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Prinses Amalia Windturbine park 2022

Statistical comparison of benthic fauna inside and outside the Prinses Amalia Wind Park fifteen years after construction; first analysis.

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1 Summary

The aim of this report is to assess potential differences in soft sediment epifaunal communities between the Prinses Amalia Windpark and reference locations, 15 years after construction in the commissioning phase.
Comparisons were made between locations inside the windpark and reference locations outside the windpark. At each location the number of species, density and diversity indices were measured and calculated. The data was statistically analysed using univariate methods, and differences in community composition were analysed with a multivariate method. In addition to statistical methods, the T15 (2022) data was used for a general comparison with data from previous years, where the survey was done using a different benthic dredge. Data from 2003 (T0), 2012 (T5), 2013 (T7) and 2017 (T10) is used to show the development of soft bottom fauna.

From this first data-exploration of the benthic dredge data of the Princes Amalia Windpark 2022, the conclusion can be drawn that there are no significant differences between the locations inside and outside the windpark, both in univariate key figures (i.e. abundance and diversity indices), and in community composition.

Differences in the sampling method in 2022 when compared to previous sampling campaigns unfortunately do not allow for a fully quantitative assessment over time. The different type of dredge used resulted in changes to the sample volume and effective track length, however the new dredge has resulted in a more accurate picture of the benthic environment in this part of the North Sea. A qualitive assessment does not reveal any clear differences over time between samples taken inside and outside the windpark.
The windpark has now been operational for fifteen years, which has given the marine environment inside the park enough time to develop in another direction than the marine environment outside the park. As a result, we do not forsee any significant changes in community composition to occur in the coming years where time is the only variable. Our data does not show evidence that the exclusion of fisheries has had a positive effect on the measured metrices within the windpark, nor is there evidence that reef forming species have become more prevalent on the soft sediment in the sample area.

Het doel van dit rapport is om mogelijke verschillen in epifaunale gemeenschappen op zacht sediment tussen het Prinses Amalia Windpark en referentielocaties te beoordelen, 15 jaar na aanleg in de inbedrijfstellingsfase.
Er zijn vergelijkingen gemaakt tussen locaties binnen het windpark en referentielocaties buiten het windpark. Op elke locatie zijn het aantal soorten, de dichtheid en enkele diversiteitsindeces gemeten en berekend. De gegevens werden statistisch geanalyseerd met behulp van univariate methoden. Verschillen in gemeenschapssamenstelling werden geanalyseerd met een multivariate methode. Bovendien zijn de T15 (2022) data gebruikt voor een algemene vergelijking met data van voorgaande jaren waarin onderzoek is gedaan met een bodemschaaf. Gegevens uit 2003 (T0), 2012 (T5), 2013 (T7) en 2017 (T10) zijn gebruikt om de ontwikkeling van zachtbodembenthos in beeld te brengen.

Uit deze eerste data-exploratie van de benthische schaafdata van het Princes Amalia Windpark uit 2022 kan de conclusie worden getrokken dat er geen significante verschillen zijn tussen de locaties binnen en buiten het windpark, zowel in univariate kengetallen (d.w.z. abundantie- en diversiteitsindices)) en in gemeenschapssamenstelling.

Door de verschillen tussen de campagne van 2022 en eerdere campagnes in het type schaaf dat gebruikt is, en de hieruit voortvloeiende verschillen in de mogelijkheid om het monstervolume en de effectieve spoorlengte te kwantificeren, is een kwantitatieve vergelijking in de tijd onmogelijk. Ook zijn deze problemen in kwantitatieve vergelijking tussen jaren niet te mitigeren of op te lossen.
Een kwalitatieve vergelijking tussen jaren is wel mogelijk en laat geen duidelijke trend zien in ontwikkelingsverschillen tussen binnen en buiten het park.

Gezien de tijd sinds de aanleg van het park verwachten we de komende jaren geen noemenswaardige divergente ontwikkeling meer. Er is geen bewijs dat het uitsluiten van visserij een positief effect heeft op locaties in het park, noch is het evident dat rifvormend benthos vaker voorkomt in het zachte sediment van het park.

2 Introduction

2.1 Aims

In previous years, monitoring and research into the effects of offshore windparks was carried out before and during the construction and during the commissioning, withach windpark undertaking it's own monitoring program. With the construction of new and larger offshore windparks, it is becoming increasingly important to investigate the cumulative effects on the ecology ofthe surrounding seafloor. In 2016 a research programme was implemented, in which the Ministry of Economic Affairs commissioned Rijkswaterstaat to develop and execute a monitoring and research program for the period 2016 – 2023. This programme is titled the Wind at Sea Ecological Program (WOZEP), Noordzeeloket.

One component of the program is research into the impact of windparks on the benthic community. Effects of windparks on benthos is mainly through two mechanisms: 1) the exclosure of bottom fishing activities from windparks and 2) the introduction of hard substrate from the turbines itself and its scour protection (Jak & Glorius, 2017).
The benthos comprises those organisms living in, on and around the bottom of the sea (or fresh water), and is an important factor in the functioning of the whole marine ecosystem. Benthic organisms are a key trophic group in the marine food chain, feeding upon detritus, algea and bacteria, and are in turn eaten by larger organisms like fish, birds and other predatory species.
In the current research only soft bottom research is carried out; turbines and scour protection were not investigated. Hence, closing the Prinses Amalia Windpark (PAWP) to fisheries in 2007 gives us a chance to investigate and compare the benthic soft bottom community inside and outside the windpark. It is thought that especially long-lived benthic species are negatively impacted in areas where fishing is done with bottom disturbing beam trawls.

The goal of this report is to assess potential differences in soft bottom epifaunal communities between the Prinses Amalia Windpark and reference locations, 15 years after construction.
Comparisons were made between locations inside the windpark and reference locations outside the windpark. On each location the number of species, density and several diversity indices were measured and calculated, and the data was statistically analysed using univariate methods. Differences in community composition were analysed with a multivariate method. In addition, the T15 (2022) data was used for a general comparison with data from previous years in which research was done using a benthic dredge. Data from 2003 (T0), 2012 (T5), 2013 (T7) and 2017 (T10), Was included in order to asses the development of soft bottom benthic fauna

2.2 Reading guide

In this report a short analysis is carried out based on biodiversity indices to show 1) statistical differences of soft bottom benthos within and outside the Prinses Amalia Windpark and 2) differences with previous surveys in PAWP following the MWTL protocol (PvE Deel C). This is called "First analysis" ("Eerste analyse"; Bijlage A: Vraagspecificatie Zachtsubstraatbenthos bemonstering PAWP 2022). After the assessment of this underlying First analysis report, a Go/ No Go descision will take place for a more extensive analysis.
When a difference in 2022 within and outside the windpark is indeed present (1), a full data analysis will be required the "Extensive report" ("Uitgebreide rapportage"). In the Extensive report, an analysis according to Leewis et al., 2018 will be executed. Here also the BISI index will be incorporated in the analyses, and sediment properties and fishing intensity should be used as explanatory factors for found differences. Also, and only then, the sediment samples taken in 2022 should be analysed in the lab for sediment properties.
When no difference is found in 2022, the underlying First analysis report is sufficient and the Extensive analysis will not be executed.

3 Methods

3.1 Locations and sampling

The field campaign was carried out with the ship 'MS Arca' of de Rijksrederij. The survey was planned between the 21st and the 25th of March 2022, of which only 22nd to 24th of March could be used for sampling due to bad weather. Fieldwork was carried out by Eurofins AquaSense and NIOZ (Schellekens & van Son, 2022), where Eurofins AquaSense was responsible for the sorting and analyses of the samples and NIOZ for the functioning of the dredge.

39 locations were planned for sampling (figure 2-1). Reference locations were on the same coordinates as the survey in 2017, but sampling locations within the windpark were on different coordinates from 2017. This change in planning was due to the long approaching distance of the dredge for sampling a transect and the need to avoid cables and windturbines.

One of the assumptions after data analyses of previous campaign was that the area was too ecologically diverse to define differences between the windpark and reference area. To zoom in into more specific circumstances, the client in 2017 defined several different 'habitats' present in both reference area and in the windpark based on bathymetry. In 2017 each habitat was sampled in at least three locations in both reference area and windpark to make a statistiscal comparison possible. In 2022 the positioning of the new sampling locations in the windpark followed this same plan; sampling each habitat at least three times in the windpark. This planning resulted in the planned sampling locations with accompanying habitat description stated in the Appendix 7.1.

Due to bad weather in the only available sampling week, only 28 of the 39 samples could be taken. Consequently, the overall sampling effort for the monitoring survey in 2022 iss as follows (figure 3-1):

- Windpark: 9 dredge samples
- Reference locations: 19 dredge samples

As a result of the limited sampling ability caused by the weather, not all habitats within the windpark were sampled. A comparison is therefore only possible between three of the habitats. Monocore samples were also taken for sediment analysis, which will only be fully assessed once a Go/No Go decision has been made following the results contained herein.

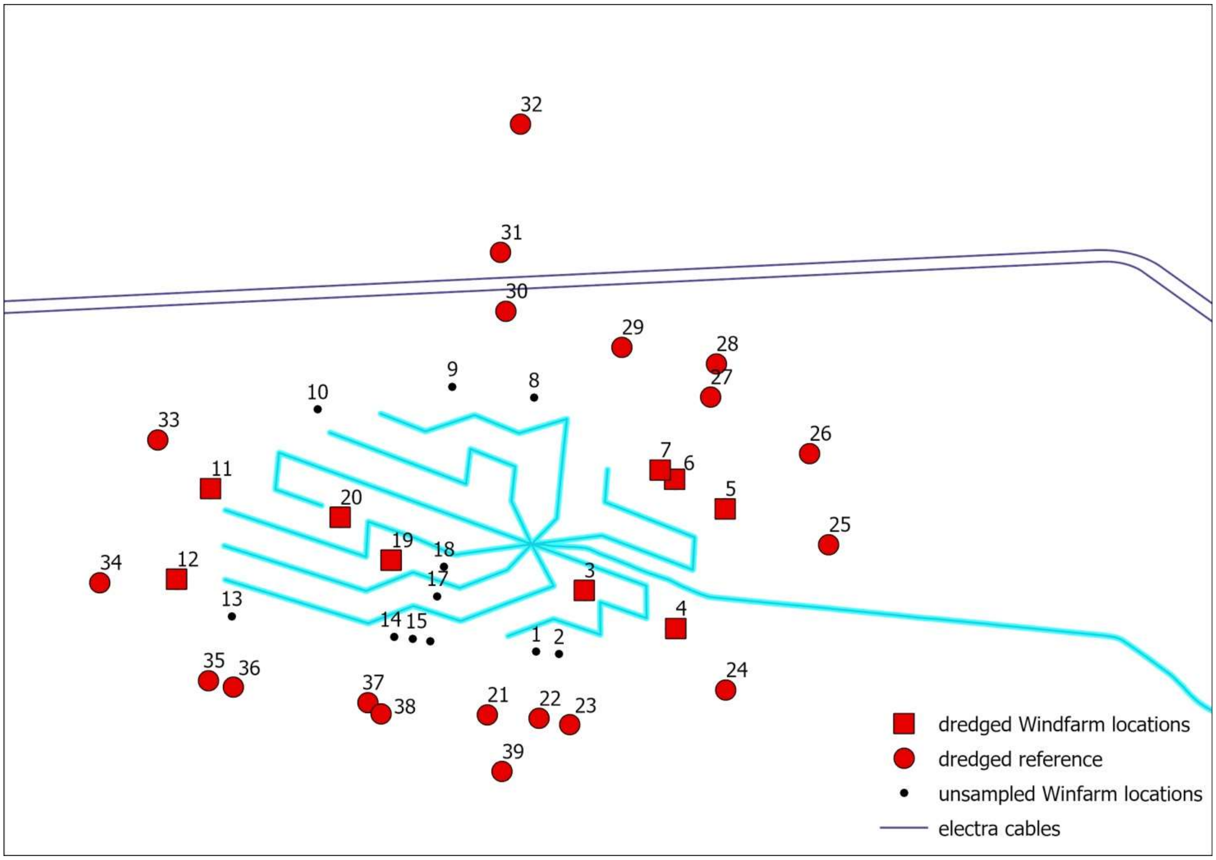

Figure 3-1. All survey sites in the PAWP area in the North Sea. Squares are survey stations within the windpark, circles are stations the reference stations outside of the windpark.

Sampling was undertaken according to the Rijkswaterstaat protocol " Voorschrift- RWSV, Code: 913.00.B080, Bemonstering en analyse van macrozoobenthos met behulp van de bodemschaaf".

In 2022, the "Triple-D" dredge was used to take the samples. This is a different dredge from the previous surveys (figure 3-2). The Triple-D dredge was chosen because other programmes and projects also make use of this type of dredge (MWTL N2000, "Zand uit Zee", Forage Fish), which therefore facilitates comparison of data between those projects, and futher expands our knowledge of impacts in the North Sea area. Additionally, the Triple-D has multiple control mechanisms to improve the quantifiability of the samples (i.e. notice of blade actually dredging the bottom and the distance, under which angle and at which depth).

The dredge samples were taken along a 100 m transect using a sediment dredge with a width of 20 cm and a mesh size of 7 mm. The Triple-D dredge has a knife that extrudes 20 cm into the sediment. Because the dredge can rock and bump over the seafloor, penetration depth is not constant and will increase when the dredge is tilted forward and decrease when tilted backwards. To make the dredge-sample as quantifiable as possible, the Triple-D dredge uses several sensors that are used to (posteriori) measure the exact dredging-length where a penetration-depth of 20cm (± 5 cm) was acheived. These sensors make both the dredging length and dredging volume more easily quantified.
A different, less complex dredge was used in previous surveys. This dredge had a width of 100 cm, a mesh size of 7 mm and a knife that extends 15cm into the seafloor, however it was not equipped with sensors to assess the penetration depth of the knife. The penetration depth is strongly dependent on the substrate type and dredging angle, and therefore the measuements obtained fom this dedge contain a certain degree of approximation. In order to properly quantify the volume of sediment, a minimum volume of catch was used.

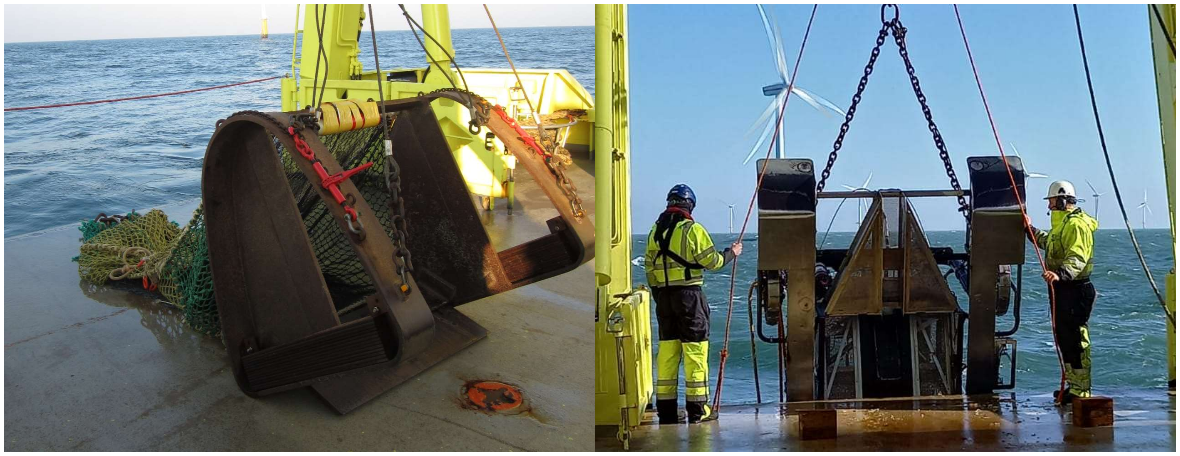

Figure 3-2: Benthic dredges used in T0 – T10 (left) and T15 (right, Triple-D)

3.2 Data preparation

Before analysis, species data were corrected for the presence of genera and species in the same sample. That is, if a sample contained for example *Ensis magnis, Ensis ensis,* and *Ensis sp.*, these three taxa were counted at two species, as it is highly likely that the specimen only identified to genera level belonged to one of the two species that could be further identified. This prevented over representation of species in the sample and therefore ensured a more accurate assessment of species diversity. Similar correction was done prior to the calculation of the diversity indices. This mainly concerned the treatment of the following taxa: *Ensis, Callianassidae, Linocarcinus, Spatangoida* and *Ammodytes*.

All data and analyses presented consist of epibenthos, without fish species, but including sandeel species (*Ammodytes tobianus*, *Ammodytes marinus* and *Hyperoplus lanceolatus*), including the 2003-2017 data. In table 3-1 shows which species were left out of the data analyses. In total these excluded taxa made up approximately 29% of the fish abundance; the remaining 71% consisting of sandeel.

Table 3-1: Fish taxa left out of the data analyses

Taxon	
Arnoglossus laterna	Merlangius merlangus
Buglossidium luteum	Pholis gunnellus
Callionymus	Pleuronectes platessa
Callionymus lyra	Pomatoschistus
Callionymus reticulatus	Pomatoschistus pictus
Ciliata mustela	Solea solea
Echiichthys vipera	Sprattus sprattus
Limanda limanda	

Polychaeta (bristleworms) are not included in the data of 2022, as this group was not to be analysed according to the protocol of Rijkswaterstaat. This is because most polychaetes will not be caught using a mesh-size of 7 mm and occurrences of polychaetes in dredge-samples will be a consequence of chance and substrate-type (a coarse substrate will fill the mesh, increasing the chance of polychaetes to be caught), and not accurately represent abundance in the area.
Polychaetes were however included in data from 2003-2017, however this analysis has not included these measurements (Leewis & Klink, 2018).

3.3 Statistical analyses

Data of 2022 was analysed with both univariate and multivariate methods. Number of species, abundances, Margalef diversity and Shannon Wiener index were analysed with univariate methods, to obtain information on differences within and outside the windpark locations. To check for normality a Shapiro-Wilk normality test was performed. For normally distributed data a one-way analysis of variance (ANOVA) was performed for the according numeric variable over the two sample groups (windpark locations and reference locations). In case of non normal distribution a Kruskal-Wallis test was used instead. To visualize the results boxplots were created. The statistical tests were performed in R statistics.

The community composition of the two sample groups (ref and wp) was analysed with non-Metric Multidimensional Scaling (nMDS). ANOSIM (Analysis of Similarity) was used to determine statistical differences in the community composition between the two sample groups of all locations as well as the habitats sampled in both sample groups (top sandridge and sandwaves, see Appendix 7.1).

Data of the previous years was not statistically analysed, but a general visual comparison was made (paragraph 4.3), according to PvE Deel C.

4 Results

Table 4-1 shows that differences in the average numbers that were calculated for each sample group are small.

Table 4-1. Averages of numeric variables within the two sample groups (Reference and Windpark).

	Reference (19 locations)	Windpark (9 locations)
Abundance (n/ha)	127495	119466
Number of species	23	22
Shannon Wiener index	2.30	2.34
Margalef index	1.87	1.84

Considering the average abundance and biomass of species-groups in each sample group, Figure 4-1 and Table 4-2 show those are very similar between the windpark locations and the reference locations. The reference locations exhibit a slightly higher average number of Gastropoda (8054 vs 2419 ind/ha) and Echinodermata (56623 vs 50858 ind/ha). In Echinodermata this is counterbalanced by a higher average biomass in the windpark locations, indicating a size difference between individuals in both sample groups.

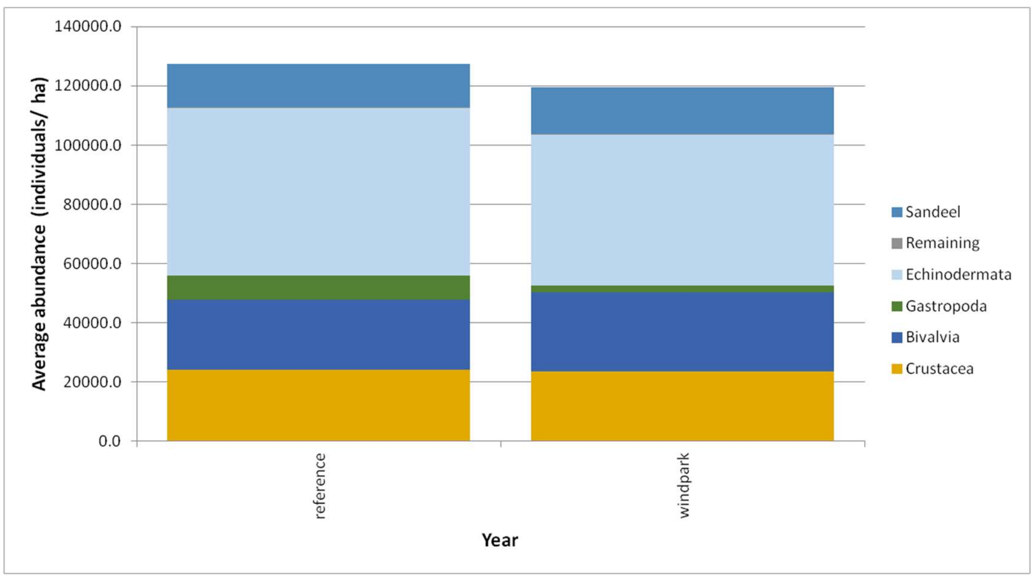

Figure 4-1: Average abundance devided into main species groups bothin the reference locations and the windpark locations

Table 4-2. Average abundance and average biomass (ww) per species group

speciesgroup	Av abundance n/ha		Av biomass g/ha	
	ref	wp	ref	wp
Remaining	367	219	498	0
Crustacea	24212	23624	28807	28414
Bivalvia	23632	26614	102889	107957
Gastropoda	8054	2419	21257	7146
Echinodermata	56623	50858	66469	71740
Sandeel	14607	15731	22275	24392
totaal	127495	119466	242195	239649

In 2022 five Crustacea species were found that were not seen in the other years, namely: *Asthenognathus atlanticus, Liocarcinus depurator, Pagurus bernhardus, Pilumnus hirtellus* and *Macropodia parva*. *Asthenognathus atlanticus* is a new species for the area, and has been found once in this survey (ref34). This species has been observed gradually extending its range northwards, and it is possible this species will become well established in the Dutch North Sea. *Liocarcinus depurator* and *Pagurus bernhardus* are expected species in this area. The first may prefer stable, silty areas, and was found once (wp12). *Pagurus bernhardus* was found on 20 locations (7 out of 9 wp-locations, 13 out of 19 ref-locations), totaling 50 individuals. *Pilumnus hirtellus* is a species associated with hard-substrate, and most likely got separated from this substrate (which is present in a windpark) causing an individual to become caught in one of the reference locations (ref24). *Macropodia parva* is considered by some to be a synonym voor *Macropodia rostrata* (WoRMS), which was reported in other years. The single individual found (on wp12) was thoroughly studied in the lab before concluding the identification.

4.1 Univariate analyses

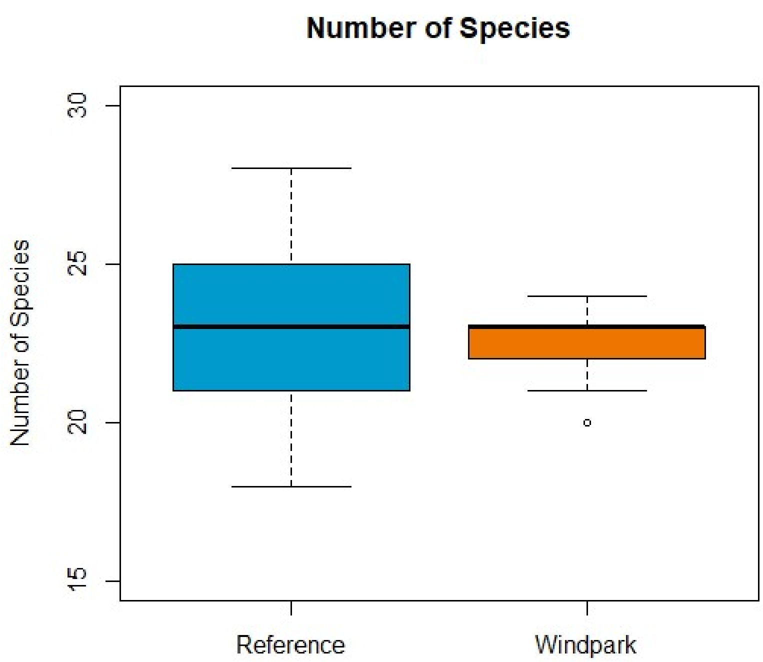

Figure 4-2: Number of species found in the reference area (blue) and in the windpark (orange).

No significant differences were found between the average number of species present in the samples taken from the windpark locations and the adjacent locations (figure 4-2, ANOVA, p=0.654).

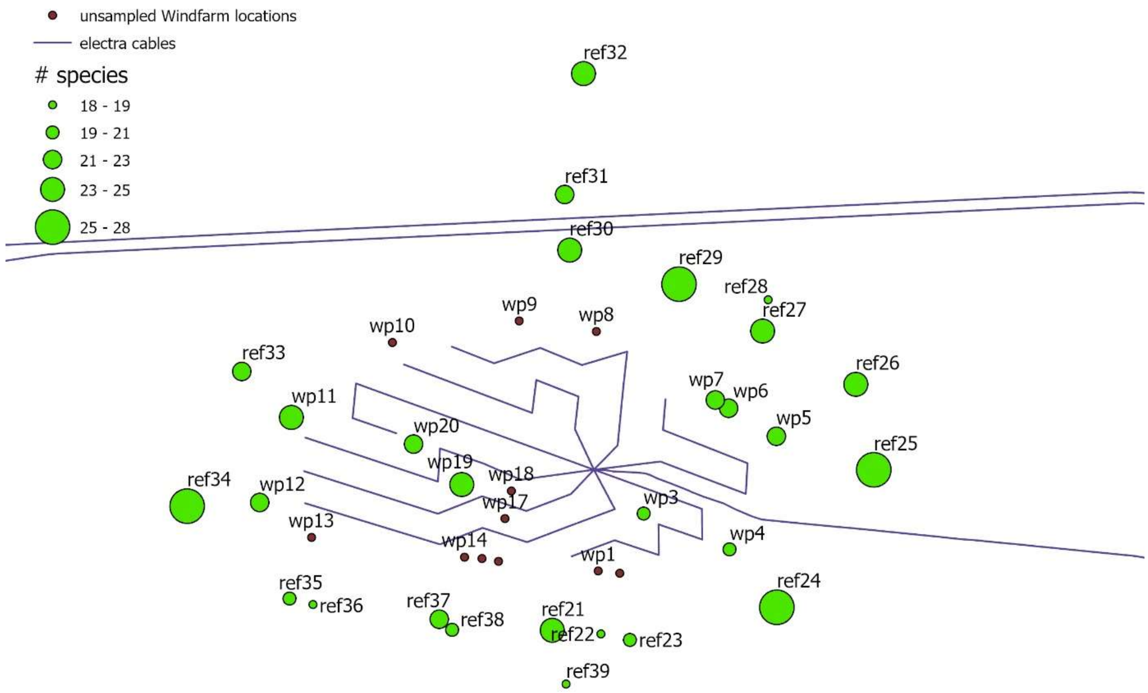

Figure 4-3: Number of species found in the windpark and outside the windpark.

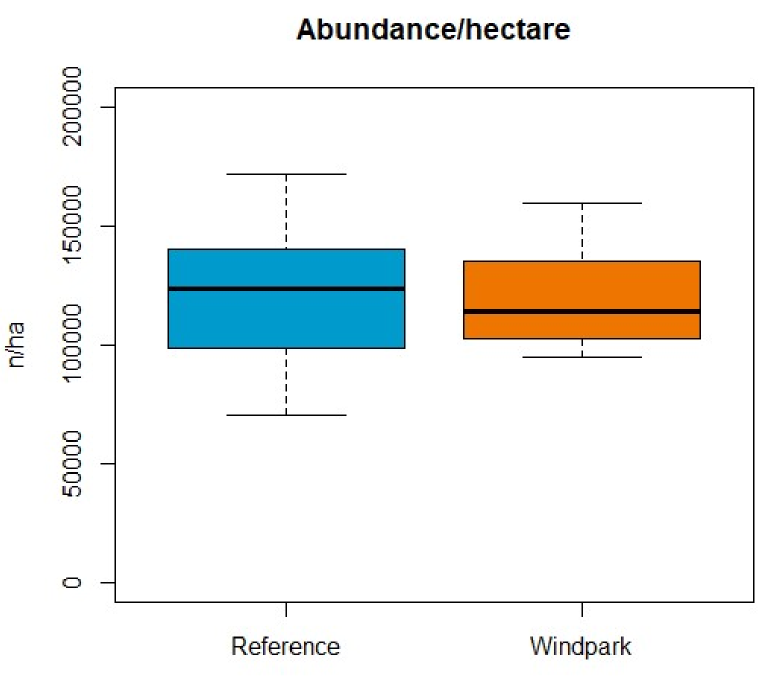

Figure 4-4: Abundance (n/ha) found in the reference area (blue) and in the windpark (orange).

The total abundance of benthic fauna (including sandeels) per sample (n/ha) is shown not to be different between windpark locations and reference locations (Figure 4-4, Kruskal-Wallis, p=0.941).

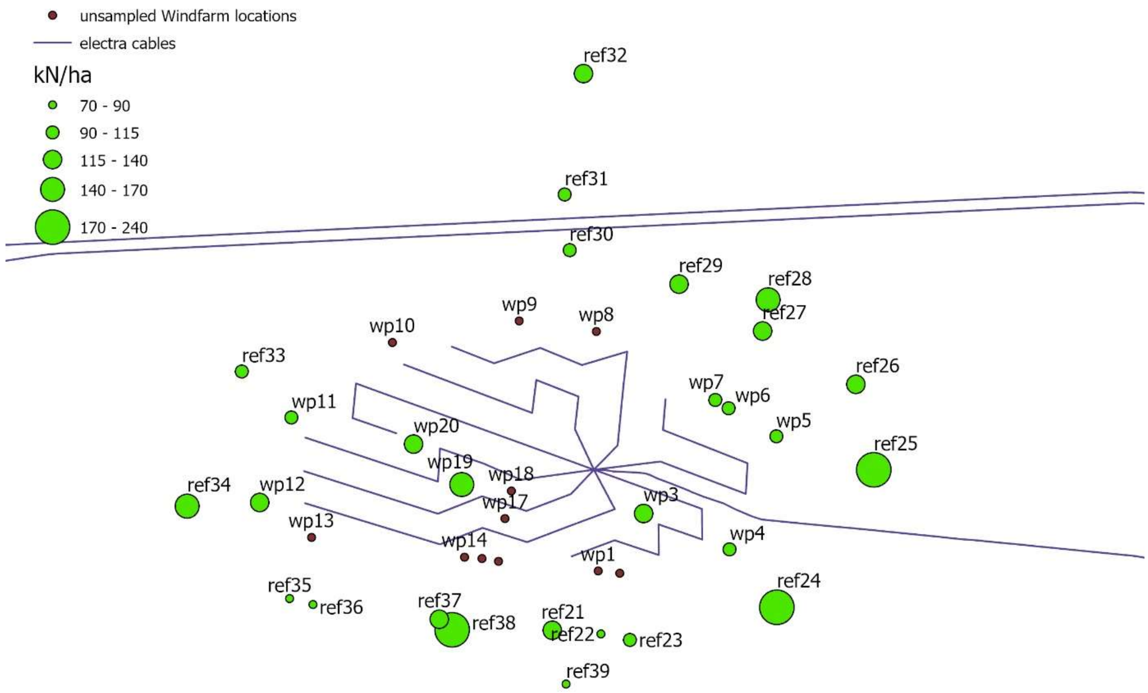

Figure 4-5: Benthic fauna abundance (including Sandeels n/ha) found in the windpark and outside the windpark.

Figure 4-6: Shannon Wiener index found in the reference area (blue) and in the windpark (orange)

No significant differences were found when comparing Shannon Wiener index values between samples from in and outside the windpark (figure 4-5, ANOVA, p=0.532), however less variation is seen in the data collected from the windpark locations (figure 4-6).

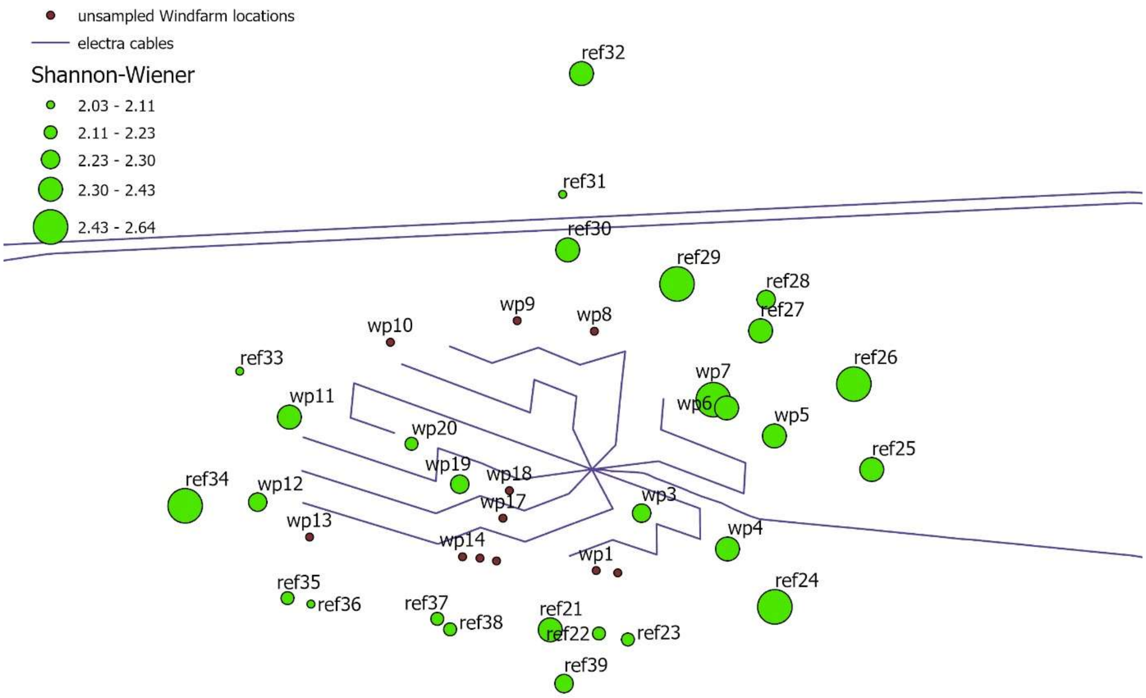

Figure 4-7: Shannon and Wiener index found in the windpark and outside the windpark.

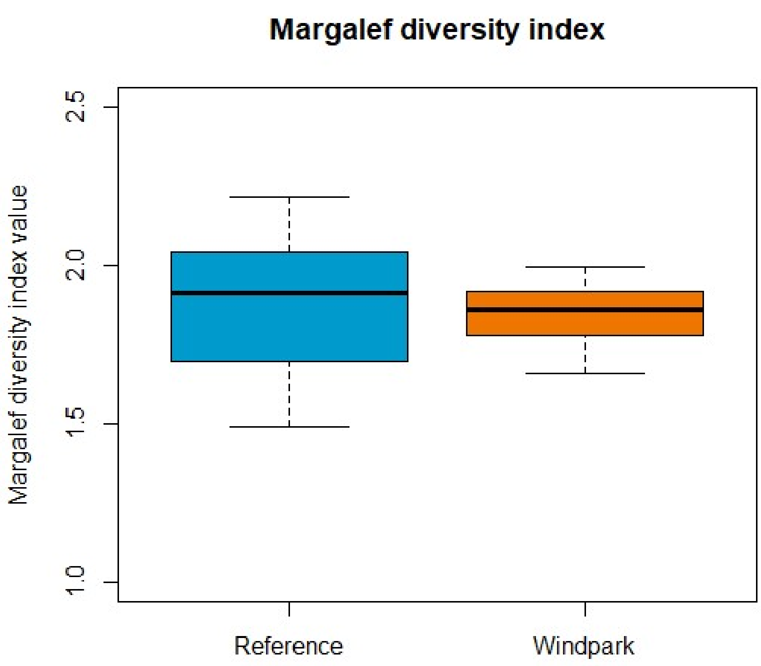

Figure 4-8: Margalef diversity index found in the reference area (blue) and in the wiindpark (orange).

No significant differences (ANOVA, p=0.532) were found when comparing Margalef diversity index values from samples taken at Windpark locations and reference locations (figure 4-8).

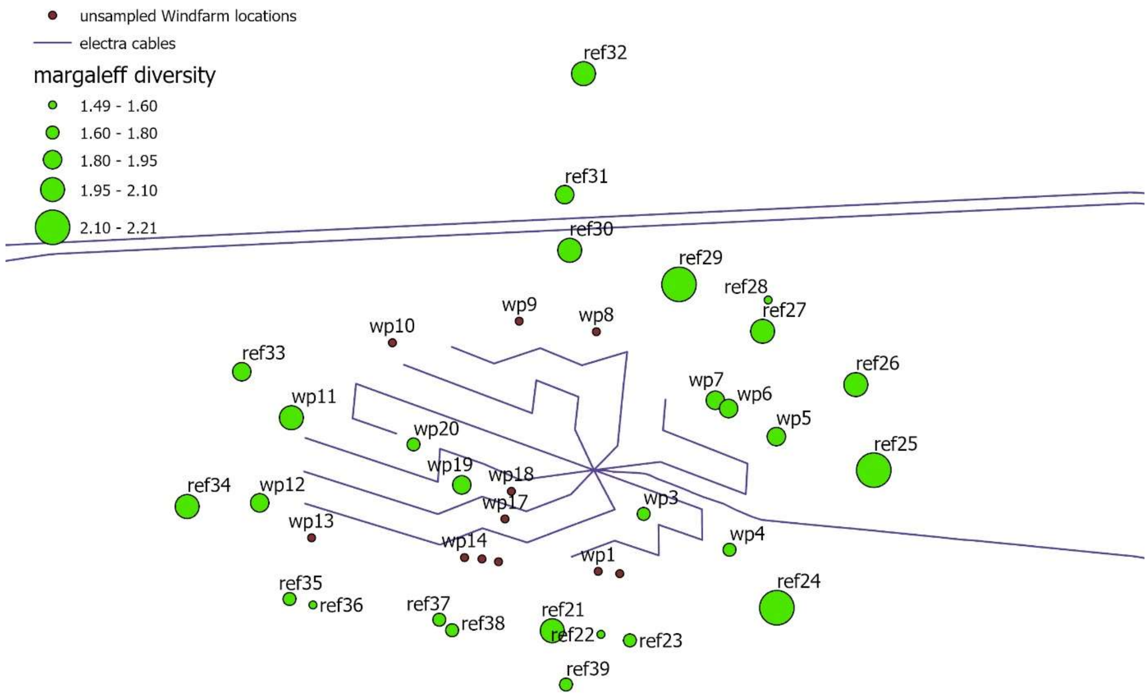

Figure 4-9: Margalef diversity index found in the windpark and outside the windpark.

Overall, it is evident that no statistical differences between the windpark locations and the reference locations were found. However, more variability is present in the reference locations, as can be seen from the boxplots. This is potentially due to the larger number of sampled locations and the greater variety of habitats sampled in the reference area, compared to the windpark locations. The species accumulation curves presented in figure 4-10 indeed indicate that more samples in the windpark would result in a higher number of species. The reference area is expected to exhibit more species at the same amount of samples (43 species at 9 samples vs 39 species at 9 samples in the windpark), but it is also spread over a much larger geographic area.
From a geographic viewpoint the reference-locations with highest biodiversity are located (north)east of the windpark (ref 24- 30). The reference locations with lowest biodiversity are located south of the windpark (ref 21-23, 35-39).

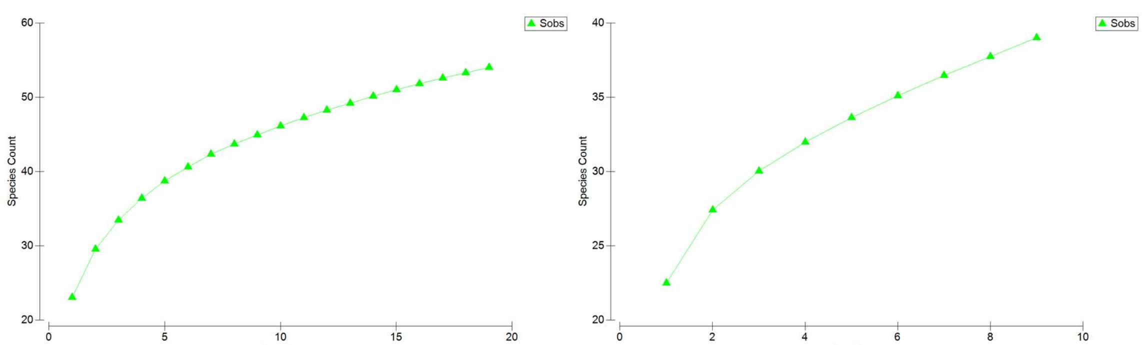

Figure 4-10: Species accumulation curves of the reference area (left) and the windpark (right)

4.2 Multivariate analyses

The nMDS based on abundance (figure 4-11) shows no distinct separations between the two groups of samples. There is a large overlap in locations, and a few locations (that are lying outside the main cluster) seem to have a somewhat different community. ANOSIM showed that no significant difference is present in the species communities within and outside the windpark.

When defining the different habitats per location and testing for differences per habitat between reference and windpark locations, no significant difference emerged. No difference between reference area and windpark were found in the habitats 'top sandridge' and 'sandwaves'. Due to the complexity and/or multitude of figures needed to show this, no figures are presented in this report.

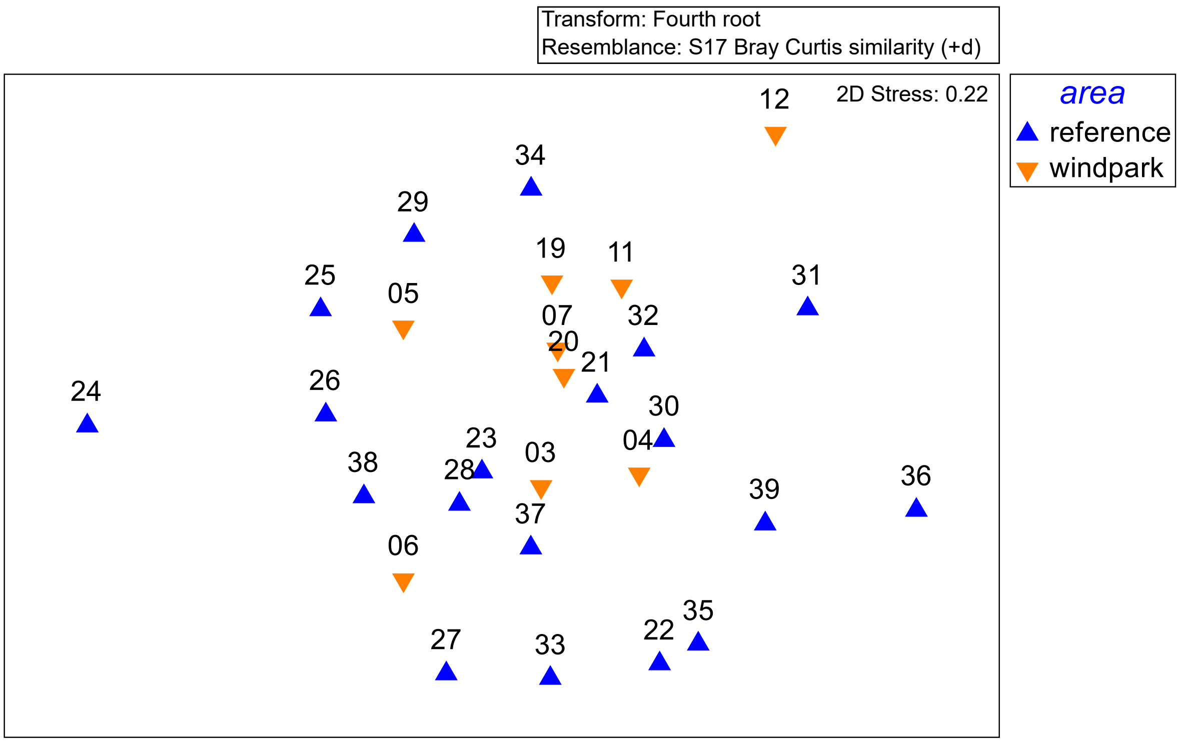

Figure 4-11: nMDS plot based on abunance at each location. Orange is inside the windpark, blue is outside the windpark, numbers are location numbers.

4.3 Development of PAWP from 2003 to 2022

Abundance
Due to the differences between T15 and previous campaigns in the type of dredge used, and the differences in the ability to quantify the sample-volume and effective track-length, a comparison of absolute abundances is not advisable. Figure 4-12 shows that the average abundance per sampled location is clearly higher in 2022 when compared to the previous years of the monitoring programme. This is both in the windpark and in the reference locations. Whereas the average abundance in the windpark is relatively constant until 2017, that in the reference area peaked in 2017. Leewis et al. (2018) shows that this increase in 2017 is likely due to the increase in number of sampling locations in the reference area, and the presence of a shellfish-bank on the newly sampled east-side.
In 2022 the same reference locations were sampled as in 2017, but different and fewer locations in the windpark were sampled, and the Triple-D dredge was used. The increase in average abundance from 2017 to 2022 in the reference area is probably for a large part due to the change in dredge, with natural developments featuring less heavily. The increase inside the windpark will be a combination of the change in (number of) locations and the change in dredge, as well as natural developments.

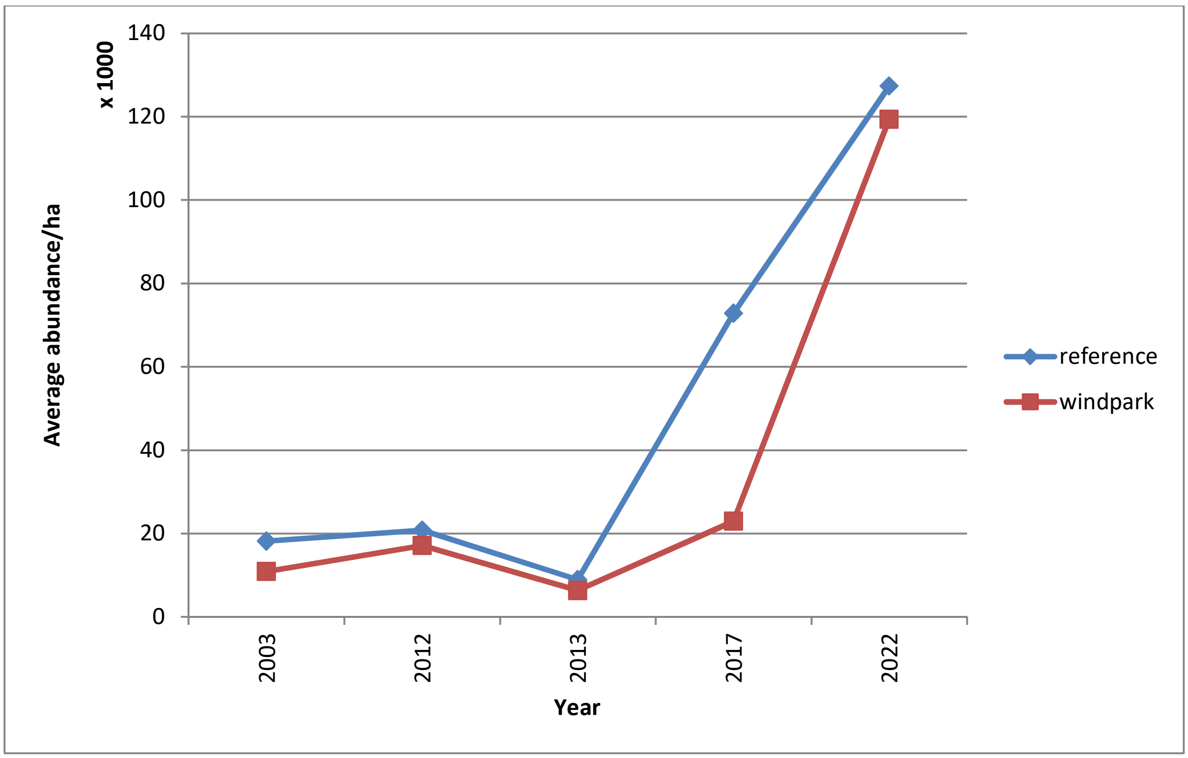

Figure 4-12: Average abundance (n/ha) per location within the windpark (red line) and in the reference locations (blue line).

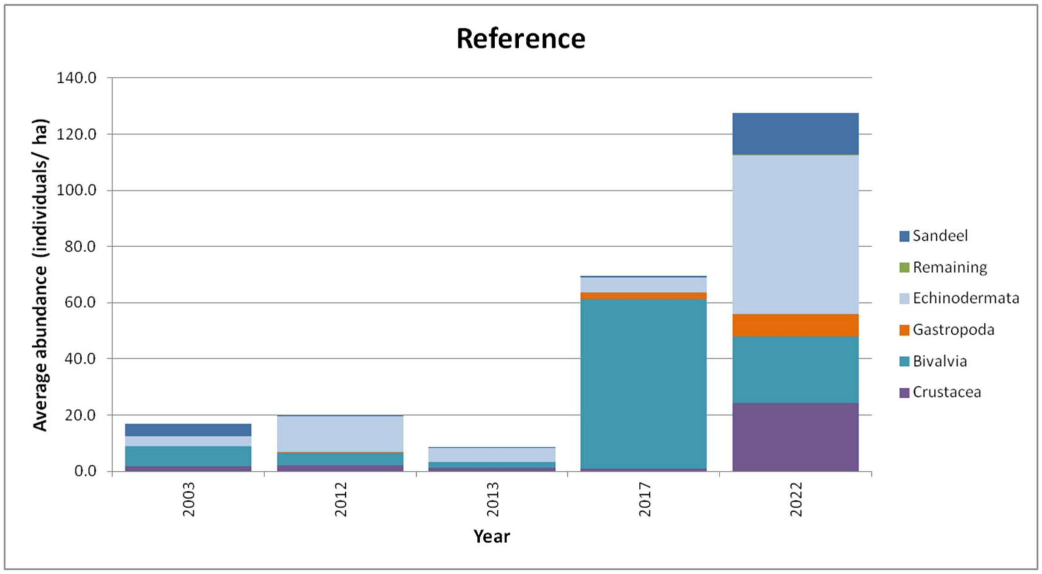

Figure 4-13: Average abundance of main species groups over the different years, in the reference locations.

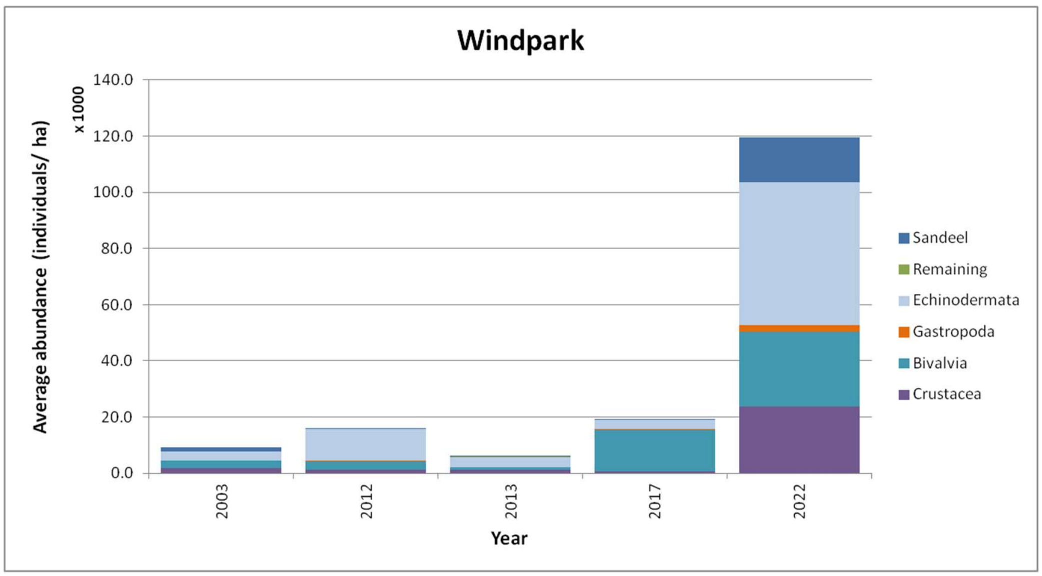

Figure 4-14: Average abundance of main species groups over the different years, in the windpark locations.

In the figures above, the average abundance in each of the main species groups is presented. It becomes clear that in 2022 the average abundance is much higher than in previous years. This increase is not due to specific species groups. Instead, we assume this increase in average abundance is caused by the change in dredge used in 2022.

While the absolute average of abundance differs between 2022 and before, due to above-mentioned reasons, a comparison in proportions of total catch (**Figure 4-15**) is much less influenced by the quantitative differences between years and enables a qualitative comparison between years.

In **Figure 4-15** it can be seen that in 2012 and 2013 Echinodermata comprised a similarly large porportion of the measured abundance found in 2022. In 2022 Crustacea in particular seem to contribute to a larger portion of the abundance than in all other years.

The year 2017 stands out with very high absolute and relative abundances of Bivalvia. The eastern part of the reference area contained large shellfish-banks that were not as prominent in 2022, and not sampled at all in previous years.

Sandeels make up a substantial part of the relative abundance in 2022 and 2003, while from 2012-2017 the relative abundances of sandeels were low. While the quantitative differences between the dredges will have influenced the changes from previous years to 2022, the fact that the relative abundance of sandeel was also high in 2003 shows that the dredges do not necessarily contribute to differing catch-rates of sandeels. More likely the changes in relative abundance of sandeels over the years is part of natural variation.

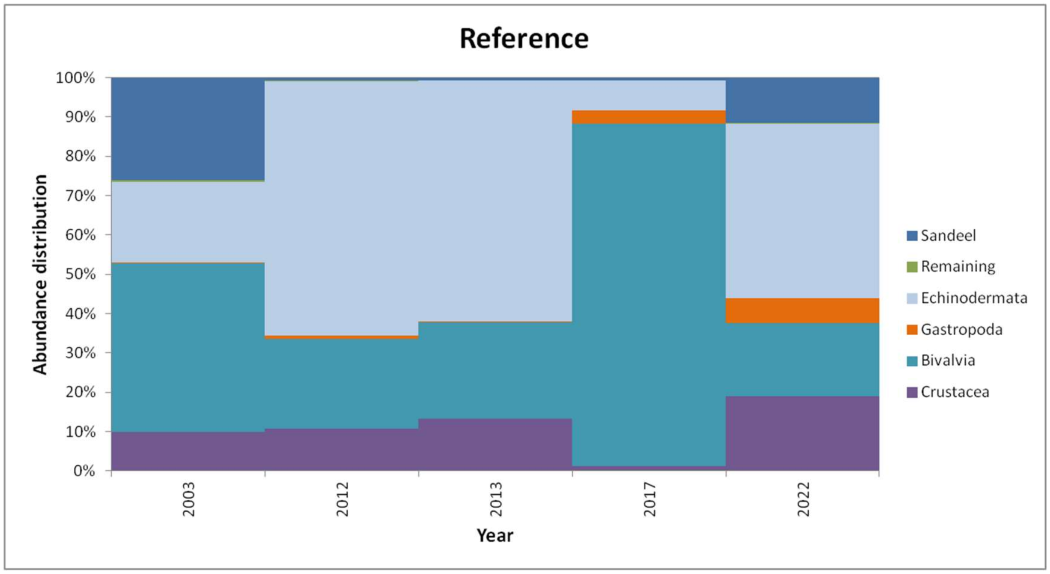

Figure 4-15: Relative distribution of abundance of the main species groups over the different years, in the reference locations.

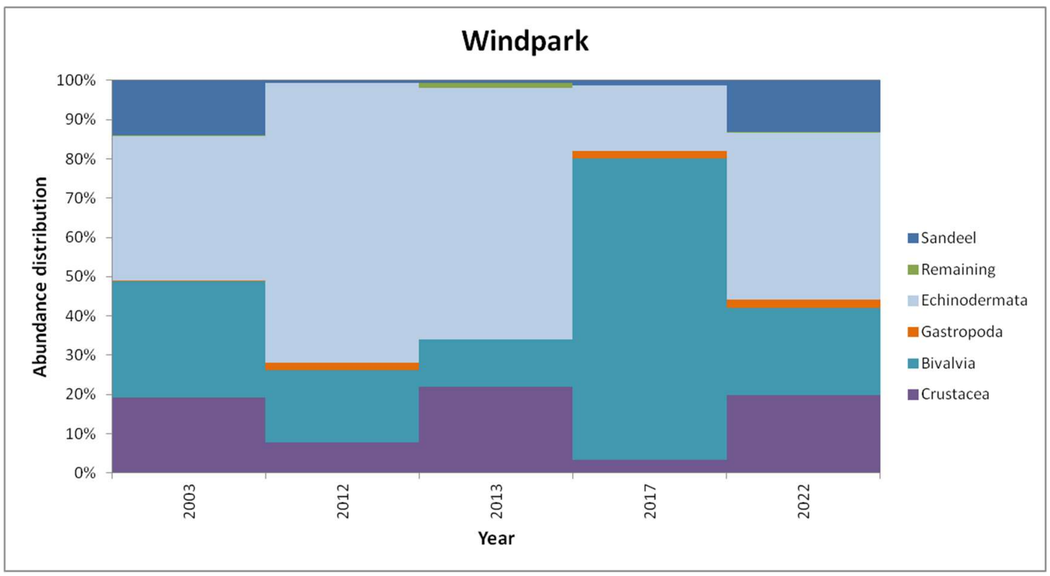

Figure 4-16: Relative distribution of abundance of the main species groups over the different years, in the windpark locations.

Number of species

The *average* number of species per location was higher in 2022 compared to other years (**Figure 4-17**), both for the windpark area and the reference area. However, the *total* number of species found in the windpark area (**Figure 4-18**) was comparable to the other years, while that in the reference area was high.

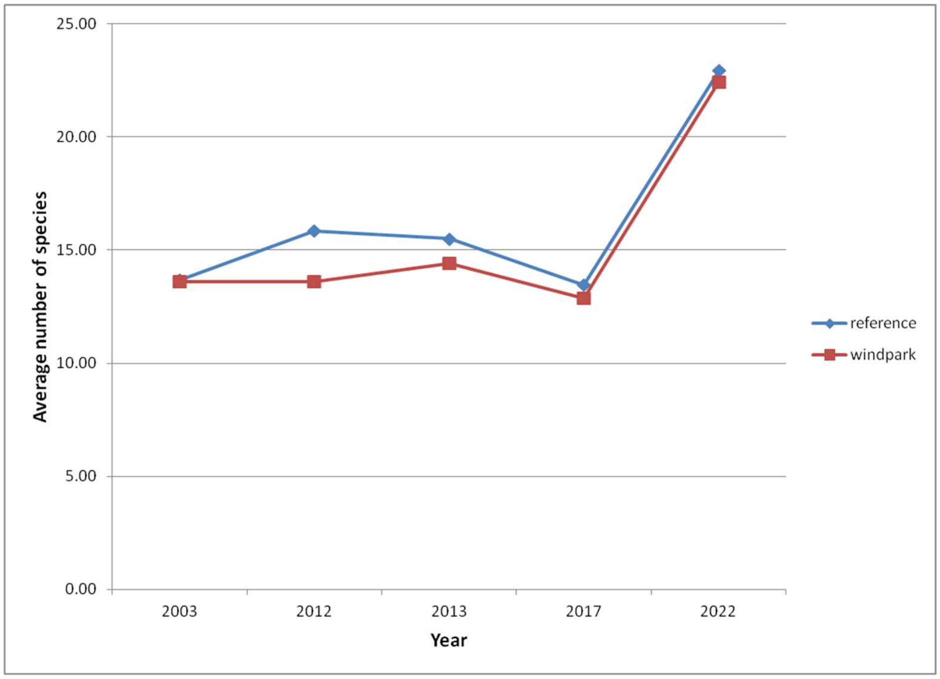

Figure 4-17: Average number of species per location within the windpark (red line) and in the reference locations (blue line).

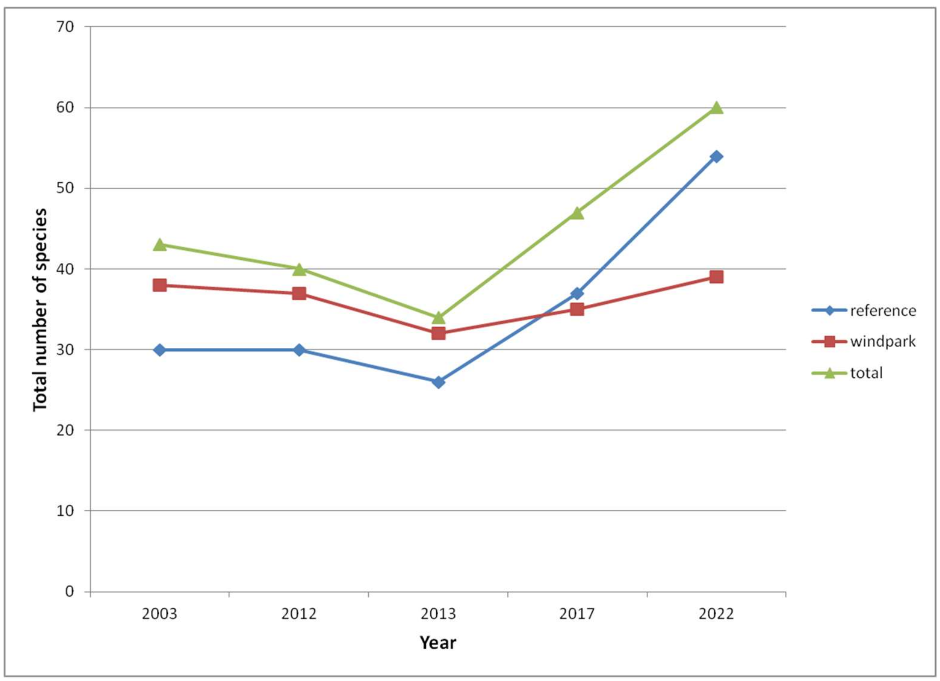

Figure 4-18: Total number of species within the windpark (red line) and in the reference locations (blue line) and in total (green line).

From the figures below, it becomes clear that for the number of species found in each species group, Crustacea stands out in 2022 when compared to other years (figures 4-19 and 4-20). We have already discussed what species influenced these differences below table 4-2.

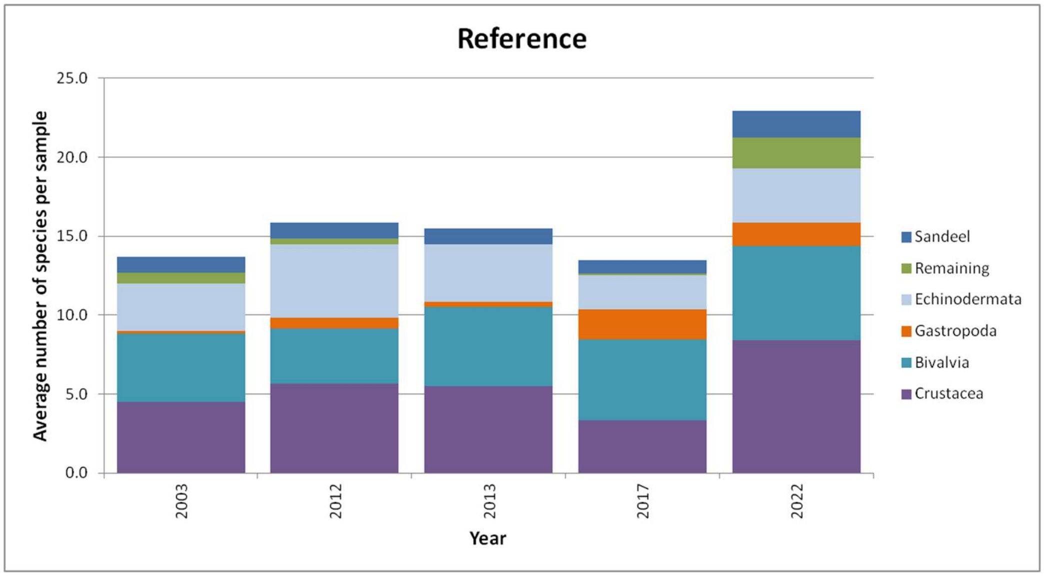

Figure 4-19: Average number of species in the main species groups over the different years, in the reference locations.

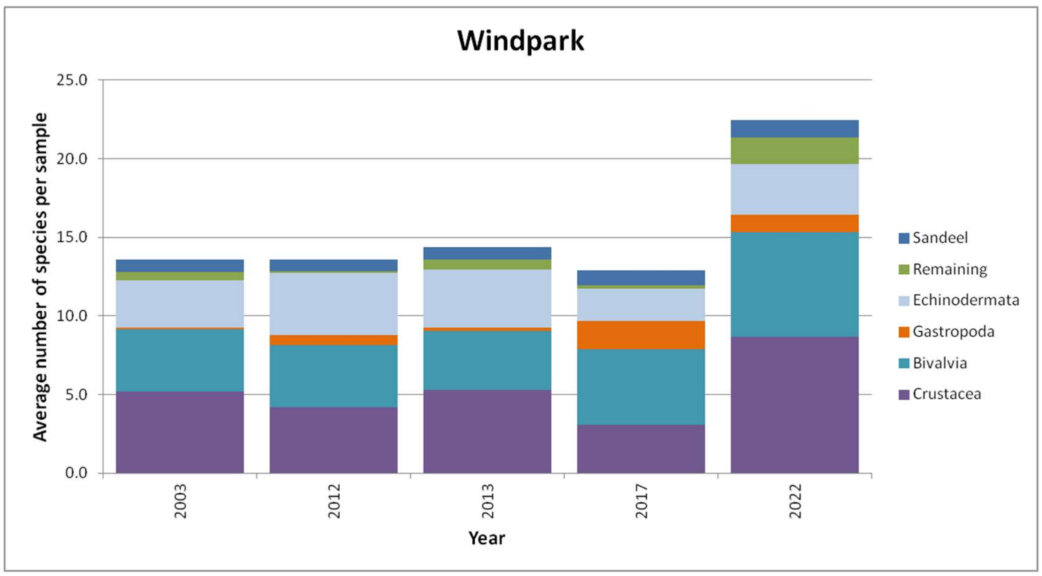

Figure 4-20: Average number of species in the main species groups over the different years, in the windpark locations.

That the results from 2022 can be qualitatively compared with previous years can be seen in figure 4-22, as the diversity indices Shannon Wiener and Margalef are only slightly higher in 2022 when compared to other years. This figure indicates that the differences found when comparing absolute numbers between years (for instance Figure 4-14) are likely largely caused by quantitative differences between the two types of dredges. A reasonable assumption is that previous years' abundances, and to a lesser extent the number of species, was more variable between locations than in 2022. When substrate or circumstances differed, the volume and/or track length differed, creating quantitative differences between locations. With the Triple-D dredge a more consistent and comparable sampling per location was performed. Even though the abundance and number of species is consistently high in 2022 compared between locations, species diversity is fairly constant and comparable across the years (Figure 4-22).

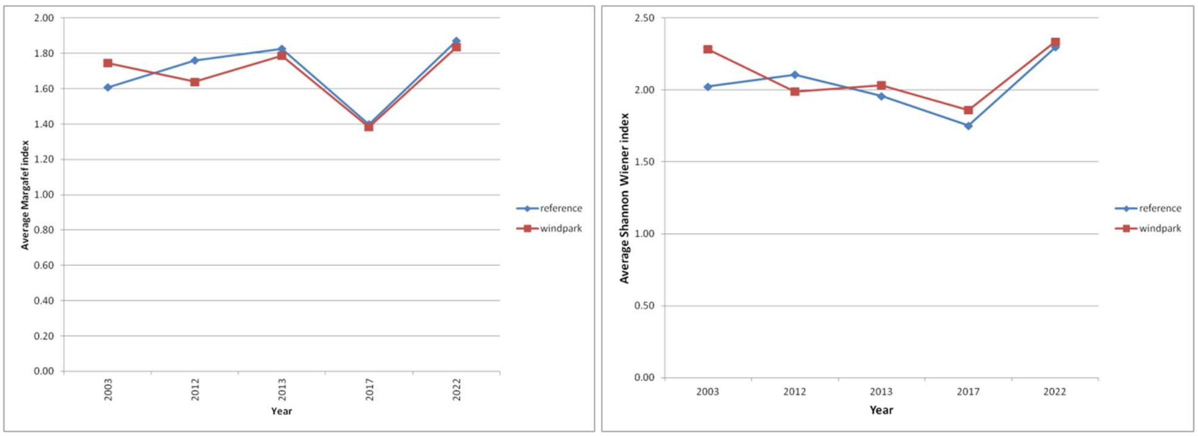

Figure 4-22: Diversity indices Margalef (left) and Shannon Wiener (right) within the windpark (red line) and in the reference locations (blue line).

5 Conclusion and Discussion

From this first data-exploration of the benthic dredge data of the Princes Amalia Windpark 2022 some conclusions can be drawn. Overall, there are no significant differences between the locations inside and outside the windpark, both in univariate key figures (i.e. abundance and diversity indices) and in community composition.

We cannot rule out that the absence of significant differerences could be due to the relatively low number of locations that could be sampled within the windpark. However, given the low variability in biodiversity indices in the windpark-locations sampled and the probable increase in variability with more locations sampled, it is likely no significant differences would have resulted from sampling more locations in the windpark.

Table 5-1. *P-values from the statistical comparison within the windpark and the reference locations for the univariate analyses that were performed. The last column shows the corresponding analysis that was used.*

Parameter analysed	p-value	statistical test
Species	0.65	ANOVA
Average abundance/ha	0.94	Kruskal-Wallis
Margalef diversity index	0.67	ANOVA
Shannon-Wiener index	0.53	ANOVA

From the general comparison between sampling years it has become clear that the abundances and the number of species found in 2022 were much higher when compared to the other years (2003, 2012, 2013 and 2017). In 2022 it was the first time that the Triple-D dredge was used. The sample depth and effective dredged length on the Triple-D can be quantified, as this is monitored using sensors, whereas the previous dredge had no monitoring capabilities, and only a qualitative measure of net-catch was maintained (actual volume of catch after hauling). In previous years this may have resulted in differences in how effective different locations were sampled, artificially creating quantitative differences in abundances and number of species between locations. Because some locations may therefore be under-sampled, this lowered the average abundance in 2003-2017. The difference in number of species between 2022 and previous years (**Figure 4-17** and **Figure 4-18**) could be attributed to a more constant catch using the Triple-D, but also natural development of the area and dispersal of species.

A study on the exact causation of differences between the data gained with two types of dredges used in PAWP is not possible at this point. To study this properly a comparative sampling campaign should be performed using both dredges side by side.

We conclude no identifiable differences in data are found in, and outside the windpark. This conclusion has been the same in analyses for previous years (Leewis et al., 2018). It was originally hypothesized that the effects of windparks on benthic fauna are mainly through two mechanisms: 1) the exclosure of bottom fishing activities from windparks and 2) the introduction of hard substrate from the turbines itself and its scour protection (Jak & Glorius, 2017). This study only assessed the species present in soft substrates, and therefore a study on hard-substrate is recommended to fully assess the development of hard-substrate fauna, and therefore contribute to the overall view of the ecology inside the windpark. The same holds true for reef-forming species such as shellfish and tube-worms, as there are no indications that the windpark favours the formation of reefs on soft-sediment. Instead, the occurrence of reef formers is highest outside the park, although as previously stated this could be influenced by the lower number of samples in the windpark.
The exclusion of fisheries can not be fully assessed because of two reasons. Firstly, the distribution of fishing effort is concentrated south of the windpark (ref21-23 and ref 35-39) and secondly, the locations in the windpark alongside this area of higher fishing effort (wp1-2 and wp13-16) have not been sampled in 2022. Given the low variability in abundance and species diversity within the windpark locations, however, it

seems probable that the locations in the windpark show lower abundance and species diversity than the reference locations with higher fishing effort. In other words, there is no indication that the exclusion of fisheries has led to an increase in biodiversity or abundance.

Whether further development of benthic ecology within the park is needed before differences between windpark and reference area can be shown is not evident. The development so far does not show a clear trend and is in a quantitative sense strongly influenced by the change in dredge used. Fifteen years can be considered adequite development-time for most benthic fauna found in the North Sea. We do not expect, therefore, that in coming years a new development will take place.

Since the community found today in the windpark on soft-sediment was largely present right after the windpark was put in place, we cannot define an effect of the exclusion of fisheries or the presence of hard-substrates on (the development of) soft sediment benthos.

6 References

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Leewis & Klink, 2017. *Prinses Amalia Windturbine park 2017. Statistical comparison of benthic fauna inside and outside the Prinses Amalia Wind Park; a preliminary analysis*. Aug. 2017.

Leewis, L., Klink, A.D., Verduin, E.C., 2018. *Benthic development in and around offshore wind farm Prinses Amalia Wind Park near the Dutch coastal zone before and after construction (2003-2017). A statistical approach.* April 2018.

7 Appendices

7.1 Planned sampling locations

Table 5-1: Planned locations including habitat defined. Colored rows are sampled locations. X-Y coordinates in ETRS89 UTM 31N.

Loc_id	Sample group	habitat	X	Y
1	wp	top sandridge	583775	5825065
2	wp	top sandridge	584010	5825030
3	wp	top sandridge	584208	5826074
4	wp	slope sandridge	585218	5825508
5	wp	slope sandridge	585679	5827525
6	wp	top sandridge	585157	5828003
7	wp	top sandridge	584992	5828107
8	wp	top sandridge	583680	5829359
9	wp	top sandridge	582836	5829533
10	wp	sandwaves	581454	5829124
11	wp	sandwaves	580385	5827768
12	wp	sandwaves	580055	5826238
13	wp	sandwaves	580628	5825612
14	wp	deep PAWP without sandwaves	582306	5825291
15	wp	deep PAWP without sandwaves	582497	5825265
16	wp	deep PAWP without sandwaves	582680	5825221
17	wp	deep PAWP without sandwaves	582741	5825986
18	wp	deep PAWP without sandwaves	582798	5826486
19	wp	deep PAWP without sandwaves	582253	5826600
20	wp	sandwaves	581784	5827377
21	ref	top sandridge	583288	5823995
22	ref	top sandridge	583836	5823952
23	ref	slope sandridge	584192	5823917
24	ref	valley sandridge	585766	5824474
25	ref	valley sandridge	586770	5826966
26	ref	valley sandridge	586392	5828385
27	ref	top sandridge	585514	5829455
28	ref	top sandridge	585331	5829542
29	ref	top sandridge	584523	5830220
30	ref	top sandridge	583393	5830880
31	ref	top sandridge	583314	5831854
32	ref	top sandridge	583436	5833905
33	ref	valley sandridge	579820	5828646
34	ref	valley sandridge	579285	5826236
35	ref	sandwaves	580463	5824552
36	ref	sandwaves	580724	5824456
37	ref	sandwaves	582054	5824161
38	ref	sandwaves	582280	5824048
39	ref	top sandridge	583498	5823132

7.2 Species matrix (n/sample)

	REF21	REF22	REF23	REF24	REF25	REF26	REF27	REF28	REF29	REF30	REF31	REF32	REF33	REF34
Abra prismatica														1
Asterias rubens	2					1					1	1	1	1
Asthenognathus atlanticus														1
Astropecten irregularis					1				>0					
Balanus crenatus				>0	>0									
Bryozoa	>0		>0	>0	>0	>0	>0	>0	>0	>0	>0	>0	>0	>0
Callianassidae		>0		2		>0		>0	2					
Cancer pagurus														
Cerebratulus marginatus							1							
Chamelea striatula	8	9	8	16	23	15	20	16	10	20	17	22	8	13
Corystes cassivelaunus	1				3	2	2	3	1	1	1		1	
Crangon allmanni														
Crangon crangon	11	8	5	18	22	12	18	6	17	10	6	14	9	12
Cylista troglodytes				1										
Diogenes pugilator	10	4	4	3	5	5	2	4		2	3	2	1	
Diplodonta rotundata					1									
Donax vittatus	4	5	2	23	4	4	11	24	15	7	1	3	2	8
Echinocardium cordatum	1		1		1	6			8			1		7
Ensis									1				2	
Ensis ensis	11	11	12	13	24	20	18	21	18	16	7	20	14	17
Ensis magnus	10	5	4	2	3	3		4	1	5	5	8		6
Ensis siliqua														
Euspira catena		1	1	2	3	2						3	1	
Euspira nitida				1										
Fabulina fabula			1	46										
Gastrosaccus spinifer														2
Hydractinia echinata						>0	>0							>0
Hydrozoa				>0										
Lineus														
Liocarcinus														1
Liocarcinus depurator														
Liocarcinus holsatus	2	1	3	8	4		1	3	6	1	2	3	1	2
Liocarcinus vernalis	1	1			3		2		1	2		1		1
Lutraria lutraria	2		1	16	15	16	1	1	2					2
Macropodia parva														
Mactra stultorum				1					1	2				
Metridium senile											1			
Mytilus edulis		1												
Nemertea											>0	>0		
Ophiothrix fragilis									1					

	REF21	REF22	REF23	REF24	REF25	REF26	REF27	REF28	REF29	REF30	REF31	REF32	REF33	REF34
Ophiura albida	65	54	75	113	119	22	29	50	36	39	50	51	79	61
Ophiura ophiura	58	18	30	62	76	36	77	77	64	33	65	60	47	62
Pagurus bernhardus	2	4	1	5	5	1	5		>0	3		3	2	1
Pestarella tyrrhena	5				10		1			1	3	2	>0	9
Philocheras trispinosus	7	3	6	14	5	15	19	10	9	13	8	3	7	17
Pilumnus hirtellus				1										
Pinnotheres pisum														
Pisidia longicornis							1							
Processa modica			1	5	4	5		2	1	1	1	2		10
Sagartiogeton undatus				5	1									
Sepiola atlantica							1						1	
Spatangoida	>0				>0	>0	>0	>0	>0	>0	>0	>0	>0	>0
Spisula elliptica	1								1	1		2	1	5
Spisula solida									1	1	1			
Spisula subtruncata				2	1	1			2		1			3
Striarca lactea														
Thia scutellata	15	11	17	24	26	42	15	24	13	9	14	7	11	16
Tritia reticulata	4	2	21	91	59	28	9	17	15	2		9	7	8
Tubularia indivisa						>0	>0			>0			>0	

	REF35	REF36	REF37	REF38	REF39	WP03	WP04	WP05	WP06	WP07	WP11	WP12	WP19	WP20
Abra prismatica														
Asterias rubens				1						1	1		2	
Asthenognathus atlanticus														
Astropecten irregularis														
Balanus crenatus														
Bryozoa	>0		>0		>0	>0		>0	>0	>0	>0		>0	>0
Callianassidae	>0		>0					3						
Cancer pagurus									>0					
Cerebratulus marginatus														
Chamelea striatula	12	14	11	14	7	20	17	7	22	13	15	16	15	16
Corystes cassivelaunus	1				2	1			2	1			2	
Crangon allmanni		1												
Crangon crangon	4	5	2	11	11	5	13	11	13	13	4	7	4	10
Cylista troglodytes		1	1			2			1					
Diogenes pugilator	3		5	6	4	2	1	1	2	1	2		1	1
Diplodonta rotundata												1		
Donax vittatus	4	1	5	10	4	4	8	20	27	16	5	6	7	2
Echinocardium cordatum		1			1	8	1	1		7	1	1	1	1
Ensis														
Ensis ensis	6	10	28	28	4	20	20	18	27	10	27	11	28	15
Ensis magnus	3	8	6	2	9	11	6		2	2	7	10	2	3
Ensis siliqua							1							
Euspira catena		1		2					3				1	
Euspira nitida														
Fabulina fabula														
Gastrosaccus spinifer	2													
Hydractinia echinata	>0		>0			>0	>0		>0			>0		>0
Hydrozoa														
Lineus					1									
Liocarcinus									>0					>0
Liocarcinus depurator												1		
Liocarcinus holsatus		2	4	2	3	3	1	3	1	3	3	4	2	1
Liocarcinus vernalis	1	1		2			1	1			3	4		4
Lutraria lutraria			1	1		1		4		1	1		4	2
Macropodia parva												1		
Mactra stultorum				>0										
Metridium senile														
Mytilus edulis								1						
Nemertea														
Ophiothrix fragilis														
Ophiura albida	38	63	90	113	53	77	39	25	25	19	32	55	88	88

	REF35	REF36	REF37	REF38	REF39	WP03	WP04	WP05	WP06	WP07	WP11	WP12	WP19	WP20
Ophiura ophiura	33	31	48	72	32	44	33	67	43	51	55	55	58	62
Pagurus bernhardus	1		3			1	1	5	1	3		1		2
Pestarella tyrrhena					1		1			2	3	12	5	7
Philocheras trispinosus	3	2	14	22	6	9	10	9	6	4	2	4	18	8
Pilumnus hirtellus														
Pinnotheres pisum									1					
Pisidia longicornis														
Processa modica								2	2	1	3	2	1	1
Sagartiogeton undatus														
Sepiola atlantica											1			
Spatangoida	>0	>0	>0	>0		>0				>0	>0	>0	>0	1
Spisula elliptica	1		1			1		2		2	1	1	3	2
Spisula solida		3									2	2	1	
Spisula subtruncata				1			1	1	1		1		3	
Striarca lactea												1		
Thia scutellata	7	4	19	20	11	13	15	36	8	15	11	21	32	26
Tritia reticulata	4	4	3	12	1	11	7	7	6	4	2		2	2
Tubularia indivisa														