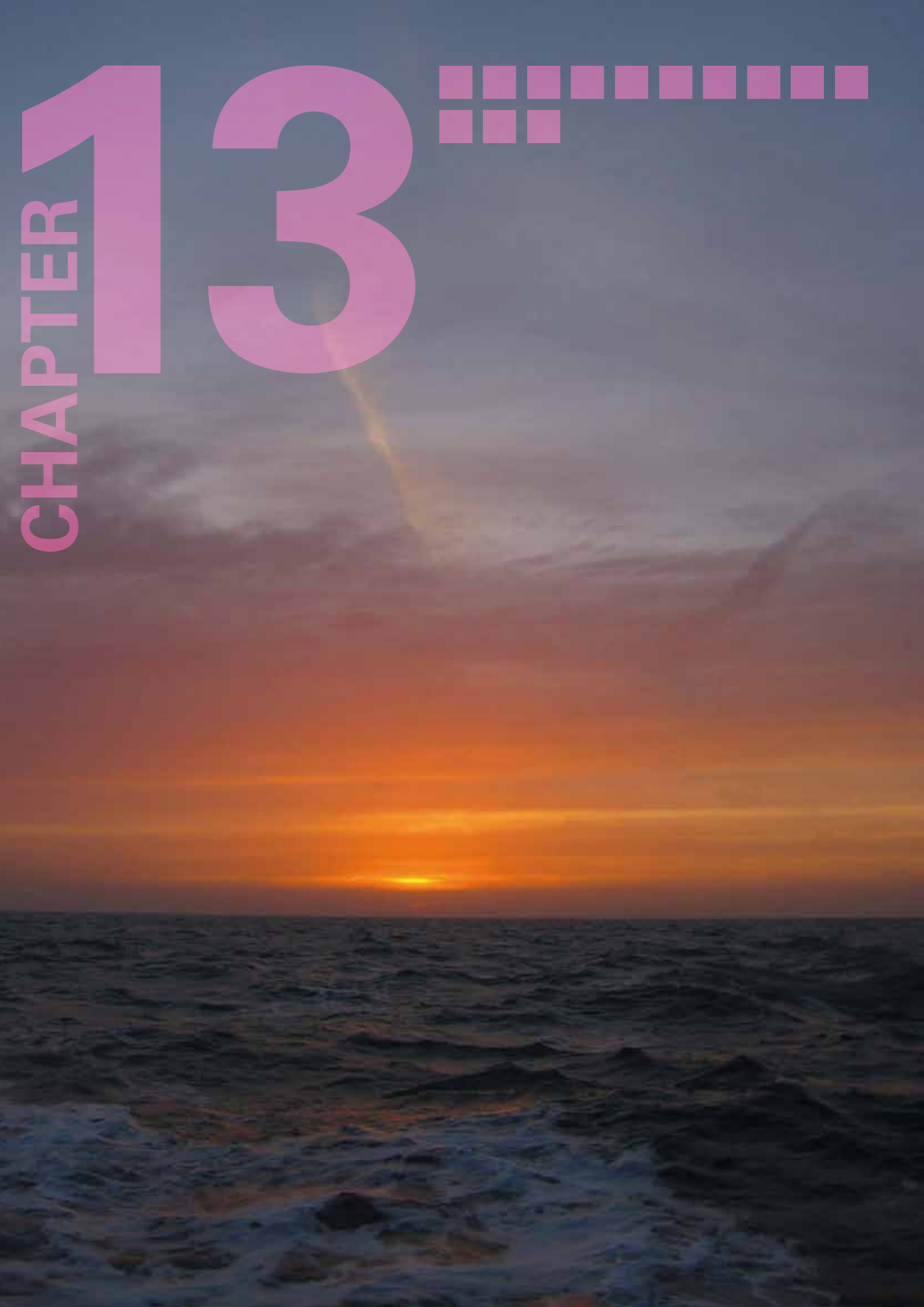


CHAPTER

1

3



# Macrobenthic enrichment around a gravity based foundation

Delphine Coates, Yana Deschutter, Magda Vincx and Jan Vanaverbeke

Epifaunal growth and changing hydrodynamics alter the soft-substrate and macrobenthic community around a foundation. The sediment and macrobenthos was sampled close to a foundation from 2010 to 2012. Observations were most notable on the Southwest side with changes recorded up to 50 meter distance. A decrease in sediment grain size and increase of organic matter content was observed, together with an enriched macrobenthic community with a dominance of hard substrate related species. However, average densities of two bristle worms increased in comparison to the baseline studies, resulting in a young and dynamic macrobenthic community evolving away from the original (*Nephtys cirrosa*) community.

## INTRODUCTION

The large scale monitoring programme revealed an effect on the soft sediment macrobenthic community straight after construction on the Thorntonbank in 2008, most likely due to the pre-construction dredging activities (Chapter 9). It was concluded that effects of the operational phase on the entire wind farm could only be measured over longer time frames or at a smaller scale. Previous studies around artificial foundations showed a change in the dominance structure of the macrobenthic community directly around foundations (1m distance), with an increase of predominantly mobile predators (Köller et al., 2006). An enhanced hard substrate community and changing local hydrodynamics around a foundation can also enrich the macrobenthic community in abundance and biomass (Maar et al., 2009). To detect local, short term effects after construction, a small scale study was initiated in 2010 following a close gradient of sampling around one gravity based foundation (GBF – D5

at the Thorntonbank). Only two years after construction (2010) it was obvious that the hard substrates were rapidly being colonised by epifaunal organisms (Kerckhof et al., 2012) together with an increase of pouting (*Trisopterus luscus*) and Atlantic cod (*Gadus morhua*) in the vicinity of the turbines (Reubens et al., 2010; Reubens et al., 2013a). This can cause an organic enrichment around the foundation, due to the depositional flow of faeces and other organic material onto the seabed (Coates et al., 2011; Köller et al., 2006). The enrichment of sediments around structures such as mussel farms has widely been reported before (McKindsey et al., 2011; Ysebaert et al., 2009). However, few surveys have been able to determine the effects of this process on macrobenthic communities around offshore wind farms (Zucco et al., 2006). Furthermore, the seabed around the foundation was thoroughly dredged and prepared before construction. Together with the installation of the foundation, its

surrounding scour protection system and possible changing hydrodynamics, this could lead to changing sedimentological characteristics, also altering the benthic community directly around the foundation (Brabant and Jacques, 2010; Hiscock et al., 2002).

The main objective of this study was to investigate the organic enrichment and sedimentological characteristics of the surrounding sediments around a GBF between 2010 and 2012 and its possible effects on the macrobenthic community. The results were applied to hypothesise an extrapolation of the eventual small scale effects of organic enrichment to a large scale impact after longer exposure periods.

## SAMPLING DESIGN

Sediment characteristics and the macrobenthic community were monitored in the vicinity of one GBF (D5) which was installed on the Thorntonbank in 2008 (Table 1). Over a period of three years (2010-2012) sediment samples were obtained around the foundation during spring along four gradients (Southwest, Northeast, Southeast and Northwest). Along every gradient, seven distances were sampled starting at one meter around the scour protection system (further named as foundation) to a maximum distance of 200 meters which was taken as a reference station (Figure 1). Samples on the Northeast gradient were limited to 1, 7, 100 and 200 meters due to the presence of high power cables on the seabed, preventing sampling at 15, 25 and 50 meters distance. The main tidal flow in this area runs along the Northeast and Southwest direction (Van den Eynde, 2005).

**Table 1.** Summary of the small scale monitoring phase carried out around one GBF from 2010-2012.

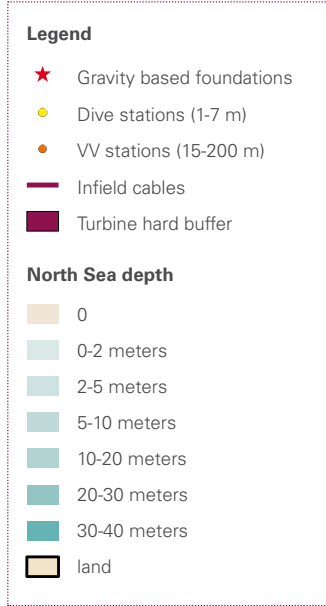
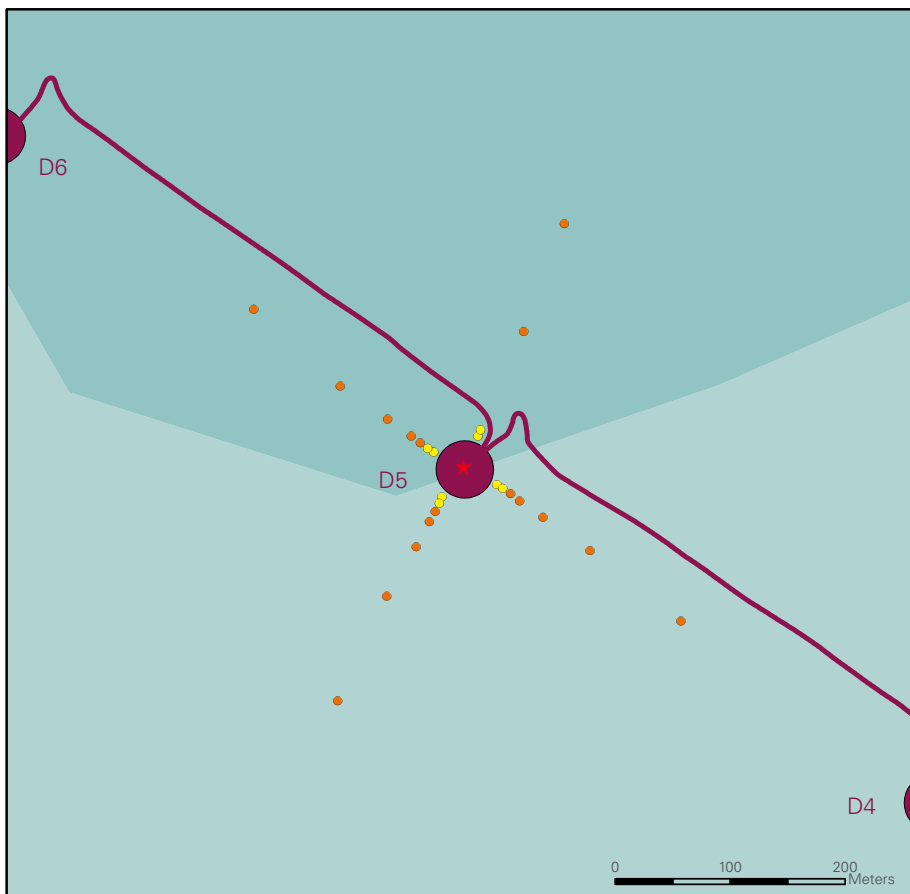
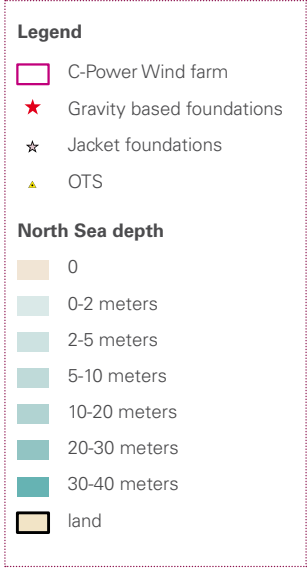
SMALL SCALE BENTHIC MONITORING D5 TURBINE THORNTONBANK				
2010	2011		2012	
Dive samples 4 gradients	1 Dive sample on Southwest	Van Veen samples	Dive samples on 4 gradients	Van Veen samples

Closest samples at one and seven meters were obtained by using an airlift suction device and benthic cores handled by SCUBA divers trained to a European scientific diving level. Samples taken at 15, 25, 50, 100 and 200 meters from the foundation were collected with a Van Veen grab from a small survey vessel (Box: Benthic sampling methods) with three replicates when possible. Due to the difference in sampling methods the samples were investigated separately. Logistical problems (weather conditions, construction works inside the wind farm, etc.), only allowed for a complete dive sampling in 2010 and 2012, and a complete Van Veen grab sampling in 2011-2012. Due to limited dive time, replication was very difficult to obtain, only providing two replicates on the Southwest

and Northeast gradients in 2012 at one and seven meters. Replication on the Southeast gradient between 15 and 200 meters was missing in 2012 due to bad weather conditions. Sediment characteristics of the seabed, such as grain size and organic matter content, were analysed for every sample. The number of individuals per species (abundance) and the biomass were standardised per square meter and averaged for every station. Together with diversity indices (such as species number per sample) this data provides information on the evolution of the macrobenthic community in sandy areas surrounding the gravity based foundation.

Sampling in an offshore wind farm





**Figure 1.** Top: Positioning of the small-scale monitoring within the Thorntonbank wind farm. Bottom: Benthic small scale sampling design around D5 gravity based foundation. Stations close to the turbine (yellow) were collected by divers, stations further away (orange) were sampled with a Van Veen grab.

## BOX: Benthic sampling methods

**Air-lift suction:** A plastic cylinder open on both sides is used to sample benthic organisms in the soft sediment close to hard structures such as wind farms and wrecks. On one side, the cylinder is attached to a diving tank to produce the desired amount of pressure; suction is made by the movement of air inside the cylinder. The sample is collected in a mesh bag (0.5 mm) connected to the other side of the cylinder. A fixed amount of sediment can then be sampled using a metal frame (0.1026 m<sup>2</sup>) as a reference ([www.mumm.ac.be](http://www.mumm.ac.be)).



**Benthic cores:** A frame with perspex cores with a diameter of 36 mm is taken down to the seabed by divers to sample vertical profiles of the sediment. These cores are sliced and dried in preparation for analysis of the grain size and organic matter content.



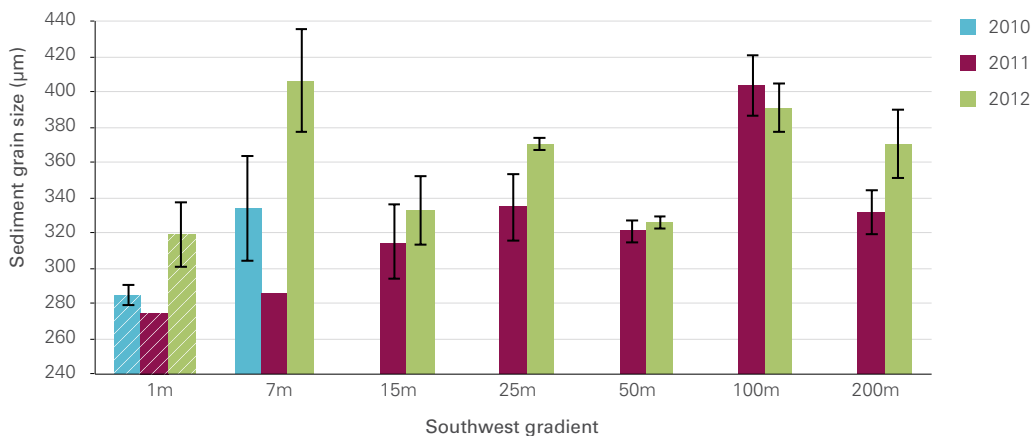
**Van Veen grab:** A grab sampler is the most common used device to sample benthic organisms in sandy sediments. When the device reaches the seafloor and the cable slackens, the grab digs into the seabed and closes. Grab samplers vary in size with 0.1026 m<sup>2</sup> as the most commonly used. For this research a smaller grab of 0.0247 m<sup>2</sup> was used due to the limitations imposed by the small research vessel. Through a lid on top of the grab, a sub sample for sediment analysis can be taken with a Perspex core.



## THE ENVIRONMENTAL CHARACTERISTICS OF THE SEABED AROUND THE GBF

Across the Belgian part of the North Sea a wide variety of sediment types occur ranging from fine mud to coarse sands. The main sediment type recorded on sandbanks situated within the Belgian wind farm zone is coarse sands with an average grain size ranging from 250  $\mu\text{m}$  to 500  $\mu\text{m}$  (De Maerschalck et al., 2006; Reubens et al., 2009).

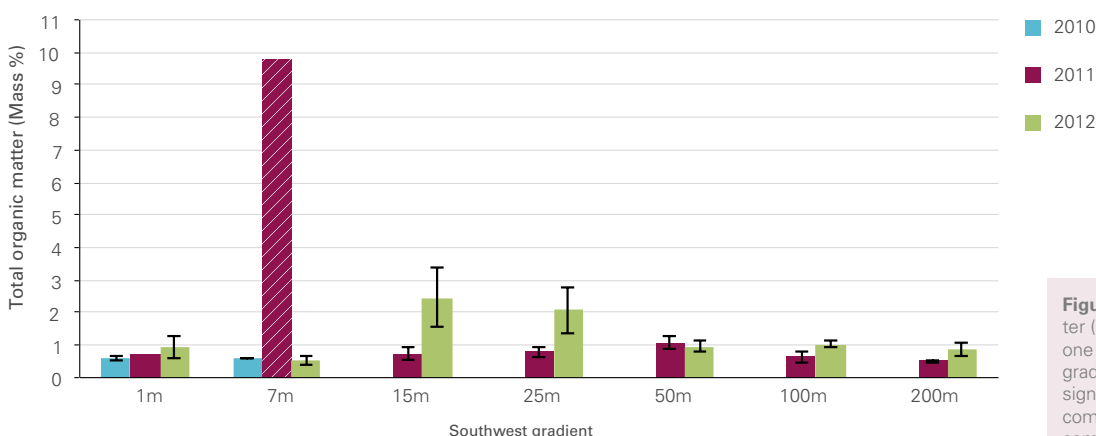
Near the D5 foundation, the average median grain size ranged between 275  $\mu\text{m}$  and  $430 \pm 87 \mu\text{m}$ . An inter-annual variability was measured on all gradients except for the Northwest. Figure 2 (showing the values for the Southwest gradient), describes the main trend distinguished on all gradients (except the Southeast) with significantly lower grain sizes at 1 m from the foundation in comparison to the furthest station at 200 m.



**Figure 2.** Average median grain size ( $\mu\text{m}$ )  $\pm$  standard error from 1 m to 200 m on the Southwest gradient. Striped bar indicates significantly lower values ( $p < 0.05$ ) compared to 200 m by pairwise comparisons (PERMANOVA).

During the construction phase in 2008, the seabed was levelled out by dredging and replaced by a foundation layer containing crushed gravel. After construction, a scour protection system (Figure 1) consisting of a filter layer with a crest diameter of 55.5 m at D5 and an upper armour layer with a crest diameter of 51 meters was installed (Brabant and Jacques, 2010; Peire et al., 2009). At first, this process will have affected the sedimentological characteristics of the seabed around the foundation but due to a strong inter-annual variability between 2010 and 2012, changing hydrodynamics will have most likely dominated the refinement process with declining current speeds along the Southwest and Northeast gradients.

The average total organic matter (mass %) ranged from 0.27% at 1 m distance (2010, Northwest) to 2.46% at 15 m distance (2012, Southwest) from the GBF. One peak value of 9.79% at 7 m distance from the GBF was recorded in 2011 on the Southwest gradient (Figure 3). Apart from that, no clear trends or significantly different organic matter contents were measured. However, in comparison to the large scale monitoring (Chapter 9) where a maximum average of 1.15% was recorded, the average total organic matter around the GBF shows a trend to higher values. These results suggest that the organic material of species growing on the hard substrate (foundation and the scour protection) are contributing to the changing sedimentological conditions of the seabed.



**Figure 3.** Average total organic matter (Mass %)  $\pm$  standard error from one to 200 m on the Southwest gradient. Striped bar indicates significantly lower values ( $p < 0.05$ ) compared to 200 m by pairwise comparisons (PERMANOVA).

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## A CLOSE UP ON THE SPECIES COMPOSITION DIRECTLY AROUND THE FOUNDATION

Near the scour protection system at 1 and 7 m, the highest average macrofaunal density, biomass and number of species were measured on the Southwest gradient in 2010 (Figure 4). In 2012 however, a maximum average biomass was only measured on the Southwest gradient. Higher densities and number of species were observed along the Southeast gradient.

In 2010, the maximum average number of species per sample was 32 both for the Northwest and Southwest gradients at 1 and 7 m respectively (Figure 4, top). The average minimum was recorded on the Southeast gradient at 7 m with 18 species per sample. Slightly lower species richness was measured in 2012 ranging from 31 species at 1 m on the Southeast to 15 species at 7 m on the Northeast gradient.

An average maximum density of 9162 ind/m<sup>2</sup> was measured at 1 m and 11501 ind/m<sup>2</sup> at 7 m away from the GBF on the Southwest gradient in 2010. Lower densities were found in 2012 ranging between 3899 ind/m<sup>2</sup> at 1 m on the Southeast gradient to 361 ind/m<sup>2</sup> at 7 m distance from the GBF on the Northeast gradient (Figure 4, bottom).

Macrofaunal biomass followed a similar trend to the densities with a maximum on the Southwest gradient in 2010 and 2012. The biomass ranged from 9537 mg.m<sup>-2</sup> at 1 m (Southwest gradient) to 498 mg.m<sup>-2</sup> at 7 m distance (Southeast) in 2010. In contrast to the densities, the biomass in 2012 was comparable to 2010 ranging from 5864 mg.m<sup>-2</sup> at 1 m (Southwest gradient) to 109 mg.m<sup>-2</sup> at 7 m (Northeast).

**Figure 4.** Top: Average total number of macrobenthic species per sample ± standard error and Bottom: Average total macrobenthic abundance (ind/m<sup>2</sup>) ± standard error, at 1 and 7 m along the four gradients for 2010-2012. Striped bar indicates significantly higher values (p<0.05) between 2010 and 2012 within gradients by pairwise comparisons (PERMANOVA).

Gradient	Year	1 m	7 m
SW	2010	28	32
	2012	24	16
NE	2010	20	29
	2012	20	15
SE	2010	27	18
	2012	31	18
NW	2010	32	29
	2012	27	20

Gradient	Year	1 m	7 m
SW	2010	9162	11501
	2012	1500	500
NE	2010	2000	8500
	2012	1000	500
SE	2010	4800	1000
	2012	3800	2200
NW	2010	3200	3200
	2012	1000	500

The high average macrofaunal abundance on the Southwest gradient in 2010 was mainly related to the occurrence of juvenile starfish (maximum of 4961 ind/m<sup>2</sup> at 7 m). Juvenile echinoderms showed dominance in 2010 on the Northeast and Northwest gradients with a maximum abundance of 2943 ind/m<sup>2</sup> at 7 m on the Northeast gradient (Figure 5).

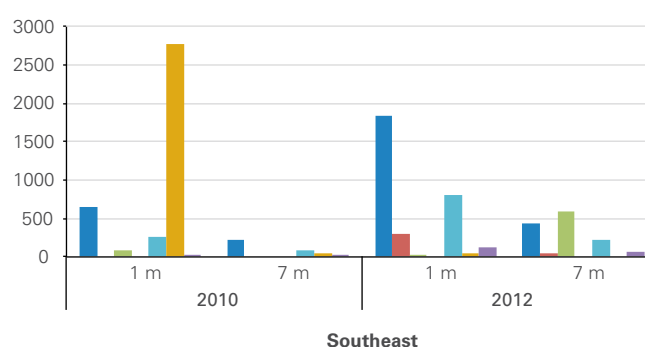
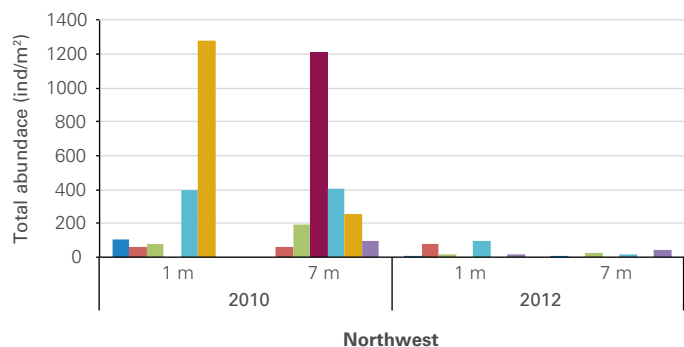
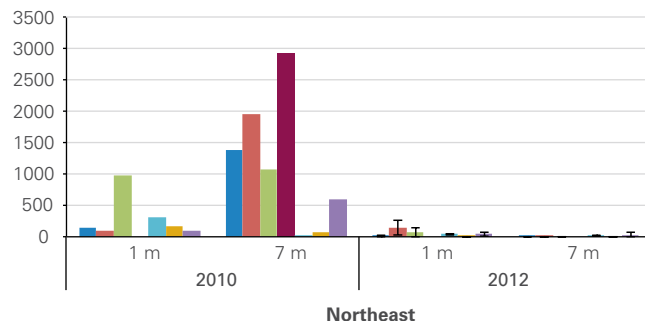
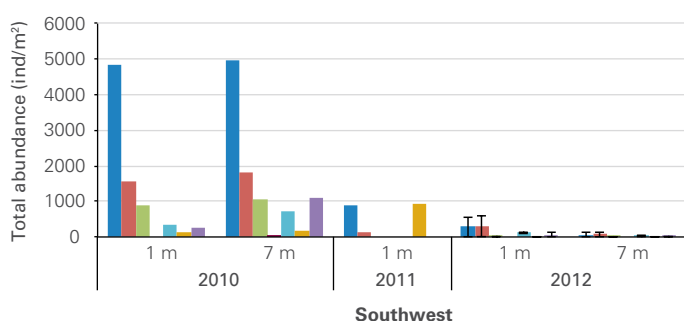
A similar assemblage of dominant species was recorded on the Southwest and Northeast gradients, with high densities for the juvenile starfish (*Asterias rubens*) and two polychaete worms (the sand mason *Lanice conchilega* and the bee spionid *Spiophanes bombyx*). A maximum density of 1949 ind/m<sup>2</sup> for *L. conchilega* and 1082 ind/m<sup>2</sup> for *S. bombyx* were both measured at 7 m on the Northeast in 2010 (Figure 6).

A typical tube dwelling, hard substrate amphipod, *Monocorophium acherusicum*, had higher densities on the Northwest and Southeast gradients with a peak density at

1 m on the Southeast gradient (2778 ind/m<sup>2</sup>). A second tube dwelling amphipod, *Jassa herdmani*, illustrated a relatively stable distribution across the four gradients with average maxima in 2012 of 809 ind/m<sup>2</sup> at 1 m on the Southeast gradient and in 2010, 730 ind/m<sup>2</sup> at 7 m on the Southwest. As *M. acherusicum* and *J. herdmani* are one of the most abundant hard substrate species recorded within the wind farms (Kerckhof et al., 2012) it is not surprising that these mobile amphipods easily find their way to the soft substrate community.

- Asteriidae juv.
- *Lanice conchilega*
- *Spiophanes bombyx*
- Echinoidea juv.
- *Jassa herdmani*
- *Monocorophium acherusicum*
- *Ophiura* juv.

**Figure 5.** Total average abundance (ind/m<sup>2</sup>) ± standard error of the seven most dominant species at 1 m and 7 m from 2010-2012 along the four gradients (Southwest, Northeast, Northwest and Southeast).



**Figure 6.** Dominant species around the GBF on the Thorntonbank

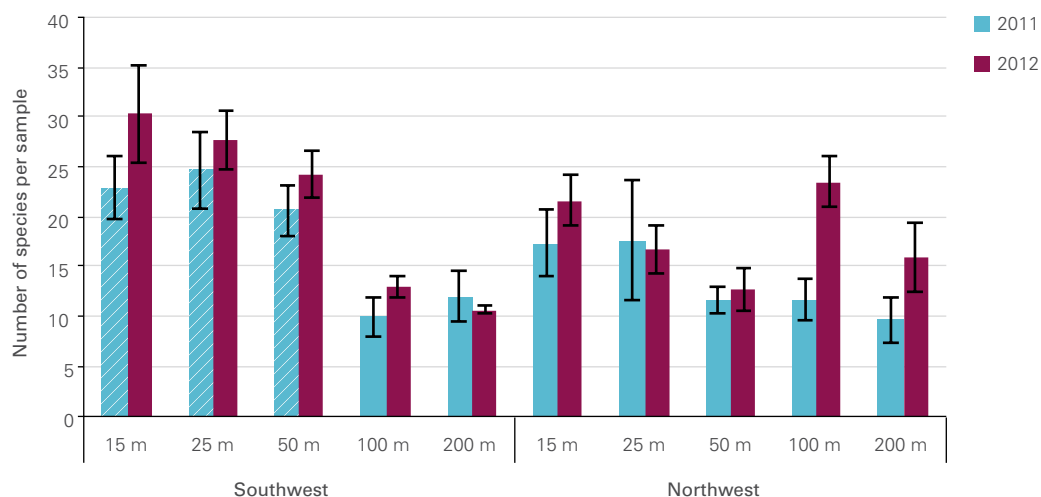
- Left above: Sand mason, *Lanice conchilega*
- Right above: Bee Spionid, *Spiophanes bombyx*
- Left under: *Monocorophium acherusicum*
- Right under: *Jassa herdmani*



## AN EVER SPATIALLY EXPANDING BENTHIC ENRICHMENT?

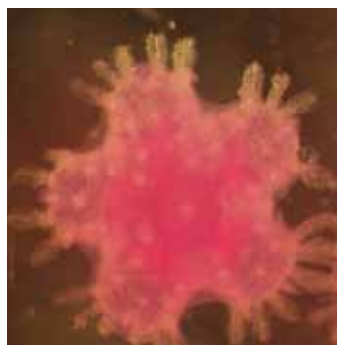
From 15 to 50 m distance around the foundation, the average number of macrofaunal species per sample was significantly higher on the Southwest gradient in comparison to 200 m distance. In 2011, a maximum average of 25 species per sample was found at 25 m on the Southwest gradient and 18 species per sample at 25 m on the Northwest. A higher average of species richness was found in 2012 with a maximum average of 30 species per sample at 15 m on the Southwest gradient and 23 species per sample at 100 m on the Northwest (Figure 7).

The total number of species around the foundation was much higher in comparison to the baseline study carried out in 2005 (see chapter 9), where the maximum amount of species per sample did not exceed 15 (De Maerschalck et al., 2006). Biomass followed the same trend on the Southwest gradient with a maximum of 13461 mg.m<sup>-2</sup> at 25 m in 2011 and 12009 mg.m<sup>-2</sup> at 15 m in 2012.

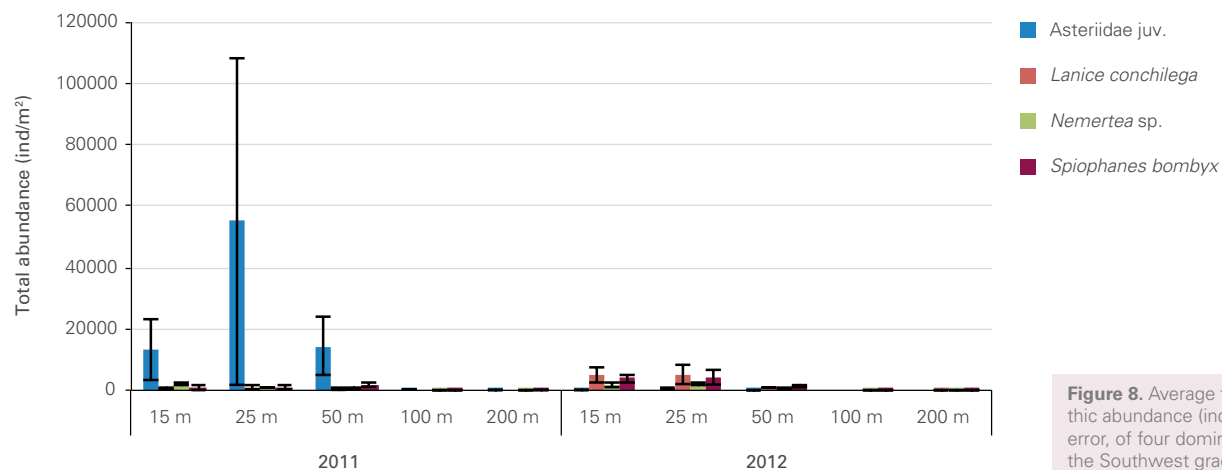


**Figure 7.** Average total number of macrobenthic species per sample ± standard error, from 15 to 200 m along the four gradients in 2011 and 2012. Striped bar indicates significantly higher values ( $p < 0.05$ ) compared to 200 m within gradients by pairwise comparisons (PER-MANOVA).

An extremely high average density (62227 ind/m<sup>2</sup>) was recorded in 2011 on the Southwest gradient at a 25 m distance from the foundation. Following the observations in 2010 at 1 and 7 m, these high densities along the Southwest gradient were caused by the occurrence of countless number of juvenile starfish (Figure 8). The spawning time and recruitment intensity of the starfish *A. rubens* has a large inter-annual variation depending on many environmental factors such as temperature and food availability (Guillou et al., 2012). Their absence during 2012 in the samples from 15 to 200 m could therefore be caused by a lower recruitment, as juvenile starfish still remained detected at 1 m on the Southeast gradient (Figure 5).



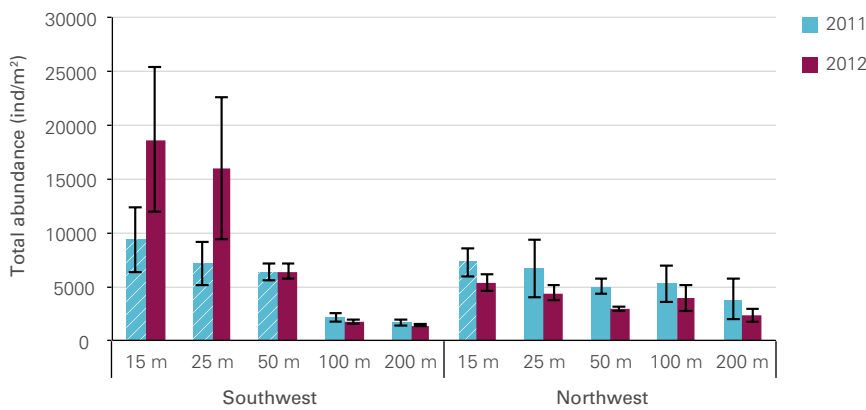
Juvenile phase of *Asterias rubens* (Asteriidae juv.)



**Figure 8.** Average total macrobenthic abundance (ind/m<sup>2</sup>) ± Standard error, of four dominant species on the Southwest gradient from 15 to 200 meters in 2011 and 2012.

Disregarding the juvenile starfish, the maximum and minimum macrobenthic densities for both years were situated on the Southwest gradient at approximately 15 and 200 m distance. A significant decrease in average density with increasing

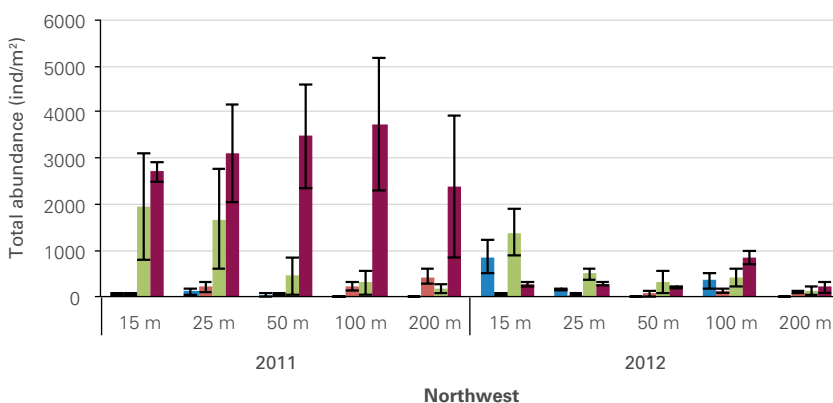
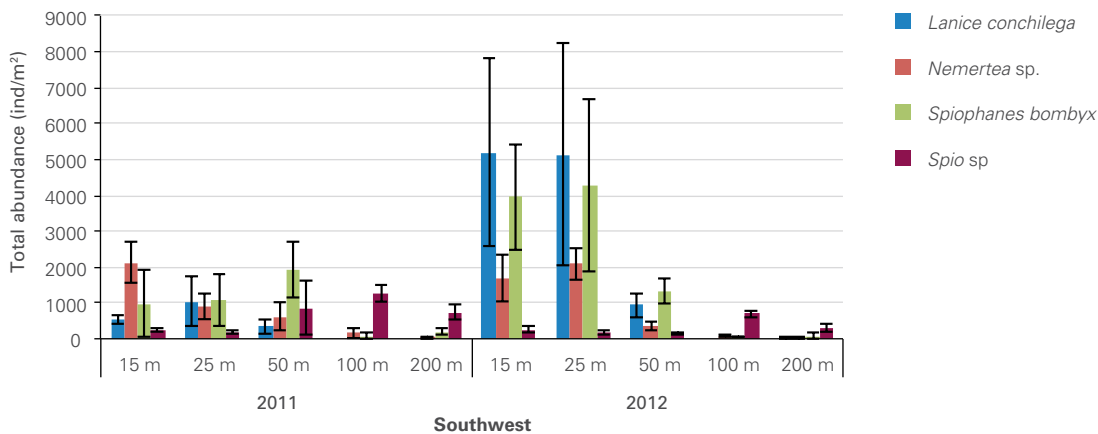
distance from the foundation was found on the Southwest but also the Northwest gradient. Average densities ranged from 9339 ind/m<sup>2</sup> to 1673 ind/m<sup>2</sup> in 2011 and from 18583 ind/m<sup>2</sup> to 1390 ind/m<sup>2</sup> in 2012. (Figure 9).



**Figure 9.** Average total macrobenthic abundance (ind/m<sup>2</sup>) ± standard error, from 15 to 200 m along the four gradients in 2011 and 2012. Striped bar indicates significantly higher values ( $p < 0.05$ ) compared to 200 m within gradients by pairwise comparisons (PERMANOVA).

The higher densities measured in 2012 on the Southwest gradient at 15 and 25 m could be due to a decline in juvenile starfish recruitment, providing the opportunity for other macrobenthic species to increase in density. Following the observations at 1 and 7 m in 2010, two bristle worms (*L. conchilega* and *S. bombyx*) showed an increase in average density close to the foundation in 2012. The maximum average density of *L. conchilega* was 5182 ind/m<sup>2</sup> at 15 m and 4291 ind/m<sup>2</sup> at 25 m for *S. bombyx* compared to 1025 ind/m<sup>2</sup> and 1066 ind/m<sup>2</sup> both at 25 m in 2011 (Figure 10, upper panel). A third dominant species belonging to the Nemertean group showed a maximum average density of 1700 ind/m<sup>2</sup> at 25 m in 2012.

On the Northwest gradient, a low recruitment of juvenile starfish was present in 2011 allowing other macrobenthic species to occupy the area. In both years however, the polychaete worm *S. bombyx* showed a clear decrease in density with increasing distance from the foundation. Maximum densities were measured at 15m with 1929 ind/m<sup>2</sup> in 2011 and 1377 ind/m<sup>2</sup> in 2012. Furthermore, the entire Northwest gradient was dominated by the bristle worm *Spio* sp. in 2011 with a maximum of 3725 ind/m<sup>2</sup> at 100 m. This pattern was not detected in 2012 (Figure 10, lower panel).



**Figure 10.** Average total macrobenthic abundance (ind/m<sup>2</sup>) ± standard error of the four most dominant species along the Southwest (upper panel) and Northwest (lower panel) gradients from 15 to 200 meters in 2011 and 2012.

Why would the recruitment of macrobenthic species mainly increase on the Southwest gradient? With a base diameter of 23.5 meters and a crest diameter of 55.5 meters for the filter layer of the scour protection system (Brabant and Jacques, 2010), the tidal current flow along the Southwest and Northeast gradients will decrease considerably. In the wake of the gravity based foundation, larval settlement will increase, enhancing the recruitment of macrobenthic species such as the tube forming bristle worms *L. conchilega* and *S. bombyx* but also hard substrate species such as the common starfish *A. rubens*. Enhancing this process, sand pits are present on the Southwest gradient due to dredging works in preparation of construction (Van den Eynde et al., 2010), most likely decreasing the current velocities and trapping larvae. The changes observed also correlate with the environmental variables as a finer grain size was measured on the Southwest

gradient, closer to the foundation (Van Hoey et al., 2004). As samples between 15 and 50 m were missing on the Northeast gradient, a clear evolution cannot be assessed for this gradient. However, samples taken at 1 and 7 m did also suggest an importance of the gradient with an increase in the abundance of the previously mentioned species.

The changing community detected in samples at 1 and 7 m from the foundation in 2010, has already extended up to a 50 m distance on two gradients. However, from 15 m onwards a lower influence of mobile hard substrate species such as the amphipods *M. acherusicum* and *J. herdmani* is measured.

*Asterias rubens* attached to a hard substrate

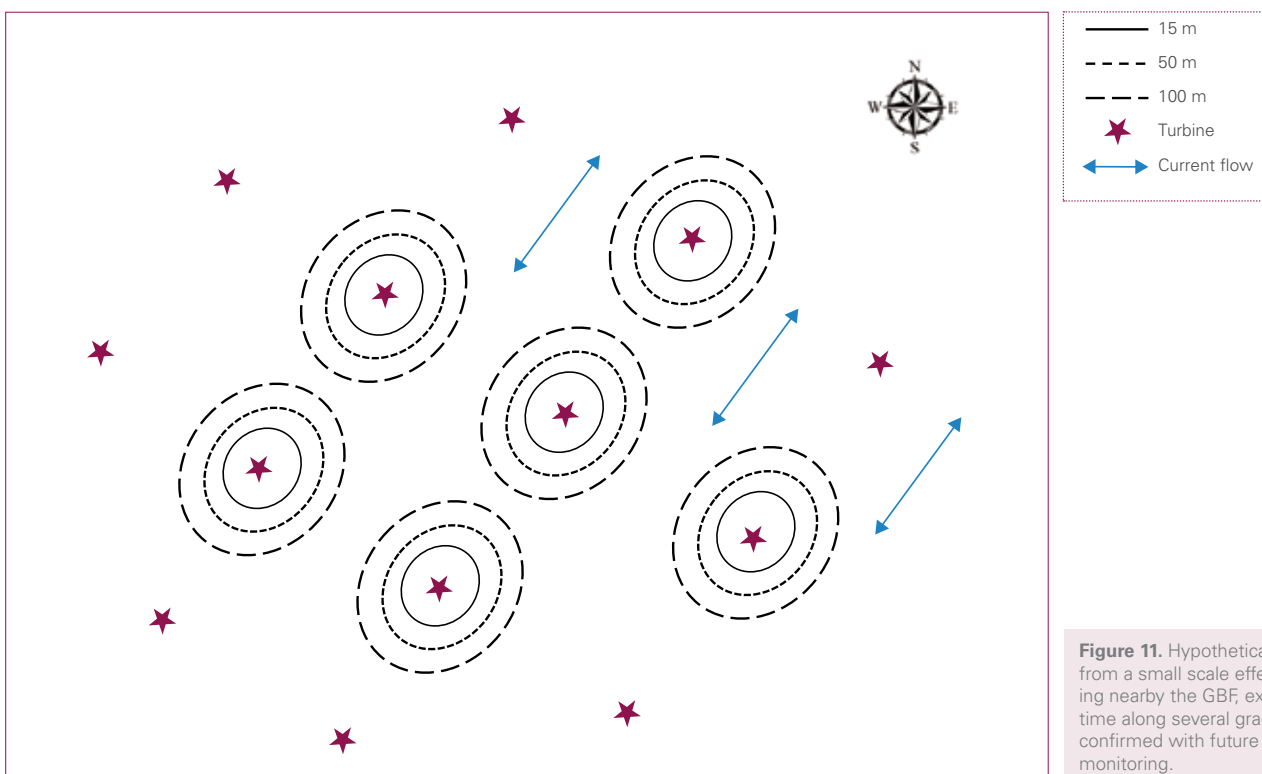


## CONCLUSIONS

After three years of small-scale monitoring, a substantial change has been recorded in the soft sediment surrounding the D5 gravity based foundation on the Thorntonbank. The macrobenthic community has evolved away from the original (*Nephtys cirrosa*) community (Coates et al., 2011; Coates et al., 2012; De Maerschalck et al., 2006). At 1 and 7 m from the foundation, high densities were measured for the juvenile phase of the common starfish (*Asterias rubens*) and two hard substrate amphipods (*Monocorophium acherusicum* and *Jassa herdmani*), highlighting the direct effect of the presence of the wind turbine. Alongside these hard substrate species, two polychaete worms (*Lanice conchilega* and *Spiophanes bombyx*), common to the soft substrate, dominated the community but in much higher abundances than would be expected. The strong annual variability of the macrofaunal densities between gradients and years suggests an unstable young community which has not reached equilibrium thus far. Until now, the effects have been detected up to a 50 m distance from the foundation on the Southwest and Northwest gradients. Changes in sedimentological characteristics, current flows and organic enrichment due to sinking detritus and faeces are most likely the main drivers in enhancing the recruitment of

certain macrobenthic species and changing the community. Our results show a strong similarity to a study carried out around a Danish offshore wind turbine where the biomass and abundance of fauna also enriched along one gradient due to the depositional flow of the Blue mussel (*Mytilus edulis*) which encompassed 97-99% of the hard substrate epifauna (Maar et al., 2009). The Blue mussel only dominates in the infralittoral zone of the GBF (see Chapter 12) but with a rich subtidal community (Kerckhof et al., 2009; Kerckhof et al., 2012) a similar flux of organic matter can be expected on the surrounding seabed.

This research focused on one of six gravity based foundations constructed on the Thorntonbank. Since 2013, this wind farm expanded with an additional 48 turbines (jacket foundations). Together with six other companies constructing or developing in this area, these results suggest a viable prediction of effects to the marine seabed at a larger scale for the future. Up scaling these results to the whole wind farm zone, with an expansion of macrofaunal densities further than 50 m around every turbine and initially in the direction of the currents, could lead to an overall change in the macrobenthic community throughout the whole wind farm zone (Figure 11).



**Figure 11.** Hypothetical up scaling from a small scale effect, originating nearby the GBF, expanding with time along several gradients. To be confirmed with future small-scale monitoring.

## FUTURE MONITORING

The small-scale, short term monitoring has proven to be essential in monitoring the effects of offshore wind farms on the soft sediment macrobenthic communities. During the coming years, gradients showing main changes in sedimentological characteristics and macrofaunal communities should be closely followed up. Furthermore, two other foundation types (monopiles and jacket foundations) have been installed in nearby areas within the Belgian offshore wind farm zone, possibly affecting the soft substrate and its macrobenthic

organisms in a different way. It is advisable to carry out a pilot study around these foundations to determine whether similar changes are occurring influencing the large scale impact considerably.