CHAPTER 5

A COMPARISON BETWEEN THE EPIFAUNAL BIODIVERSITY OF SHIPWRECKS AND OFFSHORE WIND FARMS IN THE BELGIAN PART OF THE NORTH SEA

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Abstract

In this contribution we compared the epifaunal biodiversity of shipwrecks with turbine foundations and surrounding scour protection layers of offshore wind farms in the Belgian part of the North Sea. Shipwrecks were characterized by a higher epifaunal species richness compared to offshore wind farms (165 vs 114). Species identity was also different between both artificial hard substrates, with 95 unique epifaunal species for shipwrecks and 44 unique epifaunal species for offshore wind farms. The differences in biodiversity between both structures may be attributed to the older age and the higher structural complexity of shipwrecks. Increasing the structural complexity of turbine foundations and surrounding scour protection layers might increase the epifaunal biodiversity of offshore wind farms, leading to more similar epifaunal communities as those found at shipwrecks.

1. Introduction

Several marine activities are adding a variety of artificial hard structures to the ocean environment. These activities range from shipping (in the form of shipwrecks), coastal defence and development (harbour walls, groynes, breakwaters, etc.), oil and gas extraction (platforms) to renewable energy production (offshore wind turbine foundations and surrounding scour protection layer). Also, nature conservation and restoration can actively add artificial hard structures in the marine environment in the form of (primary) artificial reefs, while the other structures can be regarded as secondary artificial reefs (Krone 2012). All these structures provide artificial hard substrates, which are colonised by epifaunal (fouling) communities (e.g., Whomersley & Picken 2003; Zintzen & Massin 2010; Kerckhof *et al.* 2012; Van Moorsel 2014; Wetzel *et al.* 2014; Schutter *et al.* 2019; Coolen *et al.* 2020).

In the North Sea, artificial hard substrates were historically mostly present in the form of shipwrecks and coastal infrastructure, and in the form of oil and gas platforms. The massive rollout of offshore wind farms (OWFs) is currently the highest contributor to new artificial hard substrates in several countries bordering the North Sea, thereby vastly surpassing the amount of other artificial hard substrates. This evolution will only accelerate, driven by the increasing demand for renewable energy production (Ellabban *et al*. 2014; Wilding *et al*. 2017). The effects on ecosystem structure and functioning of this proliferation of offshore wind can be substantial (Degraer *et al*. 2020). The structures are quickly colonised by high numbers of hemi-sessile animals such as anemones, bivalves and filter-feeding amphipods which may influence particle and nutrient fluxes, and potentially affect plankton production (Newell 2004; Maar *et al*. 2007). Foundations of offshore wind turbines can have a 35-fold higher biomass compared to surrounding soft sediments (Krone *et al*. 2013), and can influence local food web dynamics (Mavraki *et al*. 2020). The production of (pseudo-)fecal pellets by these colonising organisms also affects the surrounding soft sediments (Krone *et al*. 2013; Coates *et al*. 2014; De Borger *et al*. 2021; Ivanov *et al*. 2021). Additionally, colonising bivalves such as the blue mussel (*Mytilus edulis*) form on their turn a secondary hard substrate for the settlement of other species (Rumes *et al*. 2021). Another consequence of the addition of artificial hard substrates in soft sediment areas is the increased dispersal potential of hard substrate associated species, which may use these substrates as stepping stones to expand and establish new areas (Connell 2001; Bulleri & Chapman 2010). These species can be indigenous or non-indigenous, with the establishment of non-indigenous species becoming an increasing concern (Langhamer 2012; Mineur *et al*., 2012; Adams *et al*. 2014; de Mesel 2015; Kerckhof *et al*. 2016).

To better understand the potential effects of large-scale colonisation of offshore wind turbines by epifaunal species, including non-indigenous ones, a comparison with the epifaunal communities of long-existing artificial hard structures such as shipwrecks is a logical first step. Most shipwrecks in the North Sea have been there for decades or even longer, enabling the development of mature epifaunal communities. Because their biodiversity is much larger than that of the surrounding soft sediments, they are regarded as ‘hotspots’ for biodiversity (Zintzen *et al*. 2006). The question is whether this can also be the fate for the foundations and surrounding scour protection layer of offshore wind turbines. The comparison of the fouling communities of both artificial hard structures can potentially be of importance for the decommissioning discussion of offshore wind farms (Fowler *et al*. 2020).

In this chapter, we compare the epifaunal communities between offshore wind farms and shipwrecks in the Belgian part of the North Sea (BPNS), with special attention to the presence of non-indigenous species. The comparison will lead to a better understanding of these offshore artificial hard substrate communities and their fate throughout time.

2. Material and methods

For the qualitative comparison of the epifauna between offshore wind farms and shipwrecks in the BPNS, with all data exploration and visualization performed in R (R Core Team 2022), we used our Artificial Hard Substrate database. In this database, species records of all macrobenthic (>1 mm) species that are associated with different artificial hard substrates in the BPNS are recorded (Kapasakali *et al*. 2019). The taxonomic nomenclature was based on the World Register of Marine Species (WoRMS 2022). Soft-sediment species are occasionally found in hard substrate communities, but are not actually part of it, so these were removed from the database, as was the case for pelagic species. Furthermore, only full species records were considered; records on higher taxonomic levels such as genus, family or phylum were removed. Since we focused on hard substrate communities of shipwrecks and offshore wind farms, all records from other structures, such as groynes, harbour walls and buoys, were excluded from the analysis. As no intertidal shipwrecks are present (anymore) in the

Table 1. List of terms and definitions concerning the (non-)native status of species, adapted from Kapasakali *et al*. (2019).

Term	Definition
Indigenous	A biogeographical status indication, meaning those species that occur naturally (unaided by human action) within a particularly defined area. *Synonyms: native, autochthonous*
Non-indigenous	A biogeographical status indication, meaning those species that did not occur geographically within a particularly defined region prior to some predetermined period (after Les & Mehrhoff 1999). *Synonyms: non-native, allochthonous*
Cryptogenic	A species that is not demonstrably native or introduced (after Carlton 1996).
Introduced	A subset of non-indigenous species, whose presence in a region is attributable to human actions that enabled them to overcome fundamental biogeographical barriers (i.e., human-mediated extra-range dispersal) (modified from Richardson *et al*. 2011).
Range-expanding	A subset of non-indigenous species, whose presence into a novel region is attributable to natural dispersal; such expansion may be assisted or primarily driven by human-mediated changes to the environment (modified from Richardson *et al*. 2011).
Established	Species with a self-sustaining population in a non-indigenous region (modified from Les & Mehrhoff 1999). *Synonyms: naturalised*

BPNS, the focus was only on subtidal species. The native status of the species records in the database is also considered, and is defined according to Kapasakali *et al.* (2019 and Table 1). Species whose status is unclear, are indicated as cryptogenic (Carlton 1996).

In the BPNS, there are around 300 shipwrecks (Afdeling Kust 2022), of which at least 55 shipwrecks are older than 100 years (Demerre *et al*. 2020). Our species records were extracted from a subset of 10 shipwrecks, all at least 40 years old, as described in Zintzen (2007). There are currently nine OWFs in the BPNS, with a total of 399 wind turbines. Fouling data from the foundations and surrounding scour protection layer of the offshore wind turbines originate from samples taken at the C-Power OWF (2008-2020) and the Belwind OWF (2010-2020) and are recorded in the WinMon.BE database (see Kerckhof *et al.* 2019 and references therein). While the shipwrecks are distributed across the BPNS, with sampling sites in coastal, transitional and offshore water masses, the OWFs are situated in the Northeastern part of the BPNS, in transitional and offshore waters only.

3. Results

We retained a total of 209 species, of which 44 unique for OWFs and 95 unique for shipwrecks. OWFs and shipwrecks furthermore share 70 species (Fig. 1). Shipwrecks are more diverse, with a total of 165 species, while in OWFs, 114 species were recorded (Fig. 2).

For some higher taxa, we observed remarkable differences between habitats. OWFs and shipwrecks share one bryozoan species, while 7 bryozoan species are unique for OWFs, and 10 species unique for shipwrecks. A similar pattern is observed with the gastropods, for which both habitats share 9 species, while 8 species are unique to OWFs and 12 species unique to shipwrecks. Polychaetes are the most numerous taxon, with 18 shared species, 8 unique to OWFs and 30 unique to shipwrecks. Cumaceans, entoprocts and mysids (all represented by one species) were only found at OWFs, while pycnogonids (two species) were only present on shipwrecks. Sponges (Porifera) reached a high diversity at shipwrecks (9 unique species), but only one unique species

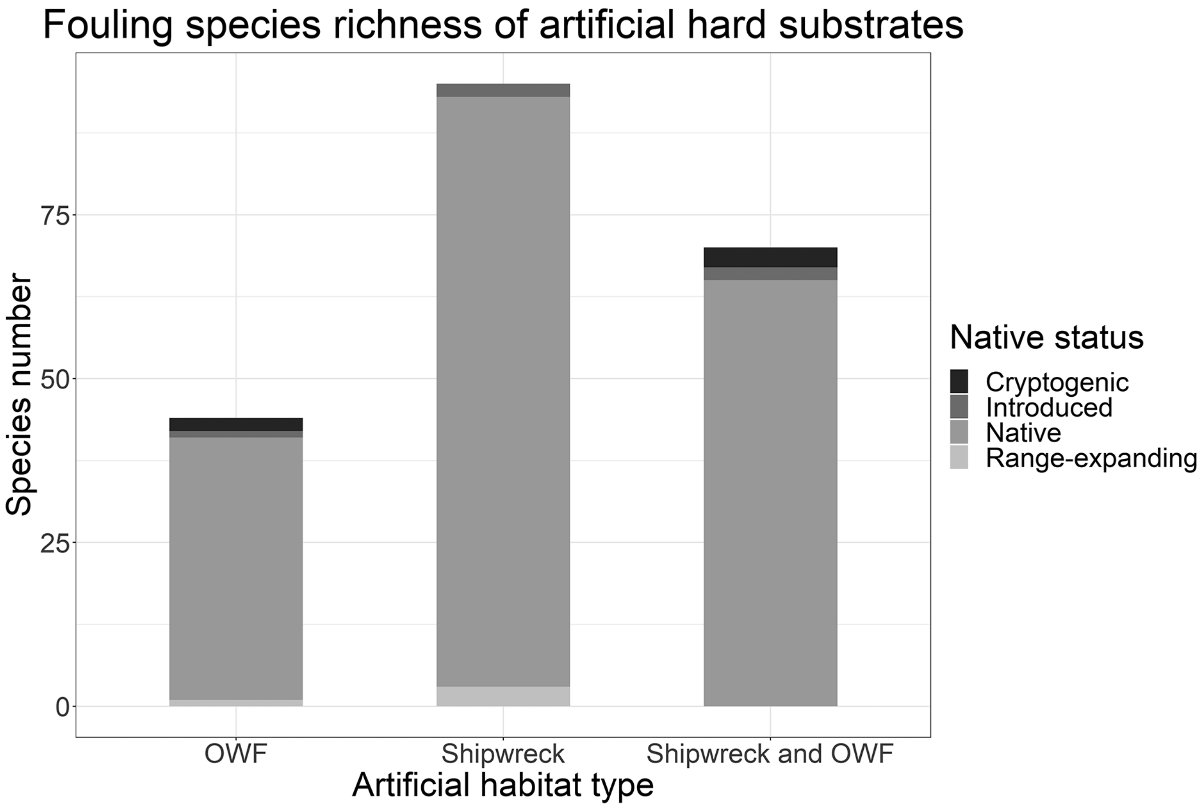

Figure 1. Number of unique native and non-indigenous macrobenthic species at offshore wind farms (OWF), shipwrecks; and present at both habitats.

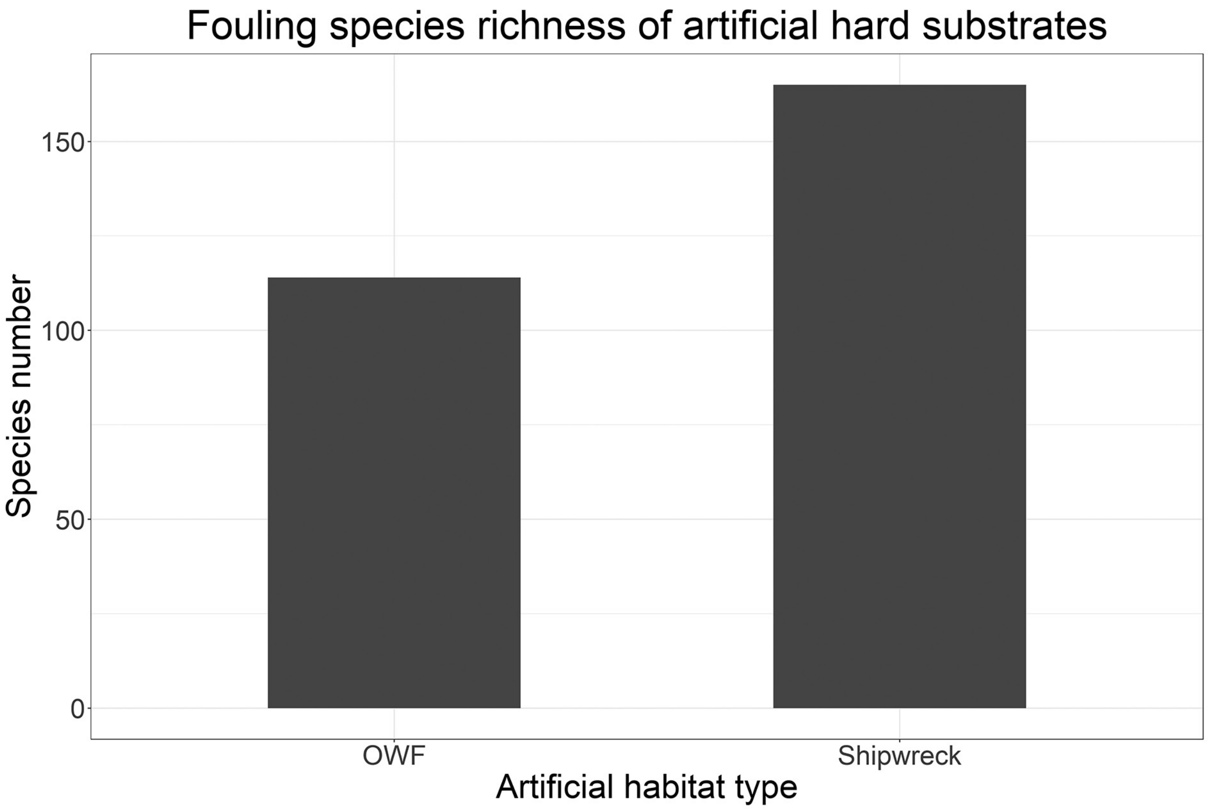

Figure 2. Number of hard-substrate macrobenthic species (subtidal only) recorded at offshore wind farms (OWF) and at shipwrecks.

Table 2. Non-indigenous species (subtidal only) at offshore wind farms (OWF) and shipwrecks.

Species	Higher Taxon	Non-indigenous	Habitat
Diplosoma listerianum	Ascidiacea	Cryptogenic	OWF
Lysianassa ceratina	Amphipoda	Range-expanding	Shipwreck
Monocorophium acherusicum	Amphipoda	Cryptogenic	Shipwreck and OWF
Monocorophium sextonae	Amphipoda	Introduced	Shipwreck and OWF
Fenestrulina delicia	Bryozoa	Introduced	OWF
Amphibalanus improvisus	Cirripedia	Cryptogenic	OWF
Perforatus perforatus	Cirripedia	Range-expanding	OWF
Crepidula fornicata	Gastropoda	Introduced	Shipwreck and OWF
Janira maculosa	Isopoda	Introduced	Shipwreck
Eulalia aurea	Polychaeta	Range-expanding	Shipwreck
Lysidice ninetta	Polychaeta	Range-expanding	Shipwreck
Hymeniacidon perlevis	Porifera	Introduced	Shipwreck

at OWFs, while another species was shared in both habitats.

The number of non-indigenous species (12, Table 2, Fig. 3) remains low compared to indigenous species (197) (Fig. 1). Of the non-indigenous species, five are species introduced through human activities, four are range-expanding species because of climate change, and for the remaining five, their true origin is uncertain. There is no clear difference in non-indigenous species richness between OWFs and shipwrecks.

4. Discussion

The current and future massive rollout of offshore wind in the North Sea will lead to a huge proliferation of artificial hard substrates. These provide additional habitat for hard substrate associated fauna in a largely soft bottom environment, and will attract species that would otherwise not be able to colonise the area. This increase in biodiversity is thus not unexpected or remarkable, but what is observed all around the North Sea (e.g., Whomersley & Picken 2003; Zintzen & Massin 2010; Kerckhof *et al*. 2012; Krone 2012; Van Moorsel 2014; Wetzel *et al*. 2014; Coolen *et al*. 2020).

We found that species richness was markedly higher on shipwrecks than on offshore wind farm foundations and the surrounding scour protection layers in Belgian waters. This can be attributed to the age of the structures, which is significantly older for shipwrecks. For example, the species richness of sponges is much higher on shipwrecks than on OWFs (10 vs 1). These slow-growing, fragile species are characteristic for ‘mature’ and undisturbed communities on hard substrates (Wahl 2009; Hiddink *et al.* 2017; Malecha & Heifetz 2017). In the Netherlands, species richness on older oil and gas platforms was also higher than on younger wind turbine foundations (Coolen *et al*. 2020), although total species richness remained below of what we have observed for the shipwrecks and OWFs in the BPNS. As offshore wind farms age, we may thus expect that the species composition might become more similar to the one observed at shipwrecks.

At the same time, shipwrecks provide more structural heterogeneity than offshore wind farms, possibly enabling higher species richness at shipwrecks. Zintzen *et al.* (2006), for example, observed a clear differentiation in species composition between horizontal and vertical sections of shipwrecks. Wind turbines lack this structural complexity, especially the foundations which are smooth, nearly vertical structures rising from the seabed. Generally, turbine foundations are massively covered by a shallow subtidal *M. edulis* zone and a deeper

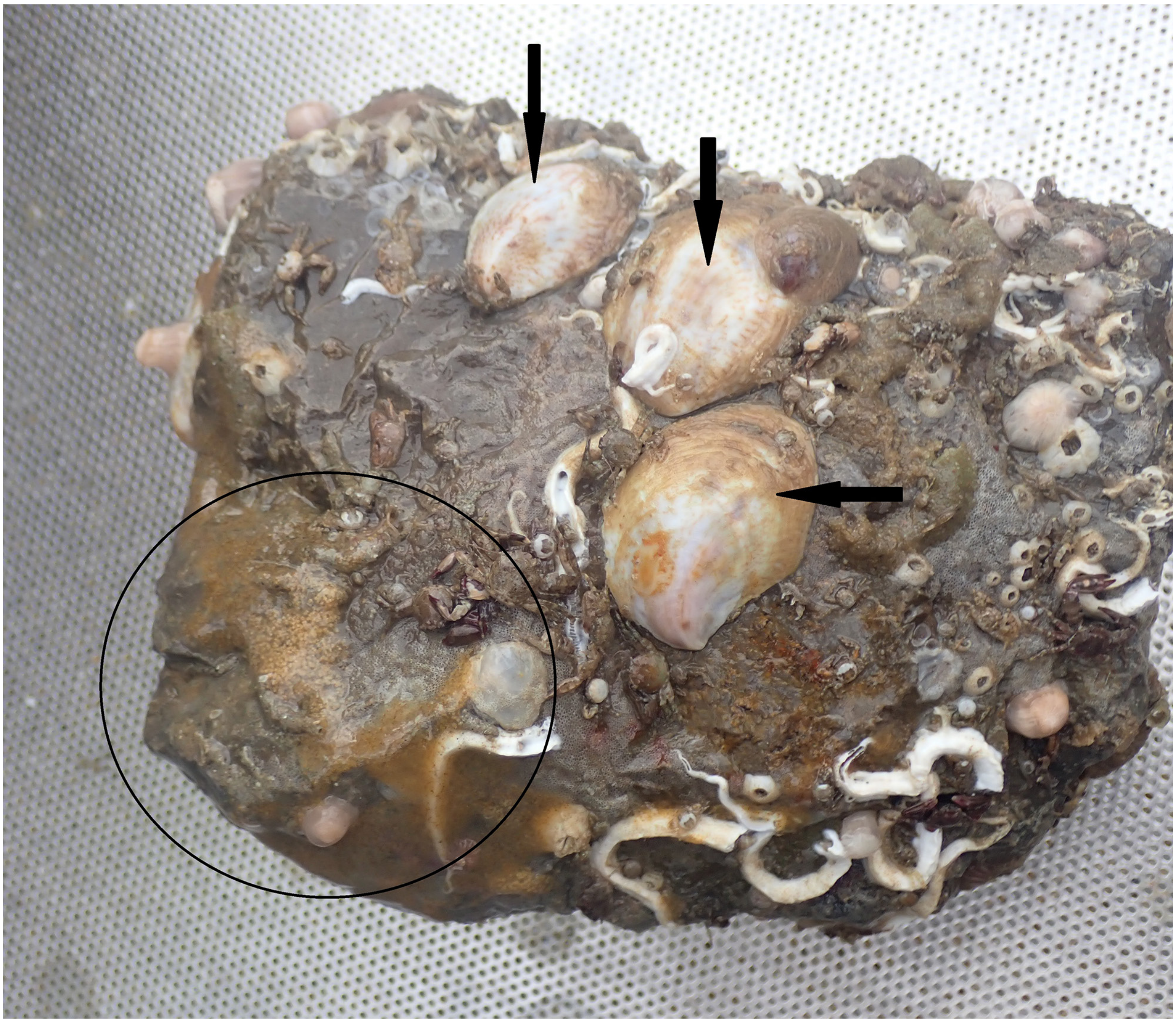

Figure 3. Scour protection rock with the non-indigenous species *Crepidula fornicata* (arrows) and *Diplosoma listerianum* (circle) (©RBINS, F. Kerckhof).

Metridium senile zone, with tubes of *Jassa* amphipods interspersed (Krone *et al*. 2013; De Mesel *et al*. 2015; Degraer *et al*. 2020). This dominance of only a few species can likely be attributed to the lack of structural complexity. Increasing the structural complexity of both the turbine foundations and the scour protection layers might increase species diversity and thus give rise to more diverse communities.

Next to a difference in species richness between both artificial hard substrates, also the species composition differs between them, with OWFs having almost 40% of unique species, and shipwrecks almost 60%. This might indicate that OWFs, which are spanning the entire water column, represent a different habitat than shipwrecks, which are only extending a few meters above the seafloor. However, the OWFs in the present study are also monitored more intensively than the shipwrecks, and their unique species might just not be recorded yet from shipwrecks.

The proportion of non-indigenous species found on the subtidal artificial hard substrates in this study is lower compared to other artificial hard substrates in intertidal and/or coastal areas. For example, seven non-indigenous species are found in the intertidal zone of OWFs, accounting for 23% of the species found (Kerckhof *et al*. 2016), while subtidally, non-indigenous species account for only 6.1% of the species (also seven species), despite the much larger substrate surface available for subtidal species. Some of these species are range-expanding species, arriving naturally in our areas as a result warming waters and the presence of suitable, previous non-existent hard substrates. Other species are introduced by human activities and would otherwise not have made it to our seas. Infamous examples of this are the subtidal slipper limpet *Crepidula fornicata*, originating from the North-West Atlantic, and the Japanese oyster *Crassostrea gigas*, coming from the West Pacific. *Crepidula fornicata* is a competitor for space, and can inhibit settlement of epifaunal species, including reef-forming species such as the European flat oyster *Ostrea edulis* and the Ross worm *Sabellaria spinulosa*. *Crassostrea gigas* can also compete for space but is more restricted to the intertidal and shallow subtidal, therefore coming less into competition with indigenous species (except with blue mussel *M. edulis*). The competition for space is, however, not only restricted to introduced non-indigenous species, also the indigenous anemone *M. senile* is a competitor for space. This ‘dominant native’ thrives on artificial hard substrates and can lead to less diverse communities (Kerckhof *et al*. 2019).

Hard substrate associated species, both indigenous and non-indigenous, can use shipwrecks and turbine foundations as stepping stones to strategically position themselves in the soft-sediment dominated North Sea and to colonise new areas herein (Zintzen & Massin 2010). The stepping stone effect of both artificial hard substrates can be regarded as synergistic. On the one hand, turbine foundations offer an intertidal and shallow subtidal zone, colonised by species such as *M. edulis* and *C. gigas* (Kerckhof *et al*. 2016), which are generally absent on deeper subtidal shipwrecks (Krone *et al*. 2013). On the other hand, shipwrecks have a higher structural complexity, providing opportunities for a more diverse set of colonising species, while both structures are strengthening the position of species such as *M. senile*, *C. fornicata* and *Tubularia* spp, which are thriving on both these artificial substrates.

Despite the high species richness and varied species composition of the artificial hard substrates investigated in this study, these substrates harbour different communities than natural hard substrates (Zintzen 2007; Krone *et al*. 2013; Kerckhof *et al*. 2017). Even if left undisturbed for decades, artificial hard substrates cannot serve as a replacement for the loss and ecological decline of natural hard substrates. Although biodiversity is expected to increase over time on artificial hard substrates, they will form their own typical assemblages, as currently evaluated by the EUNIS Habitat Classification: ‘*Faunal Communities on Atlantic Circalittoral Artificial Hard Substrate*’ (code MC1228, EUNIS habitat classification, updated version March 2022). If, however, biodiversity is a criterium in the decommissioning debate of OWFs (Fowler *et al*. 2020), it might be an option to leave at least part of the turbine foundation and the surrounding scour protection layer in place.

In conclusion, the subtidal epifaunal hard substrate communities of shipwrecks and offshore wind farms are different, with a higher species richness at shipwrecks and a marked difference in species composition between both habitats. Higher structural complexity and older age might be reasons for the higher species richness of shipwrecks. It is unclear if OWFs will reach similar species richness as shipwrecks over time, if structural complexity is not increased. Increasing the complexity of the scour protection layer surrounding turbine foundations might increase species richness and thus support biodiversity, an approach called nature-inclusive design of marine infrastructure. This is currently investigated in research projects such as the EU Horizon 2020 project UNITED or the EDEN2000 project, financed by the Belgian Federal Public Service Environment.

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