CHAPTER 6

DO WIND FARMS FAVOUR INTRODUCED HARD SUBSTRATA SPECIES?

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ABSTRACT

Offshore wind farms, like other artificial structures in the marine environment, are hypothesised to favour introduced species and as such pose a threat to the native fauna. However, this has so far never been investigated for offshore wind farms. In this study, we investigated introduced species on Belgian offshore wind farms with particular interest in (1) the position of introduced species on offshore wind farms in relation to other hard substrata in the Belgian part of the North Sea (BPNS), (2) the distribution of introduced species in the subtidal versus intertidal zone and (3) the potential of offshore wind farms for future flourishment of the introduced species. Therefore we compared different hard substratum communities, both natural and man-made, on the relative importance of introduced species in the subtidal and intertidal communities.

Overall we detected eleven introduced and two cryptogenic species on the wind turbines, seven of which are intertidal species (i.e. *Balanus (Amphibalanus) improvisus, Crassostrea gigas, Elminius (Austrominius) modestus, Hemigrapsus sanguineus, Jassa marmorata, Megabalanus coccopoma* and *Telmatogeton japonicus*) and four are subtidal species (i.e. *Corophium (Monocorophium) sextonae, Crepidula fornicata, Diplosoma listerianum* and *Fenestrulina delicia*). We found that, all but one introduced species observed on the offshore wind farms in Belgian waters (i.e. *F. delicia*), were already known from the BPNS. Clear colonisation patterns occurred in both wind farms and this can be considered a confirmation that the observed patterns are consistent and may hence be expected similar in other wind farms in the southern North Sea. In the subtidal zone, the offshore wind farms will only marginally contribute to the further spread of introduced species given the vast amount of both natural and artificial hard substrata already available in the North Sea, which already contain established populations of the same introduced species. However, for the intertidal zone, the wind farms may have the potential to substantially increase the risk of the further spreading of introduced species, given that offshore intertidal habitat still is relatively rare. Wind farms will indeed drastically increase the available habitat to intertidal introduced species. It is however expected that offshore wind farms may significantly contribute only to the spread of clear water, intertidal introduced species, as such nuancing the introduction and invasion risk posed by offshore wind farms.

6.1. INTRODUCTION

In the last decades, the predominantly sandy coastline along the southern North Sea underwent drastic changes under the influence of human activities. The number of coastal defence works increased all along the coastline (www.kustveiligheid.be), ports are expanding and other large infrastructural works are taking place (www.maasvlakte2.com; www.vlaamsebaaien.com). Even offshore waters are undergoing a major industrial development, especially with the increase of offshore wind farms (www.ewea.org; Rodrigues et al., 2015). The proliferation of all these man-made structures resulted in an overall hardening of the coast and its offshore waters.

The hardening is still ongoing. Wind farms extend further offshore and will in the future occupy large areas of the shallow waters of the North Sea (www.ewea.org). Some of the hard substrata such as wind farms create completely new habitats in the marine ecosystem. It is often postulated that wind farms, like other artificial structures in the marine environment, would favour introduced species and as such pose a threat to the native fauna (Glasby et al., 2007; Bulleri & Chapman, 2010, Kerckhof et al., 2011). For instance, wind turbine foundations create an intertidal zone, formerly non-existent in offshore North Sea waters (Kerckhof et al., 2010).

The increased availability of man-made hard substrata, together with the increased activities of vectors such as shipping, not only allows a much faster and more intense transport of certain species all over the globe but the migrants now find more suitable habitat to settle and to prosper in regions beyond their original distribution. This is explicitly the case in coastal habitats, including estuaries and harbours (Carlton, 1996b; Wolff 1999; Wolff, 2005; Galil et al., 2009).

In this study we quantified the importance of the hard substrata created by wind farms to introduced species with the specific aim of exploring the risk of wind farms to contribute to the further spread of introduced and potentially invasive species throughout the North Sea. To this extent, we focused on introduced species on Belgian offshore wind farms and investigated (1) the relative dominance of introduced species in the subtidal versus intertidal zone of offshore wind farms, (2) the colonisation pattern of introduced species on offshore wind farms and (3) the position of introduced species on offshore wind farms in relation to other hard substrata in the Belgian part of the North Sea (BPNS).

6.2. MATERIAL & METHODS

INTRODUCED SPECIES: WHAT'S IN A NAME

In this study, we defined introduced species as non-indigenous species that are introduced in a certain region – in this case the North Sea – by historical human intentional or unintentional activities (e.g. Carlton, 1996a) across natural dispersal barriers. This means that they originate from areas around the globe that are non-adjacent to the North Sea. These areas include the Mediterranean, the Black and Caspian Seas (Wolff, 2005). Thus, range-expanding species, i.e. species that are spreading into the North Sea from adjacent regions where they occur indigenously, were excluded from this study.

Additionally, we took into account cryptogenic species. Cryptogenic species are species of which the status – indigenous or non-indigenous – cannot be scientifically proved (Carlton, 1996a). The cryptogenic species included in this study meet most of the attributes proposed by Chapman and Carlton (1991), e.g. having a wide-spread occurrence in harbours and other coastal habitats, association with human mechanism(s) of dispersal. Introduced and cryptogenic species are further collectively called introduced species.

In this study, we only considered macrofaunal (retained by a 1 mm mesh-sized sieve) introduced species in the BPNS encompassing coastal harbours. We included euryhaline (>30 psu) and polyhaline (18-30 psu) species, and excluded mesohaline and oligohaline species living in brackish waters below 18 psu.

DATA AVAILABILITY

Belgian offshore wind farms

We extracted a species list for the subtidal and intertidal community on the wind turbines – foundations and scour protection – from the database with all available data from the C-Power and Belwind wind farms. Hard substrata macrofauna was collected from the C-Power and Belwind wind farms, located in the Belgian offshore renewable energy zone (see Brabant et al., 2011). The C-Power wind farm (six concrete gravity-based foundations (GBF), 49 jacket foundations) is located on the Thornton Bank some 30 km offshore. The Belwind wind farm (during the study period: 56 steel monopiles and 1 jacket foundation) is situated on the Bligh Bank at about 50 km off the coast. Both banks belong to the Zeeland Banks system (Cattrijsse & Vincx, 2001). The samples were collected late 2008-2015 from a selected set of wind turbines: D5 and D4 at the C-Power site and BBB8, BBC2 and BBC8 at the Belwind site. The samples included scrape samples on the turbine foundations and stones gathered from the scour protection (Kerckhof et al., 2011).

Out of the species pool of all species identified, we eliminated those species that were usually not associated to hard substrata such as infaunal or pelagic macrofauna that accidently occurred in the samples. This yielded a list with genuine hard substratum species. We further also classified the species according to their observed prevalent occurrence in the sub- or intertidal zone. In this study, intertidal species are those species living in the eulitoral and splash zone. Species were considered intertidal if they solely or predominantly inhabit the eulitoral and or splash zone, while species mainly having a sublitoral distribution and only occurring occasionally in the infralitoral fringe (i.e. lower mussel zone) were considered true subtidal species (e.g. Hayward and Ryland, 1990; Hiscock et al., 2005; http://www.marlin.ac.uk/).

The SACFOR scale (Connor & Hiscock 1996) was used to score the relative abundance of the offshore wind farm introduced species.

Other Belgian hard substrata

We compiled a list of introduced species associated with hard substrata in Belgian waters based on an inventory of all introduced species in Belgian waters that was assembled using various available sources e.g. Kerckhof et al. (2007) and the various Belgian reports submitted to the ICES Working Group on Introductions and Transfers of Marine Organisms (WGITMO) (ICES, 2001 – 2016).

Subsequently, we allocated the introduced species to the different habitats within which these occur. To that extent, we screened different datasets and publications dealing with the fauna on Belgian artificial hard substrata such as ship wrecks (Zintzen, 2007; Zintzen, 2010), coastal defence structures (Daro, 1969; Engledow et al., 2001; Volckaert et al., 2003; Volckaert et al., 2004; Kerckhof et al., unpubl. data EMBOS), harbour works (Derweduwen et al., 2014) and offshore buoys (Kerckhof & Cattrijsse, 2001; Kerckhof F., unpubl. data) for the presence of introduced species. The list of species detected in the subtidal samples consisted of 148 species of which 144 were considered as true subtidal species. Intertidally, we identified 30 species of which 16 were classified as true intertidal species.

We further classified the introduced species as established, non-established or extinct. We considered a species established when the species has been regularly observed (i.e. not restricted to a single observation) with several individuals, suggesting a viable and self-sustaining population for that species in the BPNS and its adjacent waters. If the introduced species did not meet these criteria it was considered non-established. We considered an introduced species as extinct if, after a prolonged period of presence, the species has not been detected anymore during the last five years even after dedicated inspection of its habitat.

6.3. RESULTS

INTRODUCED VERSUS NON-INTRODUCED SPECIES IN OFFSHORE WIND FARMS

In the intertidal zone of the offshore wind farms, six species were introduced: *Crassostrea gigas*, *Elminius (Austrominius) modestus*, *Megabalanus coccopoma*, *Jassa marmorata*, *Hemigrapsus sanguineus* and *Telmatogeton japonicus*, and one is cryptogenic: *Balanus (Amphibalanus) improvisus*. In the subtidal, three introduced species (i.e. *Crepidula fornicata*, *Corophium (Monocorophium) sextonae* and *Fenestrulina delicia*) and one cryptogenic species (i.e. *Diplosoma listerianum*), were detected.

The introduced species share is relatively high in the intertidal zone (i.e. 23 %) (Figure 1A), while in the subtidal the share is very low (i.e. 2.7 %). If the true intertidal species allocation is considered (Figure 1B), the introduced species share in the intertidal is even higher (i.e. 43 %), while with 2.8 % the share remains very low in the subtidal community.

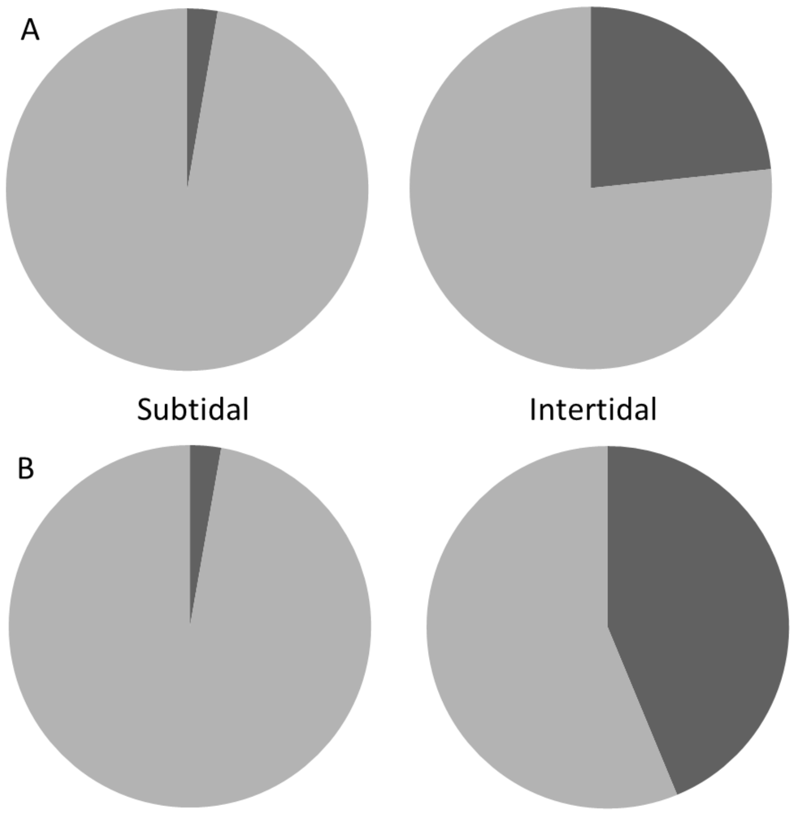

Figure 1. Intertidal and subtidal introduced versus non-introduced species richness on Belgian offshore wind farms. A, subtidal and intertidal species allocation as detected in the samples. B, true subtidal and true intertidal species allocation. Dark grey, introduced species; light grey, non-introduced species.

INTRODUCED SPECIES COLONISATION PATTERN ON OFFSHORE WIND FARMS

Subtidally, two introduced species were present from the start in both wind farms, i.e. *C. fornicata* and *C. sextonae*, but only the abundant *C. fornicata* persisted after year one (Tables 1 and 2). Two other species came in only after three years, i.e. *D. listerianum* (abundant in both wind farms) and *F. delicia* (rare and only on the C-Power scour protection).

Table 1. Colonisation pattern of intertidal (IT) and subtidal (ST) introduced species (*, cryptogenic) at the C-Power gravity-based foundation (CP) and the Belwind monopile (BW) wind farms. Semi-quantitative abundances using SACFOR scale: S, superabundant; A, abundant; C, common; F, frequent; O, occasional; R, rare.

			Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8
*Balanus improvisus**	IT	CP			O					no data
		BW	O				no data		no data	no data
Crassostrea gigas	IT	CP			O	O	O	F	F	no data
		BW					no data	F	no data	no data
Elminius modestus	IT	CP	A	A	A	A	A	A	A	no data
		BW	C	C	C	C	no data	C	no data	no data
Hemigrapsus sanguineus	IT	CP			F	F		F		no data
		BW					no data	O	no data	no data
*Jassa marmorata**	IT	CP	C	C	C	C	C	C	C	no data
		BW	C		O		no data	C	no data	no data
Megabalanus coccopoma	IT	CP	C							no data
		BW	F				no data		no data	no data
Telmatogeton japonicus	IT	CP	S	S	S	S	S	S	S	no data
		BW	S	S	S	S	no data	S	no data	no data
Corophium sextonae	ST	CP	R							
		BW	F						no data	no data
Crepidula fornicata	ST	CP	A	A	A	A	A	A	A	A
		BW	F	F	F	F	A	A	no data	no data
*Diplosoma listerianum**	ST	CP			R	O	O	O	F	F
		BW			A		S	F	no data	no data
Fenestrulina delicia	ST	CP			R	R	R			
		BW							no data	no data

Elminius modestus, *T. japonicus* and *J. marmorata* were early colonizers of the intertidal zone, all three persisting commonly to superabundantly throughout the study period (Tables 1 and 2). Another early colonizer in both wind farms, i.e. *M. coccopoma*, disappeared after one year in both wind farms. Later on in the succession, the C-Power intertidal zone became home to *C. gigas* and *H. sanguineus* from the third year onwards, while these species were not detected in Belwind until after six years. No clear succession pattern can be deducted for *B. improvisus* that was only found in low numbers on two occasions.

Table 2. Colonisation time and persistence of the introduced species at the C-Power and the Belwind wind farms.

	Early / late coloniser	**Persisting / non-persisting**
Balanus improvisus	Data deficient	
Corophium sextonae	Early	Non-persisting
Crassostrea gigas	Late	Persisting
Crepidula fornicata	Early	Persisting
Diplosoma listerianum	Late	Persisting
Elminius modestus	Early	Persisting
Fenestrulina delicia	Data deficient	
Hemigrapsus sanguineus	Late	Persisting
Jassa marmorata	Early	Persisting
Megabalanus coccopoma	Early	Non-persisting
Telmatogeton japonicus	Early	Persisting

INTRODUCED SPECIES ON OFFSHORE WIND FARMS IN RELATION TO OTHER HARD SUBSTRATA

The list of introduced species associated with hard substrata in the BPNS consisted of 32 species of which five (four barnacle species occurring only on navigational buoys and one bryozoan species found only in a marina) are considered non-established (Table 3). One species *Megabalanus coccopoma* is classified as extinct because it has not been reported since 2010. 27 other introduced species were observed regularly and in fair number and hence are currently considered established on hard substrata in the BPNS.

The largest number, 24 species, is found in harbours, of which 23 are established, followed by navigational buoys on which 15 introduced species were found, of which eleven are considered established, followed by coastal defence works with eleven introduced species of which nine are considered established. On the contrary, the lowest number was found on the wrecks and the reef balls. On the wrecks only three introduced species were found including the only two that were also detected on the reef balls. The number of introduced species was very low on the natural hard substrata, none were reported before 1910 while only one, *C. fornicata,* was detected in recent studies. The latter species is almost omnipresent, lacking so far only from intertidal offshore wind farm.

Table 3. List of introduced species associated with different hard substrata in the BPNS

species	higher taxon	coastal defence	harbours	buoys	wrecks	wind inter	wind sub	gravel (Gilson, 1900)	gravel (Houziaux , 2005 & Hinders, 2013)	reefbals
Aplidium glabrum	Ascidiacea		x							
Balanus amphitrite	Cirripedia	x	x	x						
Balanus improvisus	Cirripedia	x	x	x		x				
Balanus reticulatus	Cirripedia			x						
Balanus trigonus	Cirripedia			x						
Balanus variegatus	Cirripedia			x						
Bugula neritina	Bryozoa		x							
Bugula stolonifera	Bryozoa		x							
Bugula simplex	Bryozoa		x							
Boccardia proboscidea	Polychaeta	x								
Boccardiella hamata	Polychaeta		x							
Botrylloides violaceus	Ascidiacea		x							
Caprella mutica	Amphipoda		x	x						
Corophium sextonae	Amphipoda				x		x			
Crassostrea gigas	Bivalvia	x	x	x		x				
Crepidula fornicata	Gastropoda	x	x	x	x		x		x	x
Diplosoma listerianum	Ascidiacea		x		x		x			x
Elminius modestus	Cirripedia	x	x	x		x				
Fenestrulina delicia	Bryozoa						x			
Ficopomatus enigmaticus	Polychaeta		x							
Haliplanella lineata	Actinaria		x							
Haliclona xena	Porifera		x							
Hemigrapsus sanguineus	Decapoda	x	x	x		x				
Hemigrapsus takanoi	Decapoda		x							
Jassa marmorata	Amphipoda	x	x	x		x				
Megabalanus coccopoma	Cirripedia	x		x		x				
Megabalanus tintinnabulum	Cirripedia			x						
Molgula manhattensis	Ascidiacea		x							
Petricola pholadiformis juv.	Bivalvia	x	x	x						
Styela clava	Ascidiacea		x							
Telmatogeton japonicus	Diptera	x	x	x		x				
Tricellaria inopinata	Bryozoa		x							

The introduced species assemblages on the different types of hard substrata are different. Crustaceans and molluscs are dominant on all artificial hard substrata, while tunicates and bryozoans remain largely restricted to harbour environments (Table 4). So far no introduced porifera, annelids nor cnidarians were detected on the offshore wind turbines in the BPNS.

Table 4. Number of introduced species, grouped into higher taxa, on different types of hard substrata in Belgian waters. Number of established introduced species in parentheses.

Higher taxa	Total	Wind farms	Harbours	Coastal defence	Buoys
Chordata,Tunicata	5 (5)	1 (1)	5 (5)	0 (0)	0 (0)
Arthropoda, Crustacea	13 (8)	6 (5)	7 (7)	4 (4)	11 (6)
Cirripedia	8 (3)	3 (2)	3 (3)	8 (3)	8 (3)
Amphipoda	3 (3)	2 (2)	2 (2)	2 (2)	2 (2)
Decapoda	2 (2)	1 (1)	2 (2)	1 (1)	1 (1)
Arthropoda, Hexapoda	1 (1)	1 (1)	1 (1)	1 (1)	1 (1)
Bryozoa	5 (4)	1 (1)	4 (3)	0 (0)	0 (0)
Molusca	3 (3)	2 (2)	3 (3)	3 (3)	3 (3)
Bivalvia	2 (2)	1 (1)	2 (2)	2 (2)	2 (2)
Gastropoda	1 (1)	1 (1)	1 (1)	1 (1)	1 (1)
Porifera	1 (1)	0 (0)	1 (1)	0 (0)	0 (0)
Annelida	3 (3)	0 (0)	2 (2)	1 (1)	0 (0)
Cnidaria	1 (1)	0 (0)	1 (1)	0 (0)	0 (0)

6.4. DISCUSSION

PATTERNS OF INTRODUCED SPECIES IN BELGIAN OFFSHORE WIND FARMS

Introduced species occur in the subtidal and intertidal zones of Belgian offshore wind farms. Their presence is particularly noticeable in the intertidal zone with a percentage of no less than 23 %, or 43 % if only true intertidal species are considered (Figure 1A, 1B). The intertidal zone, as occurring now in the wind farms, is a new habitat in the offshore environment. It hence is no surprise that here species that were formerly not present offshore including introduced species thrive. The fact that introduced species however tend to prevail in the intertidal zone compared to the subtidal zone may be explained by species-poor and environmentally harsh environments such as the intertidal but also brackish water environments being particularly sensitive to introductions (Wolff, 1999; Wolff, 2005; Ruiz et al., 1997). The subtidal offshore wind farm hard substrata represent a more benign environment, where introduced (and other non-indigenous) species may have less opportunities for establishing.

Clear colonisation patterns occur in both wind farms. The predominantly similar pattern as observed in both wind farms can be considered a confirmation that the observed patterns are consistent and may hence be expected similar in other wind farms in the southern North Sea. The time of colonisation after wind farm construction as quantified in this study however needs nuancing. Not observing a species for example does not necessarily mean that the species is not present as it may simply have been missed during sampling. Many species indeed occur patchily hampering a reliable observation of their absence. This is particularly the case when the species is relatively rare. Some presumed absences in the database may hence be interpreted as such (e.g. *H. sanguineus* at C-Power in year 5 or *J. marmorata* at Belwind in year 4). The exact timing of arrival is further complicated by gaps in the data series. For example *C. gigas* was first observed at Belwind in year 6. However, no sampling occurred in the 5th year at Belwind and judging from the size and the growth rings of the *C. gigas*, these individuals are likely to have settled already during the previous year. Taking account of these facts justifies the smoothening of the data base interpretation as done is this study.

Notwithstanding the need to smoothen the data, both late true intertidal colonisers (e.g. *C. gigas* and *H. sanguineus*) consistently arrived later at Belwind compared to C-Power. This may be explained by the longer distance the Belwind wind farm is away from the coastline, where the major source populations for these species occur. It hence is not surprising that the likelihood of their pelagic larvae to reach the offshore constructions is lower at Belwind.

EXPLORING THE RISK OF WIND FARMS TO CONTRIBUTE TO THE FURTHER SPREAD OF INTRODUCED AND POTENTIALLY INVASIVE SPECIES THROUGHOUT THE NORTH SEA.

All introduced species on offshore wind farms except one, de bryozoan *F. delicia* (De Blauwe et al. 2014), were already known from Belgian waters. For the subtidal zone, the offshore wind farms will only “marginally” contribute to the further spread of introduced species given the vast amount of both natural and artificial hard substrata already available in the North Sea. These already host established populations of the same introduced species.

The largest number of introduced species is found in harbours and on navigation buoys followed by coastal defence works where the number equals that of the wind turbines. On all these man-made structures both the intertidal and subtidal habitats are present. Indeed, the number of introduced species proved to be particularly high in the intertidal zone on the wind turbines. The higher number in coastal waters accords with observations elsewhere (Wolff, 1999; Wolff, 2005; Ruiz et al., 1997) and illustrates that these habitats are prone to new introductions. The lowest number is found on the wrecks and on the reef balls, lacking an intertidal zone and also on the subtidal natural gravel beds.

For the intertidal zone, the wind farms have the potential to substantially increase the risk of further species introductions and introduced species spread given that – besides offshore wind farms – offshore intertidal habitat still is relatively rare. Wind farms will hence drastically increase the available habitat to obligate intertidal introduced hard substrata species for which offshore habitat did not exist in the southern North Sea until recently. Offshore wind farms hence make outer coast environments more susceptible to invasion by those species that have invaded to date (McQuaid and Arenas, 2009).

In case intertidal introduced species become invasive within the offshore wind farm, this should not necessarily be considered a problem, given the artificial origin of these communities. The problem of invasiveness hence only poses when potentially invasive introduced species reach natural rocky shore communities (formerly not exposed to these species) with the help of offshore wind farms.

However, as all except for one introduced species detected on offshore wind farms were already found on coastal artificial hard substrata they may already profit from an increased connectivity as a consequence of the coastal hardening. These species may as such spread throughout the North Sea and “invade” natural rocky shore communities, irrespective of offshore wind farms. This hypothesis may however only hold true for subtidal species and intertidal species thriving in turbid coastal waters, which consequently can have source populations on the coastal hard substrata, and not for species in need of intertidal, clear water habitat. In the latter case, offshore wind farms would pose a threat to the further spread of these species, potentially providing stepping stones onto the natural clear water, intertidal rocky shore communities along i.e. the eastern Scottish and Norwegian coasts.

The arrival of new introduced species on the offshore wind turbines can be expected. The wind farms are susceptible to the arrival and subsequent establishments of new introduced species. In the area, many vessels operate that often have been working or still alternately work in the offshore industry elsewhere around the globe. They could carry with them as fouling or in ballast water many exotic organisms. Climate change could enhance the introduction process, because warm water species could, after their initial introduction now find climatic conditions more suitable. Therefore, continued monitoring is needed as is also requested in the frame work of the EU Marine Strategy Framework Directive.

ACKNOWLEDGEMENTS

The authors acknowledge C-Power and Belwind for the willing cooperation throughout the monitoring, in fulfilment of the monitoring requirements of their environmental permit. Ship Time RV Belgica was provided by BELSPO and coordinated by RBINS - OD Nature. Ship time RV Zeeleeuw and RV Simon Stevin was provided by the Flemish government and coordinated by VLIZ. The sampling could not have been completed without the help of the late Jean-Sebastien Houziaux, Alain Norro and Bob Rumes and (in alphabetical order) K. Deneudt, F. Francken, P. Hendriks, G. Jones, G. Lacroix, C. Mahieu, D. Marsham, L. Meirlaen, R. Olemans, F. Pasotti, R. Picavet, J. Pire, G. Rooms, A. Simon, H. Tourneur, M. Vanespen, I. Vosselman, A. Witkowski and V. Woit.

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