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ABSTRACT

Epifauna and infauna are often sampled by different types of sampling devices including grabs, and dredges, depending on various factors such as local environmental conditions, research questions and available budget. Because grabs and dredges have a different species-specific selectivity, both methods could be complementary but for some research questions they could give comparable results. In this study, a comparison is made between macrobenthos (epifauna and infauna) sampled simultaneously by a Van Veen grab and a quantitative benthic dredge, based on a large dataset that was collected from 2010 to 2019 as part of an extensive monitoring program to study the impact of the Sand Motor, a mega beach nourishment that was implemented in 2011 on the sandy North Sea coast in the Netherlands. Because of the larger mesh size of the sieve in the benthic dredge (5 mm) compared to the Van Veen (1 mm), only larger mollusks, echinoderms and crustaceans are identified in the dredge samples. This resulted in a lower number of taxa and average densities in the 676 benthic dredge samples (42 taxa and 98.7 ind. m^{-2}, respectively) compared to the 636 Van Veen samples (228 taxa and 1380.9 ind. m^{-2}, respectively). Due to the larger sampling area of the benthic dredge (10–15 m^2) compared to the Van Veen (0.1 m^2) the chance to encounter a species is higher in a benthic dredge than in a Van Veen grab sample. Although the benthic dredge only samples a subset of the benthic community that is sampled by the Van Veen grab, multivariate (nMDS) analysis of the data showed remarkable similarities between Van Veen and benthic dredge samples with major gradients correlated to water depth and temporal changes in environmental conditions due to the presence of the Sand Motor. This suggests that both techniques are indicative for the spatial variation and development of the macrobenthic community.

1. Introduction

Benthic macrofauna is often monitored for assessment and impact studies and is used in many benthic habitat classifications (Diaz et al., 2004). Also within the Marine Strategy Framework Directive, indicators based on macrobenthos parameters (e.g. density, biomass, diversity) are frequently used to measure the 'health' of marine ecosystems (Van Hoey et al., 2010). High biodiversity of the macrobenthic community is often associated with a good ecological status, although the relation between biodiversity indicators and ecological functioning is not always clear (Hillebrand et al., 2018; ICES, 2018). Macrobenthos plays an important role in the functioning of marine coastal ecosystems through decomposition of organic matter, cycling of nutrients (Toussaint et al., 2021) and as food source for higher trophic levels (e.g. birds and fishes) (Reiss and Kröncke, 2005). Being relatively sedentary, they reflect the characteristics of their immediate environment (Pearson and Rosenberg, 1978) and due to their relatively long life spans, they integrate the environmental conditions in the sediment and the overlying water over time (Dauer, 1993; Reiss and Kröncke, 2005).

Various sampling devices are used to sample soft-bottom macrobenthos in the sublittoral including grabs, corers and towed dredges (Rumohr, 2009). They, partly, aim at sampling different parts of the benthic community, e.g. whether the target species live in or on the seabed (infauna vs. epifauna), how deep they live in the bottom, how abundant they are and how clustered their distribution is (Bergman and Van Santbrink, 1994). Macrobenthos samples from grabs and corers are usually sieved over a sieve with a mesh size of 1 mm to collect the macrobenthos (Rumohr, 2009), while larger mesh sizes are often used

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for dredge samples.

In the North Sea, the soft-bottom macrobenthos is preferably sampled with a box-corer, because of its specific design, especially suited to sample sandy sediments. Advantages are good penetration capability and relative low level of seabed disturbance and distortion of the sample, although distortion is reported due to bow-wave effects (Barnett et al., 1984), resulting in underestimation of macrofauna abundance in box-core samples compared to multicore samples (Montagna et al., 2017). Moreover, relatively calm weather and large vessels are needed to operate the heavy and expensive gear. When a box-corer cannot be employed for various reasons, the already widely used Van Veen grab (Van Veen, 1933, with the modifications described by Dybern et al., 1976, see also Ankar, 1977, Kingston, 1988, Riddle, 1989) or Day and Smith-McIntyre grabs (Gallardo, 1965) are recommended as standard sampling gear for benthic macrofauna research, because of its comparative reliability and simplicity of handling at sea. A Van Veen grab (Van Veen, 1933) is easier to apply than a box-corer in the shallow surf zone and typically samples an area of about 0.1 m^2. Penetration depth varies from 5 to 15 cm depending on the sediment type and weight of the grab (Gallardo, 1965; Riddle, 1989; Rumohr, 2009). In a comparative study by Heip et al. (1985), no statistical differences could be detected between fauna of silty sediments sampled with a Van Veen grab and a box-corer. In another study, performed at sandy sediments close to the island of Texel in the Netherlands, it was shown that deep-living species like *Lanice conchilega* and *Nephtys* spp. were under-estimated by the Van Veen grab due to the lower penetration depth compared to the box-corer (Beukema, 1974).

Benthic dredges, epibenthic nets, and beam-trawl hauls may be valuable as an alternative or complementary to grab or box-corer samples due to the larger sampling area, shorter processing times of the samples and the higher efficiency to sample larger epifauna (Bergman et al., 2009). Considerable caution, however, is required in treating benthos data from trawls and dredges in a quantitative manner owing to uncertainties in actual sampling size and species-dependent sampling efficiency (Bergman et al., 2009). Automatic closing mechanisms and/or dredge distance recorders are needed for the data to be used quantitatively (Bergman et al., 2009; Rumohr, 2009). A quantitative benthic dredge is towed over the seafloor while the distance is recorded, for example with a paddle wheel. The sampled area (ca. 10–15 m^2) is larger compared to the Van Veen grab (ca. 0.1 m^2) and the penetration depth is fixed (e.g. 10 cm). Therefore, deep (>10 cm) dwelling macrofauna will not be collected efficiently by the benthic dredge. The sample is sieved *in situ* over larger mesh sizes (> 5 mm) and, therefore, small species like polychaetes and small crustaceans are not (well) collected. Due to the larger sampling area, the probability to collect relatively rare macrofauna species with a benthic dredge is higher compared to grab samples, while it can be expected that the total number of species in a grab sample will be higher due to the smaller mesh sizes (Callaway et al., 2002). In a comparative study, Bergman and Van Santbrink (1994) showed that due to the smaller sampling area, the variation between replicate grab samples (box-corer) was higher than for benthic dredge samples. Benthic dredges are more suitable for sampling larger, low abundant infauna species like shellfish and (mobile) epibenthic species such as crabs and starfish (Bergman and Van Santbrink, 1994).

The choice of a suitable sampling device is often a compromise between the sampling specifics of the device, local environmental conditions (e.g. sediment composition, water depth, wave dynamics), specifications and availability of vessels, financial limitations, tradition and, not least, the purpose of the survey. Also the time required for processing the samples and the required level of sampling precision will influence the choice of sampling gear (Jensen, 1981; Kingston, 1988; Rumohr, 2009). Identifying and quantifying benthic samples is often expensive and time consuming and requires a high degree of taxonomic expertise (Ferraro and Cole, 1990). Depending on the research questions, the costs efficiency can be optimized by the choice of the sampling technique and protocol for processing the samples (Lampadariou et al., 2005; Mendes et al., 2007; Pruden et al., 2021).

In this paper, a comparison is made between the macrobenthos sampled by a Van Veen grab and a quantitative benthic dredge using data from ten years (2010–2019) of monitoring at the Sand Motor, a mega beach nourishment that was implemented in 2011 in the shoreface area of the Dutch North Sea coast between Scheveningen and Hoek van Holland (Stive et al., 2013). The shallow and highly dynamic shoreface, and especially the shallow surf zone, is very difficult to sample and, as a consequence, this area received little attention in the monitoring programs executed in the Dutch coastal areas (Van Dalfsen and Essink, 2001; Janssen and Mulder, 2005; Janssen et al., 2008), although a large dataset was recently presented by Holzhauer et al. (2020). The Sand Motor monitoring program has provided a very extensive dataset on the benthic community in the shallow dynamic surf zone. As part of the Sand Motor monitoring program, the infauna and epifauna in the shoreface area was sampled simultaneously by a Van Veen grab and a quantitative benthic dredge. This dataset provides a unique opportunity to compare both complementary sampling techniques systematically. We compare total number of taxa and total density between both sampling devices. Also, the changes in species composition in space and time based on both sampling techniques are compared by multivariate analyses of the data.

Because the two devices sample overlapping but different parts of the benthic community, they can be complementary. However, because the responses of both communities over time and space due to the changed in environmental conditions (Herman et al., 2021) might be similar, the univariate and multivariate patterns in community characteristics might be similar too and therefore, the methods can be interchangeable depending on the research questions. The result of this study will help scientists and managers in their decision to choose the appropriate device for macrobenthos sampling based on research questions, local conditions and budget restrictions.

2. Materials and methods

2.1. Study area

The Holland coast is a sandy coast, subject to structural erosion (De Schipper et al., 2016). To protect the coast from erosion the Sand Motor, a mega beach nourishment, was constructed in 2011 along the Holland coast between the harbor entrances of Scheveningen in the North and Hoek van Holland in the South (Fig. 1) as an alternative to the traditional beach and shoreface nourishments (Stronkhorst et al., 2018). The Sand Motor was designed to erode and enable sand transport by natural processes (waves, tidal currents and wind) to feed the dunes and widen the beach for a 20 year period (Stive et al., 2013; De Schipper et al., 2016). The Sand Motor nourishment initially consisted of a 128 ha peninsula (19 Mm^3) and two additional shoreface nourishments north (2 Mm^3) and south (0.5 Mm^3) of the peninsula (De Schipper et al., 2016). The sand for the Sand Motor was dredged 10 km offshore to a maximum depth of 6 m below the original seafloor (Pit et al., 2017). Initially, directly after construction in 2011, the Sand Motor was about 2.5 km alongshore and 1 km wide (Huisman et al., 2016). Within the first 2.5 years the morphology of the Sand Motor has changed already from a hook into a gaussian shape (De Schipper et al., 2016). In 2018, a total of 3.5 Mm^3 sand was eroded from the initial peninsula and the head has retreated about 300 m with respect to its original position in 2011 (Luijendijk, 2021).

2.2. Sampling design

An extensive monitoring campaign was set-up to study the effect of the Sand Motor on the development of the macrobenthos community in the shoreface. The benthic infauna and epifauna was monitored in a wide area surrounding the Sand Motor using a Van Veen grab and a quantitative benthic dredge. Sampling took place in autumn of the years

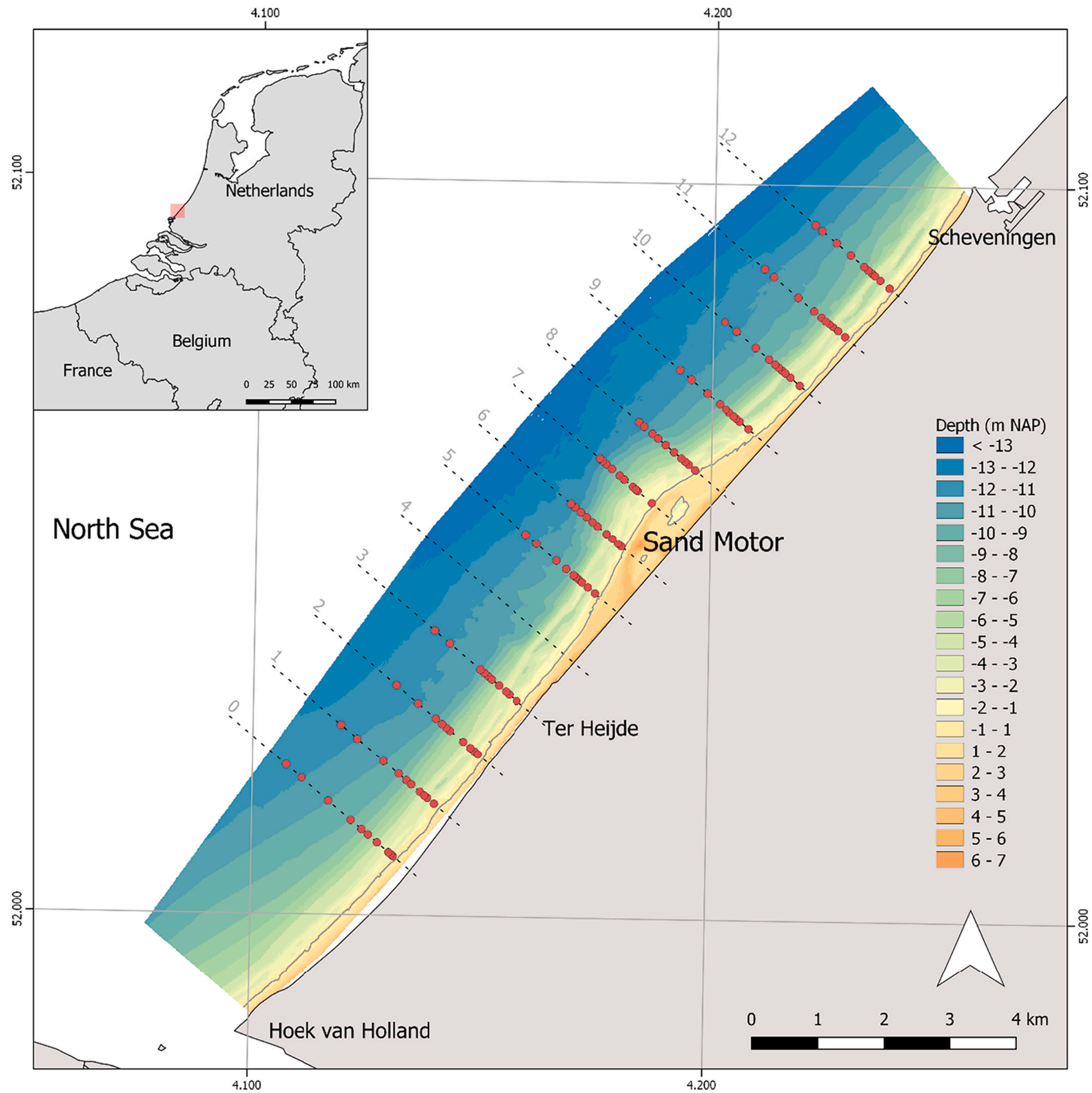

Fig. 1. Location of the Sand Motor on the Dutch North Sea coast between Scheveningen and Hoek van Holland. The bathymetric map shows the contours of the Sand Motor in august 2019. The red dots indicate the planned sampling locations for both Van Veen grab and benthic dredge in 2019. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

2010 (before construction of the Sand Motor), 2012, 2013, 2015, 2017 and 2019. To achieve a good spatial cover of the area, each year, a maximum of 120 samples were taken with both devices, evenly distributed over 12 transects perpendicular to the original coastline of 2010, stretching out over 11 km of coastline surrounding the Sand Motor (Fig. 1). Starting from 2013, an additional transect (transect 0) was sampled 1 km further southwest from transect 1 and transect 4 was skipped from the program. Along each transect, 10 locations were sampled with both devices at ten different depth classes: 1.5, 3, 4, 5, 7, 8, 9, 10, 11 and 11.5 m below NAP, i.e. Dutch Ordnance Level which is approximately mean sea level. Positions of the sampling locations were predefined based on recent bathymetry measurements.

2.3. Sampling Van Veen grab

In total 636 samples were collected in the shoreface area with the Van Veen grab (Table 1). In 2013 and 2019 it was not possible to sample all the planned location in the shallow surf zone (1.5–3 m below NAP), because of the rough weather conditions. Due to budget restrictions in 2010, only 62 samples, evenly distributed (even-numbered stations) over the area to ensure comparability with other years, were analyzed. At each sampling location a Van Veen grab sample (0.1 m^2) was collected. Onboard, the samples were sieved over a 1 mm mesh size sieve and stored in 4% buffered formaldehyde to be analyzed later in the lab. Macrobenthic organisms were identified up to species level where

Table 1
Overview (number of samples, total number of taxa and average density) of the samples collected in the nearshore of the Sand Motor with the Van Veen grab and the benthic dredge over the years.

	# samples		Number of taxa		Average density (# m^{-2})	
	Van Veen	Dredge	Van Veen	Dredge	Van Veen	Dredge
2010	62	114	77	22	951.9	18.4
2012	120	120	130	28	2163.6	136.2
2013	97	113	128	29	1356.8	100.0
2015	120	109	132	26	869.8	23.3
2017	120	107	149	27	1028.6	121.2
2019	117	113	129	32	1711.1	190.1
Total	636	676	228	42	1380.9	98.7

possible and ash free dry weight (AFDW) was measured for each species per sample. Damaged or very small individuals were sometimes identified to genus, family or higher taxonomic level. In order to avoid bias in the diversity measures (e.g. number of taxa in a sample) higher taxonomic levels were discarded from the counts of number of species whenever a lower taxon belonging to the high-level taxon was found in the sample, but it was counted as a species if this was not the case. All names were checked against the World Register of Marine Species (WoRMs - www.marinespecies.org, September 24th, 2021) and synonymized with the currently accepted names where needed.

2.4. Sampling benthic dredge

In total, 676 samples were collected with a benthic dredge (Table 1). Especially the shallow surf zone (1.5–3 m below NAP) was difficult to sample with the benthic dredge due to waves and the presence of breakwaters, resulting in an under sampled depth zone. The dredge used is similar to the device described by Bergman and Van Santbrink (1994), although the net was replaced by a stainless-steel cage (Fig. 2). The dredge was towed over the sea floor by a 40 m length fishing vessel over a distance of approximately 100–150 m parallel to the coastline, crossing the planned sampling location roughly halfway. The exact length of the sample transect was measured by a paddle wheel, equipped with a counter to record the rotations. During sampling, a stainless-steel cutting blade at the bottom of the dredge excavates a strip of sediment (10 cm wide, 10 cm deep) from the seabed. The sample is sieved *in situ* in a stainless-steel cage of 600 l with a mesh size of 5 mm. On board, the sample was further washed over a 5 mm sieve and the total volume of the sample was measured. When the sample was >6 l, a subsample of 6 l was taken. The (sub)sample was processed on-board directly. All mollusks, echinoderms and crustaceans were identified up to species level where possible and fresh weight was measured for each species per sample. Annelida were not identified and excluded from the samples, because they were not sampled quantitatively on a 5 mm sieve. Because sea potatoes (*Echinocardium cordatum*) were seldomly found intact in the dredge samples, the abundance of this species was recorded semi-quantitively. Fresh weight of hermit crabs (*Diogenes pugilator* and *Pagurus bernhardus*) was not determined as well as for otter shells (*Lutraria lutraria*), sand gapers (*Mya arenaria*) and razor clams (*Ensis* spp.) because for the last three bivalve species often only the siphons were collected. Results were stored onboard in a database. Fish, shrimps and cuttlefish, caught by the dredge were ignored in all analyses presented in this paper.

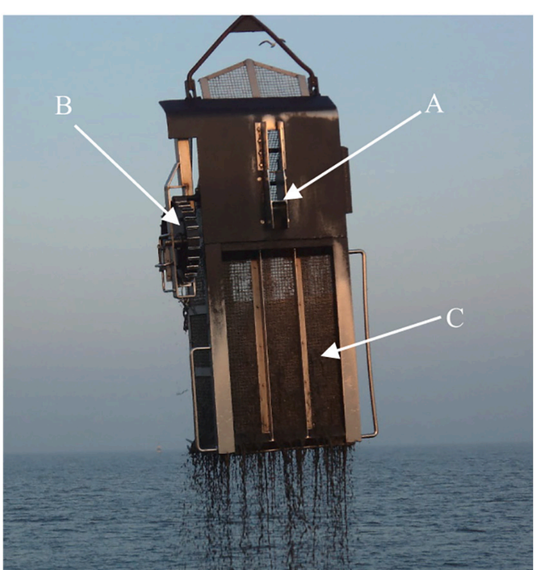

Fig. 2. Photograph of the benthic dredge filled with a sample from the bottom side. Indicated are A: stainless-steel cutting blade; B: paddle wheel to measure sampling distance and C: stainless-steel cage with 5 mm mesh.

2.5. Statistical analysis

Statistical analyses have been performed in R4.0.2. (R Core Team, 2020). Species accumulation curves were calculated using the vegan package (Oksanen et al., 2020). The average cumulative number of taxa relative to the total number of taxa, estimated as the first-order jackknife (Burnham and Overton, 1979; Palmer, 1990), was plotted against the number of samples for both the Van Veen and the benthic dredge samples.

Reduced major axis (RMA) regression was applied using the lmodel2 package (Legendre, 2018) in R to describe relationships between Van Veen samples and the benthic dredge samples with respect to the number of taxa and ln-transformed density. Stations where no living individuals were recorded in either the Van Veen grab samples or the benthic dredge samples (zero-data) were excluded from the regression analyses.

The evaluation of the patterns and changes in the macrobenthos community was evaluated by non-metric multidimensional scaling (nMDS) ordination on the density data using the vegan package (Oksanen et al., 2020) in R. The nMDS were run in two dimensions, and the minimum stress values were reached after twenty iterations for both the Van Veen and the benthic dredge data. Analyses were done separately for the Van Veen and benthic dredge data. Taxa at a higher taxonomic level than family were excluded from the analyses. Rare species are often removed from the analysis to reduce the noise (stress levels) in multivariate analyses (McCune and Grace, 2002). In this study, however, we did not remove rare species from the nMDS analyses, because they might include important indicator species for environmental conditions (Poos and Jackson, 2011). A total of 217 taxa and 635 locations were included in the nMDS analysis on the Van Veen samples and 42 taxa and 662 locations were included in the nMDS analysis on the benthic dredge samples. Before the analyses, the average abundance for each taxon was calculated per year per depth class, because there was a strong effect of water depth on the macrobenthos composition in all years (Wijsman et al., 2020). The data were transformed (fourth-root) to correct the imbalance in significance of abundant and rare taxa to the similarity (Clarke, 1993). Ordination was done on the Bray-Curtis dissimilarity indices between the groups.

In order to compare the probability of finding a taxon in a grab or dredge sample, the ratio of these probabilities under the assumption of purely random distribution of individuals in space and time was determined. The probability of finding a randomly distributed taxon in a sample is 1 minus the zero term of the Poisson distribution, with the average number of individuals per sample as the Poisson parameter. For a range of abundances, the expected number of individuals in the samples was determined based on sampled surface, and the probability of finding the taxon in both methods was compared graphically. The procedure was repeated while allowing for differences in sampled abundance, with the van Veen sampling approximately ten times higher average abundance than the dredge for the same taxon (Fig. 6).

To compare the differences in sampling effort between the Van Veen grab and the benthic dredge, the number of samples needed to find a difference between two groups was estimated using the function power. t.test() from the pwr package (Champely, 2020) in R on the data (number of taxa and fourth-root-transformed total density per sample). Calculations for a one-sample two-sided *t*-test were done using only one year of data (the most recent data of 2019) to remove the year-to-year variation. The type I error was set to 0.05, power to 0.80 and the detectable effect size to 10% of the range.

3. Results

In total 236 taxa were identified in the samples. The data from the Van Veen included more taxa (in total 228) than the benthic dredge (42 taxa) (Table 1). This is mainly caused by the larger mesh-size of the sieve present in the benthic dredge where polychaetes and small crustaceans were not identified. A total of 195 taxa identified in the Van Veen samples were not identified in the benthic dredge. On the other hand, 8 taxa (*Abra prismatica*, *Acanthocardia echinate*, *Asterias rubens*, *Corystes cassivelaunus*, *Euspira catena*, *Liocarcinus marmoreus*, *Macropodia* spp. and *Sagartia troglodytes*) recorded in the benthic dredge were not found in the samples from the Van Veen grab. A total of 34 taxa (*Echinocardium cordatum* plus the 33 taxa plotted in Fig. 6) were identified in both sampling devices. The lowest number of taxa were recorded in 2010, before the construction of the Sand Motor, both in the Van Veen grab samples and in the benthic dredge samples (respectively 77 and 22 taxa). For the Van Veen grab samples, the species accumulation curve (Fig. 3) shows that this could only be partly explained by the lower number of samples (62) analyzed in 2010, compared to the other years (Herman et al., 2021).

The first-order jackknife (Palmer, 1990) estimated a total number of 275 taxa based on the Van Veen samples and 48 taxa based on the benthic dredge samples (Fig. 3). The curve for the benthic dredge samples is steeper in the beginning than the curve for the Van Veen samples. After 50 randomly taken samples 58% of the total number of taxa are expected to be found in the benthic dredge samples, while in the Van Veen samples only 43% of the total number of taxa are expected to be found in 50 randomly taken samples. On average 14.3 taxa were recorded in a Van Veen grab sample and 5.9 taxa in a benthic dredge. In 2010 and 2013, the lowest number of taxa per sample were recorded both in the Van Veen grab (9.6 and 12.7 taxa, respectively) and the benthic dredge (2.7 and 5.0 taxa, respectively). There was a significant (RMA regression, $p < 0.05$) linear, positive relation between the number of taxa per sample in the benthic dredge and the Van Veen samples (Fig. 4; $R^2 = 0.327$; $n = 606$).

In general, the number of taxa per sample was higher in the Van Veen grab samples than in the benthic dredge. Only at 38 of the 606 locations, the number of taxa in the benthic dredge was higher than in the Van Veen.

The average density in the Van Veen grab samples was much higher (1380.9 m^{-2}) than the average density in the benthic dredge samples (98.7 m^{-2}) (Table 1). Lowest average densities were recorded both in the Van Veen and benthic dredge samples in the years 2010 and 2015. Highest average densities were found in 2012 and 2019. There is a significant ($p < 0.05$) linear relation between the (ln-transformed) density recorded in the benthic dredge and Van Veen grab (Fig. 5). The slope of the regression line (0.61) is significantly ($p < 0.05$) different from 1, indicating a non-linear relation between the density recorded with the Van Veen grab and the density recorded with the benthic dredge (Fig. 5; $R^2 = 0.39$; $n = 596$).

For the 33 taxa that were found in both sampling devices (*Echinocardium cordatum* was excluded because it was seldomly found intact), the average density in the Van Veen grab is plotted against the average density in the benthic dredge (Fig. 6). In general, there is a good correlation ($r = 0.93$) in ln-transformed average density between the two sampling devices, although on average the densities in the Van Veen are about ten times higher than the densities in the dredge. Only for *Nassarius nitidus*, the average density in the Van Veen grabs was lower than the average density in the benthic dredge. For *Spisula solida*, the density in the Van Veen was about 1.3 times the density in the benthic dredge,

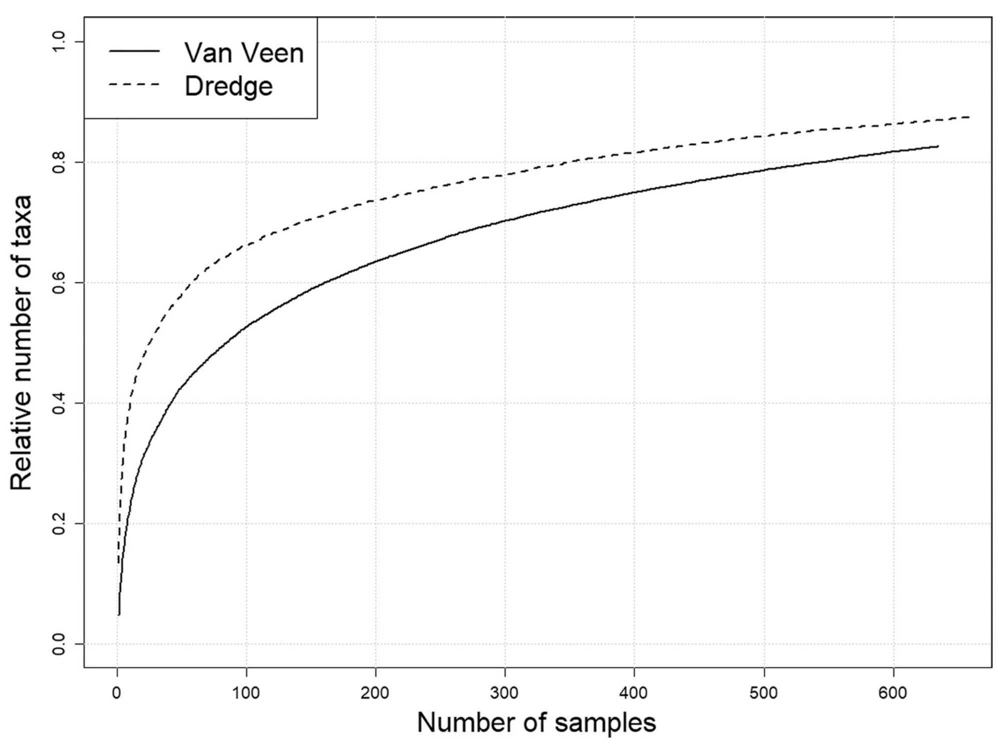

Fig. 3. Relative species accumulation curves (first-order jackknife estimates) for the Van Veen (continuous line) and benthic dredge (broken line) data.

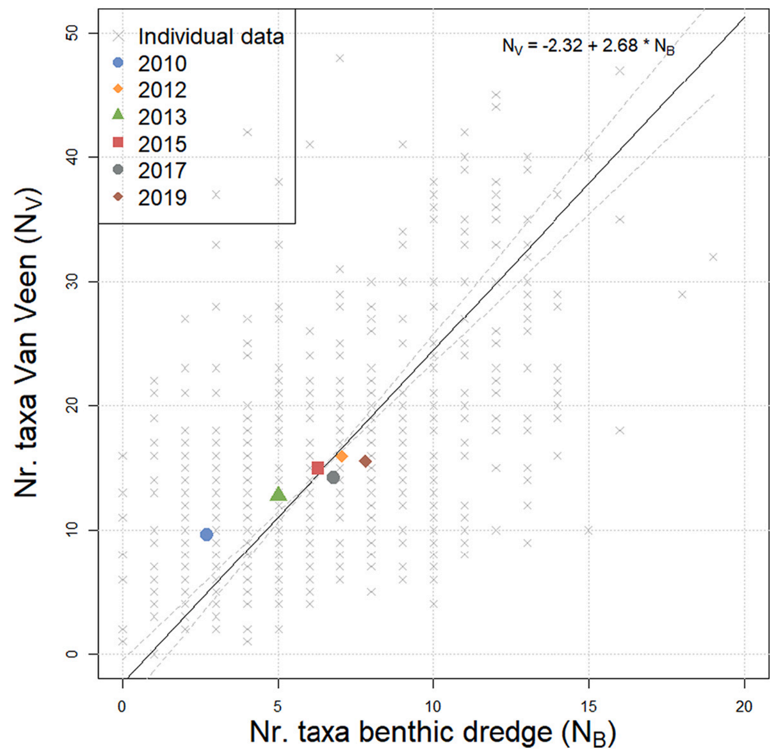

Fig. 4. Number of taxa in the Van Veen samples (N_V) against the number of taxa in the benthic dredge samples (N_B). The crosses indicate all individual sampling locations over the years where both a Van Veen grab sample and a benthic dredge sample was taken. The solid line represents the results of the model II regression through the individual data and the 95% CI ($R^2 = 0.33$). The colored markers indicate the average number of taxa per sample per year.

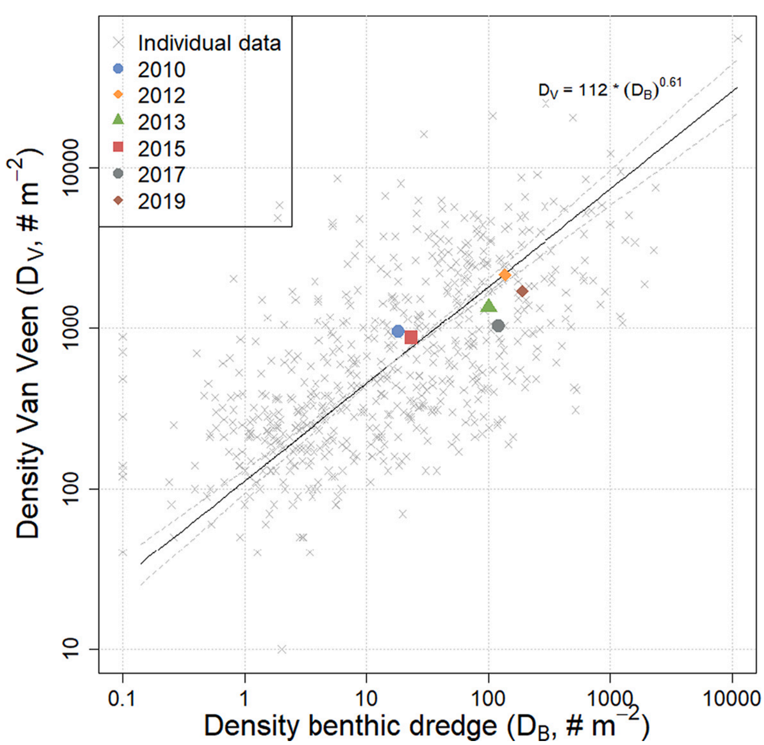

Fig. 5. Density in the Van Veen samples (D_V) against the density in the benthic dredge samples (D_B). The crosses indicate all individual sampling locations over the years where both a Van Veen grab sample and a benthic dredge sample was taken. Zero values in the benthic dredge and Van Veen are displayed in the graph as 0.1 and 10 m^{-2}, respectively. The lines represents the results to the model II regression through the individual data and the 95% CI ($R^2 = 0.39$). The colored markers indicate the average densities per year.

and for the abundant taxa *Limecola balthica*, *Donax vittatus*, *Abra alba*, *Spisula subtruncata* and *Ensis* spp., the average density in the Van Veen was about 5 times the average density in the benthic dredge. The probabilities of collecting a specific taxon, calculated by the number of samples a taxon is found divided by the total number of samples (636 and 676 for the Van Veen and benthic dredge, respectively), show that most of the 33 taxa have a higher probability to be found in a benthic dredge sample than in a Van Veen sample (Fig. 7). Considering that the surface sampled by the dredge is approximately 100–150 times larger than the surface sampled by the van Veen, this is expected. In fact, if one

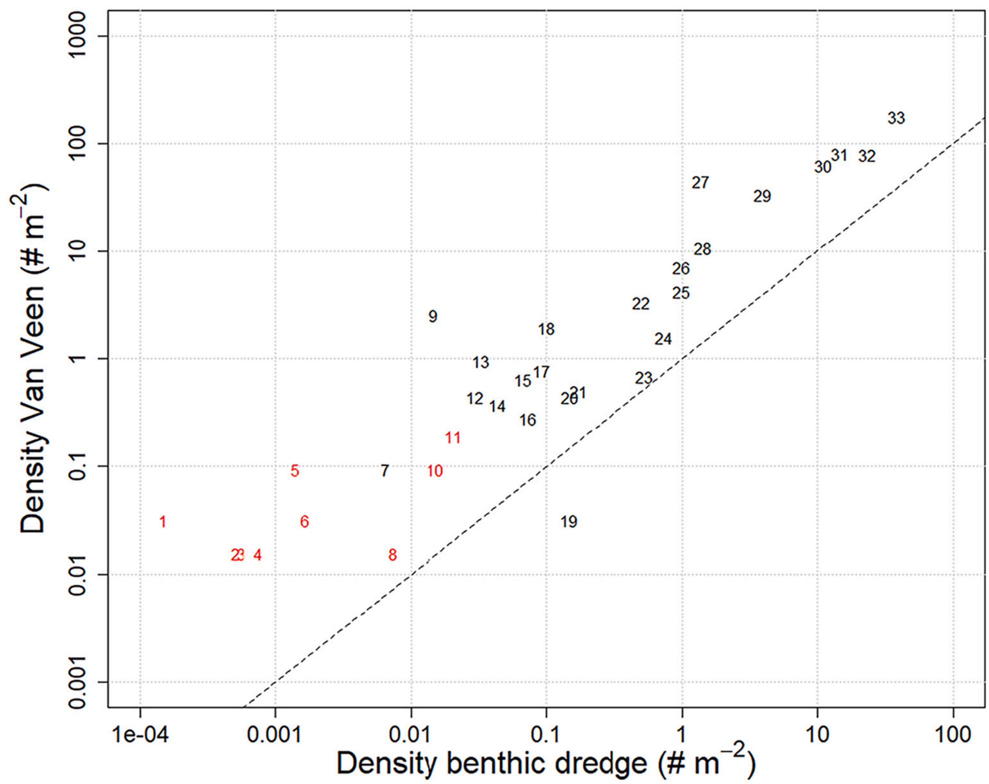

Fig. 6. Average densities (# individuals m^{-2}) in the Van Veen samples against the average densities in the benthic dredge for the 33 taxa (indicated by the numbers) that were found in both devices. (1) *Mya arenaria*; (2) *Thia scutellata*; (3) *Petricolaria pholadiformis*; (4) *Liocarcinus depurator*; (5) *Venerupis corrugata*; (6) *Pinnotheres pisum*; (7) *Carcinus maenas*; (8) *Ruditapes philippinarum*; (9) *Mytilus edulis*; (10) *Liocarcinus navigator*; (11) *Crepidula fornicata*; (12) *Ophiura albida*; (13) *Actiniaria* spp.; (14) *Macomangulus tenuis*; (15) *Spisula elliptica*; (16) *Lutraria lutraria*; (17) *Tritia reticulata*; (18) *Euspira nitida*; (19) *Nassarius nitidus*; (20) *Pagurus bernhardus*; (21) *Chamelea striatula*; (22) *Portumnus latipes*; (23) *Spisula solida*; (24) *Liocarcinus holsatus*; (25) *Ophiura ophiura*; (26) *Diogenes pugilator*; (27) *Fabulina fabula*; (28) *Mulinia lateralis*; (29) *Limecola balthica;* (30) *Donax vittatus*; (31) *Abra alba*; (32) *Spisula subtruncata*; (33) *Ensis* spp. Numbers are ordered with increasing density in the benthic dredge. Numbers in red indicate taxa that are found in <25 of the total 1312 samples. The broken line indicates where the average density in benthic dredge samples equals the average density in Van Veen samples. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

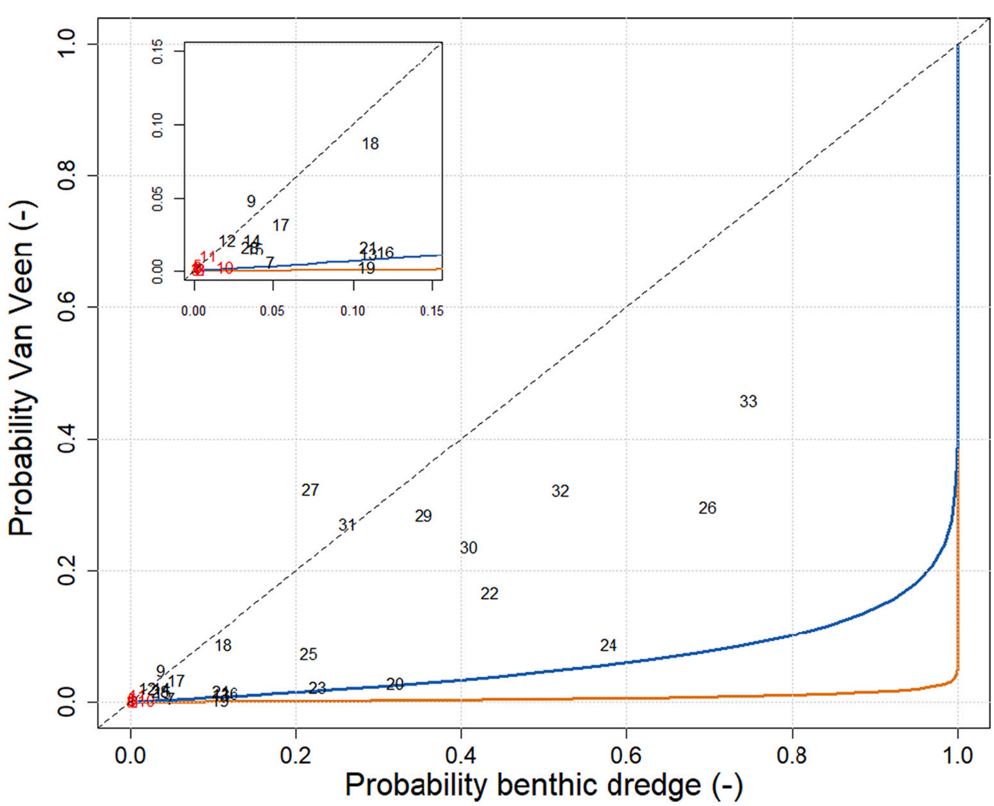

Fig. 7. Probabilities of sampling the 33 taxa with the Van Veen grab versus the benthic dredge. Numbers correspond to the taxa of Fig. 5. The orange line indicates the theoretical curve assuming a purely random distribution of the taxa and a 100–150 times larger sampling area of the benthic dredge compared to the Van Veen. For the blue line it is assumed that the Van Veen samples ten times higher average abundance than the dredge for the same taxon. The broken line indicates where the probabilities are equal for both devices. The inset shows a close-up of the lower values. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

would assume random distribution of animals over space and time, a much larger difference between the probabilities of finding the taxa would be expected (orange line in Fig. 7). Clearly, the taxa are not randomly distributed. They occur either in low (or zero) abundance and are not sampled by either method, or in relatively high abundance with a fair probability to be sampled by both methods.

The largest difference between probabilities of presence in the dredge versus the van Veen samples were found for epibenthic species like *Liocarcinus holsatus*, *Diogenes pugilator, Pagurus bernhardus, Nassarius nitidus* and *Portumnus latipes.* For these species, the difference in probability more or less conforms to the expectation from random distribution, provided one allows for one order of magnitude difference in the sampled abundances (blue line in Fig. 7), with abundances in the van Veen grab being ten times higher than in the dredge. This difference is suggested by the average abundances found (Fig. 6). The stress values of the nMDS analyses for the Van Veen data and the benthic dredge were 0.098 and 0.083, respectively (Fig. 8). The nMDS ordination plots based on the Van Veen data and the benthic dredge data show striking similarities, with an effect of water depth on the horizontal axis and an effect of year on the vertical axis. The similarity between both nMDS plots is also shown by the significant correlation ($r = 0.828$; $p < 0.001$; $n = 1653$) between the Bray-Curtis dissimilarity coefficients that the plots were based on. There is a clear distinction between stations with a water depth < 6 m NAP (depth classes 1–4) and stations with a water depth > 6 m NAP (depth classes 5–10). Characteristic species for the shallow zone are species like *Haustorius arenarius*, *Scolelepis (Scolelepis) squamata*, and *Portumnus latipes* in the Van Veen samples and *Portumnus latipes*, *Diogenes pugilator* and *Carcinus maenas* in the benthic dredge. The deeper zones are characterized by species like *Scoloplos armiger*, *Abra abra* and *Fabulina fabula* in the Van Veen and *Fabulina fabula*, *Lutraria lutraria* and *Tritia reticulata* in the dredge samples.

In both plots, there is a gradual decrease on the vertical nMDS axis from 2010 to 2019, only in the Van Veen samples, the data sampled in 2013 are more similar to 2010 than the other years. Moreover, the differences between 2012 and 2015 are more pronounced in the benthic dredge data than in the Van Veen data. Characteristic species for the first years are *Ensis* spp., *Microphthalmus similis* and *Euspira nitida*, while taxa like *Donax vittatus, Limecola balthica*, Caprellidae and *Hesionura elongata* are more abundant in the later years. The decrease of *Ensis* spp. over the time within the Sand Motor area was also described in Herman et al. (2021). The dwarf surf clam (*Mulinia lateralis*), an exotic species that was first observed in the Dutch coastal waters in 2017 (Craeymeersch et al., 2019) was observed in the Van Veen samples at the Sand Motor in 2019 at 11 locations and at 24 locations in the benthic dredge.

The power analysis on the data from the Sand Motor showed that a comparable number of samples are needed with a Van Veen grab and a benthic dredge to detect a change of 10% of the range for density (25 and 38 samples, respectively). For the number of taxa much more grab samples (43) were needed than dredge samples (9) to detect a change of 10% of the range.

4. Discussion

A well-defined sampling design, including the choice of the sampling gear is crucial to macrobenthic monitoring studies and depend to a large extent on the objectives of the study that can vary from long-term monitoring programmes following trends of macrobenthic species within ecosystems to short-term monitoring projects as part of impact studies or monitoring the effectiveness of MPAs (Kröger and Johnston, 2016; Noble-James et al., 2017). The ecological parameter of interest might range from presence, density, biomass or distribution of a particular (group of) species, to diversity indices, total density or biomass, multivariate measures or community structure (Van der Meer, 1997; Kröger and Johnston, 2016; Herman et al., 2021). Therefore, it is crucial that monitoring programmes are well-designed and statistically robust to allow conclusions to be drawn from the acquired data (Noble-James et al., 2017). The number of samples to be taken to achieve a desired level of statistical significance and of statistical power depends on the variability in the data and the required magnitude of the change to be detected (Gerrodette, 1987; Fairweather, 1991; Nicholson and Fryer, 1992; Kröger and Johnston, 2016). Thus, the sampling design of a monitoring programme, including the selected gear, determines the interpretation and the accuracy of the estimates, and of the changes therein (Van der Meer, 1997).

There are many different sampling methods and gears available to monitor macrobenthic communities in soft-sediment environments (Rumohr, 2009). Each gear has a specific selectivity that determines whether the targeted species (groups) are effectively sampled. In this study a comparison is made between a Van Veen grab and a quantitative benthic dredge. Both gears sample different, but overlapping parts of the benthic community and, as a consequence, partly lead to different results. The samples of the Van Veen grab are sieved over a smaller mesh size (1 mm) compared to the benthic dredge (5 mm). As a consequence, during the Sand Motor monitoring program, much more taxa were recorded in the Van Veen samples (228 taxa) than in the benthic dredge samples (42 taxa). Also the densities in the Van Veen samples were higher. This difference is partly due to the small species like polychaetes and small crustaceans that are collected and identified in the Van Veen but not in the benthic dredge. For another part, it is due to the difference in sieve mesh size used and possibly to different catch efficiencies, leading to an order-of-magnitude differences in estimated abundances, also for taxa sampled by both methods (Fig. 6). In comparison to a Van Veen grab, the benthic dredge samples a larger area (0.1 and 10–15 m^2, respectively). As a result, the chance for a species to be sampled by the benthic dredge is higher compared to the Van Veen grab (Fig. 7), and moreover, 8 taxa were identified in the benthic dredge that were not recorded in the Van Veen samples. Because the dredge is towed over ca 100–150 m, a single sample can be expected to be a composite of communities from slightly different habitats. Reiss et al. (2010) state that mobile epifauna is more efficiently sampled with the benthic dredge than with a Van Veen. This is partly confirmed by the fact that from the 8 taxa that were identified in the benthic dredge and not in the Van Veen, 6 species were epifauna of which 5 species were more or less mobile. Also the species with the largest difference in the probability of being sampled by the benthic dredge compared to the Van Veen (*Liocarcinus holsatus*, *Diogenes pugilator, Pagurus bernhardus, Nassarius nitidus* and *Portumnus latipes*) are relative mobile epifauna species. Yet, despite its much larger sampled surface (100–150 times larger), the dredge does not have a proportionally larger probability of finding taxa in the sample, due to the non-random distribution of individuals in space and time. Where taxa occur, they tend to occur in densities that allow the Van Veen to detect them with a relatively high probability, even if it only has a small sample surface.

Despite the obvious differences between the results from the benthic dredge and the Van Veen samples because they (partly) sample different parts of the benthic community, the spatial and temporal patterns of the communities as reflected in the ordination plots (Fig. 8) show strikingly similar responses. This indicates that both devices measure up to a certain extent the same response of the benthic community to changes in environmental conditions due to the construction of the Sand Motor. The data from both the Van Veen grab samples and the benthic dredge samples show that the macrobenthos community in the study area around the Sand Motor has changed from 2010 to 2019. The largest differences are between 2010, before the construction of the Sand Motor, and the other years, both in diversity and composition of the macrobenthos community. Herman et al. (2021) show that for the Van Veen data, the lower species diversity in 2010 compared to the other years could only be partly explained by the lower number of samples in 2010, and is primarily the result of an increase in diversity among samples after the construction of the Sand Motor. The presence of the Sand Motor has influenced the local physical characteristics (e.g. morphology, grain size and bottom shear stress) (Huisman et al., 2016; Luijendijk et al., 2017), resulting in stronger spatial differences in species richness in the shoreface area and therefore increased overall biodiversity in the area (Herman et al., 2021). Ordination plots for both gear types (Fig. 8) show that also after the construction of the Sand Motor, the macrobenthos community is developing, and is even diverging further from the situation in 2010. This can be explained by the fact that the Sand Motor was still present and active in 2019 and influenced the environmental conditions like morphodynamics,

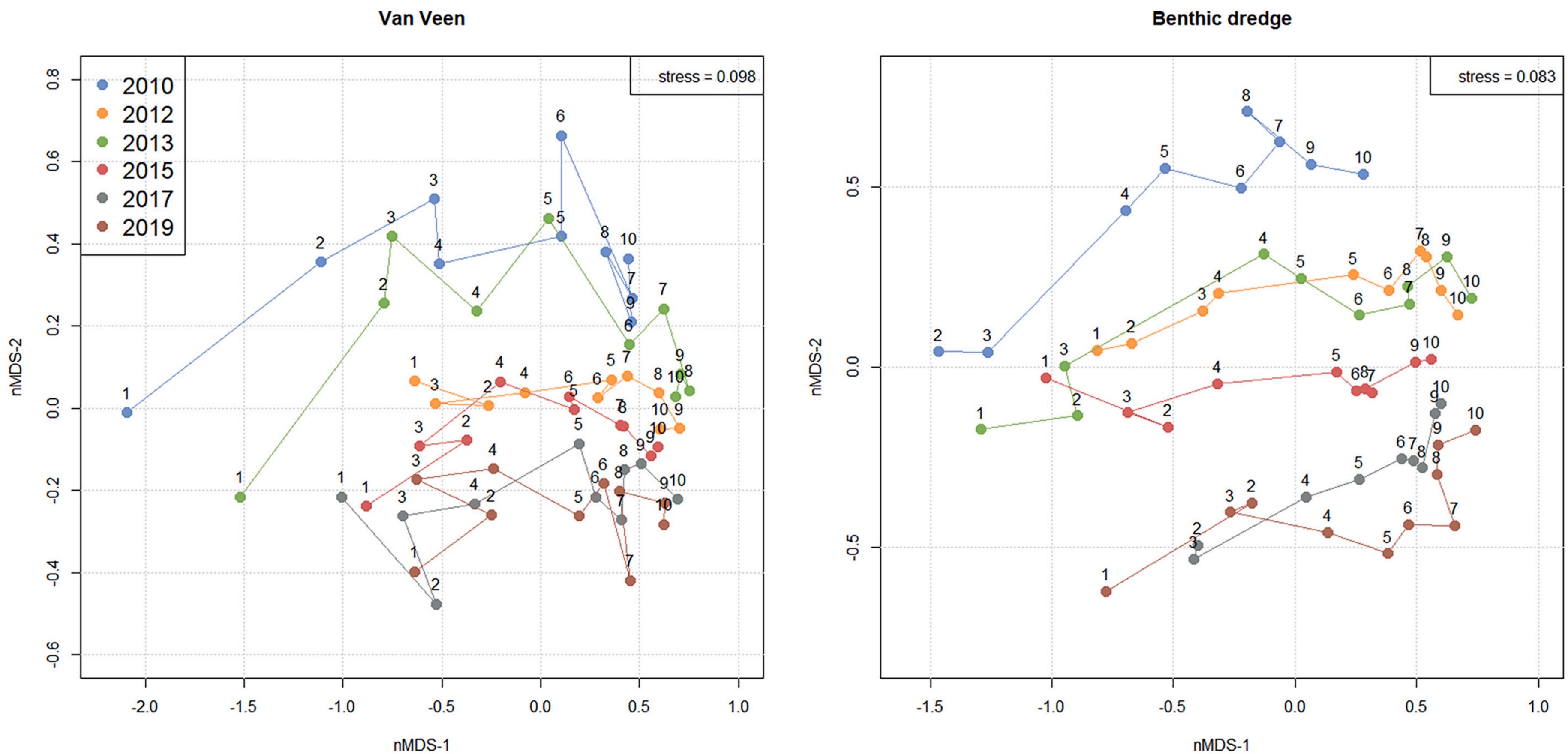

Fig. 8. nMDS ordination plots of the macrobenthos abundance in the nearshore area of the Sand Motor. The left panel is based on the data from the Van Veen grab and the right panel is based on data from the benthic dredge. The data are averaged per year (colors) per depth class (labels), where the numbers 1 to 10 represent the depth classes 1.5, 3, 4, 5, 7, 8, 9, 10, 11 and 11.5 m below NAP, respectively.

sediment composition and bottom shear stress within the vicinity of the peninsula.

Although both devices are complementary they cannot always be used simultaneously in all studies and choices should be made beforehand. In order to address questions related to biodiversity for example in the context of specific indicators, a Van Veen grab is preferred, because much more species are sampled including many smaller species (polychaetes, small crustaceans) that are not sampled by a benthic dredge. Additionally, the Van Veen grab can be used to sample sediment simultaneously with the macrofauna. Information on sediment composition can give valuable information on the local environmental conditions of the sampled benthic community (Herman et al., 2021). When questions are addressed related to fishery, or impact on higher trophic levels (fish, birds), the quantitative benthic dredge might be preferred because it likely samples the size classes (and hence species composition) of potential target species that are most important for fishery and the predatory birds and fish: shellfish and epibenthic species such as echinoderms and larger crustaceans. As can be seen from Fig. 5, the exponent of the regression is <1 indicating that the relative difference in density between the Van Veen and benthic dredge is highest at low densities. It shows that where density is low, the animals also tend to be small and difficult to catch with the dredge. This could represent a general pattern, but it could also be specific for the shallow foreshore zone, where there is a strong gradient in both density and average individual size with depth (Wijsman et al., 2020).

Both gears might also differ in the life history characteristics of the species pool sampled. Body size and longevity for example are the most important traits when considering the impacts of bottom fishing (Bolam et al., 2017). Consequently, the scarcity of vulnerable larger species in grabs or box-corers makes this sampling device less effective in finding differences in the benthic communities of fished and unfished areas (Duineveld et al., 2007). To isolate the effects of other pressures, other - often multiple - response traits might be more effective, taking into account both resistance and recovery time (Beauchard et al., 2017). This will, among others, determine the sampling device to be preferred.

There is a clear difference in effort and thus costs for sampling macrobenthos with a Van Veen grab and a benthic dredge. For a benthic dredge, a larger ship with a specific winch is needed to tow the 650 kg (empty weight) dredge over the sea floor. For the sampling with a Van Veen grab, a smaller and most likely cheaper vessel, equipped with a crane to lift the 90 kg (empty weight) grab, can be used. Moreover, a Van Veen grab can be used to sample soft-bottom macrobenthos in area's with local hard substrate structures like rocks, boulders or breakwaters, where sampling with a towed dredge is not possible.

The processing onboard of the benthic dredge samples takes more time than the processing of the Van Veen samples. This is because the sample of the benthic dredge is sorted, and almost all species are identified by specialized taxonomists onboard, while the catch of the Van Veen grab is only sieved onboard over a 1 mm-mesh sieve and the sample is preserved for further processing of the samples in the lab. On average 4 times more samples were processed on board per day with a Van Veen grab compared to the benthic dredge during the field campaigns of the Sand Motor. While the data from the benthic dredge are directly available after the field work, the processing of the Van Veen samples is labor-intensive, where 1 to 3 samples can be processed per day per person, depending on the composition of the sample, by specialized taxonomists. Overall, during the Sand Motor field campaigns, sampling with the Van Veen grab was much more labor-intensive than the sampling with the benthic dredge.

The power analysis showed that much more samples are needed from a Van Veen grab than from a benthic dredge to detect differences in the number of taxa. For differences in density, the reverse is true, and more dredge samples are needed than Van Veen samples. The difference in power reflects the sensitivity of the methods for both variables. The number of taxa found in the grabs – sampled on a 1 mm sieve – is much larger than found in the dredge (Table 1). In addition, the grabs do not average over relatively large spatial scales of order 100 m, but reflect the local community. Consequently, the variance is much larger (70.5 and 8.4 for Van Veen and benthic dredge, respectively), and more samples are needed for a given accuracy, power and detectable effect size. In reverse, it can be expected that many more subtle differences between habitats can be resolved, thanks to the higher taxonomic resolution of this sampling method. For total density, it was shown that the relative efficiency of the dredge decreases at low density (exponent < 1 in Fig. 5), and thus the dredge is more sensitive to differences in total carrying capacity of different habitats. Where Van Veen samples may reveal replacement of dominant large species by smaller species, this phenomenon remains unnoticed in the dredge samples, exacerbating the density differences. A lower statistical power is an expected corollary of this enhanced sensitivity. However, for the density of individual species the situation may be different. Bergman and Van Santbrink (1994) found that for several species much more box-corers had to be taken than dredge samples to achieve the same level of power for differences in density, due to spatial heterogeneity of the species within the study area.

Although the data used in this study only based on the monitoring within one specific area (ca 30 km^2 shallow sandy shoreface area of the Sand Motor), we assume that the results might also apply to other sandy coastal areas with comparable environmental conditions. Long-term monitoring data in the Dutch coastal waters show that the benthic community near the Sand Motor does not differ largely from the other locations (Data Wageningen Marine Research).

5. Conclusions

In this paper, unique data is presented from 10 years monitoring in the shallow dynamic waters of the Sand Motor sampled simultaneously by two different techniques, a Van Veen grab and a benthic dredge. The data from the Van Veen grab shows higher densities and species diversity than the benthic dredge samples that can to a large extent be explained by the selectivity of the devices, where smaller species (<5 mm) are not sampled or identified in the benthic dredge samples. On the other hand, mobile epibenthic species and larger species (>5 mm) that are less dominant have a better chance to be found in a single benthic dredge sample than in a single Van Veen sample. Therefore, both sampling methods can be complementary. Despite the fact that both methods sample different parts of the benthic community, they reflected similar responses over time and space in this study. The data from the Sand Motor show, for both devices, that the macrobenthos (infauna and epifauna) community in the shoreface area is strongly correlated with water depth and is developing over time. Eight years after construction, the Sand Motor still had a clear effect on the macrobenthos community in the shoreface area.

The choice between a Van Veen grab and a benthic dredge to sample the macrobenthic community depends on the research question. For questions focusing on biodiversity, a Van Veen grab, possibly supplemented by a benthic dredge, is preferred. When the questions are focusing on larger (epibenthic) species like shellfish and crustaceans, which are an important food source for higher trophic levels like birds and fish, a benthic dredge might be preferred, especially because it is less time consuming and the data become available at an earlier stage.

Data availability statement

All data used for this study are publicly available through Rijkswaterstaat Informatiehuis Marien.

Author contributions

JW: Methodology; Data curation; Investigation; Formal analysis; Writing - Original draft preparation. JC: Formal analysis; Writing - Review & Editing. PH: Writing - Review & Editing.

Declaration of Competing Interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

Jeroen Wijsman reports financial support was provided by Rijkswaterstaat Ministry of Infrastructure and Water Management.

Data availability

Data will be made available on request.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.seares.2022.102259.

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