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ABSTRACT

Offshore Wind Farms (OWFs) in the English Channel and along the coast of Normandy (France) will be installed on coarse sediments, which cover about 80% of the seabed of the English Channel. A BACI (Before After Control Impact) approach has been recommended by the French State for each of these OWFs. This provides the opportunity to acquire macrofauna data and assess the Ecological Quality Status in areas that are poorly sampled. In the case of the Dieppe-Le Tréport (DLT) OWF, for that, a sampling strategy was developed in 2014–2016 to establish a 'Before' state for the sediment and macrofauna. Results highlight that the DLT OWF project site includes three different sediment type: sandy Gravel (sG), gravelly Sand (gS) and medium Sand (mS). Taxonomic Richness and abundances are dominated by Annelids in all three habitats, followed by Arthropods and Molluscs. In terms of biomass, Molluscs (bivalves) are predominant in sG and gS, while Echinoderms and Polychaetes along with bivalves represent a high fraction of the biomass in mS. Surface Deposit Feeders are the most important group in terms of abundance, while Filter feeders largely dominate the biomass. The benthic indices based on abundances reveal a high Ecological Quality Status for the three sediment types. However, due to the predominant contribution of the bivalve *Glycymeris glycymeris* to the biomass, the habitat quality appears to vary from moderate to bad. In comparison with other similar habitats, the Taxonomic Richness and Abundances of coarse sediments and medium sand are in the same order of magnitude as other sites. However, the biomasses are among the highest so far recorded, reflecting the importance of this area as a hotspot of biomass in the English Channel.

1. Introduction

The seabed of the English Channel (EC) corresponds to an extensive network of paleo-valleys, partly filled at the present-day with coarse sediments, sometimes over several metres thick, which represent an important source of accessible aggregates (Gupta et al., 2007). This extractive activity is in full development along the French coast of the EC, with concessions having been allocated offshore of Dieppe, Le Havre and Cap Gris-Nez in the eastern part of the EC (Dauvin, 2019). Indeed, coarse sediments make up about 80% of the surficial sediments of the EC (Larsonneur et al., 1982; Dauvin, 2015, 2019).

Historically, these sediment types were sampled with dredges during explorative surveys carried out by teams led by Norman Holme (UK) and Louis Cabioch (F) in the 1960s and 1970s to assess the distribution of benthic communities (see Dauvin, 2015). The types of equipment used allowed the collection of large volume of coarse sediment including pebbles; moreover, most of collected sediment was sieved on a 2-mm mesh to prevent the sampling of juveniles and small benthic species (Dauvin, 2015). As a result, very little quantitative data has been acquired at the scale of the EC on coarse sediment type with sieving of samples on 1-mm mesh. For example, recent data has been collected during several scientific programmes, i.e. PNEC Bay of Seine (Ghertsos, 2002; Dauvin and Ruellet, 2008), INTERREG CHARM programme (Garcia et al., 2011; Foveau et al., 2013), and the 'PER Manche Orientale' site for aggregate extraction offshore in the Bay of Seine (Lozach and Dauvin, 2012); these samples were taken with a Hamon grab (0.25 m^2) and sieved on a 2-mm mesh size. Moreover, due to the difficulties of sampling such coarse sediments and their relatively long distance from the coast, quantitative data is still rather scarce (Eleftheriou and Holmes, 1984; Dauvin, 1988, 2015; Lozach and Dauvin, 2011).

Although macrobenthic coarse sediment communities have been identified and described, their functioning and their capacity to respond to natural and anthropogenic stresses remains insufficiently studied (Garcia, 2010; Foveau et al., 2013). Much of the research on these topics

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is related to aggregate extraction and the associated physical and macrobenthic disturbances (Newell et al., 1998; Bolam and Rees, 2003; Birklund and Wijsman, 2005; Foden et al., 2009, 2010; Desprez, 2000; Desprez et al., 2010; Le Bot et al., 2010; Barrio-Froján et al., 2011).

As part of the energy transition, the French government is planning the construction of Offshore Wind Farms (OWFs) at three sites in Normandy in the eastern English Channel (eEC)., i.e. Courseulles-sur-Mer in the Bay of Seine, and Fécamp and Dieppe-Le Tréport, along the coast of the Seine-Maritime department. These OWFs will be installed on seabed sediments dominated by coarse sand and gravel at the first two sites, and by pebbles at Fécamp. Moreover, this new human activity is to be introduced into an ecosystem already facing multiple anthropogenic disturbances in this part of the EC (i.e. granulate extraction, deposit sediment, fishing, maritime traffic…) (Dauvin and Lozachmeur, 2006). The installation of offshore wind farms in Normandy will begin with Fécamp in 2021 and Courseulles-sur-Mer in 2022, while Dieppe-Le Tréport (DLT) is programmed to be built after 2023. These three future OWF have been subjected to an Environmental Impact Assessment (EIA) in order to identify both the environmental conditions and ecosystem functioning in selected sites. In addition, a BACI (Before After Control Impact) approach has been recommended by the French State. Here, we present the EIA part focused on the description of the benthic communities of the future DLT OWF before its construction. Thus, this study meets the specific baseline environment guidelines of European EIA. Applying the BACI approach to the DLT site, a sampling strategy was developed in 2014–2016 to establish a ‘Before’ state for the sediments and macrofauna before any eventual industrial impact on this coastal ecosystem. This plan allowed us to acquire new quantitative data over an area of about 100 km^2 and assess its Ecological Quality Status before construction of the wind farm. In the future, stations situated near future turbines should be monitored to observe the probable changes of organic matter content and fine particles as well as any increase of small polychaetes species indicative of organic matter enrichment and so to determine the effects of OWF construction on the benthos communities. For that, the same methodology will be used in the monitoring program.

The objectives of our study are: 1) to provide quantitative data on the taxonomic richness, abundance and biomass of the macrofauna of a future OWF before its implementation; 2) to determine Ecological Quality Status not only according to abundance but also biomass; 3) to characterize the structure of the benthic trophic network. In addition, the study results were also discussing with available data for the same type of sediment in the English Channel and other parts of the worldwide Ocean.

2. Materials and methods

2.1. Study site

The eEC is a shallow epicontinental sea located between France and United Kingdom (UK), delimited by the Cotentin peninsula in the west and the Dover Strait to the east and covering an area of ~ 35,000 km^2 (Dauvin, 2019). An important physical characteristic of the eEC is its tidal range, more than 5 m on the French coast but closer to 2 m on the UK side (Dauvin, 2019). Another important feature is the resulting sea currents, which play an essential role in controlling the distribution of sediment characteristics and benthic communities (Larsonneur et al., 1982; Dauvin, 2015). Several human activities take place in the eEC, such as shipping, fishing, deposition of dredged sediment, aggregate extraction and operation of offshore wind farms (Dauvin, 2019), and this marine area is indeed considered by Halpern et al. (2008) as one of the most disturbed seas in the world.

2.2. Dieppe-Le Tréport offshore wind farm

The project is supported by “Eoliennes en Mer de Dieppe-Le Tréport, EMDT”, a subsidiary of Engie (formerly GDF Suez). The future OWF will be located 15 km from Le Tréport and 17 km from Dieppe (Fig. 1). The future OWF will cover a total area of 92 km^2, including a total of 62 turbines of 8 MW each for a combined nominal capacity of 496 MW. The foundations will be composed of jacket structures. At this site, the water depth ranges from 12 to 25 m.

2.3. Sampling design and sample treatments

To investigate the structure of the benthic communities, a sampling design was developed to acquire information on the minimum and maximum values of macrofauna abundance and biomass in the English Channel over a two-year period. Sampling was carried out on four dates at two seasons (summer: 2014/2015 and winter: 2015/2016) and during two years (year 1: summer 2014/winter 2015; year 2: summer 2015/winter 2016). The macrofauna was sampled at 25 stations: 20 stations located inside the OWF and 5 stations outside the OWF (Fig. 1). Benthic macrofauna was sampled at each station by five replicates with a 0.1 m^2 Van Veen grab (total of 0.5 m^2 for each station) adapted to sample mobile benthic macrofauna. Samples were sieved on board using a circular 1-mm mesh, with the retained material being preserved in 10% formaldehyde combined with rose Bengal staining to facilitate the sorting of organisms from sediments in the laboratory. In the laboratory, the organisms were identified at the species level whenever possible. At each benthic macrofauna sampling site, one additional station was sampled to determine the grain size distribution and organic matter.

Taxonomic richness, abundance and biomass were recorded for each replicate. To determine the biomass, each taxa was dried for three days at 60 °C (to obtain dry weight) and then calcined at 500 °C (to obtain weight after calcination) for 5 h; the biomass is the difference between these two weights, expressed as AFDW (Ash Free Dry Weight) per 0.1 m^2 sampling area and standardized to 1 m^2.

The grain size distribution of a sediment sample was determinated firstly by the estimation of the fine fraction (<50 μm) which was obtained by wet sieving and rinsed with fresh water to remove the salt. Then, the coarser sediment fractions (>50 μm) were sieved on a sieve shaker using 33 sieve-column (<50 ; 50; 63; 80; 100; 125; 160; 200; 250; 315; 400; 500; 630; 800; 1,000; 1,250; 1;600; 2,000; 2,500; 3,150; 4,000; 5,000; 6,300; 8,000; 10,000; 12,500; 16,000; 20,000; 25,000; 31,500; 40,000; 50,000; 63,000). The sieve choice was according to the Wentworth’s (1922) classification modified by Folk (1954), Folk and Ward (1957) and Folk (1966) and permit to determine the sediment type of each station with the use of Folk diagram. For each station, the sediments were characterized by three main sedimentary fractions: gravel (>2 mm); sand (2 mm – 63 μm) and silts-clays (<63 μm).

Samples for organic matter (OM) analysis were dried for three days at 60 °C and then calcined at 500 °C for 4 h.

2.4. Taxonomic diversity analysis

Data were used to calculate the Taxonomic Richness (TR, number of taxa per 0.5 m2), abundance (number of individuals per 1 m2), biomass (g AFDW per 1 m2) and diversity indices for each station. The Shannon-Weaver diversity index (H’) in $\log_2$ and Pielou’s evenness (J) were calculated both on abundance and biomass for the 25 stations at the four dates (data for 0.5 m^2). Ecological Status was estimated from H’ values according to the thresholds defined previously by Vincent et al. (2002): 0–1, bad; 1–2: poor; 2–3: moderate; 3–4: good and > 4: high. For J, the thresholds are < 0.2: bad; 0.2–0.4: poor; 0.4–0.6: moderate; 0.6–0.8: good and > 0.8: high (Dauvin et al., 2017). Data analysis was performed using the PRIMER version 6 software package (Plymouth Routines in Multivariate Ecological Research) (Clarke and Gorley, 2006). The biotic indices AMBI and BO2A were also calculated on abundance to assess the ecological status of the benthic macrofauna for each sediment type (Borja et al., 2000, 2009; Dauvin et al., 2016; Dauvin, 2018) for each sediment type.

The AMBI (AZTI Marine Biotic Index) is a tool developed by Borja

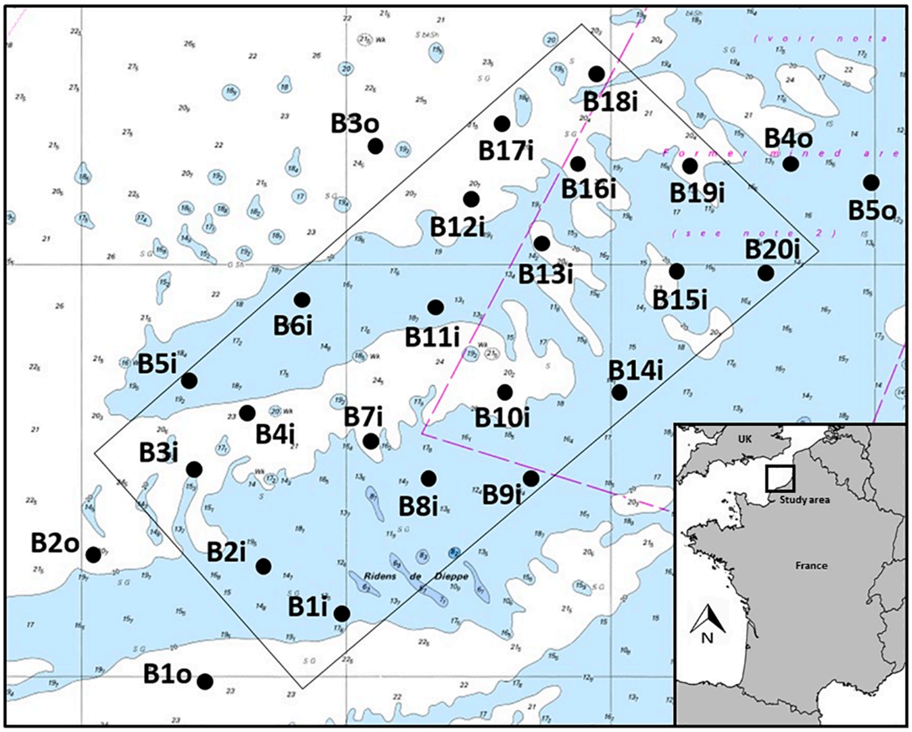

Fig. 1. Localisation of the 25 benthic stations in the perimeter of the future Dieppe-Le Tréport Offshore Wind Farm (B1i to B20i: stations inside the perimeter; B1o to B5o: stations outside the perimeter).

et al. (2000), which is applied here to analyse the proportions of five ecological groups (we use the species list published by the AZTI web site on 23 June 2017 http://ambi.azti.es/) according to a gradient of organic matter enrichment for each sediment type. Moreover, AMBI was calculated on biomass. For AMBI, the thresholds are <1.2: high; 1.2–3.3: good; 3.3–4.3: moderate; 4.3–6: poor; >5.5: bad. The BO2A (Benthic Opportunistic Annelids Amphipods) Index is calculated as $\log_{10}$ of the ratio of frequencies for opportunistic annelids and amphipods: i.e. the total number of opportunistic annelids and total number of amphipods +1 divided by the overall abundance counted in a sample (see Dauvin et al., 2016). For BO2A, thresholds are <0.0245: high; 0.0246–0.1300: good; 0.1301–0.1988: moderate; 0.1989–0.2551: poor; 0.2552–0.3010: bad.

Finally, the species were classified into six trophic groups according to those selected in Pezy et al. (2020): filter feeders, grazers, surface deposit feeders (sDF), sub-surface deposit feeders (ssDF), scavengers and predators. The biomass and the abundance of these six trophic groups were obtained from the average data of the four cruises.

2.5. Univariate analysis on the three sediment type (sandy Gravel, gravelly Sand and medium Sand)

A two-way ANOVA with interaction was used to test temporal changes; (seasons: summer (2014; 2015) and winter (2015; 2016) and years factors: year 1 (summer 2014; winter 2015) and year 2 (summer 2015; winter 2016) for sediment composition and organic matter for the three sediment type (sG; gS and mS) for all the stations. A two-way ANOVA with interaction was used to test spatio-temporal changes (season and sediment type factors) for TR, A, H', J, AMBI, and BO2A. Prior the application of this analyse, the Healy method (1962) was used to test if the number of stations in each sediment type (sG; gS and mS) was adequate for use the sediment type as factor for comparison. Prior to each ANOVA, a Shapiro-Wilk test and a Bartlett test for homogeneity of variances were performed. The Tukey Honestly Significant Difference test was applied when ANOVA showed significant differences. The R software package is used to perform ANOVA as well as the Shapiro, Bartlett and Tukey tests.

2.6. Multivariate analysis

Data analysis was performed by non-metric Multidimensional Scaling Ordination (MDS), and Hierarchical Ascendant Classification (HAC) created using group average linking with the Bray-Curtis similarity measure using the PRIMER-6 software package (Plymouth Routines in Multivariate Ecological Research). $\text{Log}_{10}(x + 1)$ transformed abundances (0.5 m^2) were used to down-weight the importance of very abundant species (factor 1,000 between taxa). Square root transformed biomass (0.5 m^2) were used to down-weight the importance of high bivalves biomass (factor 100 between taxa). All the taxa were taken into account in the analyses and an unique matrix was created (mean average of the four cruises). To identify those species within different groups which primarily account for the observed assemblage differences, SIMPER (SIMilarity PERcentage) routines were performed using a decomposition of Bray-Curtis similarity on log transformed abundance data (Clarke and Gorley, 2006). One-way ANOSIM (Analysis Of SIMilarities) permutation test is used to assess if the assemblages differences between sampling stations are statistically significant.

3. Results

3.1. Sediment characteristics

The table 1 summarizes the results obtained from the mean average of the four cruises, the Folk classification was also established from these data (Table 1). The sediments are composed of a mixture of very coarse sand and gravel (0.4 to 68.0%) and sand (30.7 to 99.8%), the percentage of fine particles (silt-clay) is very low (less than 1% except for B5o with 1.5%) (Table 1). According to Folk (1954), three sediment types can be identified: sandy Gravel (sG) (12 stations over an area covering 41.5% of the extended perimeter), gravelly Sand (gS) (8 stations over an area of 43.0%) and medium Sand (mS) (5 stations over an area of 15.5%) (Fig. 2). No significant differences of gravel and sand proportions

Table 1
Mean Gravel (>2,000 μm), Sand (63 μm – 2,000 μm), Silt-Clay (<63 μm) sediment composition and Organic Matter (OM) with standard deviation and Flok classification at the 25 sampled stations for the four cruises. i: inside the OWF; o: outside the OWF.

	Gravel	Sand	Silt-Clays	OM	Folk classification
B1i	53.1 ± 2.5	46.2 ± 3.3	0.3 ± 0.3	2.8 ± 1.3	sandy Gravel
B2i	41.4 ± 11.4	58.5 ± 11.5	0.1 ± 0.1	2.7 ± 1.5	sandy Gravel
B3i	43.8 ± 3.8	53.5 ± 3.0	0.3 ± 0.2	2.8 ± 0.7	sandy Gravel
B4i	59.6 ± 20.1	38.9 ± 19.3	0.7 ± 0.8	2.3 ± 0.9	sandy Gravel
B5i	47.1 ± 9.7	51.8 ± 9.2	0.2 ± 0.2	1.8 ± 0.4	sandy Gravel
B6i	40.0 ± 11.5	57.9 ± 13.6	0.1 ± 0.1	3.1 ± 1.7	sandy Gravel
B7i	33.7 ± 21.2	65.7 ± 21.4	0.6 ± 0.5	1.8 ± 0.5	sandy Gravel
B8i	14.2 ± 1.7	85.7 ± 1.7	0.02 ± 0.0	1.4 ± 0.1	gravelly Sand
B9i	20.5 ± 3.2	78.9 ± 2.7	0.1 ± 0.1	1.8 ± 0.8	gravelly Sand
B10i	6.7 ± 8.1	93.2 ± 8.1	0.1 ± 0.1	0.9 ± 0.3	gravelly Sand
B11i	40.4 ± 4.7	59.3 ± 4.6	0.2 ± 0.3	1.8 ± 0.9	sandy Gravel
B12i	37.4 ± 15.0	62.3 ± 15.1	0.3 ± 0.2	1.8 ± 0.5	sandy Gravel
B13i	13.5 ± 3.7	86.4 ± 3.7	0.2 ± 0.1	1.5 ± 0.2	gravelly Sand
B14i	1.1 ± 0.5	98.8 ± 0.5	0.1 ± 0.1	1.0 ± 0.4	medium Sand
B15i	0.4 ± 0.2	99.6 ± 0.2	0.02 ± 0.0	1.2 ± 1.3	medium Sand
B16i	28.1 ± 6.7	70.9 ± 6.4	0.2 ± 0.2	1.3 ± 0.2	gravelly Sand
B17i	33.8 ± 11.2	66.1 ± 11.3	0.1 ± 0.1	2.6 ± 0.2	sandy Gravel
B18i	30.4 ± 7.4	69.3 ± 7.4	0.2 ± 0.2	2.1 ± 0.3	sandy Gravel
B19i	11.8 ± 5.3	88.0 ± 5.3	0.1 ± 0.	1.2 ± 0.2	gravelly Sand
B20i	0.2 ± 0.2	99.7 ± 0.1	0.3 ± 0.2	0.5 ± 0.0	medium Sand
B1o	68.0 ± 12.5	30.7 ± 11.5	0.9 ± 1.1	2.4 ± 0.5	sandy Gravel
B2o	28.0 ± 7.8	72.0 ± 7.8	0.03 ± 0.0	2.7 ± 0.2	gravelly Sand
B3o	29.3 ± 10.4	70.1 ± 11.0	0.2 ± 0.0	2.6 ± 0.6	gravelly Sand
B4o	0.1 ± 0.1	99.8 ± 1.1	0.1 ± 0.0	0.6 ± 0.1	medium Sand
B5o	0.1 ± 0.0	98.4 ± 1.2	1.5 ± 1.3	0.8 ± 0.2	medium Sand

The OM content varies from 2.3 ± 0.9% in sG; 1.8 ± 0.7% in gS to 0.8 ± 0.6% in mS. A significant seasonal and annual variations is observed in sG (Table 2).

between seasons and the two studied years were found for gS and mS (Table 2). Moreover, significant seasonal variations of silt-clay were observed between both seasons for sandy Gravel and gravelly Sand (Table 2) with higher percentages of silt-clay observed in summer.

3.2. Main characteristics of the macrofauna

A total of 102,510 individuals from 307 taxa were recorded during the four sampling campaigns for a total sampling effort covering 50 m^2. Among these taxa, the macrofauna is dominated by Annelida (127 taxa; 43.3% of total abundance and 6.8% of biomass), Arthropoda (98 taxa; 38.1% of abundance and 1.2% of biomass), Mollusca (59 taxa; 5.1% of abundance and 85.6% of biomass) (Table 3). The other groups account for about 13% of the abundance and 6% of the biomass: Sipuncula (3 taxa; 1.1% of abundance and 0.3% of biomass); Echinodermata (14 taxa; 8.1% of abundance and 3.3% of biomass); Cnidaria (one taxa; 0.01% of abundance and 0.04% of biomass); Nemertea (one taxa; 0.8% of abundance and 0.1% of biomass); Platyhelminthes (three taxa; 0.1% of abundance and 0.01% of biomass), and Chordata (one taxa; 3.4% of abundance and 2.6% of biomass) (Table 3).

Annelida dominate the three sediment types, then Arthropoda and Mollusca (Table 3). The proportions of the two dominant zoological groups (Annelida and Arthropoda) are similar in sG, while the Annelida dominate in the two other habitats (Table 3). In terms of biomass, Mollusca are clearly dominant in sG and gS, but Echinodermata and Polychaeta represent a higher fraction of biomass in mS, while Mollusca remain dominant in this sediment type (Table 3).

Surface Deposit Feeders are the most important group on sG in terms of abundance (*Amphipholis squamata* was the most abundant species), while Filter feeders (such as *Glycymeris glycymeris*) are predominate in the biomass (Table 4). Filter feeders and predators are also well represented in abundance in this type of sediment type. The distribution of trophic groups shows similar patterns on gS as on sG. On mS, abundances are dominated by Predators, then by surface Deposit Feeders, while biomasses are comparable between Filter Feeders and sub-surface Deposit Feeders. On mS, scavengers (such as *Tritia reticulata*) represent a higher proportion of biomass than in both other sediment types (Table 4).

Table 5 summarizes the main seasonal and spatial characteristics of the macrofauna for taxonomic richness (TR), abundance (A) and biomass (B).

TR varies from a minimum of 34 taxa in winter at B15i in medium sand to a maximum of 137 taxa in summer at B11i in sandy gravel (Table 5). The mean taxonomic richness does not differ between the two seasons, but TR is higher in sG and gS than in mS (Fig. 3; Table 6). The mean abundance varies from a minimum of 283 ± 35 individuals per m^2 in winter at B15i in mS to a maximum of 11,517 ± 2,768 individuals per m^2 in summer at B1o in sG (abundance dominated by the decapod *Pisidia longicornis*) (Table 5). A significant seasonal pattern is observed in the three sediment types between summer and winter (Fig. 3; Table 6). In summer, the mean abundance is significantly higher in sG than in gS or mS, whereas, in winter, the mean abundance is significantly lower in mS than in gS or sG (Fig. 3; Table 6). The relatively important standard deviation especially for the mean abundance and biomass is due to the local heterogeneity on a station (between the five replicates) on the coarse sediment (due to the local dominance of one or several species).

The mean biomass varies from a minimum of 4 ± 2 g AFDW per m^2 in winter at B4o (mS) to a maximum of 392 ± 101 g AFDW per m^2 in summer at B9i (sG) (Tables 5 and 6). The mean biomass does not differ significantly between winter and summer (Table 6), but it is higher in sG and gS than in mS (Fig. 3; Table 6).

3.3. Ecological quality status (EcoQS)

3.3.1. EcoQS calculated with abundance

The Shannon-Weaver diversity index (H') reveals high and good values for all stations during the two seasons, except for B1o in summer (2.3) which shows a moderate ecological quality status. For H', a significant difference is observed between seasons (Tables 5 and 6), while the EcoQS is higher on coarse sand (sG and gS) than on medium sand (Tables 5 and 6). Pielou's evenness (J) values correspond to good EcoQs, except for B6i and B8i in winter, with moderate EcoQs, and B1o in summer, corresponding to a poor EcoQS (Table 5). No significant difference is observed between seasons and sediment types for J (Table 6). AMBI and BO2A indices show a high ecological quality status for all the stations during both seasons (Table 5). No significant difference is observed between seasons and sediment type for AMBI, whereas BO2A shows seasonal differences and lower values in Ms compared with sG and gS (Table 6).

3.3.2. EcoQS calculated with biomass

Apart from certain values, a moderate to bad status is obtained using the diversity indices H' and J calculated on biomass (very low values associated with the predominance of the bivalve *Glycymeris glycymeris* in terms of biomass). When using biomass, AMBI yields a similar status for most of the stations that are classified in high and good status (18 with high EcoQS and 32 with good EcoQS, whereas all stations yield a high status when assessed on abundances).

3.4. Spatio-temporal patterns of the macrofauna

For a similarity of 50%, we can detect spatio-temporal patterns in the abundance data; the cluster dendrogram separates the stations into three main groups (Fig. 4). The first group (A) corresponds to those stations

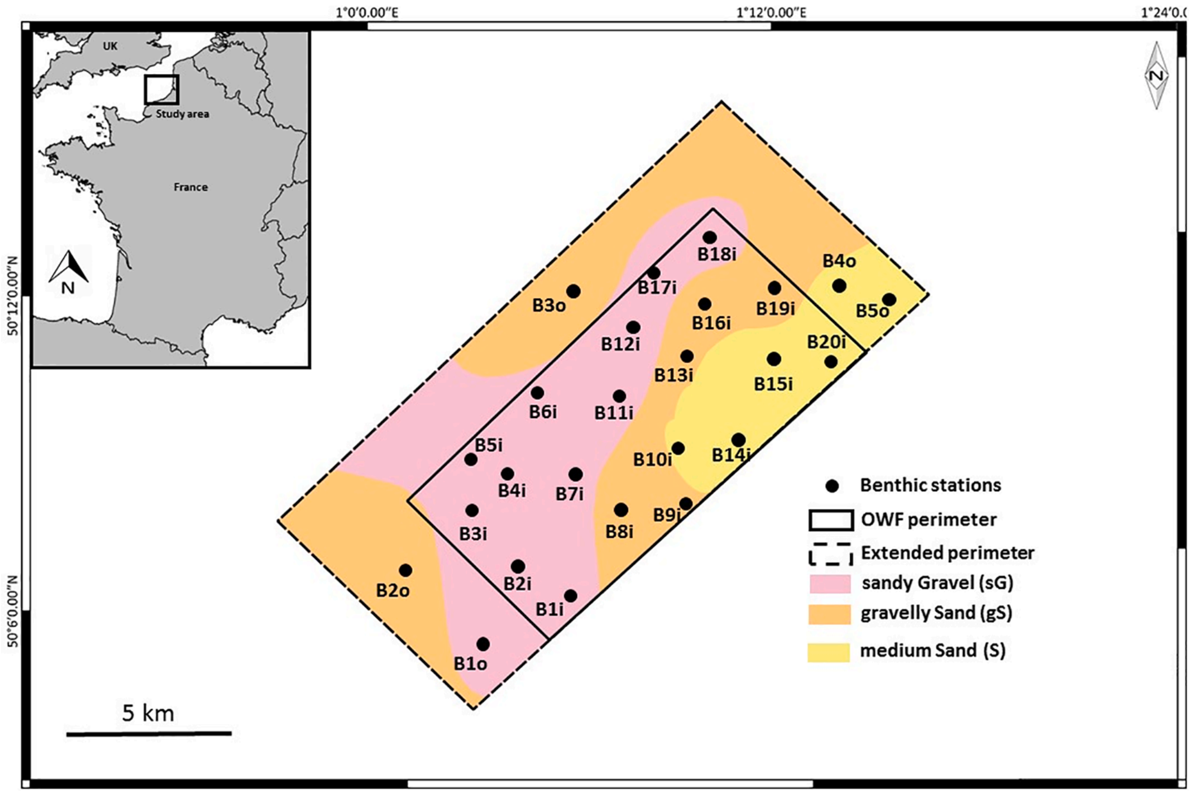

Fig. 2. Localisation of the 25 benthic stations within the perimeter of the future Dieppe-Le Tréport Offshore Wind Farm, with distribution of the three different sediment types (sandy Gravel; gravelly Sand and medium Sand).

located on coarse sediments (sG and gS) during both seasons (summer and winter). The second group (B) corresponds to mS stations during summer, while the third group (C) corresponds to mS stations during the winter. In addition, the group A can be further divided into three sub-groups. The first sub-group A1 comprises only two summer stations dominated by small polychaetes and by the amphipod *Apherusa bispinosa* (Table 7), while the sub-group A2 includes 16 stations sampled in winter that are dominated by small polychaetes but also by the ophiurid *Amphipholis squamata* and the cephalochordate *Branchiostoma lanceolatum*. The sub-group A3 is made up of 20 stations including 17 stations sampled in summer and dominated by the decapods *Pisidia longicornis* and *Galathea intermedia* (Table 7). Stations sampled in summer show seasonal settlement of crustaceans such as the isopod *Eurydice pulchra* and, as observed in coarse sediments, the decapod *Pisidia longicornis* (Table 7). Seasonal effects appear important in controlling sediment types, with high abundances of crustaceans in summer which supercede polychaetes characteristic of medium and coarse sand present throughout the year in this type of benthic community. SIMPER analysis allows us to classify 29 taxa among the ten top species of each group and sub-group. The medium sand community is characterised by the polychaetes *Nepthys cirrosa* and *Ophelia celtica*, the bivalve *Asbjornsenia pygmaea* and the mysid *Gastrosaccus spinifer*. The coarse sand community is mainly characterized by the annelid *Polygordius lacteus*, *Glycera lapidum*, several species of the polychaete family Syllidae and the ophiurid *Amphipholis squamata*. A dissimilarity exists between the three groups. The Bray-Curtis dissimilarity index = 68.84 between groups A and B (ANOSIM test, R = 0.95; p = 0.1); the Bray-Curtis Index = 78.66 between groups A and C (ANOSIM test, R = 0.98, p = 0.1) and the Bray-Curtis Index = 57.37 between groups B and C (ANOSIM test, R = 0.92; p = 0.2).

For a similarity of 38%, a spatial pattern of stations can be observed in terms of biomass; the cluster dendrogram separates the stations into two groups (Fig. 5). The first group (A) corresponds to those stations located on coarse sediments (sG and gS) during the two seasons (summer and winter), while group B corresponds to medium sand (mS) sediment during the two seasons. The SIMPER analyses shows a high contribution of the two bivalves *Glycymeris* and *Polititapes rhomboides* and, to a lesser degree, the cephalochordate *Branchiostoma lancealatum* and the annelid *Polygordius lacteus* to the macrofauna developed on coarse sand. The polychaete *Nephtys cirrosa*, the gastropod *Tritia reticulata*, the bivalves *Spisula solida*, *S. elliptica* and *Glycymeris glycymeris* and the sea urchin *Echinocardium cordatum* show an affinity for the medium sand habitat (Table 8). A dissimilarity exists between the two groups. The Bray-Curtis dissimilarity index = 79.19 between groups A and B (ANOSIM test, R = 0.96; p = 0.1).

4. Discussion

4.1. General patterns of the benthos of the Dieppe Le Tréport site

Biodiversity is considered as a major health indicator of the ecosystem; however, the biomass of species is still only rarely taken into account in the assessment of ecological indicators (Pezy et al., 2020). In the eastern English Channel, Foveau et al. (2013) have recorded a high benthic taxonomic diversity with over 860 taxa collected from a total of 318 samples (macrofauna, vagile and sessile epifauna), while 307 taxa are recorded here in the DLT area. This value is among the highest found in similar types of habitats (Table 9).

The coarse sediment assemblage sampled on sandy gravel and gravelly sand corresponds to the EUNIS habitat A5.142 "*Mediomastus fragilis*, *Lumbrineris* spp., bivalves of the Veneridae family and coarse circalittoral sands". This habitat is characterized by molluscs with a large biomass such as *Glycymeris* and *Polititapes rhomboides*. Some stations are dominated by the cephalocordate *Branchiostoma lanceolatum*, yielding an assemblage corresponding rather to the EUNIS habitat A5.145 "coarse sands and circalittoral shell gravels with *Branchiostoma*

Table 2
Two-way ANOVA with interaction of the seasons (winter 2015/2016-summer 2014/2015) and the year (year 1-year 2) on the three grain-size classes (Gravel, Sand and Silt-Clay) and organic matter for the three sediment types (sG: 48 stations; gS: 28 stations and mS: 24 stations).

Sediment type	Variables	Factors	Df	F	*p*
sandy Gravel	Gravel	Season	1	0.003	0.95
		Year	1	0.25	0.62
		Season:Year	1	0.66	0.42
	Sand	Season	1	0.04	0.84
		Year	1	0.38	0.54
		Season:Year	1	0.78	0.38
	Silt-Clay	Season	1	14.62	<0.001
		Year	1	0.69	0.41
		Season:Year	1	0.96	0.33
	OM	Season	1	14.1	<0.001
		Year	1	12.9	<0.001
		Season:Year	1	3.5	< 0.05
		∑	44		
gravelly Sand	Gravel	Season	1	0.81	0.38
		Year	1	0.03	0.87
		Season:Year	1	1.36	0.26
	Sand	Season	1	0.62	0.44
		Year	1	0.03	0.85
		Season:Year	1	1.41	0.25
	Silt-Clay	Season	1	6.49	< 0.05
		Year	1	0.12	0.74
		Season:Year	1	1.62	0.21
	OM	Season	1	0.1	0.71
		Year	1	0.9	0.34
		Season:Year	1	0.0	0.96
		∑	24		
medium Sand	Gravel	Season	1	0.75	0.40
		Year	1	0.55	0.47
		Season:Year	1	0.65	0.43
	Sand	Season	1	0.53	0.47
		Year	1	0.58	0.45
		Season:Year	1	0.54	0.40
	Silt-Clay	Season	1	0.54	0.47
		Year	1	0.06	0.81
		Season:Year	1	0.68	0.42
	OM	Season	1	2.4	0.1
		Year	1	2.2	0.2
		Season:Year	1	2.7	0.1
		∑	20		

lanceolatum". The assemblage on medium sand is characteristic of the EUNIS habitat A5.251 with *Echinocyamus pusillus*, *Ophelia borealis* and *Abra prismatica* of fine circalittoral sands established on clean dune sands and dominated by the polychaete *Nephtys cirrosa*.

4.2. Coarse sand habitat

The benthos represents a biological compartment of the ecosystem, and has been regularly studied in the English Channel mainly as regards the industrial prospects. However, most of these results are not available in the research literature, due to their confidentiality linked to studies of the impact of various human activities (extraction and deposition of sediments, coastal development) and thus remain the property of industrial stakeholders. In addition, there are few benthos studies on coarse sediments in the English Channel using sieving with a 1 mm mesh size.

Taxonomic richness on the sandy Gravel and gravelly Sand of the future Dieppe-Le Tréport OWF shows similar values as those found elsewhere in the English Channel, with a slightly higher biodiversity locally for this site (Fig. 6; Table 9). In the EC, a biodiversity decrease gradient was reported in the 1960 s and 1970 s from the western EC to the eastern EC (Holme, 1961, 1966; Cabioch and Glaçon, 1977). However, these historical studies were based on 2-mm sieving favouring the harvest of large species. By considering comparable data for samples sieved at 1 mm, it appears that the eastern EC has a greater biodiversity than that observed either in the western EC in Morlaix Bay or in the Bay of Seine (Tables 5 and 6; Table 9). Since the mid-1980 s, satellite measurements and regular surveys at long-term monitoring stations in the EC have shown an increase in sea temperature of around 0.6 to 1.3° C (Gaudin, 2017; Gaudin et al., 2018). Nevertheless, Gaudin (2017) and Gaudin et al. (2018) showed little distributional changes of the subtidal macrofauna over a few decades by comparing data from the 1960 s and 1970 s with data acquired in 2012 and 2014 on 252 stations with the same sampling techniques (dredge "Rallier du Baty" and sieving on 2 mm). Only few bivalve species (*Gouldia minima, Palliolum tigerinum, Arcopagia crassa* and *Moerella donacina*) show an average eastward progression of 23 km between the studied periods. Supplementary quantitative data will be necessary to determine the real distribution of species in coarse sediments from both basins of the English Channel.

As reported in Table 9, the abundances on coarse sediments vary from a minimum of 192 individuals per m^2 to a maximum of 4,745 individuals per m^2. Values are lowest in the western EC (Morlaix) with 192 individuals per m^2 compared to other sites in the EC and in other parts of the world (Fig. 6; Table 9). Abundances of 1,605 and 2,989 individuals per m^2 are observed for the two coarse sediment types present at the

Table 4
Distribution of trophic groups according to the mean abundance (A: number of individuals per m^2) and the mean biomass (B: g AFDW per m^2) of the four cruises on the three sediment types (sandy Gravel: 48 stations; gravelly Sand: 28 stations and medium Sand: 24 stations).

	sandy Gravel		gravelly Sand		medium Sand	
	A	B	A	B	A	B
Predators	673.1	1.866	506.3	1.613	315.8	0.965
Scavenger	163.0	0.595	30.7	0.509	81.9	0.990
Filter feeders	862.3	91.026	221.6	87.054	63.7	4.466
sDF	1,078.9	4.791	745.4	6.191	201.7	1.381
ssDF	190.8.	1.718	91.4	1.811	25.5	4.125
Grazers	20.67	0.031	9.07	0.010	4.5	0.003

Table 3
Total number of taxa found on the three sediment types (sandy Gravel; gravelly Sand and medium Sand), with respective percentages of abundance (A) and biomass (B) (sG: 48 stations; gS: 28 stations and mS: 24 stations).

	sandy Gravel			gravelly Sand			medium Sand		
	TR	% A	% B	TR	% A	% B	TR	% A	% B
Annelida	113	40.2	5.8	93	52.3	7.6	56	46.0	16.1
Arthropoda	85	42.2	1.5	67	27.3	0.5	55	32.3	1.3
Chordata	1	4.1	3.6	1	2.4	1.2	1	0.2	0.4
Cnidaria	1	0.004	0.02	1	0.009	0.03	1	0.05	0.4
Echinodermata	14	8.7	2.0	13	7.4	2.2	8	5.2	36.5
Mollusca	53	3.1	86.7	43	7.6	88.0	26	14.6	44.7
Nemertea	1	0.7	0.1	1	1.2	0.1	1	1.4	0.4
Platyhelminthes	3	0.08	0.01	2	0.08	0.005	–	–	–
Sipunculida	3	1.0	0.3	2	1.7	0.3	1	0.2	0.1
Total	274			223			149		

Table 5
Spatio-temporal characteristics of the structural and ecological quality status for the 25 stations at the two seasons (sum: summer; win: winter). TR (Taxonomic Richness), total number of species recorded on 0.5 m2; Mean abundance per m2; Mean biomass (g AFDW) per m2; H': Shannon-Weaver diversity; J: Pielou's evenness. The colour coding corresponds to the Ecological Status of the Water Framework Directive: blue, high status; green, good status; yellow, moderate status; orange, poor status. BO2A is calculated only on abundance.

	Stations	Season	TR	Mean Abundance	Mean Biomass	Abundance			Biomass			BO2A
						H'	J	AMBI	H'	J	AMBI	
sG	B1i	Sum	109	3,254±772	137±20	4.6	0.7	0.83	2.19	0.3	0.88	0.002
		Win	63	2,448±79	100±4	3.4	0.6	0.67	1.90	0.3	0.53	0.002
	B2i	Sum	120	3,241±1,045	44±49	5.1	0.7	0.84	2.74	0.4	0.47	0.008
		Win	54	698±308	14±2	4.5	0.8	0.66	2.35	0.4	0.52	0.013
	B3i	Sum	113	2,093±525	101±37	5.6	0.8	0.85	1.73	0.3	1.92	0.018
		Win	107	1,967±1727	64±22	5.4	0.8	0.81	1.84	0.3	1.65	0.018
	B4i	Sum	109	3,892±752	190±1	4.8	0.7	0.83	1.88	0.3	1.69	0.002
		Win	117	3,481±890	132±1	4.9	0.7	0.82	1.75	0.3	0.84	0.006
	B5i	Sum	115	3,915±35	60±18	5.0	0.7	0.84	2.77	0.4	0.51	0.003
		Win	89	1,520±829	64±33	4.8	0.7	0.75	1.39	0.2	0.15	0.012
	B6i	Sum	120	4,712±167	108±9	4.7	0.7	0.85	1.99	0.3	0.74	0.003
		Win	84	2,826±1,816	21±16	3.2	0.5	0.66	1.97	0.3	0.22	0.006
	B7i	Sum	127	4,399±2,434	155±61	5.1	0.7	0.87	1.79	0.3	1.28	0.010
		Win	94	1,524±953	43±23	4.7	0.7	0.70	2.20	0.3	1.88	0.006
	B11i	Sum	137	4,961±75	222±93	5.0	0.7	0.87	1.83	0.3	1.56	0.007
		Win	92	1,532±472	44±47	4.9	0.8	0.76	1.73	0.3	1.40	0.016
	B12i	Sum	119	3,063±686	182±16	5.1	0.7	0.85	1.60	0.2	1.77	0.005
		Win	84	1,645±660	127±34	4.7	0.7	0.74	1.51	0.2	1.49	0.008
	B17i	Sum	120	3,151±49	144±8	5.1	0.7	0.84	1.58	0.2	2.19	0.010
		Win	81	1,333±666	67±90	4.8	0.8	0.72	1.34	0.2	1.48	0.011
	B18i	Sum	117	1,865±35	116±22	5.3	0.8	0.83	1.79	0.3	1.98	0.011
		Win	74	1,011±352	96±76	4.9	0.8	0.70	1.91	0.3	1.99	0.008
	B1o	Sum	124	11,517±2,768	78±55	2.3	0.3	0.74	2.19	0.3	0.56	0.005
		Win	104	1,686±413	88±88	5.3	0.8	0.81	2.88	0.4	0.87	0.019
gS	B8i	Sum	68	987±86	115±94	4.4	0.7	0.71	1.25	0.2	2.28	0.003
		Win	57	869±21	39±1	3.0	0.5	0.63	0.76	0.1	2.77	0.001
	B9i	Sum	103	5,365±3,585	392±101	4.9	0.7	0.81	0.72	0.1	2.71	0.006
		Win	66	1,062±116	63±85	4.1	0.7	0.67	1.16	0.2	2.53	0.002
	B13i	Sum	111	2,308±1,230	113±70	5.4	0.8	0.84	1.91	0.3	2.05	0.011
		Win	81	689±49	16±20	5.0	0.8	0.73	1.96	0.3	2.02	0.010
	B16i	Sum	128	3,848±71	153±37	5.1	0.7	0.86	1.74	0.3	2.27	0.011
		Win	95	1,561±652	76±13	4.9	0.8	0.75	2.01	0.3	1.60	0.012
	B19i	Sum	124	2,679±864	107±114	5.4	0.8	0.87	1.90	0.3	2.16	0.008
		Win	81	1,337±177	100±10	4.7	0.7	0.73	2.27	0.4	1.93	0.009
	B2o	Sum	83	1,127±69	42±36	4.7	0.7	0.76	1.44	0.4	2.15	0.004
		Win	78	771±197	39±53	4.3	0.7	0.73	2.64	0.4	1.69	0.005
	B3o	Sum	113	1,793±731	65±39	5.5	0.8	0.86	2.63	0.3	1.25	0.003
		Win	79	720±110	24±5	4.9	0.8	0.74	1.81	0.3	1.87	0.003
mS	B10i	Sum	86	1,735±1,212	15±16	4.3	0.7	0.75	3.30	0.5	0.31	0.010
		Win	56	524±85	6±4	4.0	0.7	0.81	3.45	0.6	0.38	0.009
	B14i	Sum	57	638±17	21±15	3.9	0.7	0.92	2.13	0.4	1.86	0.003
		Win	39	379±13	8±6	3.0	0.6	0.76	3.04	0.6	1.47	0.003
	B15i	Sum	46	515±211	10±11	3.8	0.7	0.86	1.58	0.3	0.18	0.003
		Win	34	283±35	10±5	3.1		0.75	2.82	0.6	1.44	0
	B20i	Sum	48	517±157	9±5	3.5	0.6	0.83	3.06	0.5	0.45	0.001
		Win	45	459±132	33±37	3.4	0.6	0.80	2.79	0.6	1.28	0
	B4o	Sum	57	783±33	15±14	4.0	0.7	0.92	2.39	0.4	1.21	0.002
		Win	38	514±11	4±2	3.3	0.6	0.78	3.15	0.6	1.01	0
	B5o	Sum	66	1,583±1,540	24±27	3.6	0.6	0.90	1.78	0.3	0.59	0.006
		Win	37	389±129	29±37	3.7	0.7	0.80	0.84	0.2	0.17	0

Dieppe-Le Tréport site; moreover, these abundances are in the same order of magnitude as those observed in the eastern basin of the EC for similar sediment types (Fig. 6; Table 9). Many protocols have been used for the estimation of biomass (drying and calcination times), but the results are most often expressed in grams of Ash Fresh Dry Weight (AFDW). The values of these biomasses are very variable, ranging from 6 to 100 g AFDW per m^2 (Fig. 6; Table 9). The high biomasses for the coarse sediments of the Dieppe-Le Tréport site are mainly due to the high abundance of the large bivalves *Glycymeris glycymeris* and *Polititapes rhomboides*. Thus, at the level of the eastern basin of the EC, the Dieppe-Le Tréport site has the distinction of having significantly higher biomass, which is for example twice as high as that recorded in the Bay of Seine (Fig. 6; Table 9). The Bay of Seine is directly influenced by the Seine river, which provides significant inputs of nutrient salts and organic

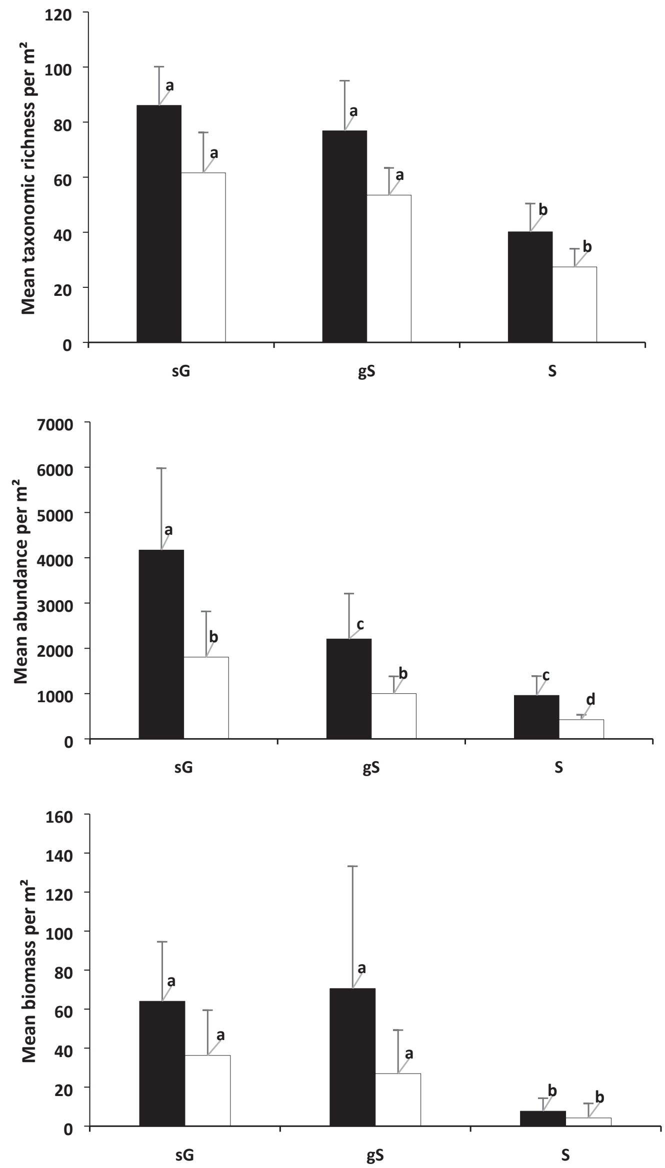

Fig. 3. Mean taxonomic richness, abundance and biomass at the three sediment types (sG, gS and S) per m^2 for the two seasons (black histogram: summer; white histogram: winter) with standard deviation and results of the Tukey tests (superscript: same letters in adjacent columns indicate no significant statistical difference between seasons, with upper whiskers indicating maximum standard deviation from mean). Sample size: sG (6 m^2 in winter; 6 m^2 in summer); gS (3.5 m^2 in winter; 3.5 m^2 in summer); mS (3 m^2 in summer; 3 m^2 in winter).

Table 6
Two-way ANOVA with interaction of the seasons (winter-summer) and sediment type (sG; gS and S) on the structural and ecological quality status for the 25 stations at the two seasons (sum: summer; win: winter). Taxonomic Richness: total number of species recorded in 0.5 m2; Mean abundance per m2; Mean biomass (g AFDW) per m2; H': Shannon-Weaver diversity; J: Pielou's evenness.

Variables		Factors	Df	F	*p*	Tukey test
Taxonomic richness		Season	1	64.24	< 0.001	
		Sediment type	2	73.48	< 0.001	mS ≠ sG; gS
		Season: Sediment type	2	1.66	0.19	
Abundance		Season	1	29.99	< 0.001	
		Sediment type	2	21.49	< 0.001	sG ≠ gS; mS
		Season: Sediment type	2	3.48	< 0.05	
Biomass		Season	1	17.74	< 0.001	
		Sediment type	2	17.72	< 0.001	mS ≠ sG; gS
		Season: Sediment type	2	2.67	0.07	
Abundance	H'	Season	1	7.65	< 0.01	
		Sediment type	2	15.30	< 0.001	mS ≠ sG; gS
		Season: Sediment type	2	1.22	0.30	
	J'	Season	1	0.33	0.57	
		Sediment type	2	2.24	0.11	
		Season: Sediment type	2	1.15	0.32	
	AMBI	Season	1	10.07	<0.01	
		Sediment type	2	2.53	0.08	
		Season: Sediment type	2	1.76	0.18	
Biomass	H'	Season	1	0.66	0.42	
		Sediment type	2	9.16	<0.001	mS ≠ sG; gS
		Season: Sediment type	2	4.67	<0.05	
	J'	Season	1	0.73	0.39	
		Sediment type	2	26.21	<0.001	mS ≠ sG; gS
		Season: Sediment type	2	7.63	<0.001	
	AMBI	Season	1	1.22	0.27	
		Sediment type	2	23.71	<0.001	gS ≠ sG; mS
		Season: Sediment type	2	0.41	0.66	
BO2A		Season	1	0.79	0.38	
		Sediment type	2	8.72	< 0.001	mS ≠ sG
		Season: Sediment type	2	2.56	0.08	

matter. As a result, this area shows a high biomass of benthic macrofauna mainly in the coastal *Abra alba* fine sand community just in front of the Seine estuary, as well as on the offshore sandy gravels (Dauvin and Ruellet, 2008). For instance, large populations of the suspension-feeder species *Ophiothrix fragilis* have been observed in the Bay of Seine (>5,000 individuals per m^2; > 50 g AFDW) (Dauvin and Ruellet, 2008; Lozach and Dauvin, 2011).

4.3. Medium sand habitat

As regards the medium sand sediment type in the eastern EC, the Dieppe-Le Tréport site is two times more diverse (149 taxa) compared with the other two sites located in the same area (80 and 89 taxa) (Fig. 6; Table 9). Nevertheless, the taxonomic diversity at the Dieppe-Le Tréport site appears similar to that observed in the Bay of Seine (MACHU site) for similar sampling surface efforts (Table 9). The diversity is also twice as high at the Dieppe-Le Tréport site compared to similar sampling situations off the coast of Northern France: 77 taxa at Dyck and 46 at Gravelines (Fig. 6; Table 9). However, in the North Sea, along the Belgian coast, the diversity on medium sand habitats is higher with 194 taxa. This difference can be mainly explained by the more intense sampling effort along the Belgian coasts during the period from 1994 to 2000, which corresponds to a total surface covered of 72.8 m^2 as against 12 m^2 for two years for the Dieppe-Le Tréport site (Fig. 6; Table 9). The abundance on medium sands in the EC and in the southern part of the North Sea varies from 212 to 1,643 individuals per m^2 (Table 9). In the eastern EC, abundances at the Dieppe-Le Tréport site are two times higher than those reported historically in the same area, but remain close to values obtained in the western EC and on the southern coast of

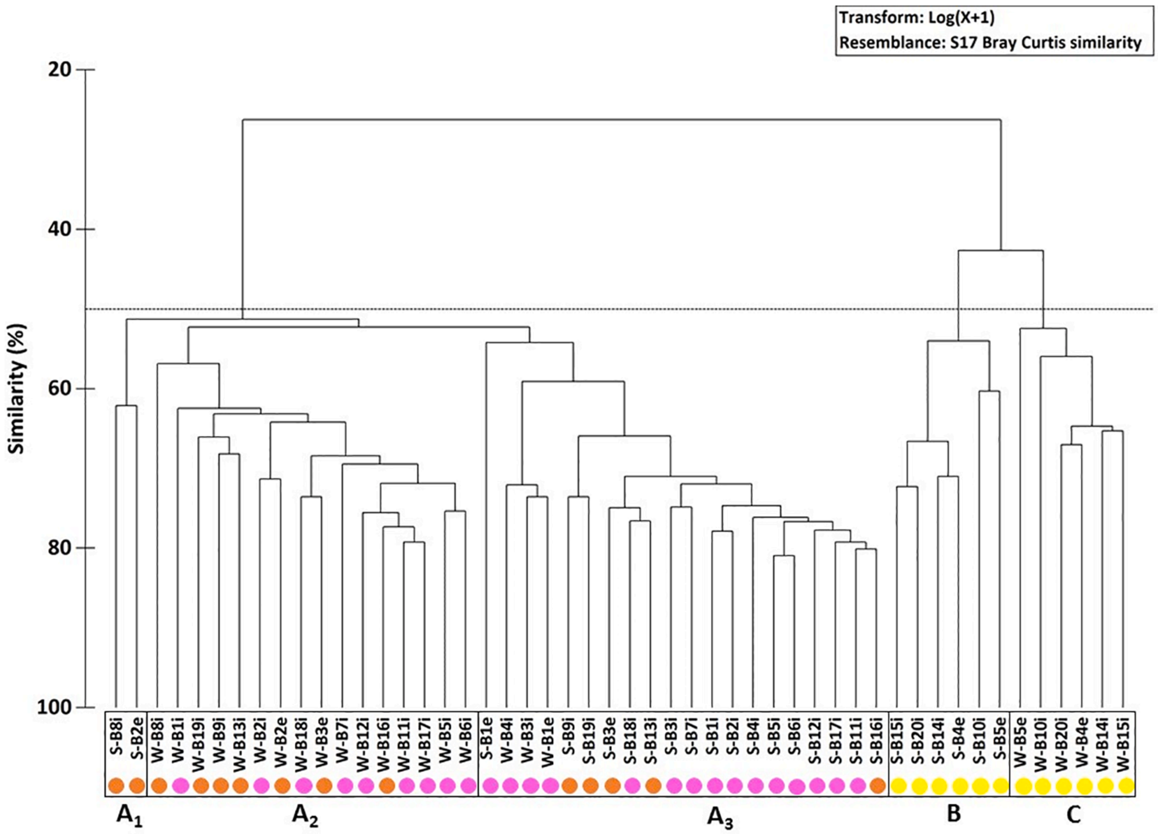

Fig. 4. Cluster dendrogram showing distribution of the 25 stations (mean abundance of the two campaigns by season) for each season according to the Bray-Curtis similarity after Log(x + 1) transformation of the abundance. Dot represent the three sediment types (pink: sandy Gravel; orange: gravelly sand and yellow: medium Sand).

Table 7
SIMPER analyses with cumulative contribution (Cc in %) of the ten top species, with indication of their mean abundance (A) expressed as number of individuals per m^2.

A_1			A_2			A_3		
Species	Cc	A	Species	Cc	A	Species	Cc	A
Polygordius lacteus	6.52	528	*Polygordius lacteus*	5.33	384	*Amphipholis squamata*	2.97	454
Glycera lapidum	10.88	105	*Glycera lapidum*	9.98	200	*Glycera lapidum*	5.76	278
Apherusa bispinosa	15.21	117	*Amphipholis squamata*	14.16	264	*Megamphopus cornutus*	8.45	197
Spio decorata	19.45	171	*Aonides paucibranchiata*	17.96	138	*Spirobranchus triqueter*	11.05	406
Syllis garciai	23.40	70	*Branchiostoma lanceolatum*	21.64	161	*Apherusa bispinosa*	13.49	559
Syllis variegata	27.03	75	*Syllis garciai*	25.26	87	*Polygordius lacteus*	15.88	300
Eurydice pulchra	30.60	49	*Syllis variegata*	28.63	64	*Abludomelita obtusata*	18.23	254
Nemertea	34.11	57	*Malmgrenia ljungmani*	31.83	70	*Syllis garciai*	20.55	162
Glycymeris	37.44	94	*Trypanosyllis coeliaca*	34.98	49	*Galathea intermedia*	22.81	219
Syllis parapari	40.61	47	*Phascolion strombus*	38.11	50	*Pisidia longicornis*	25.05	955
B			C					
Species	Cc	A	Species	Cc	A			
Nephtys cirrosa	8.37	380	*Nephtys cirrosa*	13.19	326			
Asbjornsenia pygmaea	15.40	173	*Asbjornsenia pygmaea*	23.11	107			
Eurydice pulchra	20.09	49	*Megaluropus agilis*	28.79	28			
Ophiura albida	24.66	57	*Ophiura*	34.40	28			
Megaluropus agilis	29.01	44	*Mediomastus fragilis*	39.88	23			
Gastrosaccus spinifer	33.05	53	*Gastrosaccus spinifer*	45.21	15			
Polygordius lacteus	36.94	67	*Bathyporeia tenuipes*	50.05	29			
Nemertea	40.41	30	*Ophelia celtica*	54.41	13			
Pisidia longicornis	43.80	29	*Glycera lapidum*	58.21	13			
Gastrosaccus sanctus	47.13	17	Nemertea	61.86	9			

the North Sea (Fig. 6; Table 9). The biomass on medium sands is generally low (Fig. 6; Table 9), varying from 0.9 to 15 g of AFDW per m^2. The biomass recorded on coarse sand at the Dieppe-Le Tréport site is ten times higher than that generally observed for this sediment type, except in the bay of Seine (Fig. 6; Table 9).

Even though the biomass of 15 g AFDW per m^2 obtained on medium sand at the DLT site is much lower than on coarse sediments, it still represents the highest value so far recorded on either side of the English Channel or in the southern part of the North Sea.

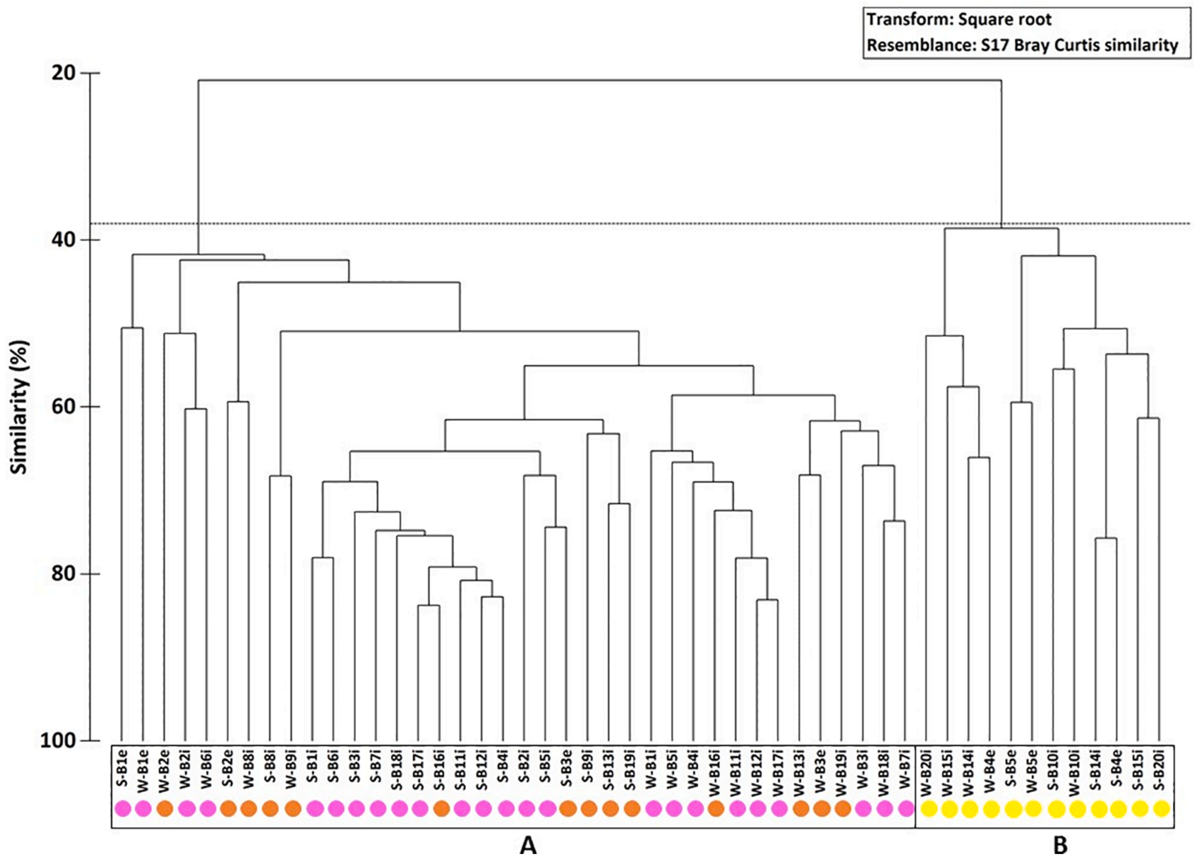

Fig. 5. Cluster dendrogram showing distribution of the 25 stations (mean biomass of the two campaigns by season) for each season according to the Bray-Curtis similarity after Square root transformation of the biomass. Dot represent the three sediment types (pink: sandy Gravel; orange: gravelly sand and yellow: medium Sand).

Table 8
SIMPER analyses with cumulative contribution (Cc in %) of the ten top species, with indication of their mean biomass (A): g AFDW per m^2.

A			B		
Species	Cc	B	Species	Cc	B
Glycymeris	27.62	53.47	*Nephtys cirrosa*	12.31	0.40
Polititapes rhomboides	46.76	28.88	*Tritia reticulata*	24.41	0.82
Branchiostoma lanceolatum	53.19	2.69	*Spisula solida*	36.24	0.39
Polygordius lacteus	58.13	4.96	*Glycymeris glycymeris*	43.40	1.86
Arcopagia crassa	61.47	1.55	*Spisula elliptica*	50.23	1.18
Phascolion strombus	64.25	0.29	*Echinocardium cordatum*	56.86	4.01
Scoletoma fragilis	66.25	0.26	*Asbjornsenia pygmaea*	62.06	0.08
Glycera lapidum	67.83	0.10	*Polygordius lacteus*	66.49	1.28
Notomastus latericeus	69.20	0.08	*Scoletoma fragilis*	69.72	0.08
Nemertea	70.54	0.10	Nemertea	72.79	0.05

4.4. Ecological quality status

The coarse and medium sands of the Dieppe Le-Tréport site show low contents of Organic Matter typical of the English Channel with strong tidal currents that are unfavourable for the deposition of fine sediment and associated OM. In such a hydrodynamic regime, opportunistic species are absent and all the benthic indices calculated on abundances of recorded species yield good to high quality status. It should be borne in mind that this status refers to a situation 'Before' OWF installation; the status of the entire site could change after the implantation of turbines and the growth of mussels on the piles which would increase the input of faeces and organic matter in the immediate vicinity favourable of the development of deposit feeders including numerous opportunistic polychaetes (Raoux et al., 2017; Wilding et al., 2017; Dannheim et al., 2019). Our present study provides the "baseline" situation before any eventual industrial impact on this coastal ecosystem. Stations situated near future turbines should be monitored to observe the probable changes of organic matter content and fine particles as well as any increase of small polychaetes species indicative of organic matter enrichment.

As suggested by several authors (see Borja et al., 2009), some benthic indices could be calculated in terms of biomass, thus taking into account differences in the structure of the benthic community according to abundances (sensitive to numerous small species) and biomass (sensitive to rare species with high individual biomass). Therefore, diversity indices H' and J calculated on biomass (very low values in relation to the predominant contribution of the bivalve *Glycymeris glycymeris* to biomass) show a degraded environment with a moderate to bad Ecological Quality Status. However, it appears that the threshold defined for the abundance is probably not adapted to the biomass in this case, and estimates should be readjusted in the future. Nevertheless, AMBI gives a similar status whether based on abundances or biomasses, with most of the stations classified in high and good status (18 for high and 32 for good, against all in high status assessed with the abundances). Our application validates the efficiency of calculating AMBI using the abundances or biomasses of species classified in the five Ecological Groups as suggested by Borja et al. (2000).

4.5. Towards an ecosystem approach

The assessment of macrobenthic biomass and its distribution

Table 9
Main structural characteristics of macrofauna on coarse sediments (sandy Gravel and gravelly sand) and medium sands from the worldwide ocean. (wEC: west English Channel; eEC: east English Channel; CS: China Sea; MS: Mediterranean Sea; NS: North Sea; UK: United Kingdom; Ss: Sampling surface in m^2; D: Depth in m; S: Sediment type; TR: Taxonomic richness: A: Abundance, number of individuals per m^2; B: Biomass, g AFDW per m^2, except for (DW) which is the biomass in g Dry Weigh per m^2.

			Site	Month	Year	Ss	D	S	TR	A (m^2)	B (m^2)	Reference
Coarse sediment	wEC	UK	West EC (A)	–	–	–	–	sG & gS	–	390	7.3	MESL, 1999a
		France	Morlaix (B)	Each month	1977–1980	32.5	17	Cs	181	192	15.4 (DW)	Dauvin, 1988
	eEC	France	Dieppe (C)	–	1996–1997	0.9	15	sG	50	1,940	8	Desprez, 2000
				–	1996–2001	0.8	15	sG	50	2,394	12	Desprez et al., 2010
			Dieppe-Le Tréport (D)	September/October	2014–2016	14	12–25	sG	277	2,989	100	This study
				February/March		24		gS	224	1,605	96	
			Bay of Seine (E)	June-August	2007	19	38–50	sG	198	1,309	19	Lozach & Dauvin, 2011
			PER Granulats du Havre (F)	February	2012	2.5	16–22	sG	117	777	44.7	Pezy et al., 2013
			Courseulles sur mer (G)	June	2009	8.1	22–28	sG	147	377	45	In Vivo, 2013
		UK	St Catherine (H)	–	–	–	–	sG & gS	–	4,590	27.9	MESL, 1996a
			West Bassurelle (I)	–	–	–	–	sG & gS	–	932	12.0	MESL, 1999b
			Folkestone (J)	–	–	–	–	Cs	–	3,051	11	Newell et al., 2001
			Isle of Wight (K)	March & September	1999	26.2	> 10	Cs	316	998	10.5	Newell et al., 2004
			Hastings (L)	–	–	–	–	sG	–	2,000	6	Cooper et al., 2007
	CS	China	Tai Long Wan (M)	Each month	2011	6	13	*As*	84	899	–	Chen et al., 2013
			Pak Lap Wan (N)						87	767	–	
	MS	Greece	Thermaikos bay (O)	August-January	2001–2003	1.4	3–10	*As*	142	3,310	–	Antoniadou et al., 2004
	NS	UK	Orford Ness (P)	–	–	–	–	sG & gS	–	4,745	15.9	MESL, 1997b
			Lowestoft (Q)	–	–	–	–	sG & gS	–	670	7.4	MESL, 1997a
Medium Sand	wEC	France	Morlaix (B)	April-September	1981	5	20	mS	116	545	1.2 (DW)	Dauvin, 1984
	eEC		Le Vergoyer (S)	February-June-October-November	1984–1985	12	12–30	mS	89	341	1.4	Prygiel, 1987
			Bassure de Baas (T)	February-March-April-June-September-October-November	1983–1985	16	9–25	mS	80	212	0.9	
			Le Dyck (U)	April-May-August-September-October-November-December	1984–1985	21	8–22	mS	77	318	1.5	
			Dieppe-Le Tréport (D)	September/October-February/March	2014–2016	12	12	mS	149	693	15	This study
			Machu (V)	March-April-July-September-November-December	2008–2011	6.9	12–19	mS	130	607	9.6	Marmin, 2013
			PER Granulat du Havre (F)	February	2012	5.5	16–22	mS	110	307	6.2	Pezy et al., 2013
	NS		Gravelines (W)	February-March-April-May-September-October-November-December	1983–1985	12	15	mS	46	541	1.6	Prygiel, 1987
			Belgium (X)	Autum & Winter	1994–2000	72.8	2–20	mS	194	1,643	–	Hoey et al., 2004

between trophic groups is a prerequisite for trophic web modelling. At the Dieppe Le-Tréport site, suspension feeders largely dominate the biomass in both coarse sand habitats, while they are less important in medium sand. The second most important trophic group making up the biomass are the Deposit Feeders; the other groups form a minority (Table 5).

Using the available data on the benthos but also on other compartments of the Dieppe Le-Tréport site, Pezy et al. (2020) modelled the trophic web before wind farm construction in order to improve our current knowledge of the system and characterize its present ecological properties. For that purpose, nine Ecopath models were built taking into account both seasons, annual means and the three distinct sediment types (sandy Gravel, gravelly Sand and medium sand). Indeed, the Ecopath approach (Polovina, 1984; Christensen and Walters, 2004; Christensen et al., 2008), which considers all biotic components of the system at the same time, can be useful to gain a better understanding of the trophic structure and functioning of the system, and predict how it might change over time when subject to perturbations (Raoux et al., 2017). One of the main results of this modelling is that the high biomass of bivalves found at the Dieppe-Le Tréport site (especially on the sandy Gravel and gravelly Sand) could act as trophic dead end or cul-de-sac for fish due to the body size of these filter feeders compared with size of fish sampled in the area (Pezy et al., 2020). Moreover, additional results highlight that the trophic structure is strongly linked to the sediment conditions and the gradation of maturity from medium sand to gravelly sand and sandy gravel. Finally, the study of Pezy et al. (2020) pointed

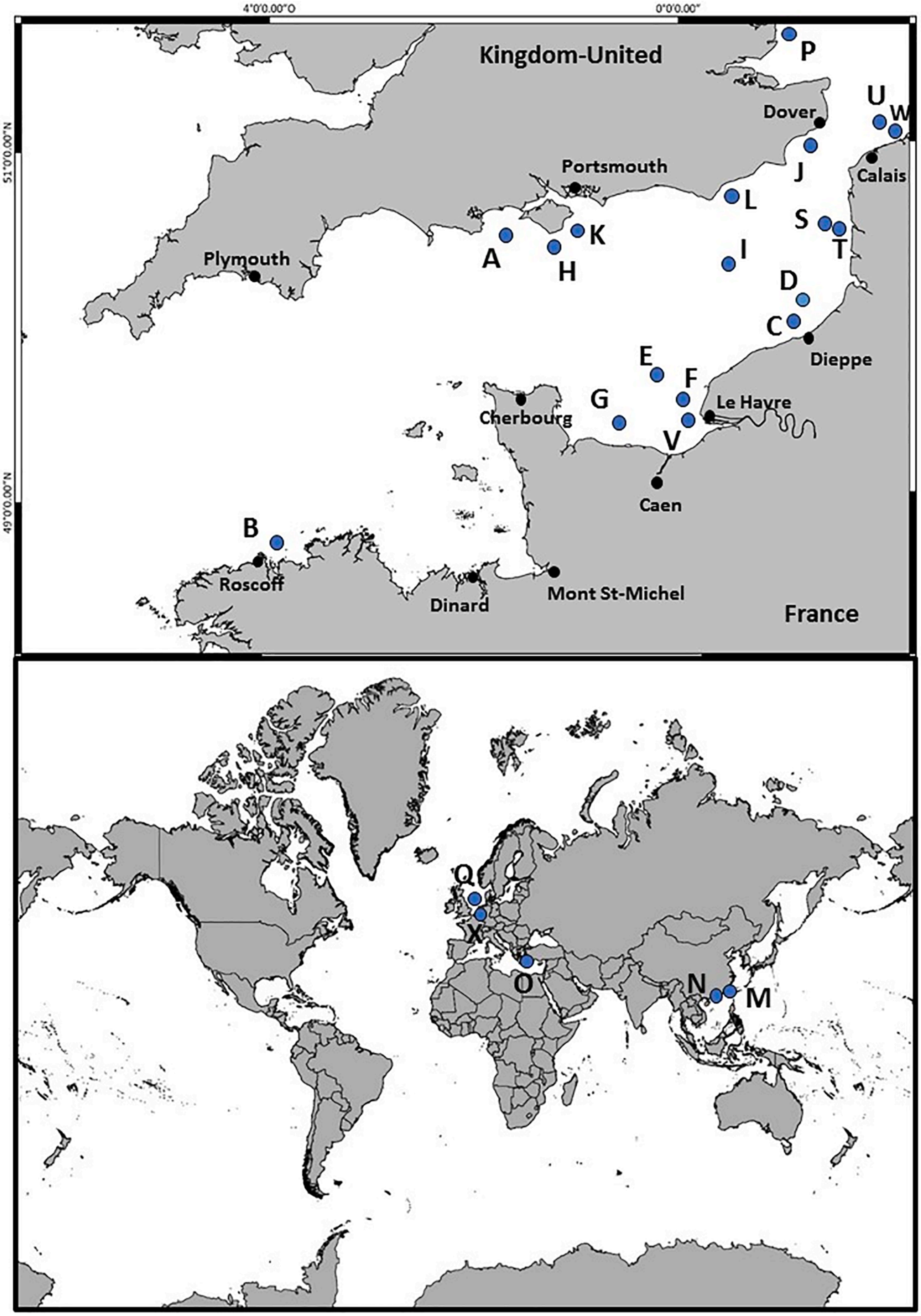

Fig. 6. Localisation of the studies on coarse sediments (sandy Gravel and gravelly sand) and medium sands from the worldwide ocean presented in the Table 9. See Table 9 for matching between letters and sites.

out that the three sediment types present at the Dieppe-Le Tréport site occur in proportions similar to those estimated across the eastern part of the English Channel (study site: 52.1% sG; 26.0% gS; 21.9% S and eastern English Channel: 42.2% sG; 35.8% gS; 22.0%).

To conclude our study highlight that the future Dieppe-Le Tréport offshore wind farm could be used as an observatory representative of the cumulative impact of offshore wind farms that are planned along the French coast in the eastern part of the English Channel and in the southern part of the North Sea.

CRediT authorship contribution statement

Jean-Philippe Pezy: Conceptualization, Data curation, Formal analysis, Writing - original draft, Writing - review & editing. **Jean-Claude Dauvin:** Conceptualization, Supervision, Writing - review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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References

Antoniadou, C., Krestenitis, Y., Chintiroglou, C., 2004. Structure of the "*Amphioxus* sand" community in Thermaikos bay (Eastern Mediterranean). Fresen. Environ. Bull. 13, 1122–1128.

Barrio-Froján, C.R.S., Cooper, K.M., Bremner, J., Defew, E.C., Wan Hussin, W.M.R., Paterson, D.M., 2011. Assessing the recovery of functional diversity after sustained sediment screening at an aggregate dredging site in the North Sea. Estuar. Coast. Shelf Sci. 92, 358–366.

Birklund, J., Wijsman, J.W.M., 2005. Aggregate extraction: A review on the effect on ecological functions. SANDPIT Fifth Framework Project. Report Z3297.10, p. 56.

Bolam, S.G., Rees, H.L., 2003. Minimizing impacts of maintenance dredged material disposal in the coastal environment: a habitat approach. Environ. Manage. 32, 171–188.

Borja, A., Franco, J., Perez, V., 2000. A marine biotic index to the establish ecology quality of soft-bottom benthos within European estuarine coastal environments. Mar. Pollut. Bull. 40, 1100–1114.

Borja, A., Rodríguez, J.G., Black, K., Bodoy, A., Emblow, C., Fernandes, T.F., Angel, D., 2009. Assessing the suitability of a range of benthic indices in the evaluation of environmental impact of fin and shellfish aquaculture located in sites across Europe. Aquaculture 293, 231–240.

Cabioch, L., Glaçon, R., 1977. Distribution des peuplements benthiques en Manche Orientale, du Cap d'Antifer à la baie de Somme. C. R. Acad. Sci. 285, 209–213.

Chen, Y., Cheung, S.G., Shin, P.K.S., 2013. A baseline study of benthic community associated with *Amphioxus* sand in subtropical Hong Kong. Mar. Pollut. Bull. 72, 274–280.

Christensen, V., Walters, C.J., 2004. Ecopath with Ecosim: methods, capabilities and limitations. Ecol. Model. 172, 109–139.

Christensen, V., Walters, C.J., Pauly, D., Forrest, R., 2008. Ecopath with Ecosim version 6 User Guide. Lensfest Ocean Futures Project 2008 1–235.

Clarke, K.R., Gorley, R.N., 2006. PRIMER V6: User Manual/Tutorial. PRIMER-E, Plymouth.

Cooper, K., Boyd, S., Eggleton, J., Limpenny, D., Rees, H., Vanstaen, K., 2007. Recovery of the seabed following marine aggregate dredging on the Hastings Shingle Bank off the southeast coast of England. Estuar. Coast. Shelf Sci. 75, 547–558.

Dannheim, J., Degraer, S., Jackson, A.C., Bergström, L., Birchenough, S., Brzana, R., Boon, A., Colen, J., Dauvin, J.C., de Mesel, I., Derweduwen, J., Hutchison, Z., Janas, U., Martin, G., Raoux, A., Reubens, J., Rostin, L., Wilding, T., Wilhelmsson, D., 2019. Benthic effects of offshore renewables: prioritizing the known unknowns. ICES J. Mar. Sci. fsz018.

Dauvin, J.C., 1984. Dynamique d'écosystèmes macrobenthiques des fonds sédimentaires de la baie de Morlaix et leur perturbation par les hydrocarbures de l'Amoco Cadiz. Thèse de doctorat d'état es-science naturelles, Université Pierre et Marie Curie Paris VI, p. 468.

Dauvin, J.C., 1988. Structure et organisation trophique du peuplement des sables grossiers a *Amphioxus lanceolatus - Venus fasciata* de la Baie de Morlaix (Manche Occidentale). Cah. de Biol. Mar. 29, 163–185.

Dauvin, J.C., 2015. History of benthic research in the English Channel: from general patterns of communities to habitat mosaic description. J. Sea Res. 100, 32–45.

Dauvin, J.C., 2018. Twenty years of application of Polychaete/Amphipod ratios to assess diverse human pressures in estuarine and coastal marine environments: a review. Ecol. Indic. 95, 437–445.

Dauvin, J.C., 2019. The English Channel: La Manche. In Sheppard C. (Ed) World Seas: An Environmental Evaluation, Volume I: Europe, the Americas and West Africa. Chapter 6, 153-188.

Dauvin, J.C., Lozachmeur, O., 2006. Mer côtière à forte pression anthropique propice au développement d'une Gestion Intégrée: exemple du bassin oriental de la Manche (Atlantique nord-est). Vertigo 7, 1–14.

Dauvin, J.C., Ruellet, T., 2008. Macrozoobenthic biomass in the Bay of Seine (eastern English Channel). J. Sea Res. 59, 320–326.

Dauvin, J.C., Andrade, H., de-la-Ossa-Carretero, J.A., Del-Pilar-Ruso, Y., Riera, R., 2016. Polychaete/amphipod ratios: an approach to validating simple benthic indicators. Ecol. Indic. 63, 89–99.

Dauvin, J.C., Bakalem, A., Baffreau, A., Grimes, S., 2017. Benthic ecological status of Algerian harbours. Mar. Pollut. Bull. 125, 378–388.

Desprez, M., 2000. Physical and biological impact of marine aggregate extraction along the French coast of the eastern English Channel: short and long-term post-dredging restoration. ICES J. Mar. Sci. 57, 1428e1438.

Desprez, M., Pearce, B., Le Bot, S., 2010. The biological impact of overflowing sands around a marine aggregate extraction site: Dieppe (eastern English Channel). ICES J. Mar. Sci. 67, 270–277.

Eleftheriou, A., Holme, N.A., 1984. Macrofauna techniques. In: Eleftheriou, A., Holme, N. A. (Eds.), Methods for the Study of Marine Benthos. Blackwell Scientific Publications, Oxford, pp. 140–216.

Foden, J., Rogers, S.I., Jones, A.P., 2009. Recovery rates of UK seabed habitats after cessation of aggregate extraction. Mar. Ecol. Prog. Ser. 390, 15–26.

Foden, J., Rogers, S.I., Jones, A.P., 2010. Recovery of UK seabed habitats from benthic fishing and aggregate extraction – towards a cumulative impact assessment. Mar. Ecol. Prog. Ser. 411, 259–270.

Folk, R.L., 1954. The distinction between grain size and mineral composition in sedimentary-rock nomenclature. J. Geol. 62, 344–359.

Foveau, A., Desroy, N., Dauvin, J.C., Dewarumez, J.M., 2013. Distribution patterns in the benthic diversity of the eastern English Channel. Mar. Ecol. Prog. Ser. 479, 115–126.

Garcia, C., 2010. Approche fonctionnelles des communautés benthiques du bassin oriental de la Manche et du sud de mer du Nord. Thèse de Doctorat, Université de Lille Nord de France, p. 396.

Garcia, C., Chardy, P., Dewarumez, J.M., Dauvin, J.C., 2011. Assessment of benthic ecosystem functioning through trophic web modelling : the example of the eastern basin of the English Channel and the Southern Bight of the North Sea. Mar. Ecol. 32, 72–86.

Gaudin, F., 2017. Effets du changement climatique sur la distribution de la macrofaune benthique en Manche. Thèse de Doctorat, Université Pierre et Marie Curie, p. 306.

Gaudin, F., Desroy, N., Dubois, S., Broudin, C., Cabioch, L., Fournier, J., Gentil, F., Grall, J., Houbin, C., Le Mao, P., Thiébaut, E., 2018. Marine sublittoral benthos fails to track temperature in response to climate change in a biogeographical transition zone. ICES J. Mar. Sci. 75, 1894–1907.

Ghertsos, K., 2002. Structure spatio-temporelle des peuplements macrobenthiques de la baie de Seine à plusieurs échelles d'observation. Thèse de Doctorat, Université des Sciences et Technologies de Lille, p. 182.

Gupta, S., Collier, J.S., Palmer-Felgate, A., Potter, G., 2007. Catastrophic flooding origin of shelf valley systems in the English Channel. Nature 448, 342–346.

Halpern, B.S., Walbridge, S., Selkoe, K.A., Kappel, C.V., Micheli, F., D'Agrosa, C., Bruno, J.F., Casey, K.S., Ebert, C., Fox, H.E., Fujita, R., Heinemann, D., Lenihan, H.S., Madin, E.M.P., Perry, M.T., Selig, E.R., Spalding, M., Steneck, R., Watson, R., 2008. A global map of human impact on marine ecosystems. Science 319, 948–952.

Healy, M.J.R., 1962. Some basic statistical techniques in soil zoology. Progr. Soil Zool. 3–9.

Hoey, G.V., Degraer, S., Vincx, M., 2004. Macrobenthic community structure of soft-bottom sediments at the Belgian Continental Shelf. Estuar. Coast. Shelf Sci. 59, 599–613.

Holme, N.A., 1961. The bottom fauna of the English Channel. Part I. J. Mar. Biol. Assoc. U.K. 41, 397–461.

Holme, N.A., 1966. The bottom fauna of the English Channel. Part 2. J. Mar. Biol. Assoc. UK 46, 401–493.

Larsonneur, C., Bouysse, P., Auffret, J.P., 1982. The superficial sediments of the English Channel and its western approaches. Sedimentology 29, 851–864.

Le Bot, S., Lafite, R., Fournier, M., Baltzer, A., Desprez, M., 2010. Morphological and sedimentary impacts and recovery on a mixed sandy to pebbly seabed exposed to marine aggregate extraction (Eastern English Channel, France). Estuar. Coast. Shelf Sci. 89, 221–233.

In Vivo, 2013. Synthèse de l'expertise "Analyse des Biocénoses Benthiques 2009. Projet de parc éolien en mer au large de Courseulles-sur-Mer (Calvados). Eoliennes Offshore du Calvados. p. 23.

Lozach, S., Dauvin, J.C., 2011. Temporal stability of a coarse sediment community from the central eastern English Channel palleovalleys. J. Sea Res. 71, 14–24.

Lozach, S., Dauvin, J.C., 2012. Temporal stability of a coarse sediment community in the Central Eastern English Channel Paleovalleys. J. Sea Res. 71, 14–24.

Marmin, S., 2013. Impacts biosédimentaires des expérimentations de clapages en baie de Seine sur la communauté des sables moyens propres à Nephtys cirrosa. Thèse de Doctorat, Université de Caen Basse-Normandie, p. 249.

MESL (Marine Ecological Survey Ltd.), 1996. Benthic Ecology of St Catherine's Licensed Dredging Area 407. Report prepared for Oakwood Environmental, Wormley, Surrey, p. 62.
MESL (Marine Ecological Survey Ltd.), 1997a. Benthic Ecology off Lowestoft Dredging Application Area 454. Report prepared for Oakwood Environmental, Wormley, Surrey, No SCS/454/1, 48 p.
MESL (Marine Ecological Survey Ltd.), 1997b. Benthic Ecology off Suffolk (Shipwash Gabbard) Dredging Application Area 452. Report prepared for Oakwood Environmental, Wormley, Surrey, No SCS/452/1, 47 p.
MESL (Marine Ecological Survey Ltd.), 1999a. Benthic Ecology south west of the Isle of Wight. Area 465/1 & 465/2 (West Channel). Report prepared for Coastline Surveys Limited, Stonehouse, Gloucestershire. p. 39.
MESL (Marine Ecological Survey Ltd.), 1999b. Benthic Ecology: Areas 458 & 46' (West Bassurelle). Report prepared for Oakwood Environmental, Wormley, Surrey, 39 p.
Newell, R.C., Seiderer, L.J., Robinson, J.E., 2001. Animal: sediment relationships in coastal deposits of the eastern English Channel. J. Mar. Biol. Assoc. U. K. 81, 1–9.
Newell, R.C., Seiderer, L.J., Simpson, N.M., Robinson, J.E., 2004. Impacts of Marine Aggregate Dredging on Benthic Macrofauna off the South Coast of the United Kingdom. J. Coast. Res. 20, 115–125.
Newell, R.C., Seiderer, L.J., Hitchcock, D.R., 1998. The impact of dredging works in coastal waters: a review of the sensitivity to disturbance and subsequent recovery of biological resources on the seabed. Oceanogr. Mar. Biol. 36, 127–178.
Pezy, J.P., Navon, M., Dauvin, J.C., 2013. Etude du benthos dans le cadre du programme de Recherches du PER Granulats Marins Havrais. Rapport de campagne de février 2013, 68 p.
Pezy, J.P., Raoux, A., Dauvin, J.C., 2020. The environmental impact from an offshore windfarm: challenge and evaluation mathodomogy based on an ecosystem approach. Ecol. Indic. 114, 106302.
Polovina, J.J., 1984. Model of a coral reef ecosystem. I. The ECOPATH model and its application to French Frigate Shoals. Coral Reefs 3, 1–11.
Prygiel, J., 1987. Etude du peuplement à Ophelia borealis et de l'annélide Nephtys cirrosa (Ehlers 1868) en Manche Orientale et en Mer du Nord Occidentale. Thèse de Doctorat 3ème cycle, Université des Sciences et Techniques de Lille Flandres Artois, 128 p.
Raoux, A., Tecchio, S., Pezy, J.P., Degraer, S., Wilhelmsson, D., Cachera, M., Ernande, B., Lassalle, G., Leguen, C., Grangeré, K., Le Loc'h, F., Dauvin, J.C., Niquil, N., 2017. Benthic and fish aggregation inside an offshore wind farm: which effects on the trophic web functioning? Ecol. Indic. 72, 33–46.
Vincent, C., Heinrich, H., Edwards, A., Nygaard, K., Haythornthwaite, J., 2002. Guidance on typology, classification and reference conditions for transitional and coastal waters. Commission Européenne, CIS WG 2.4 (COAST), p. 119.
Wentworth, C.K., 1922. A scale of grade and class terms for clastic sediments. J. Geol. 30, 377–392.
Wilding, T.A., Gill, A.B., Boon, A., Sheehan, E., Dauvin, J.C., Pezy, J.P., O'beirn, F., Janas, U., Rostin, L., De Mesel, I., 2017. Turning off the DRIP ('data-rich, information poor') –rationalising monitoring with a focus on marine renewable energy developments and the benthos. Renew. Sustain. Energy Rev. 74, 848–859.