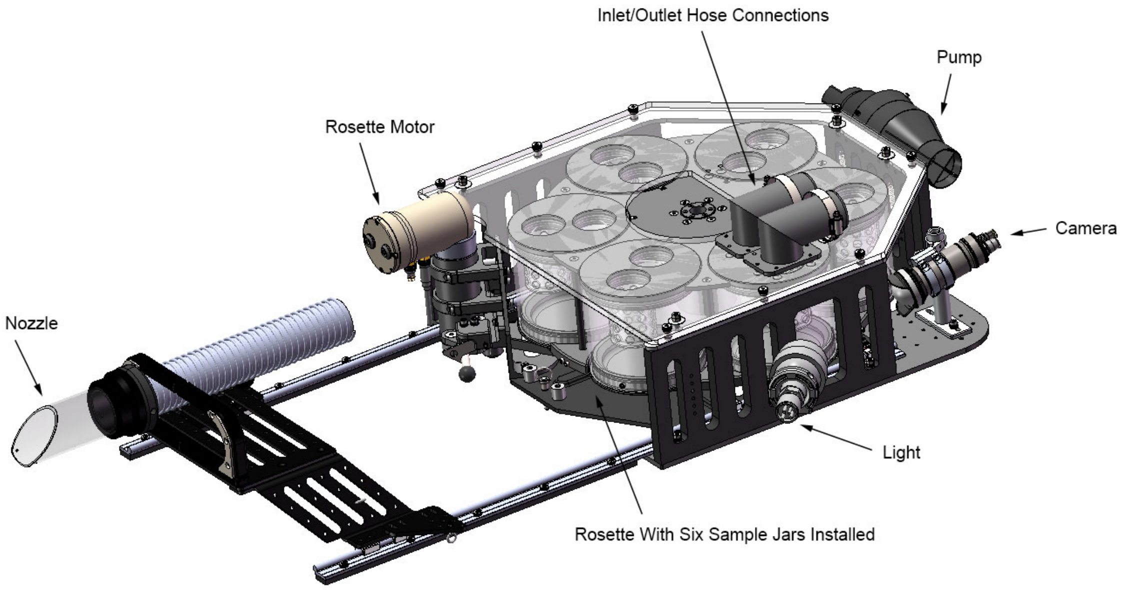

Figure 5.7 *Global Foundation for Ocean Exploration suction sampler as operated by NOAA. Image by Global Foundation for Ocean Exploration* (McLetchie and Dunn, 2019).

Vortex marine growth sampler

The marine growth sampler (Vortex Subsea Solutions, 2021a) is built to remove epifauna from artificial structures by scraping and then collecting and storing the fauna in a carousel of seven sampling nets with a mesh size of 1 mm. The tool is used in conjunction with a Vortex dredge pump. The system operates with a vortex by injecting high-pressure water at the end of the inlet hose, near the sample bag frame. This creates an under-pressure on the inlet side with the scraping tool. Thereby all fauna that is scraped off, is directly sucked into the hose and deposited in the sample nets. The tool has been applied to epifauna sample acquisition before. Although the tool is designed for working-class ROVs, which are much larger than the type described above, the producer suggested it should fit on an ROV such as the Saab Seaeye Panther-XT Plus operated by Rijkswaterstaat, if modifications, such as an additional hydraulic line to provide the additional flow need to operate the tool (personal communication by Joe Goodin, Vortex Subsea Solutions), are made. The system does not include a method to guarantee a known area is sampled in a repeatable manner.

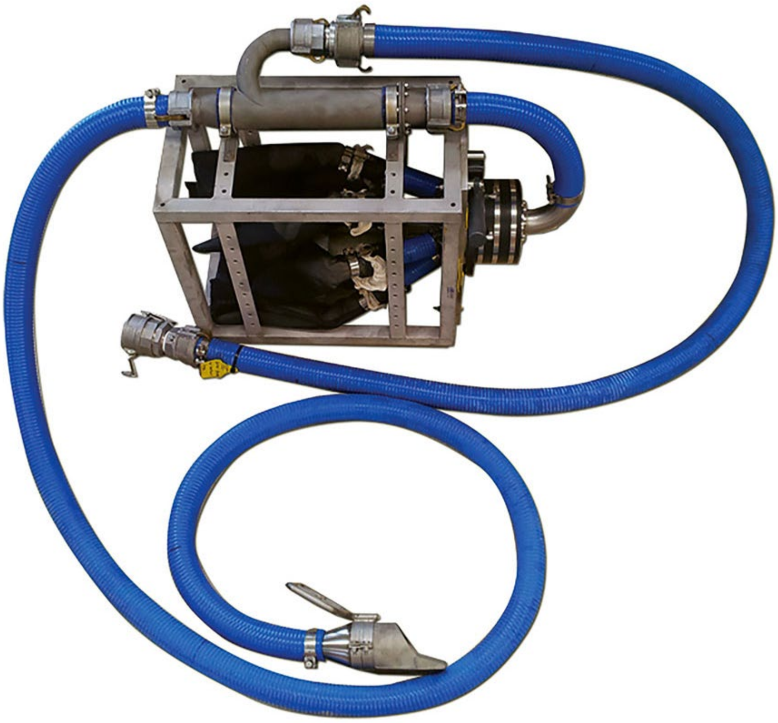

Figure 5.8 *Vortex marine growth sampler with scraping tool shown in the bottom and the frame containing the sample net revolver on top. Image by Vortex Subsea Solutions* (Vortex Subsea Solutions, 2021a).

Considering all the methods available, no single method meets all the requirements that are expected in the MONS hard substrate monitoring (Table 5.2). In particular, the sampling of a known area and then systematically repeating this known area, is not possible with any of the existing tools. Some tools are capable of removing the epifauna and all are designed for collecting it once scraped. The level of automation is high on all tools with the exception of the simple putty knife and net method, which requires many manual actions from the ROV pilot.
Overall, no tool available on the market at this time is suitable for the collection of standard sized, quantitative and sufficiently automated samples from offshore wind farm foundations.

Table 5.2 *Available ROV sampling methods overview with capability of sampling an area of known size and repeating this in a systematic manner, scraping epifauna from a wind turbine foundations, storage of the sample and level of automation, an indication of the number of manual actions required by the ROV pilot while sampling.*

Tool name	Area quantitative	Fauna scraping	Storage	Automation
Diver-like scraping-collecting	No	Yes	Yes	Low
Cellula ROV Suction Sampler	No	No	Yes	High
GFfOE suction sampler	No	No	Yes	High
Vortex marine growth sampler	No	Yes	Yes	High

5.3.1.3 ROV tools for collecting SPL rocks

In the past, divers have collected rocks from the SPL around turbine foundations by grabbing a rock, placing it in a sampling net and then in a lifting crate, or taking small rocks in nets with them during the divers' ascent. ROV tools that may be able to collect rocks in a similar manner, are described here.

ROV manipulator arms

The manipulator arms present on the ROV have been used before to collect rocks from the seabed (Figure 5.9). In OWFs small to medium sized rock that fit between the manipulator arms' fingers, could be grabbed and then placed in a basket containing a sampling net. Multiple rocks could be collected this way and placed in separate compartments in the basket. Baskets can then be lifted to the surface and processed on board. The maximum size of the rocks that can be collected depends on the size of the manipulator arms. Possibly a manipulator arm optimised for the collection of larger rocks could be developed in the future.

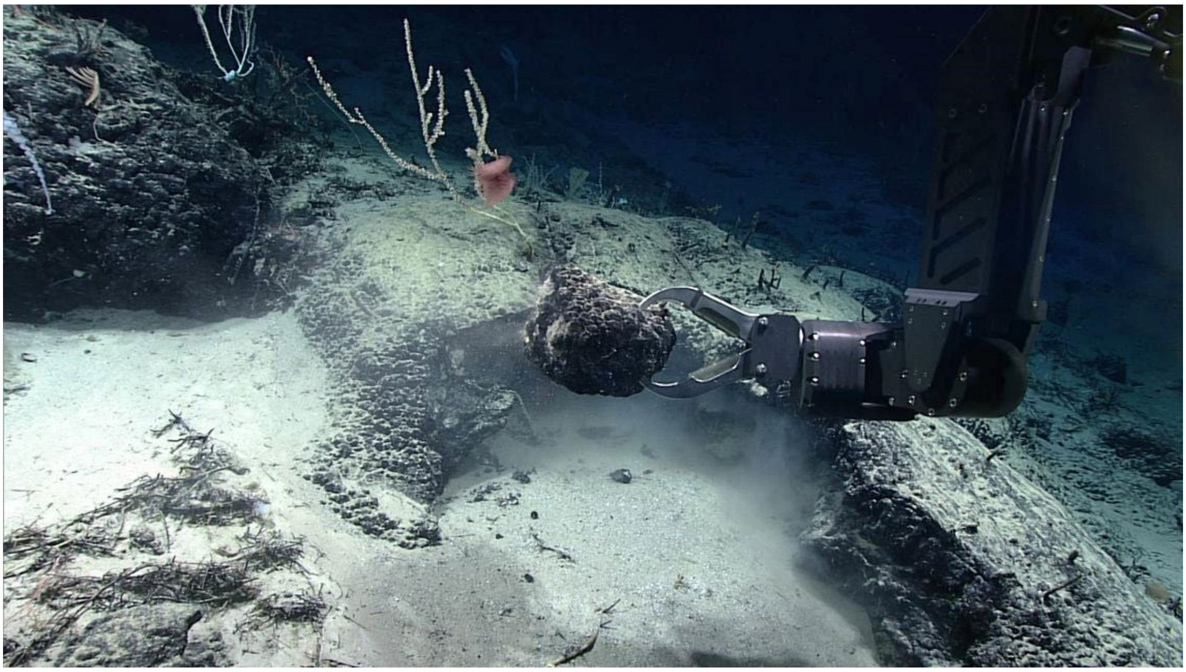

Figure 5.9 *ROV manipulator arm collecting a rock from the seabed in deep waters in the North Atlantic* (NOAA, 2021).

ROV mounted scoops

Different types of scoops have been applied to the collection of sediment and rock-like objects in the past. For example, Monterey Bay Aquarium Research Institute scientists have applied an ROV mounted clam scoop to collect shellfish from the seabed (MBARI, 2013). This scoop looks like a large candy scoop with a lid on top that can be closed remotely after dredging a clam in the container.
The Deep Trekker ROV producing company sells a sediment scoop to be mounted on their Revolution ROV (Deep Trekker, 2021). Although these relatively small types of ROVs are not used in the offshore industry in the Netherlands, a similar tool may be created for the larger ROV classes, which could possible allow the ROV to collect larger rocks than possible with a manipulator arm.

Figure 5.10 *Deep trekker Revolution ROV with sediment scoop* (Deep Trekker, 2021).

5.3.1.4 Non-ROV tools for the collection of SPL rocks

In addition to ROV mounted tools, remote surface-based tools could be considered, although using these there is limited control over where a sample is taken. When using these systems to sample the SPL, it is important to consider any potential damage to the monopile or cables on the pile and on the seabed, e.g. if there is limited control over the grab, this will be considered a risk by the OWF operator (personal communication Richard Brocx, Eneco and Rob Tegel, Vattenfall).

Van Veen grab

One of the fastest tools available to collect seabed samples, is a van Veen grab. The Vortex Seabed Sample Grab Tool (Vortex Subsea Solutions, 2021b) is similar to a van Veen grab. It consists of a grab mounted in a frame, which closes once the frame is lifted after it touches the seabed. Although not specifically designed for grabbing rocks and likely to be blocked when applied to larger rocks, it may be suitable to collect small to medium sized rocks from the SPL (Figure 5.11).

Figure 5.11 *Vortex Seabed Sample Grab Tool, A: complete tool with lifting sling visible on top, B: grab closing on the seabed, C: sampled area after lifting of the tool* (Vortex Subsea Solutions, 2021b).

Hamon grab

A much heavier tool is the Hamon grab (Figure 5.12). This is designed to obtain samples in coarse sediments and is optimised to reduce blockage by rocks in the sample. The trigger mechanism is activated once the system hits the seabed, after which a bucket scoops up a portion of the seabed. It is likely that a Hamon grab can successfully sample the SPL, but whether this type of heavy equipment with limited control over where the sample is taken exactly, is allowed on the SPL should be discussed with OWF operators.

Figure 5.12 *Hamon grab as operated by the Royal Netherlands Institute of Sea Research. The scooping bucket is visible on the middle right. The grab in this photo is placed on the frame that remains on deck, to allow the removal of samples on deck. Photo by Joop Coolen (WMR).*

Orange-peel grab

A common tool to collect rocks from the seabed for non-scientific purposes, is the orange-peel grab

(Poliepgrijper in Dutch; Figure 5.13). It is used to grab various materials from the seabed, e.g. by wreck salvaging companies. When combined with a camera it can be considered highly accurate and targeted sampling of specific rocks in the SPL can be considered feasible (personal communication Wouter Lengkeek, Bureau Waardenburg). The grab is available in many sizes, which can probably be optimised to collect certain rock sizes. Whether application is allowed on the SPL should be discussed with OWF operators.

Figure 5.13 The orange-peel grab. Photo by Bernhard Strominski under creative commons licence.

5.3.2 Suitable scrape sampling method under development

The various sample tools in use in industry and science do not meet all the requirements for a quantitative and repeatable sampling of offshore wind turbine foundations in the Netherlands. Sample acquisition from turbine foundations has been restricted partly because such a tool does not exist. In 2018, Bluestream Offshore b.v. had performed a quick scan into the available tools and potential for development of a new tool, on the request of Rijkswaterstaat. Joop Coolen from Wageningen Marine Research (WMR) was involved in a brainstorm session on this topic, together with Bluestream and Rijkswaterstaat specialists from WOZEP. After this session WMR and Bluestream continued discussing the potential to develop a tool. This finally led to the formation of a partnership and the start of the development of such a tool in 2021.

The most important engineering challenge is to make sure that all samples taken by the tool, would be of a standard size (surface area). This was included as a first priority in the development steps. The ideal final version of this ROV marine growth sample tool was envisioned to be able to do the following:

- Take samples from depths up to 200 meters (to also allow sampling outside Dutch waters);
- Take samples of a known surface area (with <10% variation in size)
    - Example area: 0.05 m^2, as used for the WMR sample campaigns (Coolen et al., 2020c, 2020a) or 0.056 m^2 as used for the Dutch wind farm sampling campaigns so far (Bouma and Lengkeek, 2013; Vanagt and Faasse, 2014).
- Have an adjustable sampling area (range: 0.01 – 0.1 m^2), depending on the running project;

- Take multiple samples in a single ROV deployment which are separately stored within the system;
- Obtain high resolution progressive (1080p or 4K) video footage from the sampled area, with size reference (e.g. laser dots/lines);
- Filter the sampled marine growth and water through nets with specific mesh sizes (e.g. 0.5 or 1 mm) to collect only the macrofaunal organisms;
- Cause no or very limited (acceptable according to WMR species identification analysts) damage to the sampled marine growth;
- Store the samples so that the collected fauna is not washed out;
- Be mountable on observation class ROVs.

To develop the final ideal system, a step-wise approach was taken, in which tools in intermediate stages of development were to be designed, built, tested and evaluated.
The first version of the tool, which is now under development, will have the following specifications:

- A single sample can be taken per ROV deployment.
- Depth rating: 300 meters.
- Sample volume: up to 10 litres.
- Known sample size/surface area 0.056 m^2 (circle = 26,70 cm internal diameter).
- Video camera/Light inside sample area to verify full sample removal.
- Sample must be captured inside a netting/filter with 1mm mesh, possibly with multiple stages of decreasing mesh size, with the final stage at 1 mm.
- Sample must remain as intact as possible.
- Expected surface of structure: concrete, (coated) round steel foundations with a minimum diameter 40 inch.

For the future version of the tool, the following additions are foreseen:

- Scale-able sample size design, other diameters possible, with variations in diameter of 0.05 – 0.08 m^2 (25 – 35 cm diameter ID).
- Multiple samples taken per deployment, which are stored independently, e.g. in a carrousel with 6 containers or sampling nets.

Currently (January 2022) first sketches have been made of the tool and a feasibility study is being carried out to decide on the best technique. Initial sketches included a cheese wire-like removal of fauna and collection using a system inspired by the Gobiesox inspection tool (Bluestream offshore b.v., 2021), a tool that adheres to the surface of a structure using pressure from a set of integrated thrusters. Later evaluations considered the cheese wire approach too complex and a new design is now considered, using a putty knife scraper with suction hose above it, attached to a rosette for multiple sample storage. Since this is work-in-progress, at this time no figures of the tool can be provided. After the feasibility study is concluded and the best design selected, the basic design will be made and a prototype will be produced and tested in controlled conditions (e.g. a pool). The test will be evaluated and the basic design updated. Then a detailed design can be made, including a manual on the sampling procedures and integration in an ROV. This will be implemented in an updated version of the prototype, which can then be tested during offshore trials. The current plan is to start the offshore trials in June 2022, but the actual moment of trials strongly depends on the design process and success of the intermediate tests.

6 Law and regulations

Offshore operations are regulated at various levels, from a labour law perspective to industry standards and operator requirements. Since diving involves the presence of humans in hazardous environments (underwater, in water currents, risk of diving related illnesses, et cetera), this has been regulated to detail. For operations using ROVs, regulations are more generic. No specific ROV related laws, regulations or decrees exist in the Netherlands. There is no Working Conditions Catalogue on ROV operations. The wind farm operators and offshore contractor interviewed for this report stated that no operator specific requirements were used for ROV operations by the company, and referred to the NORSOK standard U-102 on remotely operated vehicle services (Standards Norway, 2020) and IMCA guidance on ROV work, in particular IMCA R004 (IMCA, 2021). Both documents are used to review contractors risk assessments and method statements on ROV work in wind farms. The following sections describe the generic and ROV related regulations, followed by the diving specific regulations.

6.1 Generic regulations & requirements including ROV

6.1.1 Generic operator requirements

To assess any additional diving related requirements from operators, interviews were conducted and the Employer's Requirements on Health and Safety (ERHS) were evaluated as provided by Vattenfall (Vattenfall, 2021). These ERHS are written from the perspective of the operator as an employer to contracting organisations working within a wind farm. They however can also be seen as the expected requirements to any scientific research carried out in a wind farm. The Vattenfall ERHS document '*specifies the Employer's minimum health and safety (H&S) requirements working under the scope of the contract. It does not stand alone and shall be read in conjunction with the other contractual documents. The requirements shall be understood complementary to the applicable international and national legal requirements and other requirements the Contractor has to comply with. The purpose of the rules and requirements specified in this document is to achieve a healthy and safe working environment and to prevent injuries and illnesses. The employer strives for zero incidents and continual improvement.*' The ERHS are very detailed and when designing a future monitoring plan, all details should be covered in the plan. For the purpose of the current report, only a summary is provided below. Eneco has similar requirements as summarised here for Vattenfall (personal communication Richard Brocx, Eneco).

Any organisation carrying out work in a wind farm (contractor), shall have a valid and certified Health and Safety management system in place throughout the Works according to ISO 45001 or equivalent. All risks shall be – as far as possible – eliminated and mitigated to as low as reasonably practicable (ALARP). This shall be included in Method Statements and Work Instructions detailing the procedures necessary for the safe execution of all activities. The wind farm operator (employer) shall be invited to participate in any HIRA (hazard identification and risk analysis) workshops. A site-specific H&S Plan shall be prepared and executed. This shall be presented to the wind farm operator 30 days before mobilisation of the Site in a forum determined by the operator. The time between delivery of the document (60 days prior to the mobilisation of the Site) and the presentation (30 days prior to mobilisation of the Site) shall be used for first review cycle between the Contractor and the Employer. Contractor shall investigate, register and report all H&S incidents that occur during the Works. The Employer requires a minimum entry level of H&S education, medical fitness and training for all of the Contractor's Personnel. Contractor shall establish an Emergency Response Plan (ERP) to deal with all reasonably foreseeable emergency situations on Site and situations that require outside help. The Contractor shall specify at least six weeks prior to start of the activities which vessel will be used.

Additional documentation is required by wind farm operators, such as an Environmental Management Plan (EMP), vessel requirements, etc. These documents have not been assessed for the current report, but should be included when designing any monitoring plan for offshore wind farms.

Any method applied to a turbine foundation, will also be evaluated with regards to potential damage to the foundation. For example, a scraping tool could damage paint on the structure. Therefore, it is recommended to discuss the details of any method early in the process of designing a monitoring plan.

6.1.2 ROV standards: NORSOK U-102

NORSOK is a series of documents published by Standards Norway. Specifically, for ROV operations, a report was formulated in cooperation with the Norwegian Technology Centre (Standards Norway, 2020). The standard U-102 on Remotely operated vehicle (ROV) services aims at defining an industry wide standard for ROV operations for the oil and gas and renewable energy industry.
It describes the various classes of ROVs, of which class 2 and 3 are most relevant to the current report as these are ROVs able to work in a vertical environment such as a wind turbine foundation and can perform tasks that are more complex than video observation (Table 6.1).

Table 6.1 *ROV classes defined in NORSOK U-102, excluding classes >3 which are towed, crawling or conceptual, which is not relevant to this report. A few examples of ROV available on the market from two brands are included*

Class	Description	Product example	Weight (kg)
I	Pure observation, equipped with camera, light, sonar and small sensors, only used for observations and very simple measurements.	Saab Seaeye Falcon	10-50
II A	Observation with payload option. Capable of carrying up to two additional sensors such as digital stills cameras, video cameras without loss of original functionality.	Spectrum ROV Saab Seaeye Tiger	50-500
II B	Observation class vehicles with light intervention, survey and construction capabilities. Capable of carrying light duty manipulators and tooling skids. Through frame lift capacity of 200 kg.	Saab Seaeye Panther-XT Plus	500-2500
III A	Standard work class vehicle capable of carrying additional sensors, and fitted with two permanently installed manipulators. Through frame lift capacity of 1000 kg.	Saab Seaeye Leopard eNovus ROV	2400-3600
III B	Advanced work class vehicle, like the standard working class but with a through frame lift capacity of >1000 kg, typically 3000 kg.	Maxximum ROV	>3400

The standards require ROV teams to include 2 persons in case of class I and II work and 3 persons for class III work when working for <12 hours. ROV pilots should be formally trained, e.g. to ROV pilot technician level. Technical requirements to ROVs include the following: The ROV should be able to move in a horizontal and vertical plane. All equipment used on and including the ROV should be tested prior to use. Function tests are to be performed according to a defined test program. Testing results have to be documented. Furthermore, the functioning of the equipment should be demonstrated to the client. In case a novel ROV sample tool is developed to acquire samples from the marine growth from offshore turbine foundations, it can be expected that the wind farm operator will require such a test.

6.2 Diving specific regulations & requirements

Diving work is regulated on multiple levels, with references between regulations and international standards. The Dutch government provides high level regulations in the form of the Working under Hyperbaric Conditions regulation & decree. This applies to all types of diving work, including scientific diving, but does not specifically describe diving work in offshore wind farms.

More specific descriptions are provided in the Working Conditions Catalogue: Working under Hyperbaric Conditions, which has been created in cooperation between many organisations, including government and industry. This catalogue covers all diving work but specifies that work in offshore wind farms can only be carried out by surface supplied equipment (SSE, see §5.2.2) divers. Further regulations are provided by the operators of wind farms. These can specify additional rules, requiring to comply with international standards such as IMCA codes of practise for offshore diving and diving from dynamic positioning (DP) vessels.

In summary, the various regulations state that:

1) When diving offshore, a compression chamber needs to be at the diving location during all diving operations.
2) Diving in offshore wind farms is carried out by SSE divers. SCUBA diving is not allowed.
3) When diving from DP vessels, restrictions on the length of the divers' umbilical will result in the need of a very large vessel (>60 meters), to prevent contact of divers with the active thrusters.
4) Diving is only allowed if no alternative method is available to perform the work.

6.2.1 Dutch Working under Hyperbaric Conditions regulation & decree

Legal requirements to diving have been specified in the Dutch Working conditions regulation (Arbeidsomstandighedenregeling) in chapter 6: *Working under Hyperbaric Conditions* and annex XVI (Staatssecretaris van Sociale Zaken en Werkgelegenheid, 2016) and in the Working conditions decree (Arbeidsomstandighedenbesluit) in chapter 6, part 5: *Working under Hyperbaric Conditions* (Staatssecretaris van Sociale Zaken en Werkgelegenheid, 1997). They are listed at https://www.werkenonderoverdruk.nl/certificatieschema-s. In there, required certification and experience of people working as divers (commercial divers) is described. In summary, the regulation mandates that divers are properly trained in commercial diving techniques, are certified by a certifying institution appointed by the Dutch government and medically examined by a doctor certified to carry out commercial diver medical exams. Furthermore, planned diving at in OWFs should be reported to the State Supervision of Mines, which is the Authority on OWF. Any diving crew working in the Netherlands should meet minimum requirements such as the presence of a certified supervisor, a certified medical officer and certified diver(s) plus a standby diver. Additional conditions state that when diving work is carried out at depths > 15 meters a compression chamber should be present directly on the diving site. When diving in depths < 15 meters a compression chamber should be reachable within 2 hours travel.

In the Netherlands the following commercial diver certification categories are described:

A1: Diving using scuba equipment in aquarium or swimming pool-like conditions up to 9 meters water depth.
A2: Diving using scuba equipment by governmental organisations such as police and fire departments.
A3: Diving using scuba equipment to water depths <30 meters.
B1: Diving using SSE by governmental organisations such as police and fire departments.
B2: Diving using SSE to water depths <30 meters.
B3: Diving using SSE to water depths <50 meters excluding wet bell dives.
B4: Diving using SSE to water depths <50 meters including wet bell dives.
C: Diving using a closed bell (saturation diving).

In the Netherlands no specific category has been defined for scientific diving. Therefore, scientific divers should be certified as commercial divers in the appropriate category. Many commercial scientific divers are certified in the A3 category, but a few in the Netherlands also hold SSE certification up to B4 (personal observation Joop W.P. Coolen).

The average relevant conditions in the North Sea for commercial diving around wind farms are water depths <30 meters (although future OWF locations will likely be >30 m) and with a travel time to decompression chambers >2 hours on most locations. Some wind farms may be present at locations of >30 meters water depth. As such, following the Dutch Working under Hyperbaric Conditions regulation and decree, diving teams operating at most of the offshore locations should consist of divers certified in category A3, B2, B3 or B4 and have a compression chamber on the diving location, thus on board when working from a vessel. However, one should also note the additional requirements as included in the 'Working Conditions Catalogue: Working under Hyperbaric Conditions' (next paragraphs).

6.2.2 Working Conditions Catalogue: Working under Hyperbaric Conditions

Detailed commercial diving requirements have been described in the Working Conditions Catalogue Working under Hyperbaric Conditions (Stichting Werken onder Overdruk, 2020a, 2020b).

A Working condition catalogue (WCC) contains agreements regarding controlling of (specific) Health and Safety risks at sector-, branch - or company level. Social partners (employers and employees) agree together about how the requirements in the Working Conditions Act and legislation can be met. The Inspection SZW examines companies for compliance with the law and legislation, taking into account the solutions in the WCC. When deviating from these solutions, one has to reach a level of health and safety which is at least as high as when one would have followed the WCC.

The Catalogue is applicable on Dutch territory, within the boundary of the exclusive economic zone of the Netherlands and on sea going ships registered in the Netherlands, including permanently installed platforms operating within the boundaries of the exclusive economic zone of the Netherlands. As such it is applicable to all diving working of OWF in the Dutch part of the North Sea.

The WCC Working under Hyperbaric Conditions consists of 4 parts, being:

- SCUBA Category A1
- SCUBA Other (Stichting Werken onder Overdruk, 2020b)
- SSE (Stichting Werken onder Overdruk, 2020a)
- Dry diving bell / saturation

The SCUBA Other WCC states that SCUBA diving methods are unsuitable for use in energy production related work under hyperbaric conditions (such as diving around offshore wind turbines) because the limited supply of breathing gas for the diving causes risks. Therefore, scuba work is not considered a feasible method for scientific diving work in offshore wind farms in the rest of this work plan.

For diving around offshore energy installations such as offshore wind turbines the minimum team size is 5 persons:

1 diving supervisor,
2 diver,
3 standby diver,
4 diving assistant for the diver
5 diving assistant for the standby diver

Depending on circumstances, e.g. use of A-frames, additional personnel is required, so this list should be considered the absolute minimum. As with all offshore work, a Risk Inventory & Evaluation (RI&E) needs to be available for the diving work, which should be re-evaluated periodically. Furthermore, prior to any diving operation a Last Minute Risk Assessment (LMRA) should be carried out at the worksite by the diving supervisor and personnel.

When diving from Dynamic Positioning (DP) vessels, the vessel should meet at least an IMO equipment class 2, which is a DP vessel of which a loss of position is not to occur in the event of a single fault in any active component or system (Maritime Safety Committee, 1994). DP vessels stay in position by continuously conducting small movements of the vessel by adjusting the direction of the thrusters, which are in continuous operation. Since these moving thrusters are a risk to divers, the work should be carried out in accordance with IMCA D 010 in which i.a. safety measures are described to prevent divers from coming into contact with the thrusters (IMCA, 2020). The International Marine Contractors Association (IMCA) is the international trade association representing offshore, marine and underwater engineering companies. IMCA D 010 results in a maximum distance of the diver from the vessel which is dictated by the shortest distance to the nearest active thruster, minus 5 meters. A very simplified example: if the distance from the location where a diver enters the water, to the nearest thruster is 20 meters, the maximum length of the umbilical from the diver's basket to the diver is 15 meters. If in this scenario the vessel operates at a distance of 10 meters from a turbine foundation in shallow waters, the diver will have approximately 5 meters of umbilical left to perform the work on the turbine foundation. Furthermore, to allow a standby diver to reach the first diver in an emergency, it is likely that a second basket launch and recovery system (LARS) is needed on board, increasing the needed distance between the divers and thrusters. As a result of these requirements, diving operations from DP vessels will always require rather large vessels, to provide all divers with the required safety margins but also allowing enough umbilical length to carry out the work. For the example above, the minimum size of the vessel will be 2 times the distance to the nearest thruster (2x20 = 40 m) plus the width of two LARS (5 meters) plus the distance from the thrusters to the bow and stern of the vessel. Assuming the latter is 10 meters each, the minimum size of the vessel would be 40+5+20 = 65 meters, if the LARS is exactly in the middle of the thrusters. This example is very simplified, e.g. the position of the thrusters on the width of the vessel will change these calculations, and the actual numbers will need to be calculated on a case-by-case basis, depending on vessel and diving method used. Examples of vessels that have been used for DP diving operations in Dutch wind farms, include the Go Electra (length 80 meters), Vos Sugar (68 meters), Vos Shine (60 meters) and Strill Server (85 meters).

In conclusion, the WCC dictates that diving work around offshore energy installations can only be carried out using SSE divers and if a DP vessel is used, this will need to be large enough to allow a safe distance between the diver and the thrusters.

6.2.3 Operator specific requirements

Specifically for diving work, the Employer's Requirements on Health and Safety (ERHS) states that Vattenfall discourages any activities that require diving (Vattenfall, 2021). Only if there is no alternative to diving, a specific ALARP statement and validated risk assessment should be provided. This is also stressed in legal requirements, such as the Arbeidshygiënische strategie in chapter 4, part 4 of the Arbeidsomstandighedenbesluit (Staatssecretaris van Sociale Zaken en Werkgelegenheid, 1997) which operators and any other company needs to comply with. Furthermore, diving activities shall be undertaken according to IMCA guidance documents, among others 'D 014 IMCA international code of practice for offshore diving' (IMCA, 2019). The IMCA International Code of Practice for Offshore Diving (CPOD; IMCA, 2019) offers examples of good practice, gives advice on ways in which diving operations can be carried out safely and efficiently and includes personnel, equipment and systems guidelines for diving operations, including surface supplied air diving such as those performed in offshore wind farms in the Netherlands. The CPOD are very detailed and when designing a future monitoring plan using diving operations, all details should be covered in the plan. For the purpose of the current report, only a summary is provided below. The CPOD states that diving contractors should have a diving management system in place which should contain the management of health, security, safety, environmental and quality as a part of the overall company management system, following ISO 9001 and related standards. Furthermore, a project-specific diving project plan should be in place before work can commence. An extensive list of further required documentation and plans is given in CPOD, including insurance policies covering third party liability and diver medical insurance, risk assessments, management of change (MoC) procedure, emergency and contingency plans and procedures, suitable equipment supplied, audited, maintained and certified in accordance with the relevant IMCA documents, certification of all personnel, additional personnel such as diving superintendents when working in 24-hour operation, deck plans, self-auditing of diving systems and equipment, etc.

7 Method evaluation

In previous sections the data needs for hard substrate fauna monitoring, the available methods and legal aspects were described. To decide on the way forward, these need to be evaluated. A sampling method can only be considered feasible if all scientific and legal requirements are met and the tool is available for the application as foreseen in the MONS monitoring program. In this chapter all methods are revisited and an estimation is provided on the likelihood that a method is suitable for application in MONS.

Cost aspects are included in this overview, although no detailed analysis was performed to estimate the costs. Assumptions on what could be allowed by operators have been made and should be discussed in more detail in the future. In general it was assumed that large vessels require more budget than smaller ones and that DP vessels also require more budget. If Rijksrederij vessels are available to carry out the work, budget needs were assumed lower than when using commercial vessels. This in particular had a large impact on the estimated cost of SSE diving from DP vessels, which have been assumed to be more expensive than smaller DP vessels for ROV work. Furthermore it was assumed that ROVs can be deployed almost 24 hours per day, while divers are more restricted to low water currents and good weather. As such ROVs have a higher potential to use vessel time more efficiently than diving. All these considerations should be further explored and discussed with MONS, operators and contractors in the future.

7.1 Diving methods

7.1.1 Scuba diving

Although scuba is suitable and preferred from a scientific perspective, it is unlikely to be allowed in Dutch OWFs for legal reasons and, therefore, considered unsuitable for application in MONS to sample hard substrates in OWFs. It should be noted that these restrictions are specific for OWFs and that sampling campaigns using commercial scuba divers near other reefs, e.g. in the Dutch Voordelta, Cleaver Bank, Borkum Reef Grounds or around shipwrecks are possible.

7.1.2 Surface supplied equipment diving

SSE is preferred from a scientific perspective, since a diver in the water is more flexible than an ROV, the method has been applied in previous inventories of wind turbine foundations and is readily available. Legally the method is allowed, but operators will only allow SSE diving if no other method is suitable. In recent years this has prevented sampling campaigns on OWF hard substrates in the Netherlands from taking place. Within SSE diving various vessel types can be used, which will have budget, safety and legal implications. Whether mooring to a turbine foundation is allowed will depend on operator requirements and vessel size. Whether the non-standard option to work from a RIB with a large standby vessel nearby which holds the safety systems may be allowed, should be discussed with OWF operators. The most accepted but also most expensive SSE method is diving from dynamic positioning vessels. Whether SSE diving campaigns from DP vessels is financially feasible in MONS should be evaluated. In particular if large commercial DP vessels need to be used, budgets will increase significantly. If the work can be carried out using Rijksrederij vessels, the work will be much more cost efficient.

7.2 ROV methods

7.2.1 Manipulator arms with putty knife and macrofauna net

The use of ROV mounted manipulator arms is expected to be inefficient and imprecise. This method does not meet the sample quality requirements and, therefore, it is considered unsuitable for application in MONS.

7.2.2 ROV suction samplers Cellula and similar

The available models of suction samplers are suitable to collect and store samples, but have no method to scrape the epifauna from the foundation. Although this could be developed, still the tool would not easily allow for quantitative sampling. This method does not meet the sample quality requirements and, therefore, it is considered unsuitable for application in MONS.

7.2.3 Vortex marine growth sampler

This tool includes a scraping device and has been shown suitable to collect samples from offshore installations. However, the tool does not easily allow for quantitative sampling. This method does not meet the sample quality requirements and, therefore, it is considered unsuitable for application in MONS.

7.2.4 Bluestream & WMR sampling tool under development

This tool is still in the initial design phase. Therefore, the evaluation could only be performed on the potential of the tool. If it is built as it is currently sketched, the tool will be able to scrape, collect and store quantitative samples from turbine foundations. Once multiple samples can be taken (this is not included in the current design process), it is expected to be efficient in sample acquisition, reducing costs. However, at this point, the tool does not exist yet. The tool has potential but on the very short term no definite advice can be provided on the suitability of the tool for application in MONS.

7.2.5 SPL sampling with manipulator arms

This method is the most likely short-term solution to obtain samples of small rocks from the SPL. ROVs are often used to collect objects present on the seabed, and this method is likely to be accepted by industry. If complete rocks can be collected, this will result in a high-quality sample that meets the requirements of MONS. However, the size of the rocks depends on the size of the manipulator arm on the ROV, if a larger size rock is used in certain wind farms, this method may be unsuitable to collect samples.

7.2.6 SPL sampling with ROV mounted seabed scoop

Sediment scoops are available for very small ROVs, and it seems likely that a scoop for a larger ROV could be developed. This should be further explored. The method allows high control over the sampling activity and is likely to be accepted by industry as well as meeting the MONS requirements. It is suggested that MONS aims to develop an ROV mounted scoop SPL samples can be collected from all offshore wind farms in the Netherlands, without too many restrictions to rock size.

7.2.7 SPL sampling with surface-based grabs

The Hamon grab in particular is a suitable tool to collect small to medium sized rocks from the seabed. However, in comparison to ROV mounted tools the control over where to take a sample is very limited. There are indications that sampling with a video equipped orange-peel grab can be very precise and possible better suited than Hamon grabs. Depending on operator requirements both methods may be accepted or refused. This should be discussed further with OWF operators.

7.3 Overall evaluation of methods

No single epifauna scraping method is available that meets all essential and all preferred requirements (Table 7.1). On the short term (next 6-12 months), SSE diving from a DP vessel is the only method that meets all requirements, pending operator approval and MONS budget. On the medium term (6-18 months) version 1 of the Bluestream-WMR sample tool may become a candidate to replace SSE, although this version will likely only be able to take a single sample per deployment, increasing the time needed to carry out a sampling campaign, thus increasing the budget. However, this option increases safety for personnel and therefore is preferred by OWF operators (personal communication by Richard Brocx, Eneco). On the longer term (>12 months) a multi-sample Bluestream-WMR sample tool may become the best candidate, as at that point sample acquisition will become much more efficient. This, however, depends on the success of the development of the tool.
The use of manipulator arms to collect small rocks from the SPL is the most feasible method at this point and also preferred by operators (personal communication by Richard Brocx, Eneco). Assuming rock sizes that fit between the manipulator arms, the tool meets all requirements. The Hamon grab, however, is very efficient and if allowed, may also meet all requirements. This, however, should be discussed with industry. If larger rocks need to be collected, the development of a large ROV mounted scoop is probably the best way forward.

Table 7.1 Scrape sample acquisition methods with qualitative scoring of the level to which each method meets the requirements.

Diver / ROV \ surface lift	Method	Quantitative	Practically feasible	Legally feasible	Preferred by scientists	Acceptable to operators	Available	Budget impact
Diving	Scuba	Yes	Yes	No	Yes	No	Yes	Low
Diving	SSE DP vessel	Yes	Yes	Yes	Yes	Maybe	Yes	High
Diving	SSE moored vessel	Yes	Yes	Maybe	Yes	Maybe	Yes	Medium
Diving	SSE RIB with standby	Yes	Yes	Maybe	Yes	Maybe	Yes	Medium
ROV	Scrape-net	Maybe	No	Yes	No	Yes	Yes	Medium
ROV	Suction tool	No	Yes	Yes	No	Yes	Yes	Medium
ROV	Vortex	No	Yes	Yes	No	Yes	Yes	Medium
ROV	Bluestream WMR tool single sample	Yes	Yes	Yes	Yes	Yes	Maybe	Medium
ROV	Bluestream WMR tool multiple samples	Yes	Yes	Yes	Yes	Yes	Maybe	Low
ROV	Manipulator take rocks from SPL	Yes	Yes	Yes	Yes	Yes	Yes	Medium
ROV	Seabed scoop take rocks from SPL	Yes	Yes	Yes	Yes	Yes	No	Medium
SL	Hamon grab take rocks from SPL	Yes	Yes	Yes	Yes	Maybe	Yes	Low
SL	Orange-peel grab take rocks from SPL	Yes	Yes	Yes	Yes	Maybe	Yes	Low

8 Conclusions and next steps

This report was written to evaluate multiple aspects of the wish to perform a monitoring programme of the hard substrate communities developing on offshore wind turbine foundations and surrounding rocky scour protection layers. At this point, the only fully suitable method to obtain samples from the turbine foundations, is collection by divers using manual scraping tools and sample nets. This has been carried out many times before. This method, however, is costly and offshore wind farm operators prefer to replace diving work with remotely operated vehicles, also as part of their legal obligation to minimise health and safety risks. This is why a partnership between Bluestream and Wageningen Marine Research started developing a tool to obtain scraped samples from turbine foundations. If developed successfully, this tool could replace diver sampling in the next 2 years. In light of these developments, it is recommended that MONS facilitates the further development of this tool. If a sampling campaign has to be started in 2022, the best option is to make use of divers.
To collect small rocks from the scour protection layer, for the short term it is recommended to make use of ROV mounted manipulator arms, collecting the rocks and depositing them in sampling baskets. This has been applied in the past and the use of ROV tools increases human safety. For the long term it is recommended to start developing an ROV mounted scoop capable of collecting large rocks.

8.1 Next steps

To choose the monitoring method that meets all MONS requirements, legal requirements and operator requirements, and is financially feasible, a series of steps need to be taken. The following actions could be taken to collect the information needed to make an informed decision:

- The current report should be further discussed with offshore wind farm operators and ROV and diving contractors in more detail. This will provide insight in the potential acceptance of some of the suggested uncommon methods. An earlier version of this report was reviewed by OWF operators and an ROV and diving contractor, but since multiple operators are expected to be involved in the execution of the monitoring, the content of the report should be discussed with a wider audience of operators.
- An ROV and diving contractor should be invited to provide financial information for the various methods. This will allow MONS to better weigh the various aspects of the different methods in this report, in combination with video monitoring (Wijnhoven et al., 2022), to develop a monitoring programme likely to provide the best data to MONS within the available budget.
- The requirements to vessels in contact with turbine foundations should be discussed with operators. This will provide insight in whether past diving methods with a vessel mooring to the foundation can be accepted.
- The requirements for vessels working very close to turbine foundations should be discussed with operators. The suitability of in particular the Governmental (Rijksrederij) vessels such as Arca or Zirfaea which are likely to be used for ROV sampling campaigns, should be discussed.
- The acceptability of and limitation to ROV mounted scrape samplers should be discussed with offshore operators. Currently it is unknown whether certain aspects may limit the force by which tools can scrape epifauna, e.g. when paints could be damaged. If this is very limited, the tool may not be able to collect all fauna, in particular in offshore location with calcareous species.
- The development of the Bluestream-WMR ROV sample tool should be facilitated. If successful, this could become the primary sample tool for hard substrate monitoring in MONS. Facilitation could be provided by MONS in the form of offshore trials, e.g. using a Rijksrederij vessel and the Panther ROV to perform offshore trials on Rijkswaterstaat operated offshore measurement installations (Rijkswaterstaat meetpalen) or in wind farms.
- The development of an ROV mounted scoop to collect scour protection layer samples should be explored, to allow future sampling of larger rock sizes as well.

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10 Quality Assurance

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

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Justification

Report C003/22
Project Number: 4315100186

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

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