Marine growth sampling tool evaluation

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Wageningen
University & Research
report: C068/24B

1: Wageningen Marine Research
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3: Bluestream Offshore b.v.

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Wageningen Marine Research
Den Helder, January 2025

Wageningen Marine Research rapport: C068/24B

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Keywords: Offshore wind farm, biofouling, benthos, sampling, ROV.

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This report can be downloaded for free from https://doi.org/10.18174/678892
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KvK nr. 09098104,
WMR BTW nr. NL 8113.83.696.B16.
Code BIC/SWIFT address: RABONL2U
IBAN code: NL 73 RABO 0373599285

A_4_3_2 V34 (2024)

Contents

Summary

This report evaluates a test of the Marine Growth Sampling Tool (MGST), a remotely operated vehicle (ROV)-mounted system developed to collect biofouling samples from offshore energy structures. The MGST was designed as an alternative to diver-based sampling, which has become increasingly impractical in Dutch offshore wind farms (OWFs) due to stricter safety regulations and higher costs. Effective monitoring of biofouling communities on OWF turbine foundations is essential for understanding ecological impacts, such as changes in biofouling composition and nutrient cycling.

The MGST was tested in November 2023 at the Hollandse Kust Zuid offshore wind farm, using the damaged E04 turbine foundation. The test aimed to assess the MGST's operational performance, including depth limitations, coating damage to turbine foundations, and sample quality. The MGST, mounted on a Saab SeaEye Tiger ROV, scraped biofouling from turbine foundations at depths between 4.5 and 20 meters. Three scraper types (metal, green plastic, and blue plastic) were tested.

Over two days, the MGST successfully collected 21 biofouling samples. The tool demonstrated high precision, with only a 1% average deviation between programmed and actual sampled areas. There were no significant differences in sample quality, species richness, or abundance among the three tested scraper types, though the plastic scrapers wore down more quickly than the metal scraper.

The test also evaluated the potential damage to the turbine foundation's protective coating by quantification of particles present in the biofouling samples. Noting that all samples were collected in an MGST net with a mesh size 0.5 mm, in half of the samples no coating particles were found, and in the remainder the maximum total size of coating particles found in a sample was small, at 0.005% of the sampled area. No coating damage was observed on video. This indicates that the MGST causes negligible harm to turbine coatings, making it suitable for upscaling in long-term monitoring applications.

Taxonomic analysis revealed a diverse range of species dominated by amphipods and anemones, and the sample quality was found to be high, like that of diver-collected samples. A comparison with the international BISAR biofouling dataset confirmed that the MGST samples fell within expected ranges for species richness and abundance. Assessment of the impact of processing biofouling samples to higher taxonomic levels to reduce costs, showed that geographic patterns in the BISAR data which were visible at species level, became invisible already at genus level. It is recommended to process samples at the lowest possible taxonomic level possible, ideally on species level. This will increase the reusability of the biofouling data for scientific studies and to answer questions that currently have not been asked yet.

We conclude that the MGST is a viable alternative to diver-based sampling, offering a safer method for monitoring biofouling communities in OWFs. Further tests are needed to evaluate the efficiency of sampling harder structures, such as mussels, as well as thicker biofouling layers. Future comparative studies between MGST and diver-collected samples are also suggested to validate the tool's broader applicability.

1 Introduction

The construction of offshore wind farms (OWF) and, consequently, the turbine foundations which are often surrounded by a rocky erosion protection layer, introduces artificial hard substrate in a sandy environment. The availability of hard substrate leads to an increase in benthic biofouling species, a community of species attached to the substrate and associated with it (Degraer *et al.*, 2020; Coolen *et al.*, 2022a). This increase in macrofauna density may have effects on the rest of the ecosystem through changes in food intake via shifts from deposit to suspension feeders (Coolen *et al.*, 2020a) with increased consumption of planktonic species from the water (Mavraki *et al.*, 2022) and increased fluxes of nutrients (Coolen *et al.*, 2024). Furthermore, non-indigenous species as well as habitat forming species of conservation importance, can be facilitated to colonise the area (Bos *et al.*, 2019; GESAMP, 2024). These local changes in the ecosystem raise new information needs and questions about the role of biofouling benthos and the carrying capacity of the ecosystem (Dannheim *et al.*, 2020; Degraer *et al.*, 2020). To fill these gaps in our knowledge, information on taxonomic composition, abundances, and biomass of the biofouling species on the turbine foundations is essential data.

Biofouling is also known as epifauna, benthic fauna, fouling communities, attached macrofauna, marine growth, hard substrate fauna, and other terms with similar meaning. Throughout this report the term biofouling will be used to refer to the community of species attached to the structure and the species directly associated with these attached species.

To collect such data on local changes caused by the presence of the OWF, monitoring programmes are being carried out in most North Sea countries where OWF have been constructed. The programmes typically include sampling of the biofouling communities on the submerged parts of the turbine foundations (Leonhard and Christensen, 2006; Krone *et al.*, 2013; Coolen *et al.*, 2020b; Zupan *et al.*, 2023). In all programs carried out thus far, including those in the Netherlands (Bouma and Lengkeek, 2013; Vanagt and Faasse, 2014), these samples were taken by scientific or commercial divers. In the Netherlands, however, regulations on diving in OWF have become increasingly strict in recent years. Due to high safety requirements, including the need to work with surface-supplied divers and dynamic positioning (DP) vessels, it is neither practical nor affordable to deploy a diving team and ship for ecological research in an offshore wind farm. In practice, this has resulted in sampling by divers becoming impossible in Dutch offshore wind farm monitoring programs (Coolen *et al.*, 2022b). Using video footage for the acquisition of these data has been explored but is not capable of capturing smaller species, nor species which are overgrown by others and is therefore not likely to provide the needed data (van der Stap *et al.*, 2016; Schutter *et al.*, 2019; ter Hofstede *et al.*, 2022; Wijnhoven *et al.*, 2022). With the scaling up of offshore wind energy, there is a strong need to obtain information on the growth of organisms on and around turbine foundations. Therefore, alternatives for sampling the biofouling on wind turbine foundations are being sought.

One of the alternatives that have been developed is the Marine Growth Sampling Tool (MGST). This tool was developed by Bluestream Offshore B.V. (hereafter: Bluestream) in collaboration with Wageningen Marine Research (WMR). The MGST is designed to be mounted on an industry accepted Remote Operated Vehicle (ROV; figure 1.1), a device similar to a tethered drone, capable of 'flying' under water around offshore installations, also in the typical high current and poor visibility conditions of the North Sea.

The MGST is designed to allow the collection of scrape samples from flat or curved vertical surfaces (such as present on wind turbine or offshore platform foundations). Using the MGST, with the ROV controlled from the ship, a small section (which can be set to a any size up to 560 cm^2) of the biofouling on a wind turbine foundation can be scraped off and collected in a net via a suction system.

Figure 1.1. *The MGST mounted under the Saab SeaEye Tiger ROV, ready to be deployed for the sampling test (photo by Joop Coolen, WMR).*

Until November 2023, the MGST had only been tested in pool conditions and had not yet been deployed at sea. On behalf of the Offshore Wind Ecological Program (Wozep) of Rijkswaterstaat (RWS), Bluestream in collaboration with WMR conducted a first offshore test in November 2023 on wind turbine foundation E04 in the Hollandse Kust Zuid (HKZ) wind farm operated by Vattenfall (Figure 1.2). Due to a collision in 2022 at the time the wind farm was still under construction, no turbine was ever installed on this foundation and Vattenfall intended to remove the foundation in 2024. Therefore, Vattenfall allowed Wozep, WMR and Bluestream to test the MGST on this specific turbine foundation.

This report evaluates this test, based on experiences from the field study as well as lab analysis of the acquired biofouling samples.

Figure 1.2 *The damaged E04 turbine foundation as present in the Hollandse Kust Zuid Offshore Wind Farm, November 2023 (photo by Vattenfall).*

2 Assignment

The current project was assigned after the test had been carried out. The project assignment was to evaluate the performance of the MGST, process a selection of the acquired samples and produce a report and dataset on the evaluation.

As part of the evaluation, this report will answer the following questions:

1) Does the MGST work in offshore conditions as present in OWFs in the North Sea?
2) What are the depth limitations for the tool within which it can collect high-quality samples?
3) Does the scraping of the tool damage the coating of the turbine foundation and if so, to what level?
4) To what extent does the performance of the tool change with the use of different types of scrapers made of metal and of plastics with varying stiffness?
5) Is the quality of the macrofauna in the samples acceptable when compared to samples collected by divers in the past?
6) To which taxonomic level do the samples need to be analysed to give the level of information needed for evaluation of the ecological effects of wind farms?
7) How can the method be applied to larger scales in the future?

To address the questions, the acquired samples were analysed in the lab. Here, the abundance and biomass of taxa as well as coating particles numbers and sizes were quantified. The taxa were identified to different levels in different samples and to both detailed and high levels for a selection of four samples, to assess the time invested in processing versus the level of detail obtained.

3 Materials and Methods

3.1 Offshore test

3.1.1 Test location

The offshore test was conducted in the Hollandse Kust Zuid offshore Wind Farm (HKZ) operated by Vattenfall during a two-day campaign from 29-30 November 2023, following a short deployment and operation test outside the HKZ on 28 November.

The HKZ is located at 18-36 km off the Dutch coast between Scheveningen and Zandvoort (Figure 3.1). HKZ was constructed between 2021 and 2023 and was in partial operation at the time of the test. The OWF has 139 11 MW wind turbines placed on monopiles with a diameter of 7 to 8 meters. The foundations are placed in water depths between 17 and 28 meters (Vattenfall, 2023). During construction, a bulk carrier vessel became rudderless and was adrift for several hours in January 2022. The vessel drifted into the HKZ area and collided with HZ E04, one of the then recently installed turbine foundations (Vattenfall, 2022a). This caused damage to the turbine foundation (Figure 1.2), and it was decided that no turbine would be installed, and the foundation was planned to be removed (Vattenfall, 2022b).

During development and testing of the MGST, OWF operators had communicated reservations towards sampling their foundations using the system because they expected the scraping tool might damage the coating on the structure (Coolen *et al.*, 2022b). Since the damaged foundation was planned to be removed anyway, Vattenfall allowed the project team to test the MGST on the damaged foundation, under the agreement that damage to the coating would be assessed as well.

Table 3.1 *Location information of the E04 turbine foundation.*

	Value
Geographic position WGS84	3° 56.9806’ E, 52° 23.1142’ N
Geographic position ETRS89 zone 31 North	564 634m E, 5 804 311m N
Local water depth	23.4m

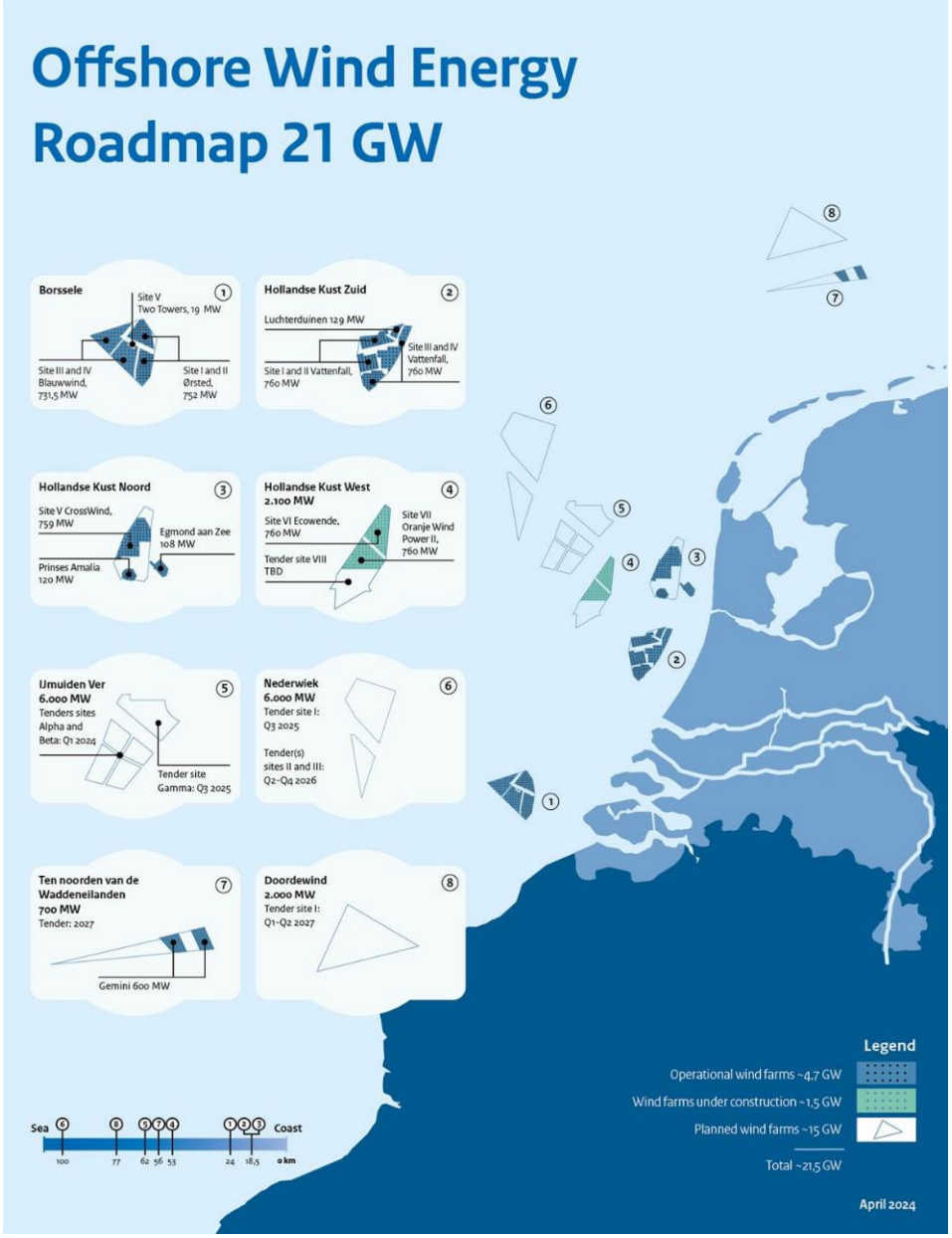

Figure 3.1 *Location of HKZ (numbered 2) where the test was conducted, within the total presence of operational and planned offshore wind farms in the Dutch part of the North Sea (source: Noordzeeloket, 2024).*

3.1.2 Vessel & ROV system

The test was conducted from the research & survey vessel Zirfaea, operated by the Dutch Governmental Rijksrederij. Zirfaea is a dynamic positioning vessel class 1 (DP1). For the test, a Bluestream operated Saab Seaeye Tiger ROV was mobilised. Housed in a single 15 feet container (Figure 3.2), the Seaeye Tiger free fly unit is the most compact offshore inspection class system of its kind. The container houses the ROV control room with all relevant ROV control and inspection & reporting equipment, as well as the deployment system and umbilical winch. The Seaeye Tiger ROV is a compact observation class vehicle which is ideal for inspection tasks. Due to its small size the ROV is nimble and capable of performing inspections at difficult to reach and narrow places. The Tiger can be equipped with a range of survey and/or inspection equipment to perform specific task. In this case the ROV was equipped with the MGST system.

Figure 3.2 *Left: The ROV container on deck, right: deployment of the ROV from the container (photos by Joop Coolen, WMR).*

3.1.3 Marine Growth Sample Tool

The MGST was developed to be mounted in a skid that is attached to the bottom of the Tiger ROV (Figure 3.3 & 3.4). The MGST has a reciprocating scraper mounted on a funnel shaped water intake, to which a highly flexible hose is connected. The hose ends in a sample containment chamber from which water is extracted using a thruster. Between the chamber inlet and exit, a macrofauna net with 0.5 mm mesh is mounted to collect the fauna while letting water pass through. A mesh size of 0.5 mm was chosen following prior sampling campaigns around offshore structures in the Dutch North Sea (Coolen *et al.*, 2015, 2020c, 2020b). On the front of the combination MGST-ROV (henceforth named MGST), at each far corner on top and bottom, left and right sides, a hold-off frame was protruding to which magnets were attached, to be pushed against the foundation to stabilise the MGST during sampling. An overview camera (Omenco OE14-366A; Figure 3.3) with live feed to the control cabin was mounted on the ROV, and a small camera (MCV8-LED) with a close view of the MGST scraper, also with live view, was mounted left of the scraper. As part of the test, three types of scrapers were used, with decreasing hardness. A stainless-steel scraper (Figure 3.5), which was the originally designed tool, was exchanged with two types of Polyurethane (PU) plastic scrapers: a green scraper of 77 shore D plastic (henceforth named green) and a blue scraper of 70 shore D plastic (blue; Figure 4.4)). The MGST was deployed with a small crane and winch, built in the back of the container. Inside the control cabin in the container, an ROV operation system and MGST operation system were present and operated by two persons.

Figure 3.3 *Positions of the cameras with red: overview camera on the ROV and green: close-up camera near the scraper (photo by Joop Coolen, WMR).*

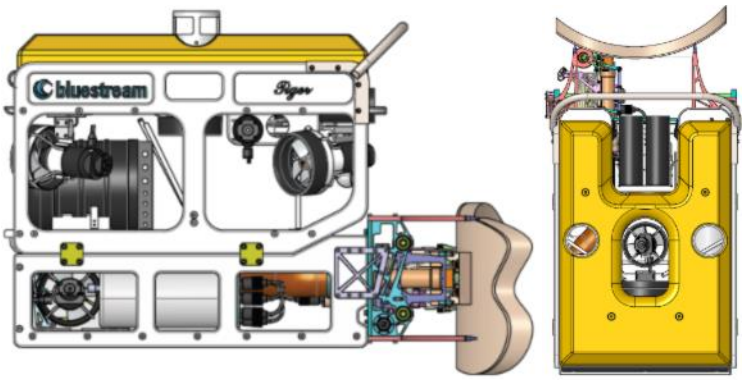

Figure 3.4 *Schematic drawings of the marine growth sampling tool mounted under the ROV, with monopile section shown (light brown curved element in front of the tool).*

Figure 3.5 *Metal scraper used in the MGST. See results section for plastic scrapers.*

After launching the MGST, a sample was acquired by pushing the four corner-mounted magnets against the foundation. Once the MGST-ROV combination was found stabile, the MGST scraper was pushed forward until it touched the foundation. Then the reciprocation of the scraper was started, the water suction activated, and the scraper was moved from right to left along the foundation whilst reciprocating and holding forward pressure. This detached the fauna, which was then sucked in the water intake due to a flow using a thruster and deposited in the sampling net. Once the scraper reached the programmed end of the sample, it was retracted from the foundation and moved back to the starting position. By stopping the scraper at the point where the first fauna was removed on the right side, the actual sample size was measured to the nearest cm^2. This was done as due to small movements of the ROV caused by wave action, sometimes the system moved while scraping fauna, causing larger or smaller areas than the intended 560 cm^2 to be sampled. Both the programmed sampling size and actual sampled size were registered on a sheet. This sheet contained the following (meta)data for each sampling attempt:

- Sample number
- Date and time of sampling start
- Sampling depth as measured by the ROV depth sensor
- Orientation of the ROV in compass degrees
- Scraper type used
- Planned sample size
- Actual sample size
- Sample acquisition quality from poor, to acceptable and good
- Biofouling dominant species visible
- Visible damage to the coating
- Coating colour (in percentage of total if more than one colour was visible)

Once the sample was acquired and the MGST finished, it was recovered on deck and secured. Then the sample chamber was opened, and the net exchanged for an empty one. The net containing the sample was then processed.

3.1.4 Sample processing on board

On board a laboratory container was available to process the samples. Each sample was removed from the net, after which the net was rinsed and cleaned to prepare it for the next use in the MGST. Then the sample was deposited in a white tray, a label with sample number and ruler with mm indicator added and a photo made (Figure 3.6).

Figure 3.6 *Sample photograph with label and ruler.*

In the tray, the sample was inspected for any noteworthy or unexpected damage, with a comparison with diver collected samples in mind. The sample quality was registered on the sampling sheet. If the quality was good, the sample was placed in a storage container and ethanol 99% was added with a volume of at least two times the estimated volume of the sample. After 24 hours, the ethanol was drained from the sample and replaced with 99% ethanol, to attain an end concentration of >70%. Then the samples were stored for later analysis in the laboratory.

3.2 Lab analysis

3.2.1 Macrofauna analysis

To assess how much processing time would be shortened by reducing the taxonomic level of detail of the identification, the samples were processed in the lab using three different methods:

1. 13 out of 21 samples were processed in full, identifying all individuals to the lowest taxonomic level. Most were identified to species level and only juveniles too small for species level and adults missing characteristics needed for identification to species level, were identified to higher levels.
   These samples were processed as part of the KIA-LWV funded KOBINE project (reference: LWV20.230).
2. Four samples were processed to a reduced detail taxonomic level only, to reduce lab processing time. This was done by identifying most taxonomic groups to higher levels while only processing easy-to-identify groups to species level (table 3.2).
3. Four samples were identified to the reduced taxonomic level (table 3.2), while recording total processing time, and then processed to the fully detailed taxonomic level, again recording total processing time.

For all methods, analysis in the laboratory followed methods applied to similar samples in previous studies (Coolen *et al.*, 2015, 2020b, 2024; Mavraki *et al.*, 2023). All samples were first pre-sorted into practical taxonomic groups, after which they were identified, using the World Register of Marine Species (WoRMS Editorial Board, 2022) as a reference for taxonomic nomenclature. Samples containing >200 individuals of one species/group were sorted, removing all species except the abundant (>200 ind.) species, which was left in the main sample. Then the remaining sample was sub-sampled using a Motoda-box sample splitter

(Motoda, 1959) to a level at which between 100 and 200 individuals of the species were left in the sub-sample. Next, the last sub-sample was processed like the full sample, noting the sub-sample fraction in the dataset for all specimens identified in the sub-sample. All other sub samples were set aside and not processed further for taxonomic identification. Individual taxa were counted, while for colonial taxa the projected surface area covered by the taxon was estimated to the nearest cm^2. After quantification, counted taxa were wet weighed, then, in collaboration with the benthos laboratory at NIOZ Royal Netherlands Institute for Sea Research, dried at 60 °C for 72 h and weighed after acclimatisation to room temperature in a desiccator. Then the samples were incinerated at 560°C for a minimum of 4 h, and weighed again after acclimatisation to room temperature in a desiccator to obtain the ash weight.

Table 3.2 *Higher taxonomic level identification reference table.*

Phylum	Taxonomic cluster observed	Identify to
Annelida	Polychaeta	Family
Annelida	Oligochaeta	Subclass
Annelida	Echiura	Subclass
Arthropoda	Amphipoda	Order
Arthropoda	Amphipoda: Caprellidae	Family
Arthropoda	Decapoda	Species
Arthropoda	Isopoda	Order
Arthropoda	Mysida	Order
Arthropoda	Thoracica (Sessilia)	Infraclass
Arthropoda	Hexapoda	Class
Arthropoda	Cumacea	Order
Brachiopoda		Phylum
Bryozoa		Phylum
Cephalorhyncha	Priapulida	Phylum
Chaetognatha		Phylum
Chordata	Cephalochordata (i.a. *Branchiostoma lanceolatum*)	Class
Chordata	Tunicata	Species
Cnidaria	Anthozoa: Actiniaria	Order
Cnidaria	Anthozoa: *Metridium senile* >10 mm	Species
Cnidaria	Hydrozoa	Class
Cnidaria	Hydrozoa: Tubulariidae	Family
Echinodermata		Species
Hemichordata		Phylum
Mollusca	Bivalvia	Species
Mollusca	Ensis	Species
Mollusca	Mya	Species
Mollusca	Lutraria	Species
Mollusca	Gastropoda	Family
Mollusca	Opisthobranchia	Infraclass
Mollusca	Cephalopoda	Class
Nemertea		Phylum
Phoronida		Phylum
Platyhelminthes		Phylum
Porifera		Phylum
Sipuncula		Phylum

3.2.2 Coating analysis

All 21 samples were analysed for the presence of coating residues. Each of these samples had previously been used for benthos analysis, during which the organisms were removed for counting and identification. All remaining material, which mainly consisted of organic material (seaweed and algal residues, organic sludge, etc.) and calcareous material (empty shells, worm tubes, etc.), was preserved in ethanol and then used for the coating residue analysis.

For the analysis of the coating residues, the samples were rinsed over a 125 µm sieve with tap water. Since this is the same sieve size that was used for the benthos analysis, there was hardly any material <125 µm that passed through except for some sand grains, in which no coating particles were found. The remaining material was collected in a glass jar filled with a 1 M potassium hydroxide (KOH) solution and stored at room temperature for about 14 days. The oxidizing action of the KOH breaks down organic material and is also used in this way in studies on the presence of microplastics in fish (Foekema *et al.*, 2013; Kühn *et al.*, 2020).

After 2 weeks, the sample was rinsed and divided into three sieve fractions: <212 µm, 212-500 µm, and >500 µm. Each sieve fraction was then treated with 37% hydrochloric acid to dissolve calcareous parts such as shell residues and worm tubes. The remaining material, now stripped of organic and calcareous components and thus significantly reduced in volume, was thoroughly searched under a binocular microscope, and all unnatural material was collected. Each material type (coating, plastic, etc) was identified based on external characteristics. Only particles that were considered coating residues were sorted by colour and photographed. Based on the photos, an estimate was made of the surface area of the different coating particles.

Before processing the field samples, a test sample of the topcoat-paint layer on the turbine foundation (paint based on Sika permaxor 2230 VHS) had been received from Vattenfall. This test sample was used to confirm that the KOH and acid treatments did not affect the colour or appearance, nor that they did visibly damage the coating in any way.

3.3 Video analysis for taxa and coating damage

The video footage recorded by the ROV camera for all samples of acceptable or good quality was analysed. Bluestream provided an ROV camera file and an MGST camera file for each sampling event. The quality of the MGST images was unsuitable for analysing benthos taxonomy or coating damage because it showed only a very small portion of the sample's surface, primarily focusing on the MGST blade, making the fauna and coating generally not visible in sharp detail. Therefore, only the ROV camera files were analysed.

The ROV camera file was in a video format with a resolution of 852x480 pixels and a duration of 3 to 18 minutes per sampling event. During sampling, this provided a stationary view of the fauna 20-30 cm above the sampling point for approximately 2-3 minutes. Then an inspection of the sampled surface followed, during which the entire sampled area came into view. Based on this, it was determined whether the sample was taken in the intended rectangular shape or if it deviated due to ROV movement during sampling.

Figure 3.7 *Screenshots of the overview camera (left) and scraper camera (right), on which the green blade is visible removing anemones and amphipods (scraper: bottom part of right image).*

The low resolution of the footage limited identification of most species. Therefore, the species analysis of the footage was performed as a quick scan and only the observed taxon list is reported here. The footage was viewed in one-minute blocks. During the first minute, all visible taxa were recorded, with frequent rewinding and pausing until all visible taxa had been noted. If possible, identification was made at the species level, but most taxa were only identifiable at higher levels, as there was insufficient detail visible to score at a lower level. Only the presence of visible taxa was recorded. The subsequent minutes generally showed the same view because the ROV remained stationary. These minutes were played at normal speed, with pausing or rewinding only when a new taxon appeared. New taxa were added to the previous species list. Once the ROV finished sampling and started inspecting the sampled surface, species identification ended.

In the following video minutes, coating damage and the quality of the sampling were assessed. This included checking for visible damage to the coating of the turbine foundation and whether the sample had a rectangular shape with even horizontal edges. If not, the shape was described in text, such as "upper side slightly uneven". Any fauna left inside the sampled area were noted as an estimated percentage of the total sampled surface in steps of <1%, 5%, and up.

Presence of coating damage was noted separately. At the start of the project, it was the intent to develop a scoring system for coating damage, based on the first observations of damage, but no coating damage was observed in any of the video footage, so the scoring system was not developed.

3.4 Data analysis

3.4.1 Data preparation

Data analysis was performed using R version 4.3.3 (R Core Ream, 2024) in RStudio version 2023.12.1 (RStudio Team, 2024). The analysis was performed in multiple steps. First, all sub sampled fauna data (counts and biomass) were multiplied by the sub-sample level to estimate the actual number of individuals per sample. In samples processed to the lowest possible taxonomic level, higher-level taxa were merged with a lower taxonomic level of the same lineage found in the same sample, following methods applied in previous projects (Coolen *et al.*, 2015, 2020b; Mavraki *et al.*, 2023; Spielmann *et al.*, 2023; Zupan *et al.*, 2024). When multiple lower levels were observed, the higher levels were distributed proportionally (by abundance) among those. This was repeated until all higher-level taxa in a sample were merged with the lowest level of the lineage in that sample. If no species level taxa in the same lineage were present in the same sample, taxa remained at higher levels. For each sample, total biomass, total number of individuals and total number of species were calculated, as well as totals per m^2, by converting the totals based on the observed sampled area. The taxonomic data were merged with the results from the coating analysis, for which total number of particles, total coating particle size per sample and total size of the particles relative to the sampled area were calculated. The resulting data were combined with the meta-data registered in the field, including information on scraper type and sampling depth.

3.4.2 Existing biofouling data

To assess the similarity of the MGST data with existing biofouling data acquired by divers elsewhere, an international dataset on biofouling on offshore artificial structures named BISAR (Biodiversity Information of benthic Species at ARtificial structures) was used (Dannheim *et al.*, n.d.). BISAR also contains data from the Princess Amalia Wind Farm (Coolen *et al.*, 2020b) which is close to HKZ. Since BISAR includes data from structures of a wide range of materials, ages, and sampling depths, only samples taken on steel foundations, from depths between 4 and 20 meters and from structures sampled <5 years after construction were included. To correct for differences in sample size within BISAR and in MGST samples, number of individuals and weights per sample were converted to number and weight per m^2. Number of individuals was available for all samples included in BISAR, while ash free dry weights were only available for data from the Dutch and part of the German data.

3.4.3 Comparisons & statistical tests

To assess differences in species richness, number of individuals, number of particles and size of particles between samples collected using different scraper types and at different depths, data were visualised using ggplot (Wickham, 2009) and tests for significance of differences performed with generalise additive models (GAM) using the mgcv package (Wood, 2011). GAMs were used as the effect of depth on species patterns has previously been reported as a non-linear relation with maxima at intermediate depths (van der Stap *et*

al., 2016; Coolen *et al.*, 2020b, 2022a) for which linear models are not ideal. GAMs allow to include this non-linear pattern, while still providing linear results if no non-linear pattern is detected and when no non-linear variable is inserted, the GAM behaves as a generalised linear model. For count-type (integers and non-negative) of data, a Poisson distribution was assumed. For biomass and size data (continuous and non-negative) a Gaussian distribution with log link was assumed. Difference in species composition between scraper types within the MGST dataset as well as between MGST and BISAR was assessed using nonmetric multidimensional scaling (nMDS) plots.

To assess the impact of higher and lower levels of taxonomic details when assessing biofouling data, the MGST data processed at higher and species levels were compared using a nMDS plots, plotting the samples by scraper type. However, as already in the species level data, no structure among the samples could be identified, the difference between the two levels of taxonomic detail could not be adequately interpreted. Therefore, the effect of taxonomic level was explored further by converting the BISAR data to six different levels of detail. This was done by aggregating all data on genus, family, order, class and phylum level, summing the counts of the same new taxon within a sample. Then an nMDS plot was generated for each dataset, plotting the samples coloured per country. This analysis was performed using number of individuals per m^2 as well as ash free dry weight (afdw) per m^2.

4 Results

4.1 Offshore test

4.1.1 Environmental conditions

Wind speeds encountered during the survey were 10 knots on 29 November and 6 – 10 knots on 30 November. The significant wave height (Hs) was 1.2 m on 29 November and 0.8 – 1.0 m on 30 November. Water temperature was approximately 5 °C. Workable current conditions were encountered most of the time, excluding when currents went above approximately 1.2 knots (0.6 m/s). Currents are locally enhanced around turbine foundations, but by flying the ROV down-stream of the foundation (in the 'shadow'), the work could still continue most of the time. However, the position of the ROV was also restricted by protruding objects such as anti-corrosion systems present on the outside of the foundation, so an optimal position in the shadow was not always available. Some down-time due to current was therefore experienced.

4.1.2 Acquired samples

During the test, a total of 25 attempts to acquire a sample were carried out. During the first attempt in shallow depth (1 m) a sample (BT23DHR0970) was acquired and stored but this was found of unacceptable quality as no clear sampled surface area was attained. After all subsequent attempts without known observed sampled area, the samples were discarded and not stored for later processing. This applied to two further attempts to sample in shallow water (at 1.8 and 2.8 m) and an attempt during which the presence of a weld in the sampling area was observed in 18 m depth. In these cases, the sample was registered as 'sample failed' (Table 4.1). A total of 21 samples were registered as acceptable quality of the sample taking process.

Table 4.1 *Sampling meta-data. Sample = sample number, Start time = time at which the MGST commenced sampling, measured depth in meters seawater below the water surface during sampling, orientation = degrees of point of view of the ROV, scraper type = the scraper type used.*

Sample	Date	Start time	Depth	Orientation	Sampled area programmed	Sampled area observed	Scraper type	Sample taking quality	Biofouling type	Coating damage visible?
BT23DHR0960	29-Nov	18:52	20	150	560	560	metal	acceptable	Jassa – Metridium	no
BT23DHR0961	29-Nov	19:15	18.3	152	560	560	metal	good	Jassa – Metridium	no
BT23DHR0962	29-Nov	20:38	15	23	560	560	metal	good	Jassa – Metridium	no
BT23DHR0963	29-Nov	20:57	10	16	560	480	metal	poor to acceptable	Jassa – Metridium	no
BT23DHR0964	29-Nov	21:19	10	14	560	500	metal	poor to acceptable	Jassa – Metridium	no
BT23DHR0965	29-Nov	21:40	12	28	560	560	metal	acceptable	Jassa – Metridium	no
BT23DHR0966	30-Nov	07:19	15	165	560	610	green	acceptable	Jassa – Metridium	no
BT23DHR0967	30-Nov	07:38	15	171	560	560	green	good	Jassa – Metridium	no
BT23DHR0968	30-Nov	08:23	15	156	560	560	green	good	Jassa – Metridium	no
BT23DHR0969	30-Nov	08:44	15	19	560	560	green	good	Jassa – Metridium	no
BT23DHR0970	30-Nov	09:07	1	13	560	NA	metal	unacceptable	Mytilus	no
SAMPLE FAILED	30-Nov	09:27	2.8	12	560	NA	metal	unacceptable	Mytilus	no
SAMPLE FAILED	30-Nov	09:54	1.8	30	560	NA	metal	unacceptable	Mytilus	no
BT23DHR0973	30-Nov	10:28	15	19	560	560	blue	good	Jassa – Metridium	no
BT23DHR0974	30-Nov	12:32	15	14	560	560	blue	good	Jassa – Metridium	no
BT23DHR0975	30-Nov	12:49	15	15	560	560	blue	good	Jassa – Metridium	no
BT23DHR0976	30-Nov	13:07	15	13	560	560	blue	good	Jassa – Metridium	no
BT23DHR0977	30-Nov	13:28	9.5	16	560	560	green	good	Jassa – Metridium	no
BT23DHR0978	30-Nov	13:44	8	14	560	510	green	acceptable	Jassa – Metridium	no
BT23DHR0979	30-Nov	14:06	6.5	18	560	560	green	good	Jassa – Metridium	no
BT23DHR0980	30-Nov	14:23	4.5	15	560	580	green	acceptable	Jassa – Metridium	no
BT23DHR0981	30-Nov	14:46	12	19	560	560	green	good	Jassa – Metridium	no
SAMPLE FAILED	30-Nov	15:37	18	148	560	NA	green	unacceptable	Jassa – Metridium	no
BT23DHR0983	30-Nov	16:01	18.4	151	560	560	green	good	Jassa – Metridium	no
BT23DHR0984	30-Nov	16:20	20	156	560	560	green	good	Jassa – Metridium	no

4.1.3 General performance evaluation of the MGST

After some initial tests of the MGST during which tip-points instead of magnets were also tested and found to slip too easily, sampling started at 18:52 on 29 November 2023. The last sample was finished at 16:45 on 30 November 2023. Including down-time during strong currents and resting time at night, 21 samples were taken in less than 22 hours. The turnover time between samples (without additional activities such as changing scrapers) was an average of 22 minutes (Figure 4.1). The first night, samples were taken between 18:52 h and 22:00 h, while the team was on stand-by for 60 min between samples 2 and 3. Thus, the first 6 samples were acquired in approximately 2 h and 10 min. On the second day, work started at 07:14 h and ended at 16:45 h, with standby time for approximately 2 h around noon, thus taking 15 samples in 7.5 h.

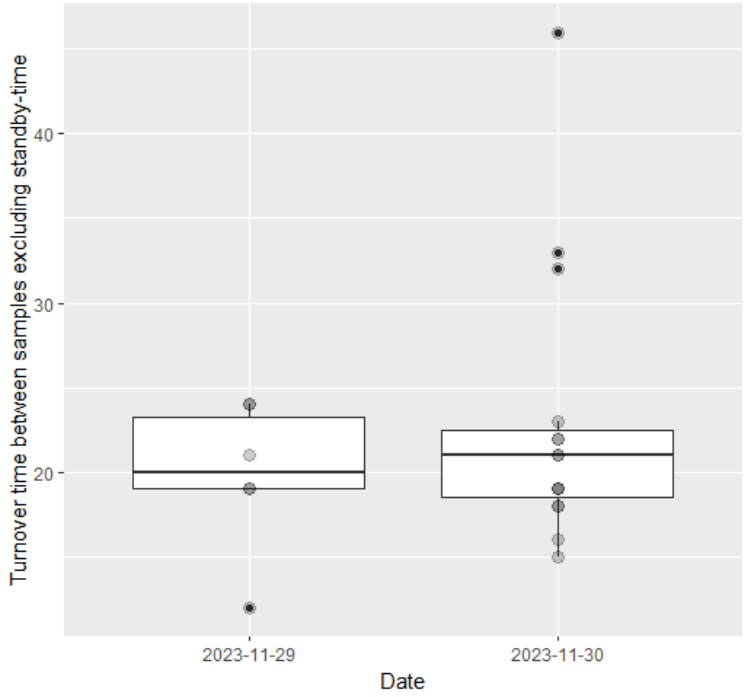

Figure 4.1 *Time spent per sample (min), excluding resting and standby time, per date.*

The test showed that, within a restricted depth range, the MGST can acquire biofouling samples from an offshore turbine foundation in conditions present in the Dutch North Sea. Sixteen out of 21 accepted samples were taken with the exact sampled area observed as programmed. For 3 of the other 5 samples, the sampled area deviated <10% of the programmed area while 2 samples deviated 12 and 14% (Figure 4.2). The average deviation of the tool was 1%.

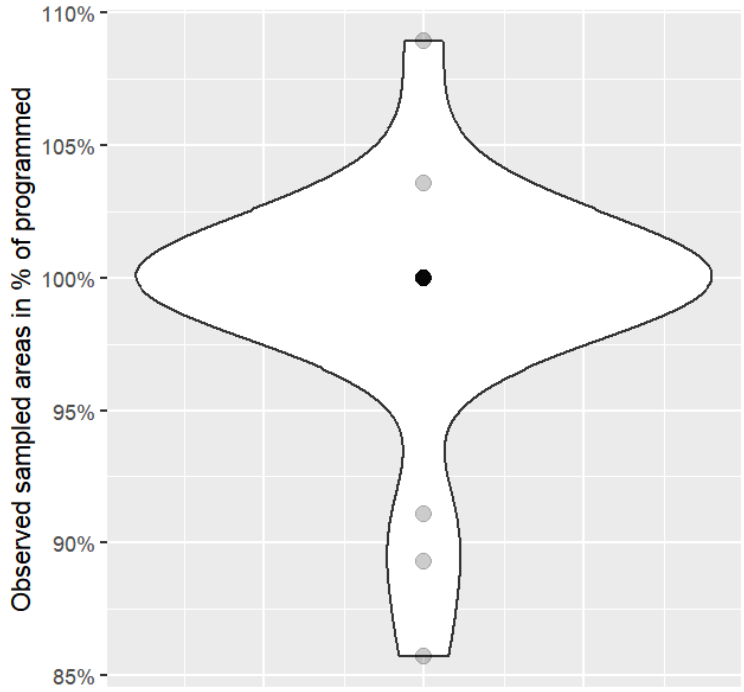

Figure 4.2 *Violin plot of the observed sampled area as percentage of the programmed area (560 cm²). Overlapping samples shown with dark dot, single samples with grey dot. Width of the wide area indicative of number of samples.*

4.1.4 Depth and current limitations

In the environmental conditions encountered during this test, the depth range at which the MGST successfully acquired samples was 4.5 to 20 meters. Shallower attempts resulted in too much uncontrolled movement of the ROV.

Within the samples for which an observed sampled area could be registered, there was no statistically significant ($p>0.05$) association with depth (Figure 4.3).

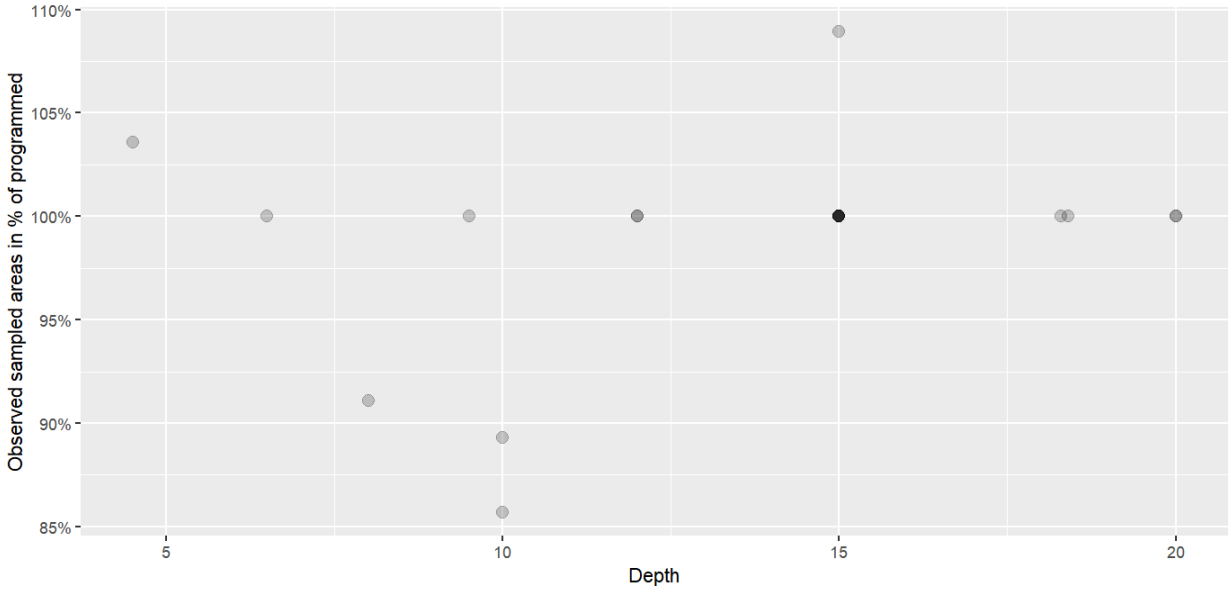

Figure 4.3 *Depth of sampling in relation to the deviation of sampled area. Grey dots: single observations, dark dots: multiple overlapping observations.*

4.1.5 Performance of three scraper types

During the test, there was no visible difference in success rate between the three scraper types. All scrapers scraped the samples in similar durations. It was noted that the plastic scrapers showed damage to the sharp edge after collecting a few samples (Figure 4.4). The metal scraper did not show any significant damage. No

damage to the coating on the turbine foundation was observed on the video live-feed with any of the scraper types.

Figure 4.4 *Green and blue scraper with damage (bottom sides in photos) after scraping 4 samples each.*

4.1.6 Fauna removal efficiency & sampled area shape

Based on the video data, it was estimated that the MGST removed 100% of the fauna in 15 out of 21 cases (Figure 4.5, Table 4.3). The minimum removal percentage of 95% was observed in a single case. In 5 of the cases the removal percentage was >99%. The average percentage of removed fauna was 99.5 ± 0.2 (standard error) %. The metal scraper performed slightly better than the other scrapers, but with all types, the average removal percentage was above 99%.

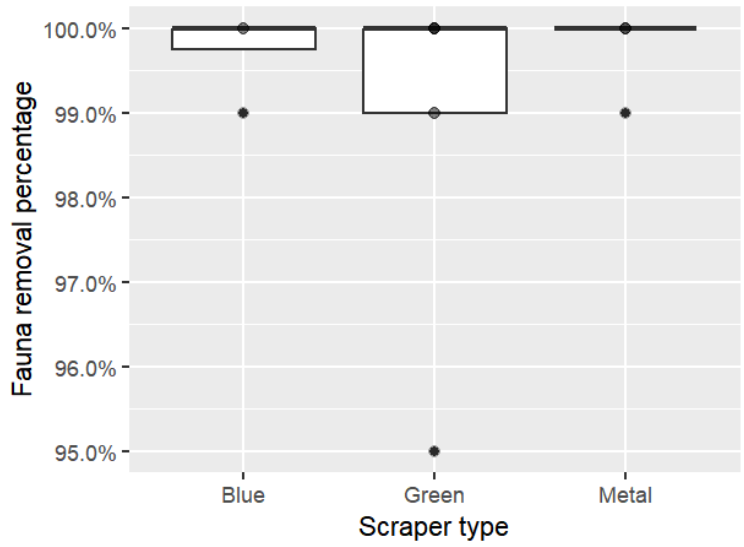

Figure 4.5 *Fauna removal percentage per scraper type. Grey dots: single observations, dark dots: multiple overlapping observations.*

Video analysis also showed that the sampled area was rectangular as intended in 14 out of 21 samples. In 7 samples there was a deviation in shape of the area visible in the recorded video, but during sampling, the sample collection activity was judged to be of acceptable quality anyway. In 2 cases, the deviation appeared to be caused by ROV movement. This was the case, for example, when the ROV moved in the vertical direction during sampling, not interfering with the total sampled area (BT23DHR0965; Figure 4.6 top left) or when the MGST magnets touched the sampled area after taking the sample (sample BT23DHR0980; figure 4.6 top right). In the 5 other cases, the deviation appeared to be caused by the presence of a species that caused either too much removal, remained attached to the substrate after sampling, or appeared to cling to other species, e.g. at the left edge of a sampled area when the scraper lifts off.

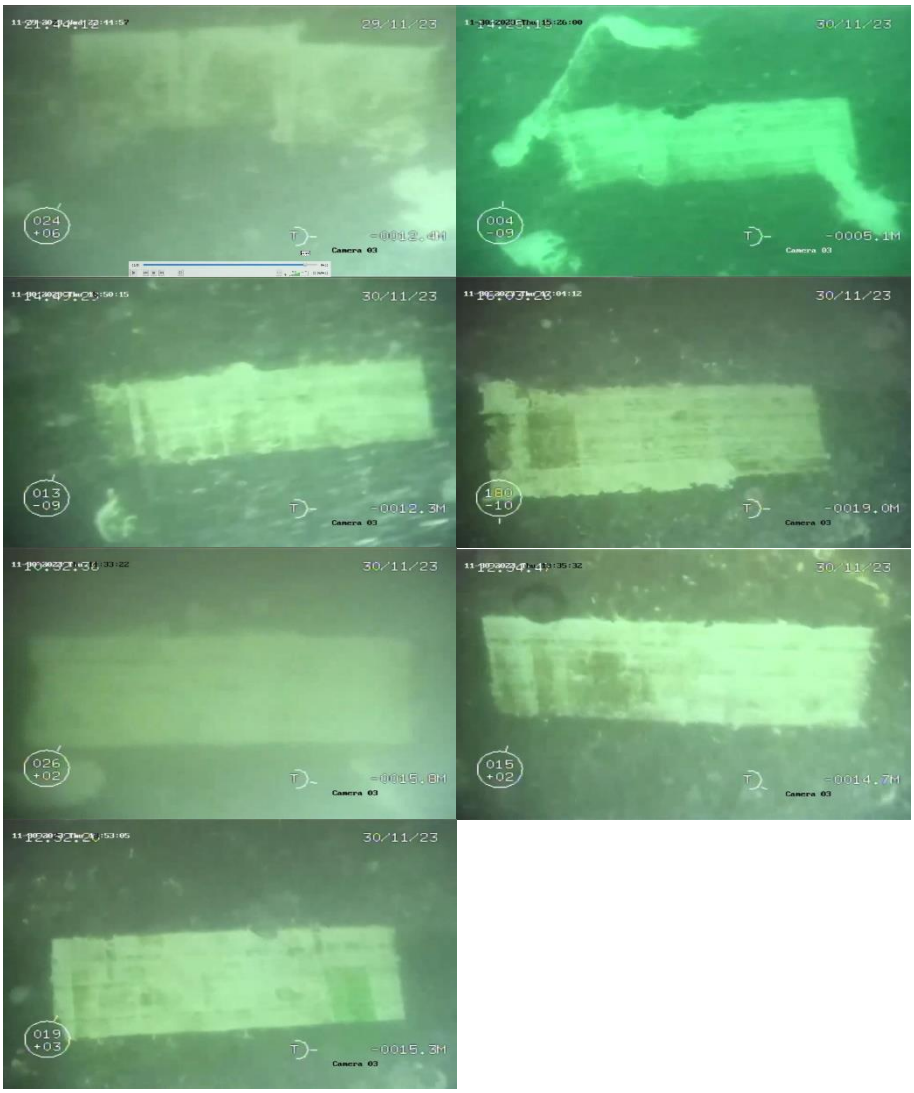

Figure 4.6 *Examples of samples with deviation from a rectangularly shaped sampled area assumed to be caused by ROV movement (top row) and deviations likely caused by the species present (lower rows).*

4.2 Taxonomic results

4.2.1 Sample quality

Sample quality on board was assessed as 'good' for every sample. There was no unexpected damage visible to species. The MGST appeared to properly remove, transport and store the species present on the foundation. During later processing in the lab, no unexpected damage to species was observed and generally, sample quality was good. Damaged individuals are commonly present in biofouling samples taken by scraping, during which attached individuals need to be removed forcefully, and the observed damage was similar to samples collected by divers in the past.

Although, following the WMR protocol for processing macrofauna samples, zooplankton species were not registered during sample processing, the analysts observed a relatively high number of copepods in the samples. Furthermore, there was a single observation of the Atlantic bobtail *Sepiola atlantica*.

4.2.2 Difference between scrapers

Between scraper types, the number of individuals per m^2 and the number of species (detailed taxonomy samples only) varied but did not differ significantly ($p>0.05$) and showed a clear overlap in range (Figure 4.7). The average number of individuals varied between $1.06 * 10^5$ individuals per m^2 and $4.42 * 10^5$ individuals per m^2 with an average of 2.65 ± 0.19 (standard error) $* 10^5$ individuals per m^2. Richness (unique species per sample) varied between 11 and 29 species per sample with an average of 19.3 ± 1.1.

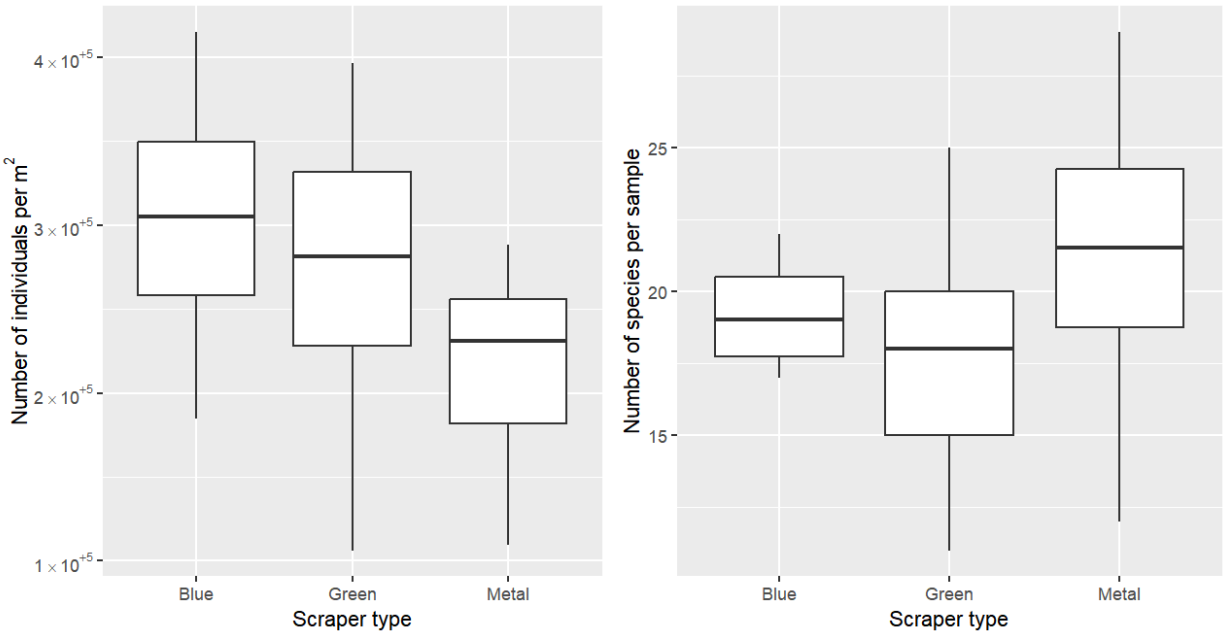

Figure 4.7 *Number of individuals per m² (left) and number of species per sample, per scraper type.*

Between scraper types, there also was no clear difference in densities of phyla, indicating that the performance of the scraper to remove different taxa with various growth forms was similar (Figure 4.8).

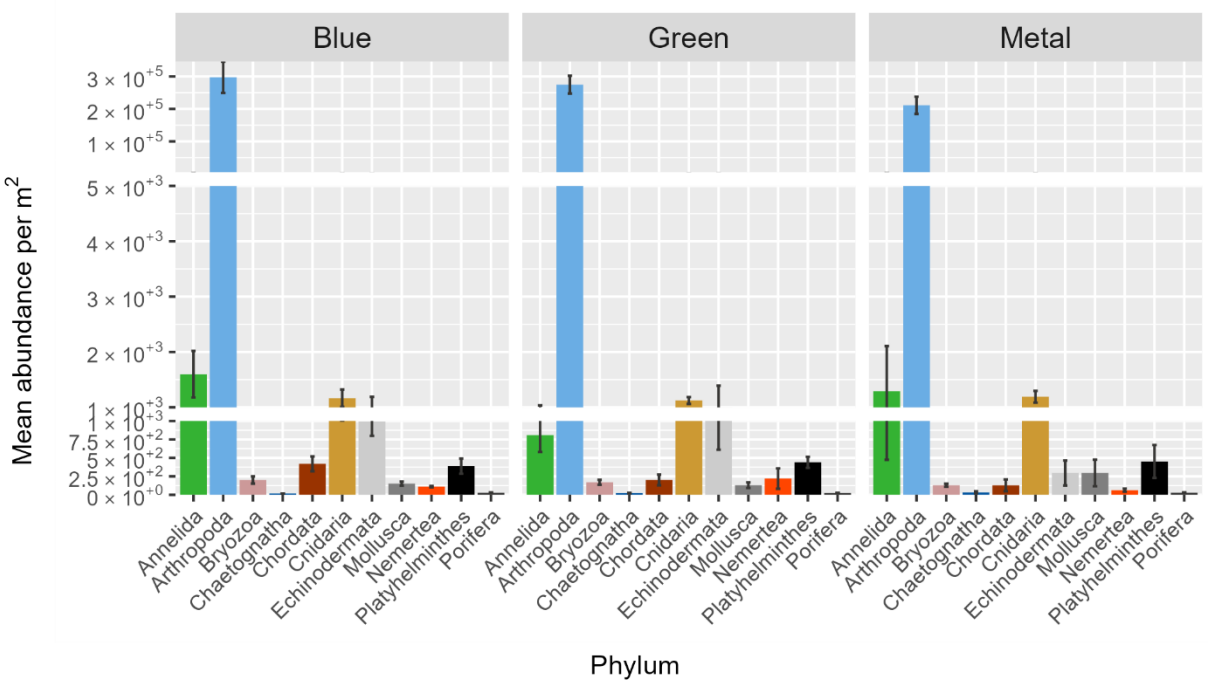

Figure 4.8 *Mean number of individuals per m² with standard error bars, for each Phylum observed, per scraper type. Note the y axis scale is displayed using 3 different ranges.*

The nMDS plot (2 dimensions, 999 iterations, stress = 0.14) showed a strong overlap between the ordination of the different scraper types, again suggesting that no effect on species removal and collection efficiency was present from the scrapers (Figure 4.9).

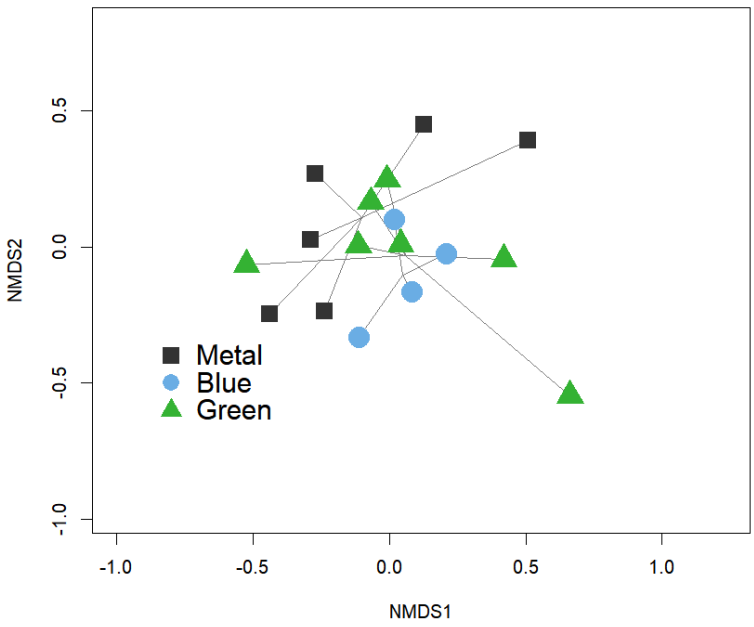

Figure 4.9 *Non-metric multidimensional scaling plot (stress 0.14) for samples processed on lowest taxonomic level (n = 17).*

4.2.3 Comparison to published diver collected data

After filtering on the selection criteria, the subset of the BISAR dataset (Dannheim *et al.*, n.d.) to which the MGST data was compared contained 1015 biofouling samples from offshore wind farms from Belgium (2 OWF), the Netherlands (1), Germany (2) and Denmark (1) and 2 offshore test sites (FINO projects) in Germany. The values for number of individuals and richness as observed in the MGST samples fell within range of the data from the diver collected samples in BISAR. Although variation in MGST samples' numbers and richness was large, it was similar to the observations in BISAR (Figure 4.10). Further in-depth analysis of the patterns observed in BISAR and analysis of environmental variation explaining differences between BISAR and the MGST samples were not performed as part of this project.

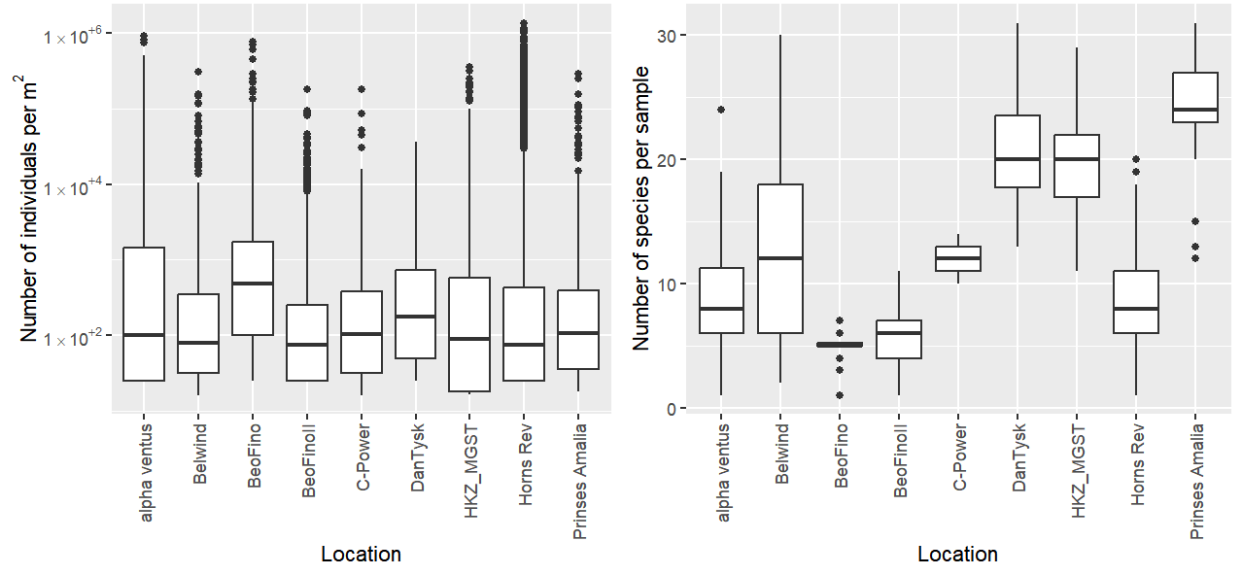

Figure 4.10 *Number of individuals per m² (left) and number of species per sample, per location in BISAR and the MGST-data from HKZ (HKZ_MGST).*

4.2.4 Evaluation of levels of detail in taxonomy

Time spent on the different levels of taxonomy was registered per sample type (Table 4.2), not per sample. For the samples processed for taxonomy to the lowest level possible, a total of 311 hours on 13 samples,

leading to an average of 23.9 hours per sample was spent processing the samples and inputting the data in the database. For the higher-level taxonomy, this was a total of 115 hours on 8 samples, leading to an average of 14.4 hours per sample.

Table 4.2 *Overview of identification level per sample*

Sample	Species level	Higher level
BT23DHR0960	X	X
BT23DHR0961	X	-
BT23DHR0962	X	-
BT23DHR0963	X	-
BT23DHR0964	X	X
BT23DHR0965	X	-
BT23DHR0966	X	-
BT23DHR0967	X	-
BT23DHR0968	X	-
BT23DHR0969	X	-
BT23DHR0970	X	-
BT23DHR0973	X	-
BT23DHR0974	X	-
BT23DHR0975	X	-
BT23DHR0976	X	-
BT23DHR0977	-	X
BT23DHR0978	-	X
BT23DHR0979	X	X
BT23DHR0980	X	X
BT23DHR0981	X	
BT23DHR0983	-	X
BT23DHR0984	-	X

4 out of 8 samples processed for higher level taxonomy, were later also processed for detailed level, as additional budget became available in the project. Since this was applied to already processed samples, which were then handled twice, leading to an increase in total processing time, the detailed level part of this work was not included in the averages presented in the above. It was estimated that the additional processing of four high-level samples to species level took a total of 49 hours with an average of 12.3 hours per sample.

In the multivariate comparison between samples processed on the lowest level possible and higher level (Figure 4.11) no obvious structure was visible in either level of taxonomy and therefore, the impact of different levels of detail on the structure in the data was inconclusive. To further explore the effect of changes in taxonomic detail, the BISAR data were utilised.

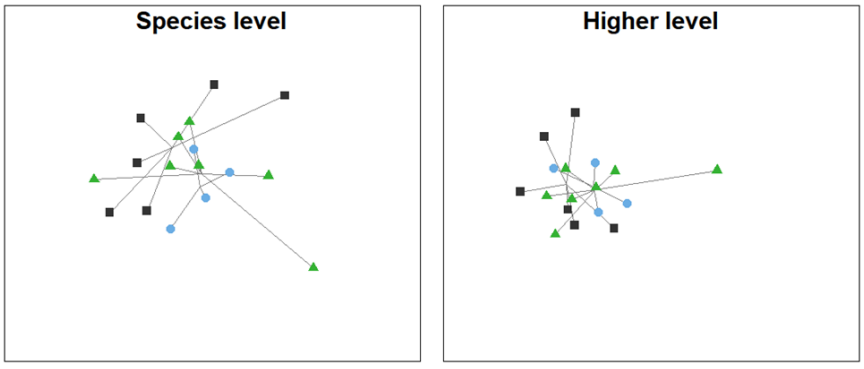

Figure 4.11 *Non-metric multidimensional scaling plots based on n per m^2 for samples processed on lowest taxonomic level (left, n = 17) and samples processed on higher level combined with low level samples converted to high level (right, total n=17).*

Using BISAR data, clustering in two multivariate dimensions in an nMDS plot using abundance data (n per m^2) showed two distinct clusters at country level (Denmark vs the others, Figure 4.12 top left). No clear

clustering of the MGST samples outside the spread of BISAR samples was visible. This suggests that the community composition in the MGST samples does not strongly deviate from that observed in at least part of the BISAR data. The samples from Princes Amalia Wind Farm (the most proximate OWF) clustered relatively close to the MGST data. After conversion of the BISAR and MGST data to aggregations at different taxonomic levels, the structuring at country level was absent in all taxonomic levels (Figure 4.12). This suggests that processing biofouling samples at genus or higher level, can remove patterns that are visible at species level.

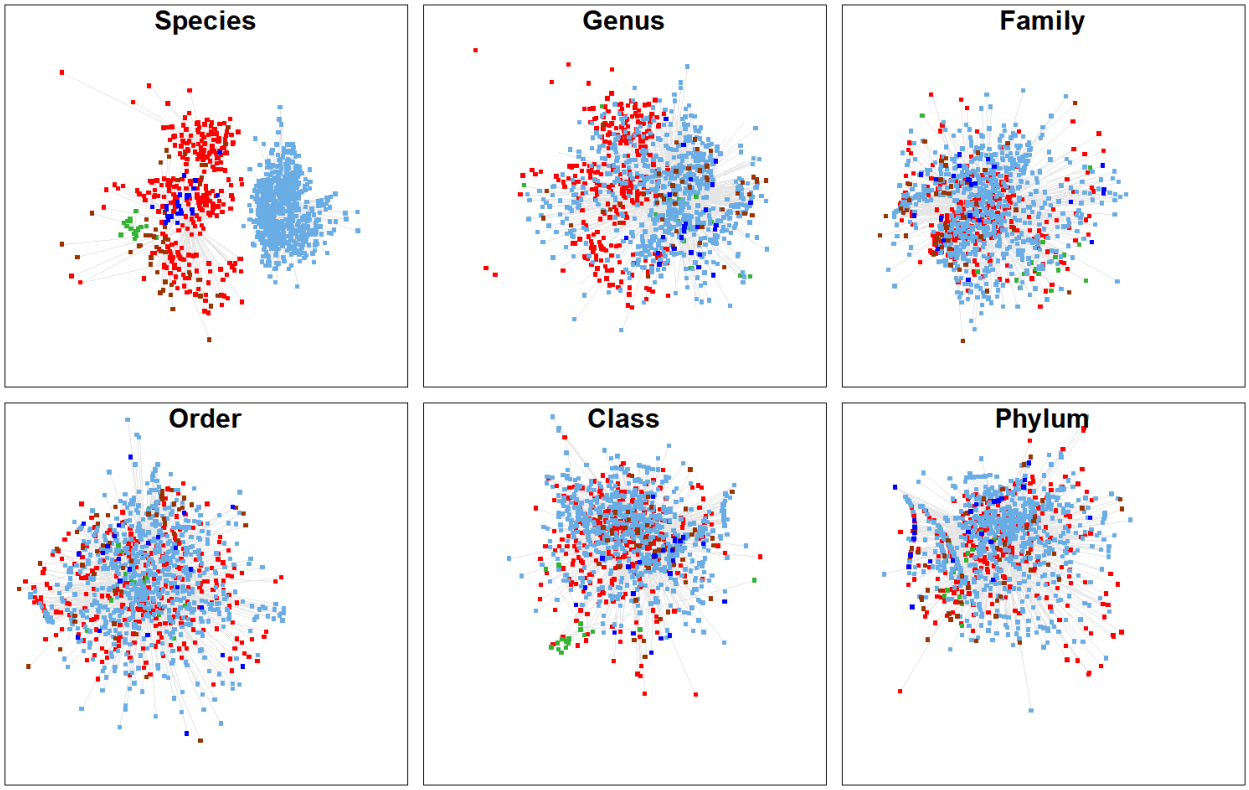

Figure 4.12 *Non-metric multidimensional scaling plots for MGST samples based on n per m^2 processed on lowest taxonomic level (n = 17, green dots) versus BISAR samples (n = 1015, dots per country: Belgium = brown, Netherlands = dark blue, Germany = red, Denmark = light blue), with grey spider lines drawn for each wind farm cluster.*

For the nMDS using ash free dry weights, the data from Belgium, Denmark and part of the German data had to be excluded as these did not contain afdw. The resulting dataset contained 209 out of the 1015 available samples. The nMDS on afdw (Figure 4.13) did show clearer clusters on wind farm level than were visible in the nMDS on n per m^2. Again, this pattern was strongly reduced when plotting with higher level taxonomy, which showed much more overlap between wind farm clusters as well as countries than the species level did.

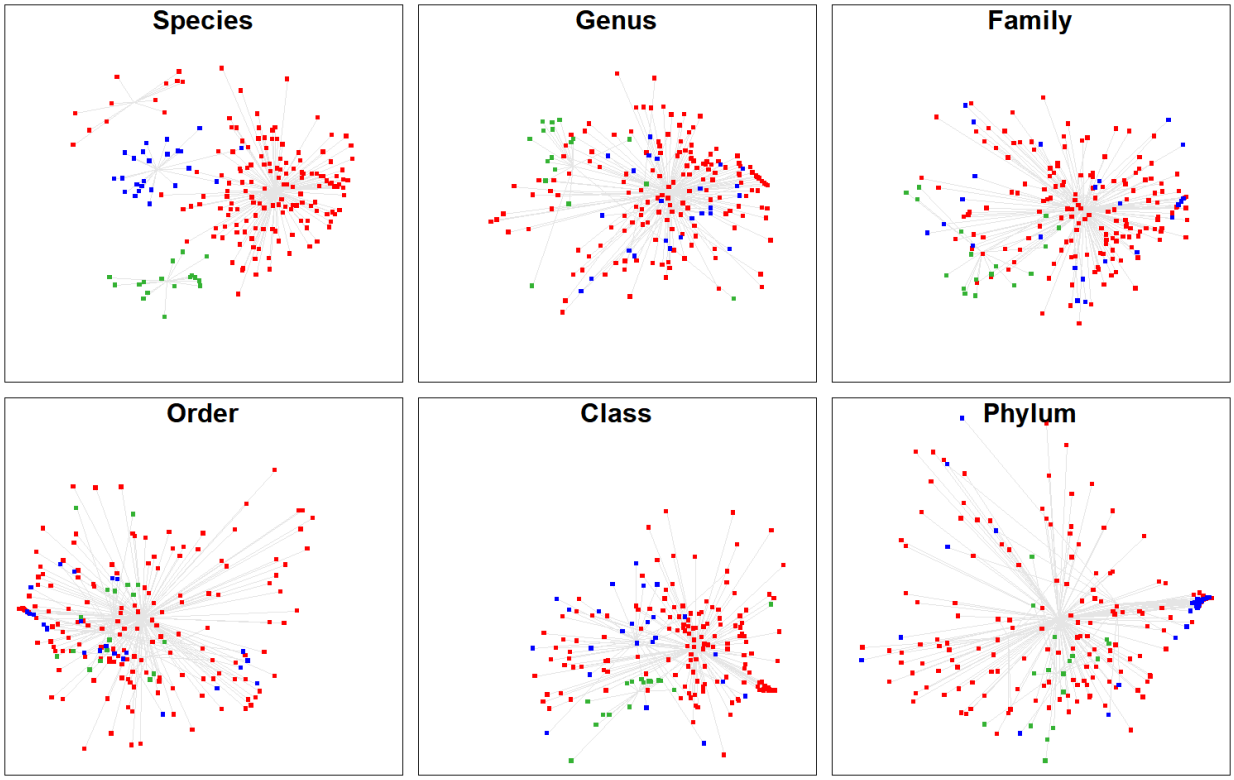

Figure 4.13 *Non-metric multidimensional scaling plots for MGST samples based on afdw per m^2 processed on lowest taxonomic level (n = 17, green dots) versus BISAR samples (n = 209, dots per country: Netherlands = dark blue, Germany = red), with grey spider lines drawn for each wind farm cluster.*

4.2.5 Video analysis results

During the video analysis, 3 species and 5 higher level taxa could be identified. In general, the video quality was poor and sometimes turbidity was high, both raising a challenge to identify species with an acceptable level of certainty (Table 4.3). Due to the low number of identifiable taxa, these data were not used to further assess any patterns in the data.

Table 4.3 *Video-analysis results with species presence indicated by p.*

Sample	Percentage fauna not removed	Coating damage	Notes on sampled area shape	*Metridium senile*	*Cylista troglodytes*	Cylista	Serpulidae	Brachyura	*Pisidia longicornis*	Amphipoda	Amphipod tubes	Porifera
BT23DHR0960	1	0	As planned	p	p	p	p				p	
BT23DHR0961	0	0	As planned	p	p	p	p				p	
BT23DHR0962	0	0	As planned	p	p	p					p	
BT23DHR0963	0	0	As planned	p	p	p					p	p
BT23DHR0964	0	0	As planned	p	p	p	p	p		p	p	
BT23DHR0965	0	0	With vertical offset	p	p	p			p	p	p	
BT23DHR0966	0	0	As planned	p	p	p	p				p	
BT23DHR0967	1	0	As planned	p	p	p	p			p	p	
BT23DHR0968	5	0	As planned	p	p	p	p			p	p	
BT23DHR0969	0	0	As planned	p	p	p		p	p		p	
BT23DHR0973	0	0	As planned	p	p	p		p			p	
BT23DHR0974	0	0	As planned	p	p	p	p				p	
BT23DHR0975	1	0	As planned	p	p	p					p	
BT23DHR0976	0	0	As planned	p	p	p					p	
BT23DHR0977	0	0	As planned	p	p	p					p	
BT23DHR0978	1	0	As planned	p	p	p			p		p	
BT23DHR0979	0	0	As planned	p	p	p					p	
BT23DHR0980	0	0	With offset and some surface area irregularities probably caused during lift off at end of sampling	p	p	p					p	
BT23DHR0981	0	0	Upper part slightly uneven possibly caused by removed anemone	p	p	p		p			p	p
BT23DHR0983	1	0	Lower right border with thin stripe not scraped off; upper left corner of sampling area irregular probably caused during lift off at end of sampling	p	p	p	p		p		p	
BT23DHR0984	0	0		p	p	p	p				p	p

4.3 Coating results

All the samples used for the different taxonomic levels were also used to quantify the presence of coating particles in the samples. Three different colours of coating (white, yellow and orange) were observed (Figure 4.14), most of which were white. Although a green substance was observed covering part of the coating underneath 2 samples, and later during sample processing small particles of green substance were observed attached to the bottom side of calcareous worm tubes, this colour was not detected during the later coating analysis and was therefore assumed to be of other material than coating. Observations of non-coating particles, such as microplastics, are not presented in the results.
In total, 16 coating particles were found in all samples combined. In 11 samples, no coating particles were detected. In 10 samples, 1 to 3 particles were found, of which 5 samples contained a single particle and 1 sample contained 3 particles. The largest total coating particle size in a sample was 2.6 mm^2. The mean total particle size per sample was 0.64 ± 0.18 (standard error) mm^2. When converted to percentage of the observed sampled area, the relative coating size ranged between 0% (no particles in sample) to 0.0046% (Figure 4.15). All single observations of coating particles are presented in Table 4.4.

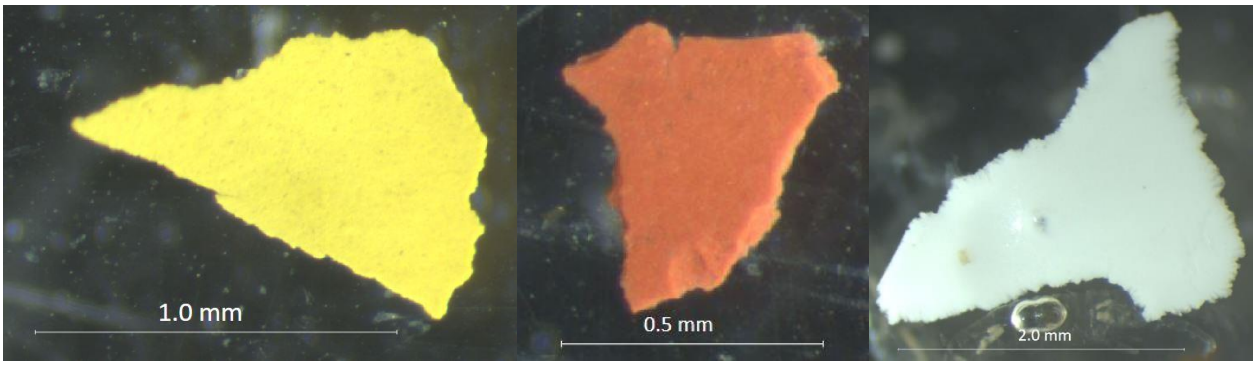

Figure 4.14 *Examples of coating particles of the three observed colours, with scale bars.*

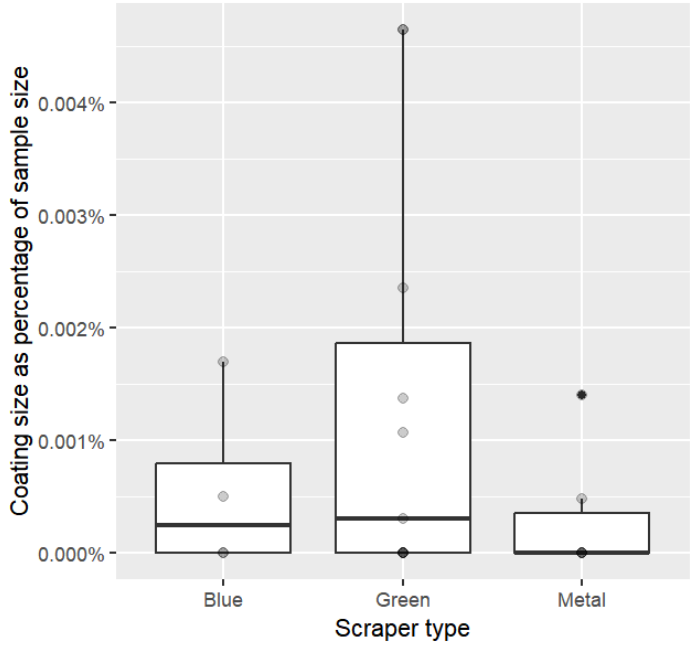

Figure 4.15 *Total size of the coating particles observed in samples, as percentage of the sampled area. Grey dots: single observations, dark dots: multiple overlapping observations.*

Table 4.4 *Raw data on each observed coating particle with coating colour and size. No coating particles were present in fraction 0.212-0.125 mm.*

Sample number	Sieve fraction (mm)	Colour	Size (mm²)
BT23DHR0962	>0.212	Orange	0.15
BT23DHR0962	>0.212	Orange	0.12
BT23DHR0964	>0.500	Yellow	0.7
BT23DHR0967	>0.500	White	2.6
BT23DHR0968	>0.212	Orange	0.17
BT23DHR0975	>0.500	Yellow	0.35
BT23DHR0975	>0.500	White	0.45
BT23DHR0975	>0.212	Yellow	0.15
BT23DHR0976	>0.500	White	0.28
BT23DHR0977	>0.500	White	0.3
BT23DHR0977	>0.500	White	0.3
BT23DHR0978	>0.500	White	0.3
BT23DHR0978	>0.500	Yellow	0.9
BT23DHR0979	>0.500	White	2.1
BT23DHR0979	>0.500	White	0.5
BT23DHR0980	>0.500	White	0.8

5 Discussion

In general, the test showed the marine growth sample tool is capable of collecting biofouling samples from vertical offshore energy structures from communities dominated by amphipods and anemones, from depths between 4 and 20 meters. Sample quality was good and similar to the quality of samples collected by divers.

5.1 Environmental conditions and depth

The current test was successful in depths below 4 m. Attempts to sample shallower parts of the foundation failed due to uncontrolled movement of the ROV. The precision of the MGST depends on the movement of water during sampling relative to the ROV position. Relative water movement depends on the wave height at the water surface and frequency of the waves, as well as the orientation of the ROV in relation to the waves, currents, and the sampling depth. The orientation of the ROV was restricted by current direction and it could not always be positioned in a direction which was optimal for both wave direction and current. As a result, the MGST is limited to a certain depth range, which likely varies between different weather conditions and tidal cycles.

It is expected that during perfect weather conditions (i.e. flat sea surface during Bft 1 winds) and slack tides (currents below 1 knots) the MGST should be capable to acquire samples from minimum depths of 2 m. Shallower depths are not considered feasible as the ROV needs a certain water height above the top thruster and the MGST is positioned at the bottom of the ROV. However, minimum depth also depends on wind direction versus current direction, the shape of the studied object (i.a. diameter of the monopile) and other environmental conditions. A precise statement on workable conditions can therefore not be made. Generally, the MGST and ROV will be easier to operate in shallow water with low wave height and low water current speeds.

5.1.1 Further testing and improvements

It is recommended to attempt to sample shallow parts (2-6 m depth) of different types of foundations during future tests to generate further experience with the stability of the system during different environmental conditions. Based on these experiences, optimisation of the MGST may be needed. This may be sought in increasing stability, e.g. by using stronger magnets on the MGST corners. Stronger magnets, however, are typically larger as well, and may be more obstructed by biofouling when trying to push through the layer, thus increasing the distance between the foundations' steel and magnets, decreasing its ability to 'stick' to the structure. Furthermore, the magnets' power should be considered; if the total power of the magnets is more than the ROV thrusters can pull, the ROV may not be able to come loose. The magnets used during the test were already reaching this limit: the ROV was not being able to release itself from a flat wall under onshore testing conditions. As under offshore conditions the holding strength is less, due to a curved surface (monopile) and biofouling between the magnet and monopile steel, likely the magnets could be increased to one size-class larger without high risk to the ROV.

There is an option to investigate the use of electromagnets. This could create larger holding strengths with smaller surface area, but probably requires custom design and additional power electronics. Electromagnets require contact with the steel to work properly, so if too much biofouling is present in between the magnet and the steel they will not function properly. The currently used fixed neodymium magnets have a larger gap tolerance and thus are less sensitive to biofouling. More experience with stronger magnets could be gained during further testing.

The quality of the video footage was low, as the test was not set up to assess biofouling species from the footage. It is possible to optimise the video quality, but options depend on the ROV model used and required resolution. The easiest solution would be to use an HD-SDI IP based camera over fibre or ethernet. This allows for higher resolutions, but also requires a separate recording PC which is not part of the standard Tiger ROV setup. Depending on the video resolution requirements, the recording mechanism can become complex and expensive (Jan-Jelle Huizinga, personal observations). Costs of improved camera systems should be weighed against the limited added value to the already acquired highly detailed data from the samples.

5.2 Sampling and sample quality

5.2.1 Deviation from sampled area

With a mean deviation of 1% between the programmed and observed sampled area, the accuracy of the sampled area is high. It should be noted that during sampling with divers, the actual sampled area can also deviate from the planned area (personal observations by Joop Coolen), but this is not regularly quantified. Rather, the planned sampled area is typically reported without evaluation of the accuracy of the area. The use of the MGST with camera and capability to measure the actual area at the end of a sampling action, does allow for the quantification of the actual sampled area. This would then also allow to include a maximum deviation percentage in sampling protocols. A lower percentage would increase the number of rejected samples, thus an optimum between high quality and sample taking efficiency should be sought. Based on expert judgement (Joop Coolen, personal observations) we believe the typical deviation in diver samples is below 10%. Therefore, we recommend including a maximum deviation of 10% in MGST sampling protocols. In the current MGST test, this would have resulted in the rejection of 9% of the samples in additional to the already rejected samples. As this was the first time the ROV team performed a sampling campaign with the MGST, it is expected that future rejection rates under similar circumstances will be lower. However, this strongly depends on working conditions. When high wave action is encountered, the MGST may loose position during sampling more often, which will increase the deviation size and thus rejection rates. More experience with the MGST under a variety of environmental conditions needs to be gained to better estimate the typical deviation and rejection rates when using the system in future OWF monitoring.

5.2.2 Sampled biofouling community type

The biofouling communities encountered during the test were mostly dominated by amphipods mixed with small anemones. Only in samples taken shallower than 4 m, the community changed to one dominated by mussels. However, all samples in shallow depths failed due to uncontrolled ROV movement as a results of wave action. Therefore, all samples from mussel-dominated communities were rejected on sample-taking quality and were not processed in the lab. As a result, only samples from amphipod and anemone dominated communities could be evaluated here. It is well known that multiple species groups can dominate biofouling communities on North Sea offshore structures (Krone *et al.*, 2013; Coolen *et al.*, 2022a, 2024; Mavraki *et al.*, 2023; Zupan *et al.*, 2023). Generally, in the currently present near-shore wind farms shallow parts of foundations are dominated by mussels, intermediate depths by a mix of hydrozoans and amphipods (mainly *Jassa herdmani*) and deeper parts by anemones (mainly *Metridium senile*). Far offshore, in regions where future wind farms are now planned, also calcareous tube worms or soft corals can be encountered as dominant species (Coolen *et al.*, 2020b). In most cases, these dominant species deviate from what was encountered during the current test. We expect that calcareous species such as mussels and tube worms will be challenging for the MGST to collect samples from. Furthermore, during previous sampling campaigns on older structures such as platforms (Coolen *et al.*, 2020b) and shipwrecks (personal observations Joop Coolen), much thicker biofouling layers were encountered and often caused blockage of tubes used to suck in sampled fauna. Unfortunately, on the visited turbine foundation, mussels were present only in the very shallow part where wave action was too high to perform a successful test. As a result, no mussels were sampled under stable conditions, and it remains unknown whether the MGST can samples of known size from mussel dominated communities.

It is recommended to perform further tests with the MGST, including performance tests on biofouling communities dominated by mussels of varying sizes, high densities of calcareous tube worms and all fauna community types in thicker layers than the estimated ~1 cm thickness encountered during the current test. This can be done as part of the future OWF monitoring programme or in dedicated tests, on structures of which the presence of these species groups in deeper waters is known, for example older installations such as the Offshore Windfarm Egmond aan Zee (Bouma and Lengkeek, 2013), Princes Amalia Wind Farm (Vanagt and Faasse, 2014) where mussel abundance is likely high, or far offshore gas platforms such as D15-A with high densities of calcareous tube worms (Coolen *et al.*, 2020b).

5.2.3 Uncommon taxa in the samples

The high number of copepods observed in the samples, is uncommon for biofouling samples from structures in Dutch waters (personal observations Oliver Bittner & Babeth van der Weide). Furthermore, Atlantic bobtail squid *Sepiola atlantica* was observed in one of the samples, which is rare in biofouling samples. In 1740 hard substrate samples in the unfiltered BISAR data (Dannheim *et al.*, n.d.), which includes scour protection data

and geogenic reef data from the Borkum Reef grounds (Coolen *et al.*, 2015), no single observation of this squid species is present, although it may have been sampled but not registered if non-macrofauna species are ignored. In the MGST samples, the presence of copepods and bobtail squid is likely caused by the high suction speed of the water intake in the funnel attached to the scraper, which is absent in most sampling tools used by divers (personal observations Joop Coolen). Assuming large quantities of water are ingested and then passed through the sample net, large individuals of copepods might be retained on the sampling net or within other fauna clumps. Squid typically swim away when approached by divers (personal observations Joop Coolen) and would therefore not likely be sampled with a diver method, but here the high suction force might have been larger than the swimming speed of the squid, or it was not scared away by the ROV. The volume of water passing through the chamber was not assessed during the development or testing of the MGST. To provide more insight in the effect of water intake by the MGST on copepod ingestion and retention, it is recommended to quantify the amount of water ingested per unit of time in future studies. Although the water intake via a thruster is not as stable as, for example, by using a dedicated water pump (Jan-Jelle Huizinga, personal observation), it would provide a rough indication of how much water could be ingested at different thruster speed settings. The ingestion of these uncommon groups, however, will likely not cause significant problems: when unwanted in the dataset, they can be ignored during lab processing of the samples.

5.3 Coating damage

During the offshore test and later video analysis, no visible coating damage was observed. During later lab analysis, in 52% of the samples, no coating particles were present. In 48% of the samples, coating particles up to a total size of 0.005% of the sampled area were present. Particles made of other material than coating (for example microplastics) were ignored during the analysis as their origin was unknown. Coating particles were small, with the largest total particle size in a sample of 2.6 mm^2 far exceeding the average total particle size (0.64 mm^2). No significant difference in coating particles between scraper types was observed. It should be noted that the biofouling samples were collected in a bag with a mesh size of 0.5 mm (0.25 mm^2). Coating particles <0.25 mm^2 may have been lost during the sampling process. However, multiple particles present in the samples were smaller than 0.25 mm^2, suggesting that at least to some degree, particles smaller than the mesh size were retained.

Based on the observed particles and video observations, scraping action of the MGST appeared to cause very limited damage to the coating. Possibly, the small coating particles are the result of the scraping of higher peaks in the coating layer, which would result in the removal of the small areas where the coating has a higher thickness, leaving the lower lying base coating layer intact. The test did not include an assessment of the patterns in which the coating particles were removed from the lower layer. Based on the maximum removal of 0.005% however, and the low numbers of samples per turbine foundation that can be expected in a future monitoring program, we conclude that the damage to the coating caused by biofouling studies on OWF foundations can be considered negligible.

5.4 MGST vs diver collected samples

Based on the comparison with samples from the BISAR there is no indication that MGST samples deviate in quality from samples previously collected by divers. However, the spatial and temporal spread in the BISAR dataset with many years (Dannheim *et al.*, n.d.) is large in comparison with the 2 days of sampling at a single location conducted with the MGST. To validate the MGST as a tool capable of delivering data of the same composition and quality as divers, a direct comparison is needed. To attain this, it is recommended to perform a comparative study between diver-collected samples and MGST-collected samples, by collecting samples using both methods at the same time and place, at the same depths, possibly repeating this at multiple locations and then analysing the samples using identical methods. If this cannot be done in collaboration with the Dutch offshore wind industry, it may be of interest to industry outside of the Netherlands or could be performed in collaboration with the oil and gas industry where diving is part of inspection, repair and maintenance cycles of most platforms.

5.5 Taxonomic level of detail

The difference between processing time spent on samples at high level and species level taxonomy can be explained by a decrease in time spent identifying, counting, and weighing, since less taxonomic groups are included in the higher level. Furthermore, higher level taxonomic details can more often be discerned without the help of magnification by stereo microscopes, which saves additional time. Clearly, time and therefore budget needed for the research can be lowered by processing the samples to a higher taxonomic level. In the current test this difference was an increase of 40% in the lab processing cost. It should be noted, however, that the relative increase would be much lower when considering full monitoring projects, i.a. including a large DP vessel with crew, a team of ROV operators and scientists, (de)mobilisation of equipment and project management time. The benefits of performing taxonomic work in as much detail as possible, should be included in this consideration. Although the current primary aim of Wozep is to provide biomass data to ecosystem models (personal communication Edwin Verduin, Wozep), in the future new questions might be asked for which more detailed data might be needed.

Higher level taxonomic data allows for comparisons of patterns in total sample biomass as well as total sample abundance, as these are not dependent on the taxonomy. It also remains possible to perform total biomass and total abundance comparisons with previously collected data in a Dutch as well as international context, since detailed level international data can be converted to higher taxon level data. The reverse, however, is not possible. Once higher-level data has been collected, there is no method to add the detailed levels to the results afterwards, without additional sample processing. If ash free dry weight is measured on the higher-level samples, this additional processing at later stages would not be possible.

The NMDs analysis of the BISAR data at decreasing levels of taxonomic detail, showed that country or OWF patterns visible at species level, could no longer be identified at higher levels. Based on this, identification of future samples to the lowest possible taxonomic level is recommended. Furthermore, lowering the detail also reduces the suitability of data to be reused in future, currently unforeseen scientific studies. To date, studies in Belgium (De Mesel *et al.*, 2015; Zupan *et al.*, 2023), the Netherlands (Bouma and Lengkeek, 2012; Vanagt and Faasse, 2014; Coolen *et al.*, 2020b), Germany (Krone *et al.*, 2013; Gutow *et al.*, 2014) and Denmark (Leonhard and Christensen, 2006) have all been carried out to the lowest possible taxonomic level, with organisation or country specific differences but generally using the same methods. This standard approach makes the data suitable for inclusion in scientific studies, which provide insights in larger scale ecological patterns, beyond the scope of national monitoring projects. For example, the BISAR database (Dannheim *et al.*, n.d.) in which international scientists exchange data, has been used in multiple studies which were not intended at the time of data-collection. All these studies evaluated the biodiversity patterns of species in different wind farms. The studies applied BISAR data to meta-analysis of the national monitoring projects (Coolen et al., 2022a, but using the predecessor of BISAR), different OWF decommissioning scenarios (Spielmann *et al.*, 2023), life-cycle analysis of OWF effects (Li *et al.*, 2023), scour protection designs in wind farms and at platforms (Zupan *et al.*, 2024). Ongoing research is using the BISAR data to study the effects of artificial structures on functional traits of benthic species (in prep, but plans were described in Vanaverbeke and Coolen, 2021), patterns of non-indigenous species on OWF foundations (Coolen et al., unpublished data) and food web network models (Coral et al., n.d., Ulrike Braeckman, RBINS, during Data to Decisions Symposium, 8 November 2024 in Middletown RI, US). Further initiatives using international datasets can be expected which might have a need for species level taxonomic data, as our understanding of OWF effects increases and more questions are formulated. From multiple overarching data aims (Table 5.1), only the generation of total biomass and total number of individuals per sample or m^2 is clearly possible with higher level data. Only a few of the other applications of taxonomic data from biofouling communities are perhaps possible (depending on conditions applied) but most of them would need species level data. Therefore, it is recommended to continue processing samples taken in future monitoring programs to the lowest possible taxonomic level, to facilitate the use of the data in scientific studies to answer a wide variety of questions, including those that have not been asked yet.

Table 5.1 *Suitability of species level vs higher level data for overarching data applications.*

Data aim	Species level	Higher level
Total number of individuals per m^2	✓	✓
Total biomass per m^2	✓	✓
Number of individuals per species	✓	X, although possible for some larger species
Biomass per species	✓	X, although possible for some larger species
Species richness	✓	X
Diversity indices	✓	X
Non-indigenous species detection	✓	X
Policy relevant species detection	✓	X, although possible for some larger species
Functional trait analysis	✓	X
Food web models	✓	X, typically species level data are used
Ecosystem models	✓	✓ Under the assumption that total biomass or densities can be used
Dynamic energy budget based models	✓	X

5.6 Upscaling of the MGST methods & cost considerations

Within the restrictions of the current test, the MGST can be considered suitable for upscaling, applying the method to more offshore wind farms in the Dutch North Sea. In general, the MGST method can be upscaled by repeating the campaign as carried out for the current test, with single deployments of the MGST per sample. The combination of the Saab Seaeye ROV and MGST works well for the biofouling type encountered during the test and is available to be used in larger scale monitoring. It is however recommended to perform additional tests to validate the method and likely, the MGST will need to be modified after new insights in its performance under new conditions have been collected (see the recommendations section).

It is advised to aim for the lowest possible taxonomic level (ideally: species) when upscaling the method. Although this will result in higher costs for the lab analysis of samples, it will make the resulting data more suitable for wider application in scientific studies. Also, it makes the data most likely to be suitable to answer future questions that at this point have not been asked yet and for which data requirements are unknown.

Increased detail in the data will only increase the lab work, while the significant costs of sample acquisition, such as vessel charter, survey team and reporting will remain the same. A possible solution to mitigate the cost of monitoring programmes of biofouling on OWF foundations, may be found in active collaboration with industry or scientific projects, e.g. using vessels for multiple purposes at the same time. For example, during inspection, repair, and maintenance activities of industry, placing an additional ROV team on board to acquire samples using the MGST, would incur low costs in comparison to a vessel dedicated to the MGST tool alone. Industry might be convinced to allow this as the monitoring results can help facilitate the future expansion of offshore wind, as understanding of the environmental effects will increase, decreasing uncertainties in planning and possibly, tender requirements (Courtney and Sen, 2023). Collaboration with scientists could provide similar opportunities, e.g., by sampling during scientific work in OWFs, but also by combining resources to process samples in laboratories, after which the results can be used for the Wozep monitoring purposes as well as in the scientific project. We recommend Wozep to approach the intended monitoring as a joint industry-science-government project in which all organisations benefitting from the data in one way or another collaborate to collect the best possible monitoring data on biofouling communities on offshore wind turbine foundations.

5.7 Recommendations

Based on the evaluation of the field test, lab work and data analysis, we recommend the following to progress the development and validation of the MGST.

Perform additional tests to optimise sampling

Within the conditions encountered in the current test, the MGST can be used to collect samples from wind turbine foundations in a larger scale programme. However, we recommend performing additional offshore tests to assess the performance of the MGST in other conditions, on more mature biofouling communities on older turbine foundations or offshore platforms:

- Sample biofouling communities dominated by hard biofouling species such as mussels *Mytilus edulis* and calcareous tube worms *Spirobranchus triqueter*.
- Sample thicker biofouling layers from matured communities such as Hydrozoans dominated by amphipods, anemones *Metridium senile* and soft coral *Alcyonium digitatum*.
- Test with multiple contact methods for different biofouling types and foundation (member) diameters. Large magnets show the best result but have a large footprint, which poses problems with hard biofouling (mussels, tube worms). Tips or points can be used to stab through the mussels, but these can slip more easily than magnets.

Based on the results, the functioning of the MGST can then be optimised and the design altered, or species-specific field protocols developed. Further testing of the tool in different weather conditions with lower wave heights is needed to provide insights in the weather-dependent behaviour of the ROV, which will help in planning future sampling campaigns.

Identify taxa to the lowest taxonomical level

We recommend processing samples collected in future monitoring programmes to the lowest level possible taxonomic level (species in most cases), as has been done in most monitoring programmes carried out in offshore wind farms to date. Although some costs are saved when processing on higher taxonomic levels, the reusability of the data is strongly reduced, making it unsuitable for many applications. We don't see a need to perform additional coating damage testing as the current results suggest any coating damage caused is negligible. However, if the offshore industry would demand further testing, we recommend collecting dedicated samples for coating damage assessment alone, using smaller mesh sizes in the macrofauna net to reduce any loss of very small particles trough the net. In how far the MGST can utilise smaller mesh sizes should first be tested as to date only 0.5 mm mesh size has been used.

Perform validation tests

We recommend validating the MGST as a method in the following manner:

- Measure the amount of water passing through the sampling net per unit of time at different thruster speeds and with varying amounts of sample blocking the net, to estimate the potential effect on ingesting zooplankton organisms.
- Assess the similarity between diver-collected and MGST-collected samples via a direct test. This can be done by sampling with divers and the MGST at the same location, at the same time of year, at the same depths, possibly at multiple replicate locations, followed by a comparative analysis. This test should only be done once tests on performance of the MGST on other biofouling types have been successful.

Requirements to the field protocol for sampling

We recommend adding the following requirements to the field protocol when using the MGST:

- Use a maximum deviation of the observed sampled area of 10% of the programmed sampled area to increase sampled area accuracy.
- Use the metal scraper as no clear improvement was observed for coating damage, no large difference was observed in species removal efficiency, while the plastic scrapers did wear faster than the metal scraper, causing increased turnover times when scrapers need to be replaced.
- Collect shallow water samples during high tide slack water, when samples can be taken as near to the intertidal zone as possible.
- Samples from the intertidal zone and above should be taken using other methods, such as from an inflatable boat during low tide, as has been done during previous projects (Bouma and Lengkeek, 2013; Coolen *et al.*, 2020b).

6 Conclusions

6.1 Conclusions on research questions

This test was performed to address a series of questions on the MGST as a method to perform future biofouling monitoring in offshore wind farms for which a series of answers can be provided.

1) Does the MGST work in offshore conditions as present in OWFs in the North Sea?

The test has shown that the marine growth sampling tool (MGST) is capable of scraping samples from a known sampled area with an average precision of 99%, from a biofouling community dominated by amphipods and anemones, in depths between 4 and 20 meters.

2) What are the depth limitations for the tool within which it can collect high-quality samples?

No precise workable conditions statement can be given, as ROV stability depends on current strength and direction, wave height and direction, the shape of the object that is sampled and the presence of other sub-structures on the object. Generally, application to depths between 2 and 4 meters is likely possible under perfect environmental conditions, without any waves and at slack tide. Sampling in water <2 meters depth will not be possible and will need to be done using other methods (e.g. manually from a rubber boat).

3) Does the scraping of the tool damage the coating of the turbine foundation and if so, to what level?

Coating particles were absent in half of the samples, and in samples with coating particles the maximum total size was 0.005% of the sampled area. Therefore, the damage to the coating caused by anticipated biofouling studies on OWF foundations using the MGST can be considered negligible.

4) To what extent does the performance of the tool change with the use of different types of scrapers made of metal and of plastics with varying stiffness?

No clear difference in sample quality or species removal efficiency between the different types of scrapers was observed. The plastic scrapers showed more wear after a few samples than the metal scrapers did. No clear difference in coating damage between scraper types was observed. It is recommended to use the metal scraper in future MGST application.

5) Is the quality of the macrofauna in the samples acceptable when compared to samples collected by divers in the past?

Generally, the sample quality was good. No clear difference with the data from previous biofouling studies in offshore wind farms was observed. Based on the current test, the quality of the MGST acquired samples is like that of samples collected by divers.

6) To which taxonomic level do the samples need to be analysed to give the level of information needed for evaluation of the ecological effects of wind farms?

Although processing biofouling samples to a higher taxonomic level does save some costs, these savings are likely small on the level of a full monitoring project. At the same time the higher-level taxonomy would make the data less suitable for use in future projects, trying to answer questions on offshore wind effects that have not been asked yet. Furthermore, our assessment showed that patterns present in species-level data, can be removed already by converting the data to genus-level. Therefore, it is recommended to analyse biofouling samples to the lowest possible taxonomic level (ideally: species) in future monitoring of biofouling communities on offshore turbine foundations.

7) How can the method be applied to larger scales in the future?

It is recommended to perform additional tests and then optimise the MGST to collect samples from biofouling types not encountered during the current test. This can be the first step towards inclusion in the future upscaling of the methods for application in a larger monitoring programme of biofouling on offshore turbine foundations. We recommend Wozep to collaborate with industry and the scientific community to start a joint monitoring programme.

6.2 General conclusion

We conclude that the MGST is a viable alternative to diver-based sampling, offering a safer method for monitoring biofouling communities in offshore wind farms. Further tests are recommended on biofouling species with harder structures, such as mussels, as well as thicker biofouling layers. Future comparative studies between MGST and diver-collected samples are also suggested to validate the tool's broader applicability.

7 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.

Acknowledgements

The processing of samples was partly funded as part of the KIA-LWV funded KOBINE project (refence: LWV20.230). The field test, processing of further samples and the evaluation were funded by the Dutch Offshore Wind Ecological Programme. The BISAR data were kindly provided by the ICES Working Group on Marine Benthal and Renewable Energy Developments (WGMBRED). We are grateful for the support of: The Zirfaea crew for helping acquire the samples, Vattenfall for allowing us to perform the test, Loran Kleine Schaars and Dorien Oude Luttikhuis from NIOZ for weight measurements, students Anna Schröder and Vienna Timmers, for their help processing samples in our lab, Fecco van der Heide and Erwin Hilberts (Bluestream Offshore B.V.), for helping with project management and performing the field test, respectively.

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Justification

Report: C068/24B
Project Number: 4315100227

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

Approved: Oscar G. Bos
Senior scientist

Signature: 

Date: 15 January 2025

Approved: dr. Ir. T.P. Bult
Director

Signature: 

Date: 15 January 2025

Annex 1 Full species list

Table: All species observed in the MGST samples that were processed to the lowest possible taxonomic level, with abundance per sample, mean abundance per m^2, ash free dry weight in mg per sample and per m^2, with standard errors. NA: no standard error could be calculated.

Species	Phylum	Abundance	Abundance m^2	AFDW	AFDW per m^2
Eulalia viridis	Annelida	8.88±5.64	159.12±100.67	0.66±0.33	12.31±6.11
Harmothoe aspera	Annelida	1±NA	17.24±NA	0.1±NA	1.72±NA
Harmothoe extenuata	Annelida	2.78±1.13	50.93±19.32	2.27±2.27	47.22±47.22
Lepidonotus squamatus	Annelida	2.17±0.44	39.94±8.98	6.45±0.78	115.6±8.85
Polydora cornuta	Annelida	1±NA	17.86±NA		
Spirobranchus lamarcki	Annelida	1.37±0.24	24.28±4.45	0.8±0.32	13.86±5.57
Spirobranchus triqueter	Annelida	14.75±1.43	265.78±25.3	18.94±2.83	339.88±50.83
Syllis vittata	Annelida	105±89.37	1876.98±1594.68	0.97±0.97	17.26±17.26
Abludomelita obtusata	Arthropoda	64±NA	1049.18±NA		
Apolochus neapolitanus	Arthropoda	80±48	1619.05±1047.62		
Balanus crenatus	Arthropoda	1±NA	17.86±NA		
Bathyporeia elegans	Arthropoda	34.78±16.21	684.61±347.8	0.73±0.73	13.1±13.1
Caprella equilibra	Arthropoda	1±0	17.86±0		
Diastylis bradyi	Arthropoda	1±NA	17.86±NA		
Gastrosaccus spinifer	Arthropoda	1.93±0.38	34.24±6.44	0.46±0.3	7.75±4.99
Gitana sarsi	Arthropoda	32.17±0.17	574.53±3.1		
Jassa herdmani	Arthropoda	10713.16±974.45	192520.23±16863.08	583.15±68.12	10511.51±1207.52
Jassa marmorata	Arthropoda	1470.94±NA	26266.82±NA		
Macropodia rostrata	Arthropoda	1.07±NA	17.56±NA		
Megaluropus agilis	Arthropoda	72.17±20.11	1360.63±453.48		
Mesopodopsis slabberi	Arthropoda	2.5±0.76	43.18±13.23	0.03±0.03	0.6±0.6
Monocorophium acherusicum	Arthropoda	3170.57±320	57399.95±5871.15	83.58±14.99	1517±268.1
Monopseudocuma gilsoni	Arthropoda	7.62±3.45	145.94±70.67		
Nototropis swammerdamei	Arthropoda	17±15	303.57±267.86		
Phtisica marina	Arthropoda	63.28±49.7	1240.81±995.33	8.36±7.48	165.84±149.71
Pilumnus hirtellus	Arthropoda	26.43±3.08	478.14±57.39	20.37±4.73	369.09±86.01
Pisidia longicornis	Arthropoda	20.56±3.16	370.31±56.23	12.06±2.76	217.96±49.35
Pontocrates altamarinus	Arthropoda	32±NA	571.43±NA		
Pseudocuma (Pseudocuma) simile	Arthropoda	3.46±1.6	66.44±32.59		
Scopelocheirus hopei	Arthropoda	64±NA	1049.18±NA		
Stenothoe monoculoides	Arthropoda	150.18±36.42	2724.1±661.07		
Stenothoe valida	Arthropoda	85.01±14.67	1581.91±297.64	0±5.76	0±102.86
Verruca stroemia	Arthropoda	1.4±0.24	25±4.37		
Callopora dumerilii	Bryozoa	1±0	17.49±0.37		
Conopeum reticulum	Bryozoa	1±0	17.99±0.31		
Electra pilosa	Bryozoa	8.5±1.22	153.2±21.66		
Scruparia chelata	Bryozoa	1±0	17.67±0.18		
Tricellaria inopinata	Bryozoa	1.5±0.5	26.79±8.93		
Diplosoma listerianum	Chordata	12.94±3.44	235.08±62.8		
Alcyonium digitatum	Cnidaria	1±0	17.86±0		
Clytia hemisphaerica	Cnidaria	1.2±0.2	22.02±3.47		
Metridium senile	Cnidaria	59.71±2.62	1078.36±52.39	1361.88±127.2	24469.79±2214.56
Obelia bidentata	Cnidaria	1.08±0.08	19.47±1.5		
Tubularia indivisa	Cnidaria	1.5±0.34	26.79±6.1		
Asterias rubens	Echinodermata	1±NA	17.24±NA	0.7±NA	12.07±NA
Psammechinus miliaris	Echinodermata	2±NA	41.67±NA	21±NA	437.5±NA
Corambe obscura	Mollusca	3.32±1.58	59.78±26.76	1.15±1.15	19.83±19.83
Crepidula fornicata	Mollusca	3.02±1.48	54.68±26.21	246.48±97.57	4517.95±1725.96
Epitonium clathratulum	Mollusca	2.57±0.86	47.62±15.18		
Mytilus edulis	Mollusca	3.67±1.67	65.48±29.76	7±6.15	125±109.85
Pusillina inconspicua	Mollusca	2.29±0.93	41.67±16.3		
Sepiola atlantica	Mollusca	1±NA	17.86±NA		
Sycon ciliatum	Porifera	1±NA	17.86±NA		

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