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ARTIFICIAL HARD SUBSTRATE COLONISATION IN THE OFFSHORE HYWIND SCOTLAND PILOT PARK

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Abstract. Artificial substrates associated with renewable offshore energy infrastructure, such as Floating Offshore Windfarms, enables the establishment of benthic communities with similar diversity species composition to that of naturally occurring rocky intertidal habitats. The size of the biodiversity impact and the structural changes on benthic habitats will depend on the selected locations. The aim of the study was to assess colonisation, zonation, quantify diversity and abundance, and identify any non-indigenous species of fauna and flora present within the wind farm. This article is based on work undertaken within the offshore floating Hywind Scotland Pilot Park, the first floating offshore wind park established in the world, located approximately 25 km east of Peterhead, Scotland. The floating pilot park is situated in water depths of approximately 120 m with a seabed characterised predominantly by sand and gravel substrates with occasional patches of mixed sediments. The study utilised a Work Class Remotely Operated Vehicle with a mounted High Definition video camera, deployed from the survey vessel M/V Stril Explorer. A total of 41 structures, as well as their associated subcomponents, including Turbines (Substructures), Mooring Lines, Suction Anchors and Infield Cables, were analysed with regards to diversity, abundance, colonisation, coverage and zonation. This approach provides comprehensive coverage of whole structures in a safe and time-saving manner. Eleven phyla were observed with a total of 121 different taxa, macrofauna as well as macro- and filamentous algae, identified on the different structures. The submerged turbines measured approximately 80 m in height and exhibited distinct patterns of zonation. Plumose anemone *Metridium senile* and tube building fan worm *Spirobranchus sp.* dominated the bottom and mid-sections (80 m – 20 m) of the turbines while kelp and other Phaeophyceae with blue mussel Mytilus spp. dominated top sections of the turbines (20 m – 0 m).

1 Introduction

The effects on local benthic habitats during installation works and operations of Offshore Wind Farms (OWF) are of a complex nature and extend both below and above the surface of the sea. Previous studies have shown that OWFs can impact areas through the introduction and spread of alien species (Wilhelmsson and Malm, 2008; Vattenfall, 2006), affect sediment composition (Degraer et al., 2019) and alter community structures (Degraer et al., 2019; Vattenfall, 2006; Wilhelmsson and Malm, 2008) through the loss of soft sediment habitats and the subsequent introduction of artificial hard bottom substrates. The recorded impacts also show an increase in biodiversity indirectly as a result of reduced trawling activities (Vattenfall,

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2006) as well as an increase in nurseries for commercially important and/or protected species (Vattenfall, 2006). The submerged structures (turbines and subcomponents on the seabed) introduce hard substrates into areas in which there were formerly lacking, thus facilitating colonisation.

Studies conducted at OWFs around the North Sea show that the faunal and floral communities on turbines can further be categorised into distinct zones from the splash zone to the intertidal and deep subtidal zone (Degraer et al., 2019; Vattenfall, 2006; De Mesel et al., 2015; Whomersley and Picken. 2003). These communities tend to develop over time (typically five to six years from the initial settling of organisms to reach the climax stage (Degraer et al., 2019; Vattenfall, 2006) and evolve in characteristics, progressing from a pioneer stage (years 1 and 2) with sparse colonising taxa to an intermediate stage (years 3 to 5) exhibiting higher diversity followed by the final climax stage (from 6th year and onward) which is dominated by mussels, anemones and algae. The time taken to reach this final stage is dependent upon the fundament type (Degraer et al., 2019).

Global primary energy production has seen a 21% increase in consumption between 2009 and 2019, where electricity from renewable sources, as of 2019, comprises 5 % of the total consumed primary energy (BP, 2020). Conventional wind farms are generally confined to shallow coastal waters (<60m) by technical and engineering constraints. A FOWF, not subject to these restrictions, opens up new possibilities with regard to installation locations.

1.1 Aim

The aim of this study was to 1) Ascertain whether or not similar impacts, with regards to colonisation on turbines and associated structures, to those observed at traditional OWFs were present at the Hywind Scotland Pilot Park, and 2) Assess if any zonation patterns were present on the Hywind Scotland Pilot Parks structures, similar to those observed at traditional OWFs. 3) To quantify diversity, abundances and 4): identify if any non-indigenous species were present.

2 Methodology

2.1 Study area

The worlds first commercial Floating Offshore Wind Farm (FOWF), The Hywind Scotland Pilot Park, was constructed in 2017 and became operational the same year. The FOWF is located approximately 25 km east of Peterhead on the Scottish east coast and consists of five turbines, located in water depths of 100 to 130 m. The seabed comprises mainly sand and gravel substrates with mega ripples and occasional boulder fields classified as mixed sediments (Fig. 1).

Unlike conventional, non-floating turbines whose fundaments are secured directly to the seabed, the floating turbines are attached to the seabed using three suction anchors attached to the turbine by heavy chains. The turbines extend approximately 80 m below the sea surface, acting as a pendulum to keep the structure steady.

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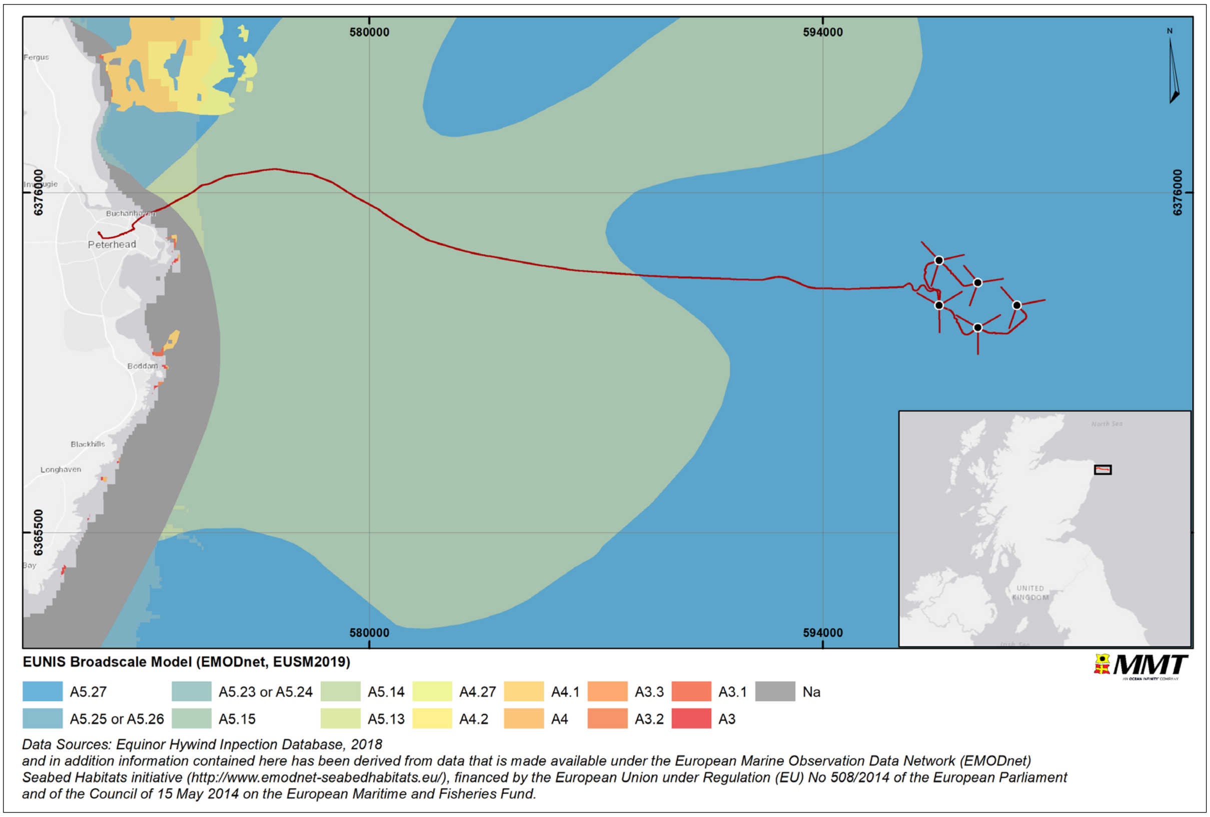

Figure 1 Overview of the survey area and habitat according to EUNIS classification. The main habitat found in the survey area is A5.27: Deep circalittoral sand. Basemap sources: © OpenStreetMap contributors 2021. Distributed under the Open Data Commons Open Database License (ODbL) v1.0.

2.2 Data collection

The environmental survey was performed in collaboration with REACH Subsea and occurred simultaneously with a recurring structural inspection of the Hywind Scotland Pilot Park. Video footage was obtained using an HD colour camera attached to a Work Class Remotely Operated Vehicle (WROV) supported by LED Flood and Spotlights. Two lasers were positioned 10 centimetres apart. The WROW maintained a survey speed of 0.3 knots (0.6km/hour). Video footage was recorded during the entire structural inspection of substructures (turbines), mooring lines, suction anchors and infield cables (Fig. 2). Additional video footage, collected solely for the environmental survey, was collected for substructures HS01, HS02 and HS04, infield cables QA01, QA02, QA04 and QA05, as well as the protective concrete mattress located on top of the QA01 cable (Fig. 3). The three priority structures (HS01, HS02 and HS04) were investigated at a slower speed and on three sides (12 o'clock (north), 4 o'clock and 8 o'clock). In contrast, non-priority structures HS03 and HS05 were investigated simultaneously as the structural inspection. The priority structures were investigated from top to bottom with a sufficient distance from the structures to record zonation and from bottom to top at a closer distance to record species composition. The live feed from the WROV

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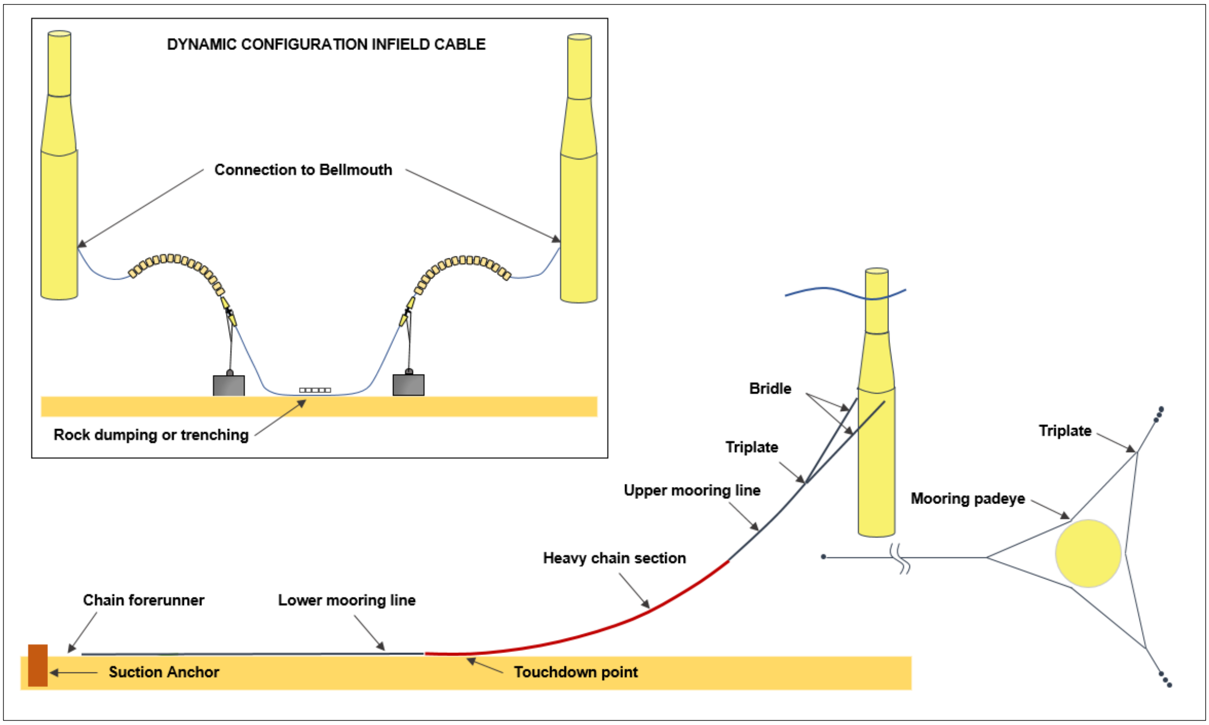
was monitored by one of the marine biologists on shift. This approach allowed for the fauna/areas of interest to be examined in closer detail if required.



80 **Figure 2 Layout of Turbines, Mooring Lines, Suction Anchors and Infield cables. Figure based on schematic provided by Equinor.**

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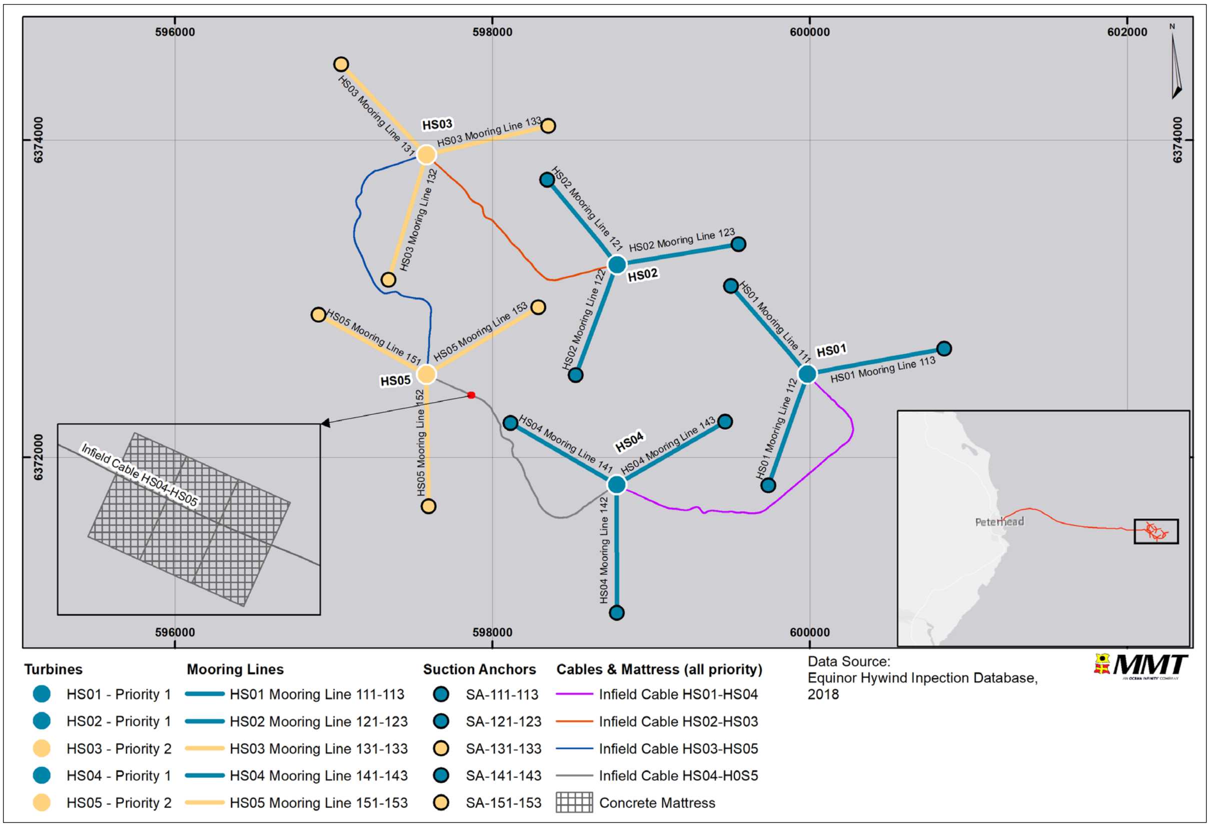

Figure 3 Overview of survey area and priority and non-priority structures. Basemap sources: © OpenStreetMap contributors 2021. Distributed under the Open Data Commons Open Database License (ODbL) v1.0.

2.3 Analyses methodology

The post-survey analyses of video data acquired were performed in two steps. The first step was analysed in real-time, from the live video feed, and included documenting zonation, colonisation and common species. The second step included QC of the first step and enumeration of individuals and assessment of percentage coverage of epifouling species. Fauna was identified to the most detailed taxonomic level possible, mainly species, and counted. When a species could not be identified with certainty, the specimen was grouped into the nearest identifiable taxon of a higher rank, i.e. genus, family, order, etc.

Epifouling faunal (colonial and non-colonial) and floral species, including the phyla Annelida, Bryozoa, Chlorophyta, Cnidaria, Phaeophyceae, Porifera, and Rhodophyta, together with species of fish, Sessilia, tunicates, bivalves, and cephalopod eggs were all noted as Present (P). Eggs from cephalopods, nudibranchs and gastropods identified during the survey were excluded from statistical analysis. Asteroidea and sea urchins were occasionally present in such abundance that it was difficult to count each individual, resulting in a likely underestimation of abundance.

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2.3.1 Additional analyses

Data collected by REACH Subsea during the visual inspections of the structures in 2018 and 2020 was compiled, and changes in faunal coverage and thickness were compared. The visual inspection in 2018 was not performed by marine biologists, and species were not recorded but rather growth, shape and, in some cases, phylum/order. Faunal and floral growth was observed for all different components and structures of the wind turbines by REACH Subsea. In this paper, data has been grouped into the three main parts; Substructures, Mooring Lines and Suction Anchors, and presented as mean value ± Standard Deviation (SD). Structures and subcomponents not reported on during the 2018 campaign have been excluded in this comparison.

3 Results

The analyses of data from the Hywind Scotland Pilot Park yielded a total of eleven phyla, with 121 different taxa. A total of 48 taxa were identified to be epifouling fauna. A total of 73 mobile taxa were identified, and an estimated number of 15 997 individuals were recorded during the analyses of the survey data (Table 1). The most abundant mobile taxon was Asteroidea, likely the common sea star *Asterias rubens*, followed by small sea urchins (*Psammechinus miliaris* and/or *Strongylocentrotus droebachiensis*). Different species of crustaceans were present within the whole survey area and represented the dominating mobile phylum on the seabed.

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Table 1 Phyletic composition of fauna and flora identified during visual inspection.

Phyla	Number of Epifaunal taxa	Number of Mobile taxa	Number of Individuals of Mobile Fauna
Annelida	7	-	-
Arthropoda	1	18	3 713
Bryozoa	5	-	-
Chlorophyta	1	-	-
Chordata	4	28	-
Cnidaria	21	-	-
Echinodermata	-	17	12 070 (probably underestimated)
Mollusca	1	10	214
Phaeophyceae	4	-	-
Porifera	1	-	-
Rhodophyta	3	-	-
Total	**48**	**73**	**15 997**

3.1 Turbine substructures

The epifouling colonisation was found to be high (~80 % to 100 %), comprising predominantly species *Metridium senile* and *Spirobranchus sp.* across the majority of the turbine surfaces (Fig. 4). The lower intertidal depths were dominated by blue mussels, *Mytilus spp.* and brown algae. Mobile taxa present in high abundances included Echinidea, Asteroidea and Galatheoidea. Squat lobsters were generally noted below 40 m, while grazers such as sea urchins, sea stars and nudibranchs and *Aeolidia papillosa* were found all over the substructures (Fig. 4). Sea urchins and sea stars occurred at all depths but were most abundant between 10 m and 25 m, whereas nudibranchs were more abundant below 40 m.

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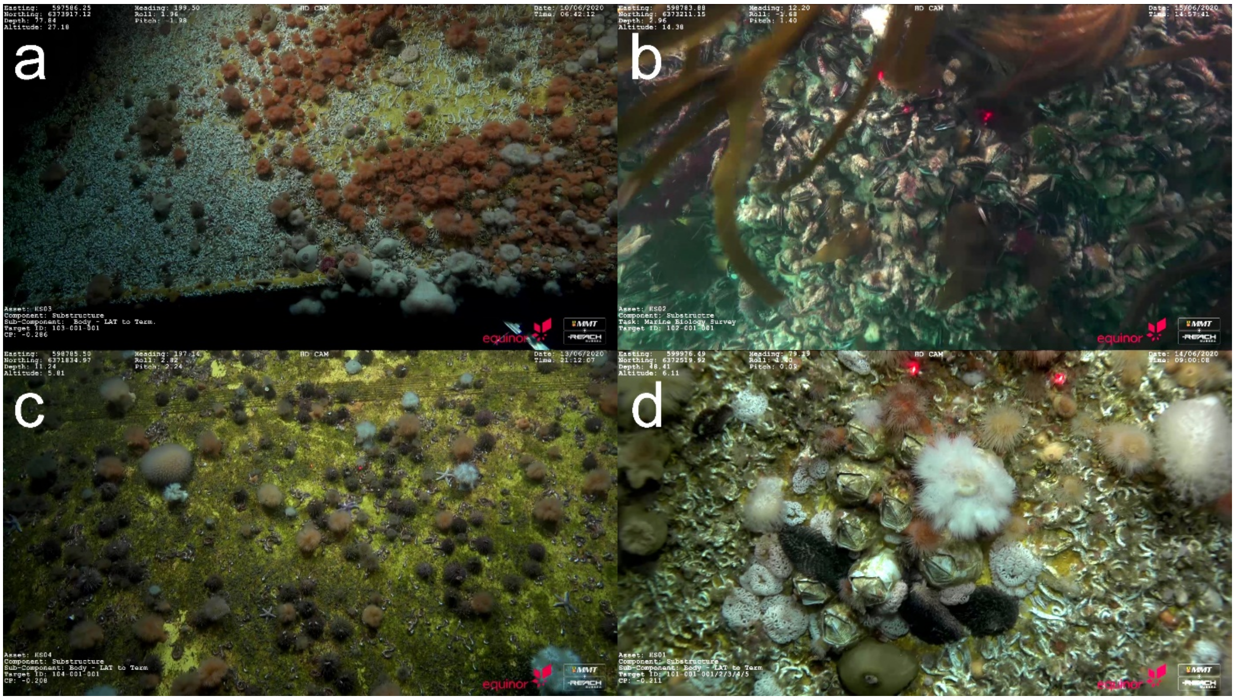

Figure 4 Example of epifouling colonisation on turbine structures. a. *Spirobranchus sp.* and *M. senile* at the bottom of HS03 substructure. b. Substructure HS02, with *Mytilus spp.* and *Laminaria sp.* at three m depth. c. Substructure HS04, grazing sea urchins at 11 m depth. d. Substructure HS01, Nudibranch *A. papillosa* and barnacle Balanoidea at 48 m depth.

All turbines were further assessed with regard to zonation and faunal composition. The estimated vertical zonation is illustrated in Fig. 5, with the top of the figure representing the sea surface at 0 m extending down to a depth of approximately 77 m representing the bottom of the substructure (turbine). Four distinct faunal zones were identified at HS01, while HS02 – HS05 comprised five different faunal zones. Substructure HS01 comprised *M. senile* (50 %) and *Spirobranchus* sp. (50 %) from approximately 30 m to 77 m. At substructure HS03, a change in dominating species occurred at approximately 45 m and lower, where *Spirobranchus* sp. was noted to dominate completely. This pattern was also noted for substructures HS02, HS04 and HS05 between 60 m to 77 m. Species composition between 4 m and 15 m below the surface differed between the five substructures. Substructure HS01 was colonised by biofilm and Phaeophyceae, HS02 by *M. senile* and *Laminaria* sp., HS03 by *Laminaria* sp. and Phaeophyceae, HS04 by *M. senile*, *Spirobranchus* sp. and biofilm, and HS05 was dominated by *M. senile*, Biofilm and Phaeophyceae. At substructure HS01, HS02 and HS03, *Mytilus* spp. and *Laminaria* sp. were the dominating taxa from 0 m to approximately 4 m and at HS04 and HS05, *Mytilus* spp. and different species of Phaeophyceae were dominant.

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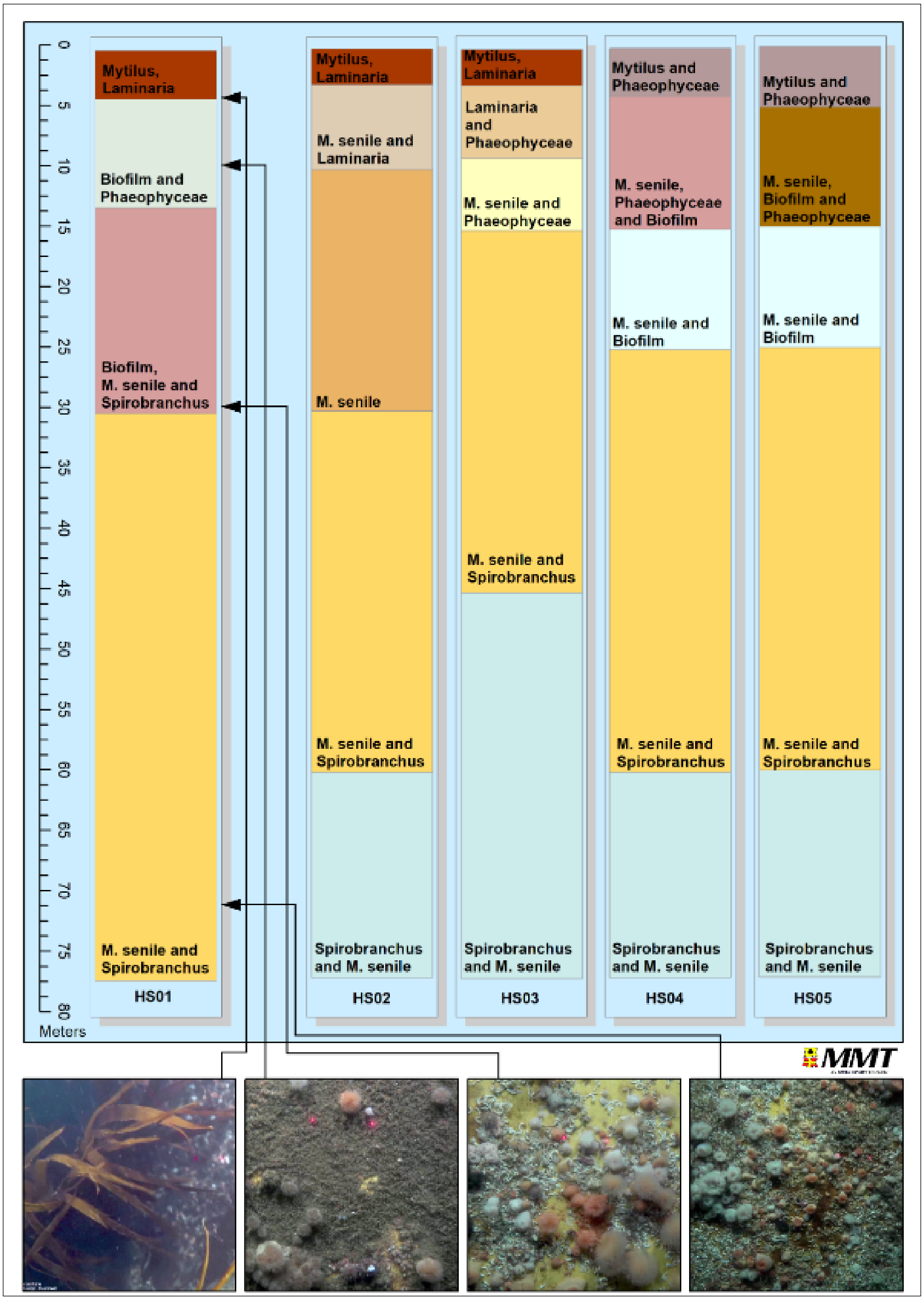

Figure 5 Illustration of faunal zonation at substructure HS01 – HS05.

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3.2 Suction anchors

There were no substantial differences between the epifouling communities on Suction Anchors associated with individual turbines or between the different turbine groups. Each Suction Anchor was inspected along the top of the structures and separately around the sides. Different hydroids, predominantly *Nemertesia ramosa* and *Ectopleura larynx*, dominated the top of the Suction Anchors with coverage ranging from 20 % to 80 %. *Spirobranchus sp.* and *E. larynx*, with patches of barnacles, dominated the sides of the Suction Anchors with coverage from 60 % to 90 %. Mobile fauna such as Galatheoidea, *Cancer pagurus*, Palaemonidae, *Lithodes maja* and nudibranchs were frequently observed.

3.3 Mooring lines

No significant differences were noted on the mooring lines between the turbines, but distinct zonation patterns were observed from top to bottom. The top chain was almost entirely covered by Balanoidea, *M. senile* and *E. larynx,* with an overall coverage ranging from 60 % to 100 %. The upper-middle chains were similar to the top chains, although the epifouling decreased as the chains descended towards the seabed with an overall coverage from 40 % to 80 %. The lowest parts of the chains, closest to and on top of the seabed, were dominated by crusts of *Sabellaria spinulosa* and *E. larynx* with coverage ranging from 80 % to 100 %. The Mooring Lines were estimated to have 100 % coverage or close to 100 %, and the composition of the middle chain was similar for all five turbine areas. Mobile fauna found on and adjacent to the mooring lines was *A. rubens*, Galathiodea, *C. pagurus*, *L. maja* and Paguridae. An example of the colonisation along a typical Mooring Line (Turbine HS01's Mooring Line 111) is presented in Fig. 6, from top to bottom. The top chain was estimated to have an overall coverage between 60 % and 95 %, with an abundance of *M. senile*.

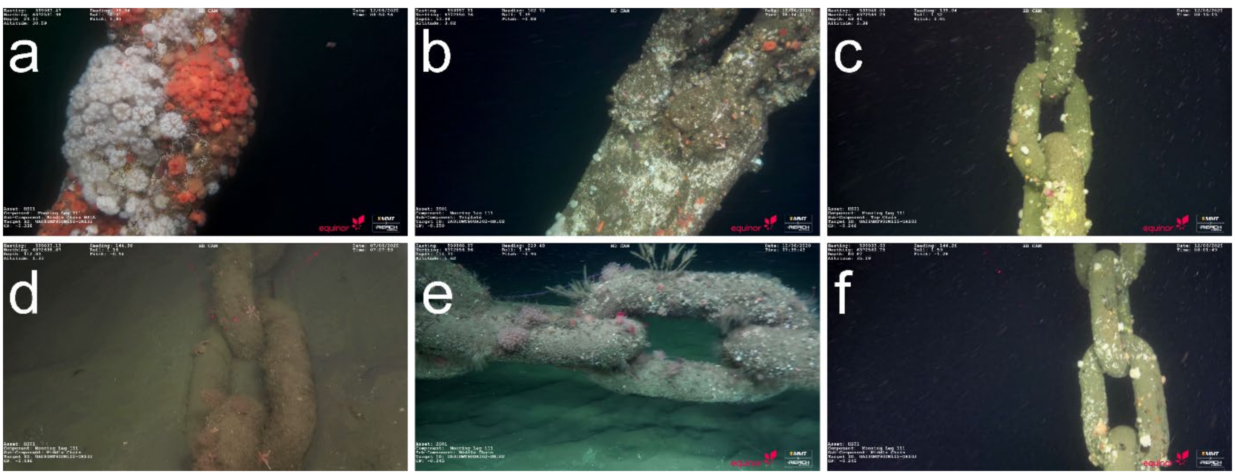

Figure 6 Example images along a typical Mooring Line (Turbine HS01's Mooring Line 111) top to bottom. a. Top Chain, Bridle Chain. b. Top Chain, Triplate. c. Top Chain. d. Middle Chain, on the seabed. e. Middle Chain, off the seabed. f. Top Chain.

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3.4 Infield cables and concrete mattress

From the Bellmouth to Touchdown, the overall dominating species was barnacle Balanoidea, present abundantly along all four infield cables. Infield cables QA01 and QA02 comprised an overall faunal coverage of 100 % from each Bellmouth to Touchdown, whereas QA04 and QA05 comprised areas with lower faunal coverage. The infield cables were buried between each touchdown, and no faunal colonisation was therefore present.

The concrete mattress, located on top of QA01, was predominantly buried, and the overall faunal coverage was 40 %. The dominating species were *S. spinulosa* and *E. larynx.* Other epifouling fauna present included other hydroids such as *N. ramosa*, *Tubularia indivisa*, and *Urticina* sp. Mobile fauna observed on the structure included Asteroidea, Galatheoidea, Paguridae, *L. maja* and *C. pagurus*. One individual of Pleuronectiformes, *Homarus sp*. and *Molva molva* was present on the concrete mattress.

3.5 Comparison of faunal growth

Data from the 2018 inspection campaign, provided by REACH Subsea, was compared to the data acquired during the 2020 campaign. The difference in coverage of epifauna between 2018 and 2020 showed an overall increase in both hard and soft marine faunal growth (Figs. 7-8). The overall change in faunal thickness has decreased in both hard and soft faunal growth, excepting several substructures on multiple turbines, which saw a considerable increase in thickness leading to the high variance.

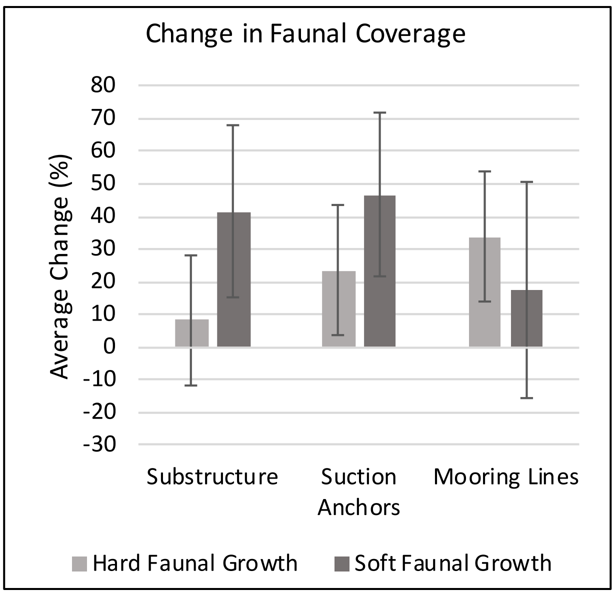

Figure 7 Change in coverage of hard and soft faunal growth presented as average ± SD.

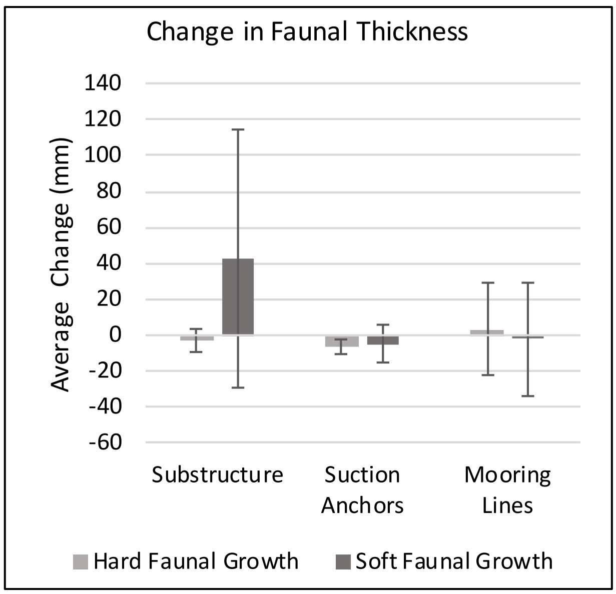

Figure 8 Change in thickness of hard and soft faunal growth presented as average ± SD.

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4 Discussion

4.1 Identified species and non-indigenous species

No invasive or non-indigenous species were identified during the 2020 survey. However, it should be noted that the use of a WROV without any physical sampling limits the ability to identify smaller species and identify certain filamentous species of red and brown algae.

The non-native American lobster, *Homarus americanus*, has been reported from the North Sea and the British islands (Stebbing et al., 2012). Thus, it cannot with certainty be determined whether any of the lobsters observed during the current survey were *H. americanus*. *Homarus gammarus* and *H. americanus* are differentiated morphologically by the absence or presence of spines on the rostrum and are therefore difficult to distinguish without a physical specimen. Hybridisation between these species has also been recorded.

The barnacles observed on the structures were difficult to identify to species level and are grouped in the superfamily Balanoidea. Two possible species have been considered, *Balanus crenatus* and *Chirona hameri*. External experts were consulted and considered *C. hameri* as the probable species, but *B. crenatus* cannot be excluded without a physical sample.

The Mooring Lines and Suction Anchors on the seabed surface have provided additional opportunities for settling and colonisation by *S. spinulosa*, which was identified in the area during previous surveys (MMT, 2013). As the species occurs naturally in the area, the facilitated establishment created by the structures for *S. spinulosa* should not have a negative impact on the habitat. *S. spinulosa* habitats are often associated with high faunal biodiversity, which creates feeding grounds for different species of fish. After the installation of the wind park, no trawling occurs in the area, which could further benefit commercial fish species.

A possible young colony of the deep-water coral *Desmophyllum pertusum*, previously *Lophelia pertusa*, was identified at QA02 – HS01 Buoyancy Modules (Fig. 9). The deep-water coral *D. pertusum* has not previously been recorded in this area, although colonies have been observed on offshore structures in the North Sea (Roberts, 2002; Bergmark and Jørgensen, 2014). The shape of the coral is atypic for *D. pertusum*, however, dome-shaped colonies have been recorded on oil platforms in the North Sea (Gass and Roberts, 2006).

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Figure 9 QA02 – HS01 Buoyancy Modules. Possible young colony of *D. pertusum*.

Further, cold-water coral reefs also occur naturally on the continental shelf of western Scotland in water depths of 130 m to 2000 m (Marine Scotland, 2016). Simulations of larval dispersal of *D. pertusum* from offshore structures in the North Sea demonstrate that there is potential for larvae to settle in the survey area (Henry et al., 2018). However, a physical sample would be required to confirm the species observed during this survey.

Species observed on the seabed in close proximity to the structures included different crustaceans (the brown crab *C. pagurus*, the Norway king crab *L. maja*, different species of squat lobsters, and a few individuals of the lobster *Homarus spp.)*. Demersal fish, including different species of flatfish Pleuronectiformes, haddock *Melanogrammus aeglefinus,* and ling *M. molva,* were also found in high abundances around the structures. Squids, octopuses and rays were also observed.

4.2 Epifouling colonisation and dominant species

The high abundance of *M. senile* is consistent with findings from offshore structures in the North Sea (Whomersley and Picken, 2003; Kerckhof et al., 2012; De Mesel et al., 2015; Kerckhof et al., 2019). Species of the amphipod *Jassa spp*. have previously been identified as one of the dominating species on offshore structures in the North Sea with anemones and hydroids (Lindeboom et al., 2011; Krone et al., 2013) but were not observed during the current survey. These small amphipods are small crustaceans and are challenging to identify without a physical sample. A veneer layer observed on the blue mussels could be *Jassa* tubes combined with biofilm, but a physical sample would be required to confirm this.

The epifouling colonisation differed between the different structures with regard to species diversity. The painted substructures lacked the diversity generally found on the uncoated Mooring Lines. The tube building worm *Spirobranchus sp.* dominated the painted substructures while Balanoidea together with hydroids dominated the uncoated structures. Uncoated structures have been noted to comprise more diverse communities than steel monopiles (Kerckhof et al., 2012).

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The Concrete Mattress was partially covered by sediment and is likely to be completely buried in the future. The structure provides a hard substrate for epifouling taxa, including Hydroids and *S. spinulosa*. Several mobile taxa noted were lobster, squat lobsters, flatfishes and ling. Should the structure remain exposed, it could continue to provide a suitable habitat for commercially important species and possibly maintain an *S. spinulosa* reef in the area.

4.3 Zonation

A depth zonation similar to other wind turbines in the North Sea (Whomersley and Picken, 2003; Lengekeek and Bouma, 2009; De Mesel et al., 2015) was noted within the current survey area. Due to safety restrictions concerning close approaches to the turbines, estimating the epifouling above the sea surface was not possible. The low intertidal zone was dominated by *Mytilus spp.,* which was in line with previous studies conducted in the North Sea (Wilhelmsson and Malm, 2008; Krone et al., 2013; Bergström et al., 2014). The deep subtidal zone extended from 10 m to 15 metres below the surface and continued down to the bottom. Between the low intertidal zone and deep intertidal zone, there was a high presence of biofilm and fewer epifouling species, which could be due to grazing fauna that were occasionally numerous.

Four depth zonations' were observed at Substructure HS01 and five on Substructures HS02 to HS05. Substructure HS01 lacked the deepest *Spirobranchus sp.* dominated zonation found at the other four Substructures. The difference is likely due to local variation and faunal spread. The differences were not significant enough to indicate whether or not the currents or the distance to shore would affect the zonation and growth of epifaunal species. The zonation noted along the Mooring Lines comprised a different species community than those identified at the substructures. The top and upper-middle sections of the Mooring Lines were dominated by *M. senile* and Balanoidea. The middle chain comprised, overall, lower faunal colonisation.

4.4 Succession

Discussions with the survey team who performed the initial visual inspection in 2018 confirmed that faunal composition had changed between the two years, indicating a succession. The same trend regarding succession stages on offshore installations in the North Sea (Rumes et al., 2013; Whomersley and Picken, 2003) can be observed within the current survey. Tubeworms and hydroids have been reported as the first to colonise the structures. The second colonisers were *M. senile* and *Alcyonium digitatum,* who out-competed the early colonisers by over-growing and would indicate that the park is currently in the species-rich intermediate stage, moving towards a more *M. senile* dominating stage with less biodiversity. As in previous studies in the North Sea (De Mesel et al., 2015; Whomersley and Picken, 2003), a zonation was established in just a few years after the installation of the structures. Echinoderms were present in high abundance and are considered an important grazer that affects the epifouling community (Witman, 1985) and could keep the epifouling colonisation growth suppressed.

4.5 Comparison of faunal growth

Coverage of both hard and soft faunal growth is assessed to have increased from 2018 to 2020. Soft faunal growth had increased more compared to hard faunal growth supporting the shift in succession from a *Spirobranchus sp.* dominated stage to an

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intermediate stage. The change in thickness is more variable compared to coverage, but most structures and substructures have had a decrease in thickness of both hard and soft faunal growth.

Several substructures on multiple turbines saw a major increase in thickness leading to the high variance. This major increase, as well as the observed decrease, could be natural causes occurring or due to variable measuring techniques relying on the qualitative assessment conducted in 2018. It should also be noted that no lasers were utilised during the 2018 survey, which could be a contributing factor to the variation observed in thickness.

5 Conclusion

Species characterisation during visual inspection gave a good overall view of the survey area and the higher phyletic community composition. The species detail level was limited when fauna was small and/or the environmental conditions (i.e. strong currents, poor weather, etc.) were poor. To confirm the presence or absence of invasive and non-indigenous species on the structures, physical samples are recommended for future surveys as a complement to the visual inspection. Overall, the approach provides comprehensive coverage of whole structures in a safe and time-saving manner.

The epifouling fauna and flora identified were all species naturally occurring in Scottish waters and around the North Sea. However, the community structure, with its high abundances of M. senile, is different when comparing the structures to that which is generally observed on rocky intertidal habitats. *Metridium senile*, *Spirobranchus sp*., *M. edulis* and barnacles are predominant species typically observed on artificial structures in UK waters and seem to take advantage of newly installed surfaces (Bessel, 2008).

Four mobile taxa featured on the Scottish Biodiversity List and as Priority Marine Features were identified in close proximity of the structures: Atlantic cod *Gadus morhua*, ling *M. molva*, sand eel *Ammodytes spp*. and whiting *Merlangius merlangus*. The overall epifaunal colonisation was assessed to almost 100 % on the different structures, with some minor local variations noted. Epifouling colonisation observed during the survey showed overall similarities with the colonisation of other artificial structures in the North Sea regarding early colonisers and epifouling structures.

Data availability

The data set consists of video files that are too heavy to upload. Data sets are available upon request.

Author contribution:

Ane Kjølhamar and Kari Mette Murvoll together funded, conceptualised the survey and reviewed the manuscript. The survey was carried out by Rikard Karlsson and Malin Tivefälth. Methodology, data analysis and the manuscript draft were equally contributed to by Rikard Karlsson, Malin Tivefälth and Iris Duranovic.

Competing interests:

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