Map of the benthic communities of the sandy shores of the Eastern English Channel and the Southern Bight of the North Sea (France)

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Explanatory note

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Preface

It is with a great pleasure that I became aware of this work concerning the mapping of the benthic communities of the sandy shores of the Eastern English Channel and the Southern Bight of the North Sea (Nord – Pas-de-Calais region, France). I actually have a real emotional connection with this kind of work as a contributor, as well as a former student and lecturer at the Marine Research Station of Wimereux. I also have long-time links with several of the authors who friendly asked me to write this preface.

This work falls within an old tradition of studies on macrobenthic communities in the English Channel. As judiciously underlined by the authors, the subtidal area has been mapped long ago. In the 70'S, studies conducted in collaboration between researchers from the Biological Station of Roscoff, the Maritime Laboratory of Dinard and the Marine Research Station of Wimereux resulted in spectacular advances in the knowledge of subtidal macrobenthic communities. This knowledge was subsequently completed and assembled as maps, notably thanks to modern techniques of data analysis. On the contrary, only a few studies concerned intertidal macrobenthic communities, usually focusing at relatively small scales.

These works, essentially descriptive, are sometimes considered with a little disdain, probably because of their relative long history, contrary to some more recent approaches in the field of biology and ecology, considered as more "sexy" until their potential next obsolescence, a new technique quickly driving out another one in our technological world.

It is however true that, starting from an almost non-existent knowledge, the first works of this type almost constituted an end in itself. They now represent a preliminary, yet essential, step that allows drawing a general frame of knowledge on the structure of the studied ecosystem. An accurate knowledge on the sedimentary characteristics and the structure of the macrobenthic diversity allows asking essential questions regarding the functioning of the ecosystem and its interactions dynamics.

This work will thus serve as a base for numerous studies in the littoral environment of the region; it is a tool for policy makers and managers. It marks a clear and rigorous step between old and fragmented studies and the current or future surveys dictated by the increasing anthropogenic impact on the coastal areas and the inevitable climate change.

I thus greet with pleasure this work and their authors, and wish to this beautiful realization the widest possible distribution.

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I- Introduction

The shore of the Nord - Pas-de-Calais region, extending from Bray-Dunes to the Authie Bay, is composed of a large diversity of habitats, such as coastal dunes, marshes, cliffs and includes some habitats flooded at high tide and uncovered at low tide: these are beaches and estuaries which represent a total surface area of 104 km^2. These habitats, forming the intertidal area or the foreshore, are located at the interface between marine and terrestrial areas and are subjected to many natural (e.g. erosion of the coastline, storms…) and anthropogenic (recreational activities, coastal structures and exploitation…) disturbances. As contact areas between marine and terrestrial ecosystems, beaches and estuaries are specific ecosystems called ecotones. They support a unique set of interacting species (called biocenosis), species which often have high patrimonial value. In the Nord - Pas-de-Calais region, the littoral zone is mainly constituted of sandy and muddy-sand beaches, littoral rock areas being sparse. The present study will be related only to these littoral soft sediments. These areas have a unique ecological role as nursery for some fish species and they also regularly receive shorebirds during migration, wintering and breeding.

Benthic macrofauna (*i.e.* macrozoobenthos) live in constant contact with the sediment (sand, mud…) during their adult life stages and constitute an important part of the species inhabiting beaches and estuaries, both in quantity and diversity. These species (worms, molluscs, crabs, shrimps, etc…) are largely sedentary and interact both with each other and with their environment, to constitute a constantly evolving macrobenthic community.

It is therefore critical to have an accurate knowledge on the characteristics of these communities, especially on their spatial distribution, a necessary step before attempting to implement actions of conservation for these systems. Unlike the macrobenthic communities of the subtidal area (areas of sediment permanently underwater), that were described across the Eastern English Channel and in the Southern Bight of the North Sea (Cabioch et Gentil, 1975; Cabioch et Glaçon, 1975 ; Cabioch et Glaçon, 1977 ; Souplet et Dewarumez, 1980 ; Souplet et al., 1980 ; Prygiel et al., 1988 ; Davoult et al., 1988 ; Gentil et Cabioch, 1997 ; Desroy et al., 2003 ; Foveau, 2009), there is, to date, no overall view of the intertidal area at the scale of the Nord - Pas-de-Calais region (Richard et al., 1980 ; Davoult, 1983). In this scientific and geographical framework, the **MACROFONE** project (**MACRO**benthic communities of the sandy shores in the Nord - Pas-de-Calais region: structure and **E**cological **FUN**ctioning, relationships with wintering shorebirds) aims to study the relationship between

macrofauna and shorebirds and has to provide, in a first step, an answer to a prerequisite question: What are the macrobenthic communities encountered along the coast of the Nord - Pas-de-Calais region (spatial distribution and biodiversity)?

The mapping of macrobenthic communities of the sandy shores of the Nord - Pas-de-Calais region has been carried out to be a useful and practical tool for policy makers, managers and users of the littoral area, but also as a prerequisite for any functional study of these coastal ecosystems. This mapping should be seen as a snapshot, the distribution of the intertidal soft sediments macrobenthic communities being relatively stable over long time scales (except in the case of strong disturbances). The reader should, however, note that a fast dynamic may somewhat locally change the accuracy of the spatial distribution of the macrobenthic communities in estuaries (Canche and Authie).

The following document is based on scientific and statistical analysis. Only the final products, voluntarily cleaned up from any scientific jargon and specialized representation, are presented.

II- Data origin – Methods

A- Samples

Maps were based on 358 sandy shore stations sampled between 1998 and 2012 on the entire intertidal area of the Nord - Pas-de-Calais region (from the Belgian border to the Authie bay included) during late winter-early spring. Stations covered the different levels of the intertidal area at low tide with 3-5 stations sampled along a radial from the upper to the lower shores of the beaches, and sampling was thus conducted during spring tides. A total of 205 stations was sampled on the beaches, 75 in the Canche Bay and 78 in the Authie Bay. Among these 358 stations, and to complete the geographical coverage, 106 stations were specifically sampled in 2012 for the mapping project.

B- Field work

For each station, three samples were collected for macrofauna using a corer (20 cm in inner diameter, i.e. a surface of $1/40^{th}$ m^2) pushed into the sediment, down to a depth of 30 cm. The sediment core was then washed through a 1 mm mesh sieve to recover individuals larger than 1 mm, also called benthic macrofauna (Figure 1). After sieving, samples were

labelled and immediately fixed and preserved in a 10% formaldehyde-seawater solution before analysis in the laboratory. An additional core was also sampled for sediment analysis (ca. 100 g of sediment).

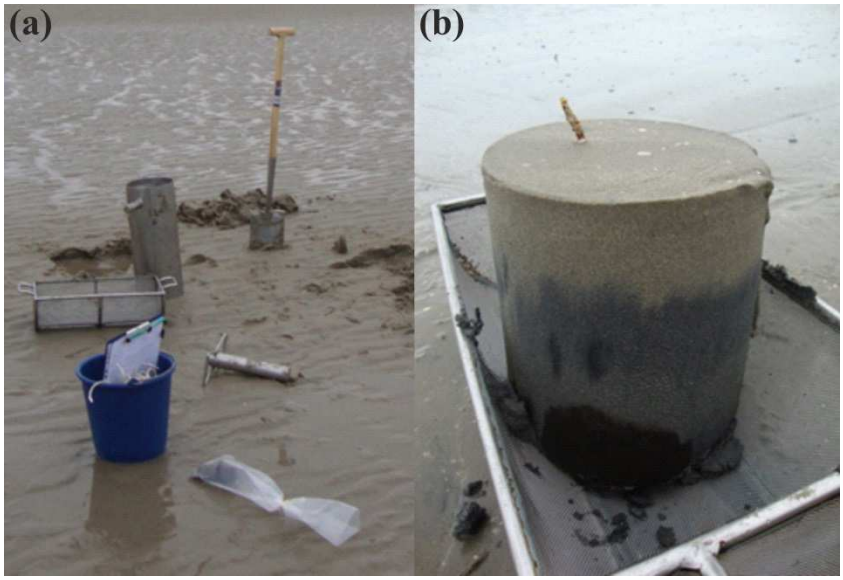

Figure 1. (a) Sampling equipment for the study of macrofauna on sandy beaches (corers and sieves) and (b) core for the analysis of macrofauna, before sieving (© Céline Rolet)

C- Samples analysis

1) Benthic macrofauna

In the laboratory, samples were sorted and macrobenthic organisms were counted and identified to the species level, whenever possible (except for Oligochaeta, Nemerta and Nematoda) with the French, Belgian and British fauna. The names of the identified species were updated according to the international register: the World Register Of Marine Species WORMS (http://www.marinespecies.org). Biomass (the mass of organic matter) of the organisms collected was then determined using the ash free dry weight AFDW (ICES, 1986): individuals of each species (gathered by sampling station) were placed in an oven at 60°C during 48 hours and then weighted to obtain the dry weight (DW). They were then calcinated in a furnace (520°C for 6 hours) to allow the complete removal of organic matter without altering the present mineral matter. They were then weighted again to obtain the ash weight (AW). The estimate of biomass was obtained by calculating the difference between the dry weight and the ash weight (DW – AW) and corresponded to the ash free dry weight AFDW.

2) Sedimentological analysis

Sediment samples collected at each station were used to characterize the grain size. Sediment grain size was defined following the Larsonneur classification (1977) and was based on six categories ranging from muds to coarse gravels (Table 1). For each station, the percentage of each sedimentary class was calculated to define the nature of the substrate.

Table 1. Sedimentary class derived from the Larsonneur classification (1977)

Sedimentary classes	Sediment grain size (mm)
Pebbles	[20-50[
Coarse gravels	[5-20[
Fine gravels	[2-5[
Coarse sands	[0,5-2[
Medium sands	[0,2-0,5[
Fine sands	[0,05-0,2[
Muds	< 0,05

D- Data analysis

1) Biological descriptors

For each sampled station, the species richness, defined as the number of identified species at a given spatial scale (Frontier et al., 2008), the densities (number of individuals per m^2), the biomass and the Shannon Diversity Index (H) were computed. The Shannon Diversity Index expresses the diversity, and reflects the dynamic state, of a community based on the number of species collected and the number of individuals of each species following the formula (Frontier et al., 2008):

$$H = -\sum_{i=1}^{n} p_i . \log_2 . p_i$$

With:

n: the number of species

p_i: the relative frequency of the species i in the sample $p_i = n_i/N$

n_i: the number of individuals of the species i

N: the total number of individuals in the sample

H is generally bounded between 1 and 4.5; a value < 1 indicating a very low diversity (Frontier et al., 2008).

Finally, to assess the equitability (E) of the distribution of the species in the community, the "Pielou's evenness" was calculated from the Shannon Diversity Index (H) and the maximal diversity (based on the species richness; Frontier et al., 2008) as:

$$E = H / \log_2 n$$

The common evenness found in communities of small size is in the range of 0.7-0.9 (Frontier et al., 2008).

2) Statistical analysis

The identification and delineation of the different macrobenthic communities were performed using a conventional approach in community ecology that coupled a multivariate ordination (gradients) and a clustering (breaks; Clarke & Warwick, 2001; Legendre & Legendre, 2012). Details are given in the Annex 1 of the present document.

3) Mapping

Macrobenthic communities identified through statistical analysis were then characterized and described according to the EUNIS classification (levels 4 and 5; Connor et al., 2004; Davies et al., 2004). This classification was developed in response to the implementation of the "Habitats Directive" of the European Union and aims to become the reference typology of habitats in Europe. It is organized in 6 hierarchical levels and was initially based on the "Marine Habitat Classification for Britain and Ireland" (Connor et al., 2004; Davies et al.,

2004; Galparsoro et al., 2012). At level 1, habitats are distributed among marine habitats (code A) and other (terrestrial and freshwater habitats). The level 2 distinguishes marine habitats depending on the type of substrate (sediment or rock), depth and permanent or non-permanent immersion (e.g. A2 for coastal sediments). The level 3 allows classifying according to the abiotic conditions (e.g. nature of sediment, exposure or hydrodynamic energy, salinity: A2.2 for littoral sands or muddy-sands). At level 4, the classification is based on the biocenosis (the present fauna such as Polychaetes, Amphipods, and Bivalves…; e.g. A2.23 for "Polychaete/Amphipod-dominated fine sand shores"). At the levels 5 and 6, the resolution further increases in the description of the habitat with the macrobenthic species (e.g at level 5 with A2.223 for "Amphipods and *Scolelepis spp.* in littoral medium-fine sand" and at level 6 with A2.2232 for "*Eurydice pulchra* in littoral mobile sands"). Details on this classification are available at http://eunis.eea.europa.eu/ (accessed the 18/04/14).

The final mapping of the macrobenthic communities of the sandy shores in the Nord - Pas-de-Calais region was performed using aerial photographs (© Ortho Littorale 2000) coupled with a GIS (Geographic Information System) software (ArcGIS 10 ®) according to the method recommended by Godet et al. (2009).

III- Macrobenthic communities of the sandy shores in the Nord - Pas-de-Calais region

Seven macrobenthic communities were identified, based on the analyses described before:

- The strandline coded A2.21.
- The Amphipods and *Scolelepis spp.* in littoral medium-fine sand community coded A2.223.
- The Polychaete/Amphipod-dominated fine sand shores community coded A2.23.
- The Polychaete/Bivalve-dominated muddy sand shores community coded A2.24.

Three sub-communities of the A2.24 community were also identified at level 5 of the EUNIS classification:

- The *Cerastoderma edule* and Polychaetes in littoral muddy sand community coded A2.242.
- The *Bathyporeia pilosa* and *Corophium arenarium* in littoral muddy sand community coded A2.244.
- The *Lanice conchilega* in littoral sand coded A2.245.

At the scale of the Nord - Pas-de-Calais region and under this study, 108 species of macrofauna were identified for littoral sediments (Annex 2). They were distributed as follow:

- 36 Annelids Polychaetes
- 45 Crustaceans :
    - 22 Amphipods
    - 5 Isopods
    - 12 Decapods
    - 4 Cumaceans
    - 2 Mysids
- 19 Molluscs :
    - 16 Bivalves
    - 3 Gastropods
- 2 Echinoderms
- 1 Sea spider
- 1 Fish
- 1 Nematode

- 1 Nemertean
- 1 Oligochaete
- 1 Insect

The mean species richness, diversity, density and biomass calculated for each identified macrobenthic communities are reported in Table 2.

Table 2. Number stations belonging to each EUNIS community, number of identified species, mean species richness (mean ± standard deviation), Shannon diversity index (H ; mean ± standard deviation), Pielou's evenness (E ; mean ± standard deviation), mean density (ind.m^{-2} ; mean ± standard deviation) and mean biomass (g.m^{-2} ; mean ± standard deviation) for each macrobenthic community of the sandy shores in the Nord - Pas-de-Calais region

EUNIS community	A2.21	A2.223	A2.23	A2.24	A2.242	A2.244	A2.245
Number of stations	19	143	92	93	2	2	7
Identified species	16	60	80	37	24	3	26
Mean species richness	0.8 ± 0.8	5.3 ± 2.6	6.5 ± 3.6	6.3 ± 2.7	17.5 ± 4.9	2.0 ± 1.4	7.1 ± 4.7
Shannon diversity index (H)	0.05 ± 0.17	1.53 ± 0.71	1.92 ± 0.67	1.33 ± 0.68	2.67 ± 0.08	0.73 ± 1.03	1.48 ± 0.73
Pielou's evenness (E)	0.05 ± 0.17	0.69 ± 0.22	0.77 ± 0.16	0.55 ± 0.25	0.65 ± 0.05	0.46 ± 0.65	0.58 ± 0.32
Mean density (ind.m^{-2})	124 ± 352	983 ± 1449	682 ± 1835	6774 ± 11239	4749 ± 3698	47 ± 47	3132 ± 5565
Mean biomass (g.m^{-2})	0.09 ± 0.17	2.17 ± 3.70	6.59 ± 14.79	21.59 ± 72.36	12.80 ± 10.81	0.07 ± 0.09	5.17 ± 8.27

The strandline (A2.21) had a low species richness (a mean of 0.8 species, 16 species recorded in total) and thus a low diversity (H = 0.05 ± 0.17). The *Bathyporeia pilosa* and *Corophium arenarium* in littoral muddy sand community was also characterized by low species richness (2.0 ± 1.4), only 3 species recorded, a limited number of individuals and a low diversity (H = 0.73 ± 1.03). Three macrobenthic communities were identified on all the beaches of the Nord - Pas-de-Calais region: A2.223, A2.23 and A2.24. They exhibited similar mean species richness (5 to 6 species). The muddy sand community (A2.24) had the highest densities (6774 ± 11239 ind.m^{-2}) compared to the two other communities (A2.223 and A2.23), but was characterized by relatively low diversity and evenness (H = 1.33 ± 0.68 and E = 0.55 ± 0.25). Thirty-seven (37) species were collected in A2.24, *vs.* 60 and 80 respectively for the A2.223 and A2.23 macrobenthic communities. The *Cerastoderma edule* and Polychaetes in littoral muddy sand community (A2.242) had the highest mean species richness (17.5 ± 4.9

for 24 species recorded in total), high densities and the highest diversity (H = 2.67 ± 0.08). For the *Lanice conchilega* in littoral sand community (A2.245), mean densities were important (3132 ± 5565 ind.m^{-2}), mainly due to the presence of the Polychaete *Lanice conchilega*; the relatively high species richness (7.1 ± 4.7 species) was due to the presence of numerous accompanying species (26 species identified in this community).

The highest biomasses were found within muddy-sand communities A2.24 and A2.242 (21.59 and 12.80 g.m^{-2} respectively), and the lowest within communities located in the upper shore: A2.21 and A2.244.

However, species richness, diversity, densities and biomass observed for each macrobenthic community were similar to those in the same type of beaches in Belgium (Degraer et al., 2003).

Table 3. Sedimentological characteristics in % of muds, fine sands, medium sands, coarse sands, fine gravels and coarse gravels for each macrobenthic communities

EUNIS community	Muds	Fine sands	Medium sands	Coarse sands	Fine gravels	Coarse gravels
A2.21	-	28	71	1	-	-
A2.223	-	27	68	4	1	-
A2.23	-	52	44	3	1	-
A2.24	3	32	61	3	1	-
A2.242	3	18	77	2	-	-
A2.244	-	29	54	10	4	3
A2.245	-	64	30	3	3	-

The sediment analysis highlighted a sedimentary gradient from the upper to the lower shores. The upper shores (A2.21) were dominated by sediments constituted of medium sands (71%) and fine sands (28%), the mid shores (A2.223) by medium to fine sediments (68% of medium sands, 27% of fine sands, 4% of coarse sands and 1% of fine gravels) and the lower shores (A2.23) were characterized by a majority of fine (52%) to medium (44%) sands, without mud (Table 3). Some beaches of the coastline Nord - Pas-de-Calais, such as the Hemmes de Marck and Gravelines beaches, and the upstream of the Authie and Canche estuaries, comprised in some areas a non-negligible fraction of mud: sediments was then composed of 61% of medium sands, 32% of fine sands, 3% of muds and 4% of coarse

particles (A2.24 community). A comparison of sediment characteristics between the Authie bay and the Cape Gris-Nez and between the Cape Gris-Nez and the Belgian border (Bray-Dunes) highlighted that sediments were thinner between the bay and the Cape, and coarser between the Cape and the Belgian border.

The different zones of the shore can often be visually identified in the field. Figure 2 allows the example at a beach (Zuydcoote, France) where each zone corresponded to a EUNIS community.

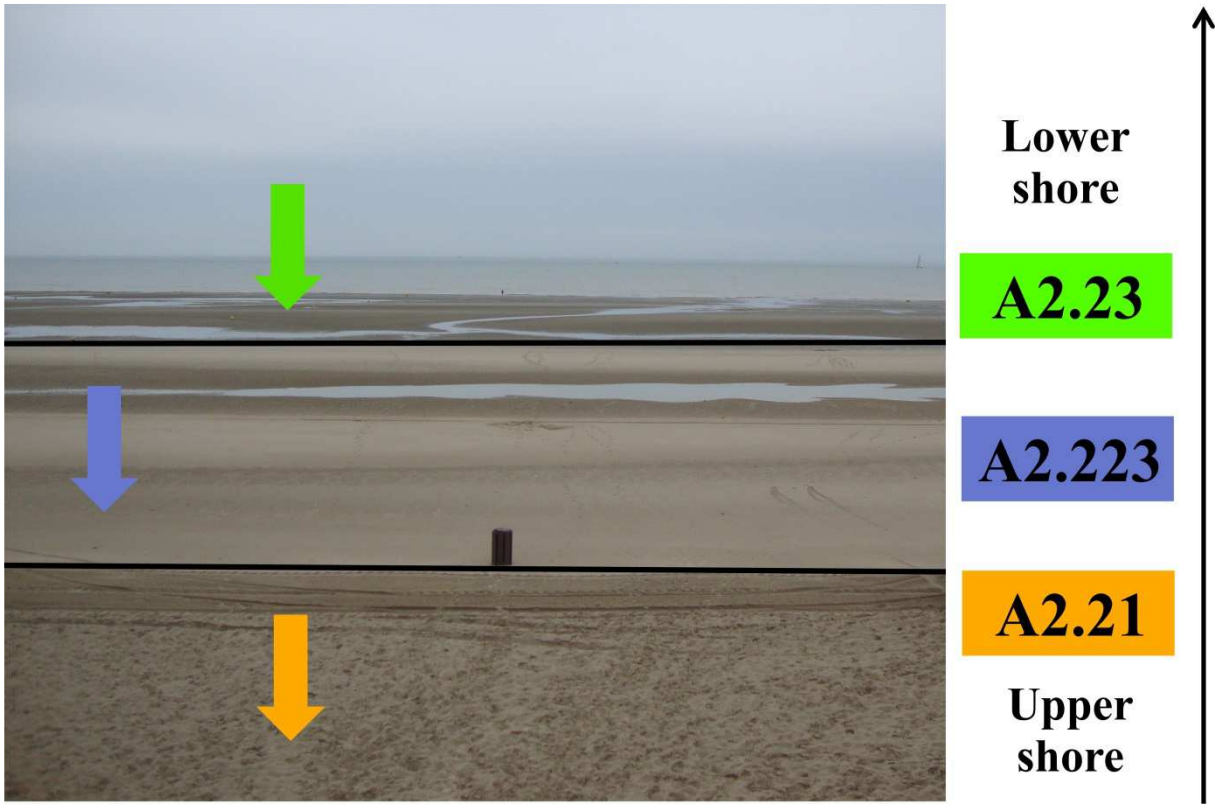

Figure 2. Direct field observation of the different zones: from the upper shore with the strandline A2.21, the mid shore characterized by the A2.223 community and the lower shore characterized by the A2.23 community (Zuydcoote, © Céline Rolet)

A- Strandline (A2.21)

The strandline (A2.21) was located in the upper beach and was thus submerged only during spring tides (see maps). This area of the sandy beach was dominated by 71% of medium sands, followed by 28% of fine sands and only 1% of coarse sands (Table 3 and Figure 3).

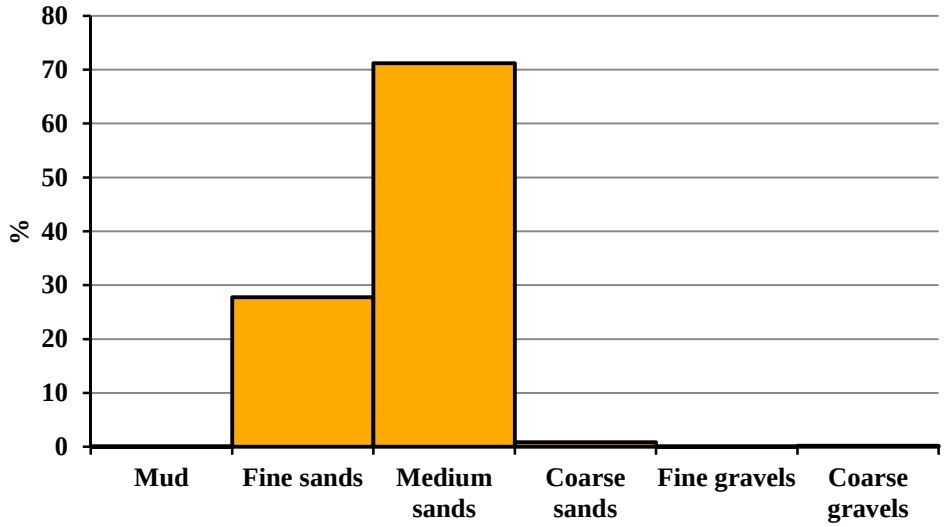

Figure 3. Characteristic granulometry of the strandline (A2.21)

The mean species richness was very low (0.8 ± 0.8 species; the strandline being locally devoid of macrobenthic fauna i.e. azoic), as well as the diversity (Shannon index = 0.05 ± 0.17). The mean density was 124 ± 352 ind.m^{-2} with a negligible biomass (0.09 ± 0.17 g.m^{-2} ; Table 2). Sometimes, the strandline was colonized by the Amphipod *Talitrus saltator* also known as the "sand hopper" (Figure 4). Densities of this species were dependent on food availability in the high tidemark (macrophytes wrecks and decomposing fauna). Oligochaetes can be abundant in this area of the beach (1500 ind.m^{-2} counted in a station located on the Hemmes de Marck beach, east of Calais). Insects, such as Coleoptera and Diptera, also colonize this area (Dauvin et al. 1997).

This community was located from Berck-sur-Mer to Boulogne-sur-Mer, absent between Wimereux and the Cape Gris-Nez (replaced by dykes and/or littoral rock) and then present from Tardinghen to the Belgian border (Bray-Dunes; see maps). It covered 4.1 km^2, *i.e.* 4% of the studied coastline.

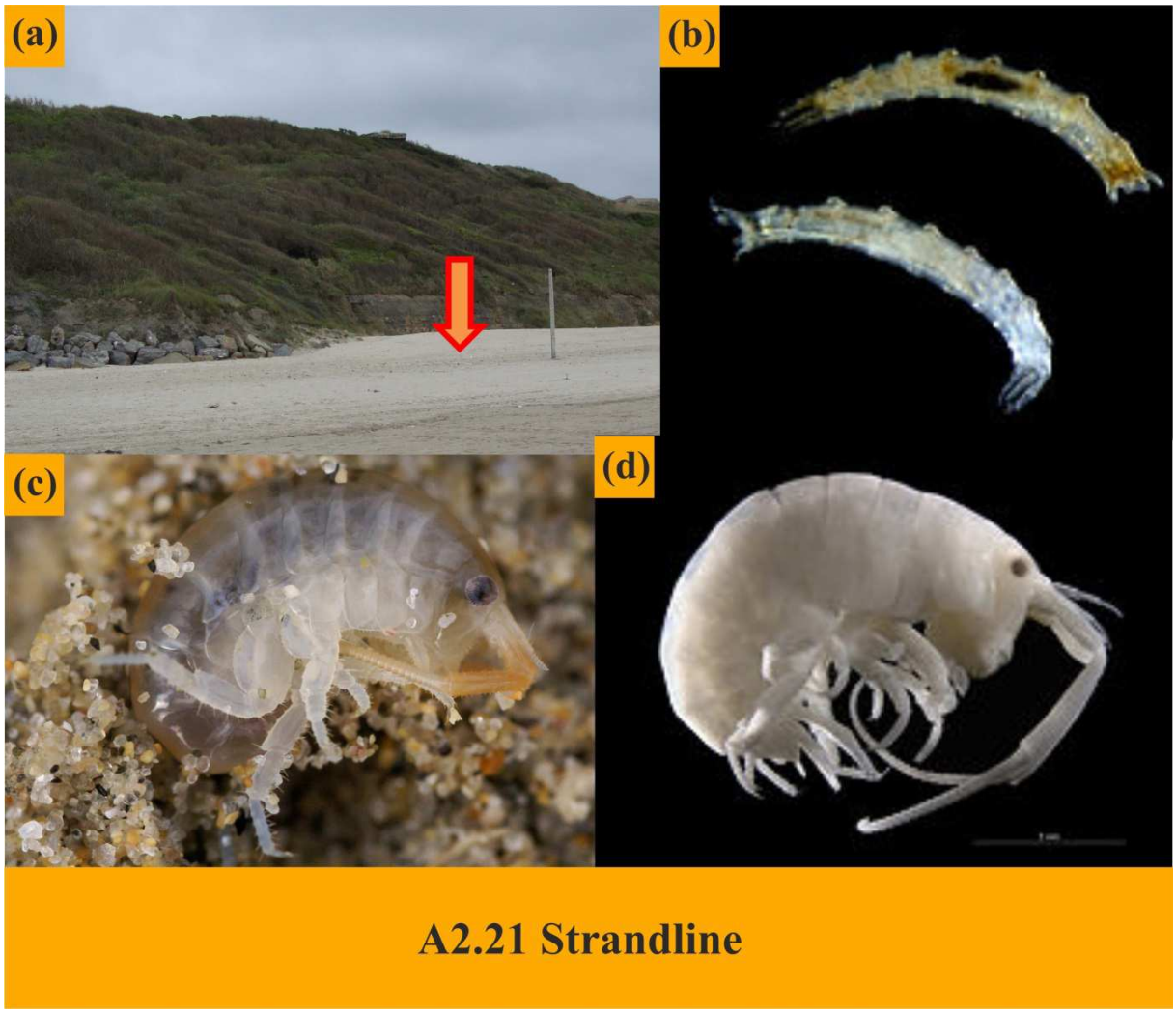

Figure 4. (a) Strandline located in the upper beach (picture from Equihen-Plage, France; © Céline Rolet), (b) insects' larvae (height 20 mm; © Hans Hillewaert), (c) and (d) the Amphipod *Talitrus saltator* or the "sand hopper", characteristic species of the strandline (© Marc Cochu and © Hans Hillewaert)

B- Amphipods and *Scolelepis spp.* in littoral medium-fine sand community (A2.223)

The Amphipods and *Scolelepis spp.* in littoral medium-fine sand community (A2.223) was located on all the beaches of the Nord - Pas-de-Calais region, as well as in bays (Canche and Authie), but was absent in harbour areas. It was encountered from the upper intertidal part down to the mean high water level at neap tide (MLWN; see maps). The sediment was characterized by medium (68%) and fine (27%) sands. Coarse sands (4%). fine gravels (1%) and coarse gravels (0.5%) were also present in weak proportions (Table 3 and Figure 5).

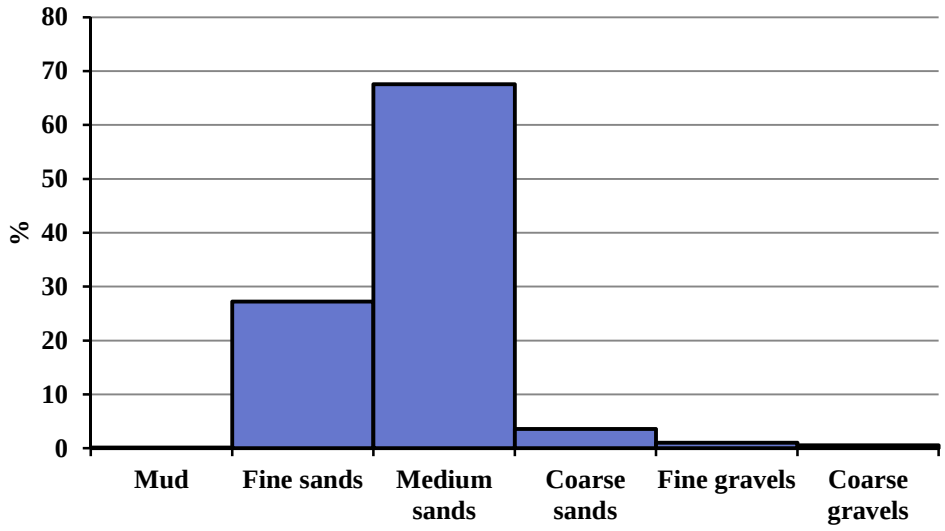

Figure 5. Characteristic granulometry of the Amphipods and *Scolelepis spp*. in littoral medium-fine sand community (A2.223)

The mean species richness of this community was 5.3 ± 2.6 species with a total of 60 species identified, a mean density of 983 ± 1449 ind.m^{-2}, a mean biomass of 2.17 ± 3.70 g.m^{-2} and a Shannon index of 1.53 ± 0.71. The evenness of 0.69 highlighted a good distribution of the individuals among the different species encountered in this community (Table 2). The major species were the Amphipods of the Genus *Bathyporeia* (*B. pilosa* and *B. sarsi*) and *Haustorius arenarius*, the Isopods *Eurydice pulchra* and *Eurydice affinis*, and the Polychaete *Scolelepis squamata* (Figure 6).

This community covered 30.5 km^2 of the intertidal zone at the scale of the Nord - Pas-de-Calais area, equivalent to 29% of the total area of the shore.

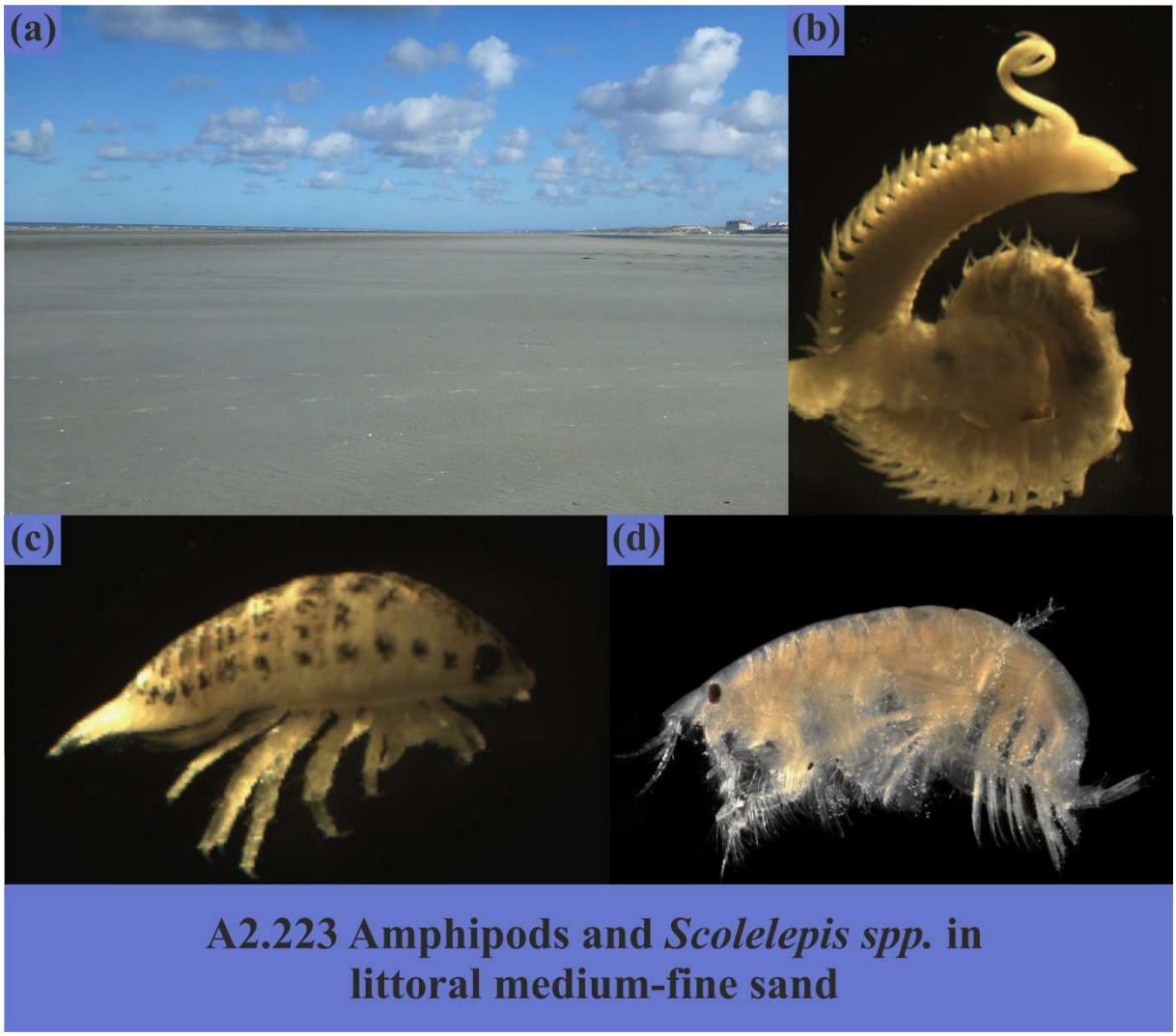

Figure 6. (a) The mid shore colonized by the Amphipods and *Scolelepis spp.* in littoral medium fine sand community (picture from Merlimont, France; © Christophe Luczak), (b) the Polychaete *Scolelepis squamata* (height 50 to 80 mm; © Céline Rolet), (c) the Isopod *Eurydice Pulchra* (height 8 mm; © Céline Rolet), (d) the Amphipod *Bathyporeia pilosa* (height 6 mm; © Hans Hillewaert)

C- The Polychaete/Amphipod-dominated fine sand shores community (A2.23)

The Polychaete/Amphipod-dominated fine sand shores community (A2.23) was located on all the beaches of the studied area including the mouth of the Canche and Authie bays. It was characteristic of the lowest shore and extended to the subtidal zone (infralittoral area; see maps). Sediments were mainly composed of fine (52%) and medium (44%) sands. Weak proportions of coarse sands (3%) and fine gravels (1%) were also observed (Table 3 and Figure 7).

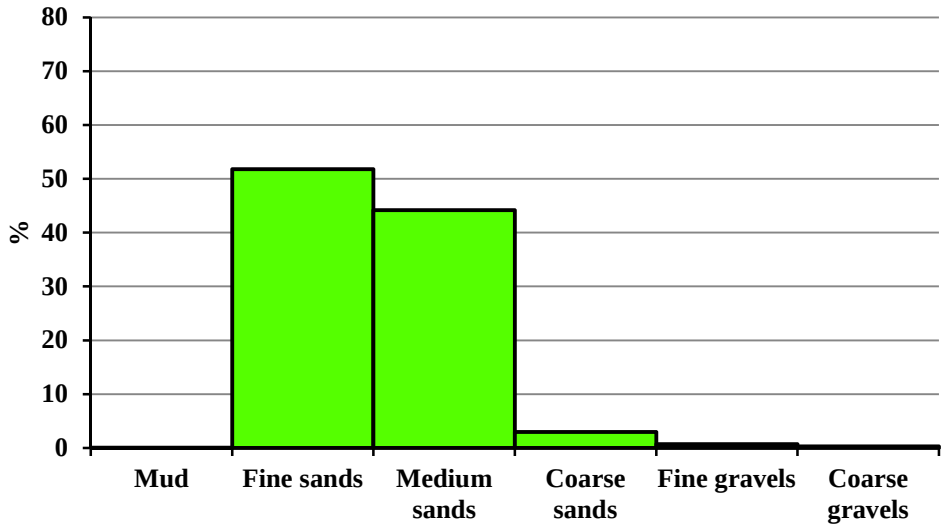

Figure 7. Characteristic granulometry of the Polychaete/Amphipod-dominated fine sand shores community (A2.23)

This community exhibited a mean species richness of 6.5 ± 3.6 with a total of 80 species identified, a mean density of 682 ± 1835 ind.m^{-2}, a mean biomass of 6.59 ± 14.79 g.m^{-2}, a Shannon index of 1.92 ± 0.67 and a Pielou's evenness of 0.77 ± 0.16. This last value shows a good distribution of the individuals among the different species, close to the maximum possible (*i.e.* 1; Table 2). The species encountered were Amphipods such as *Bathyporeia pelagica* and *Urothoe poseidonis*, Polychaetes such as *Nephtys cirrosa*, *Spio martinensis* and *Spiophanes bombyx*, and Bivalves with *Donax vittatus* and *Ensis directus* (Figure 8).

Its surface area was 56 km^2; it was the most represented community on the coastline of the Nord - Pas-de-Calais region (52% of cover).

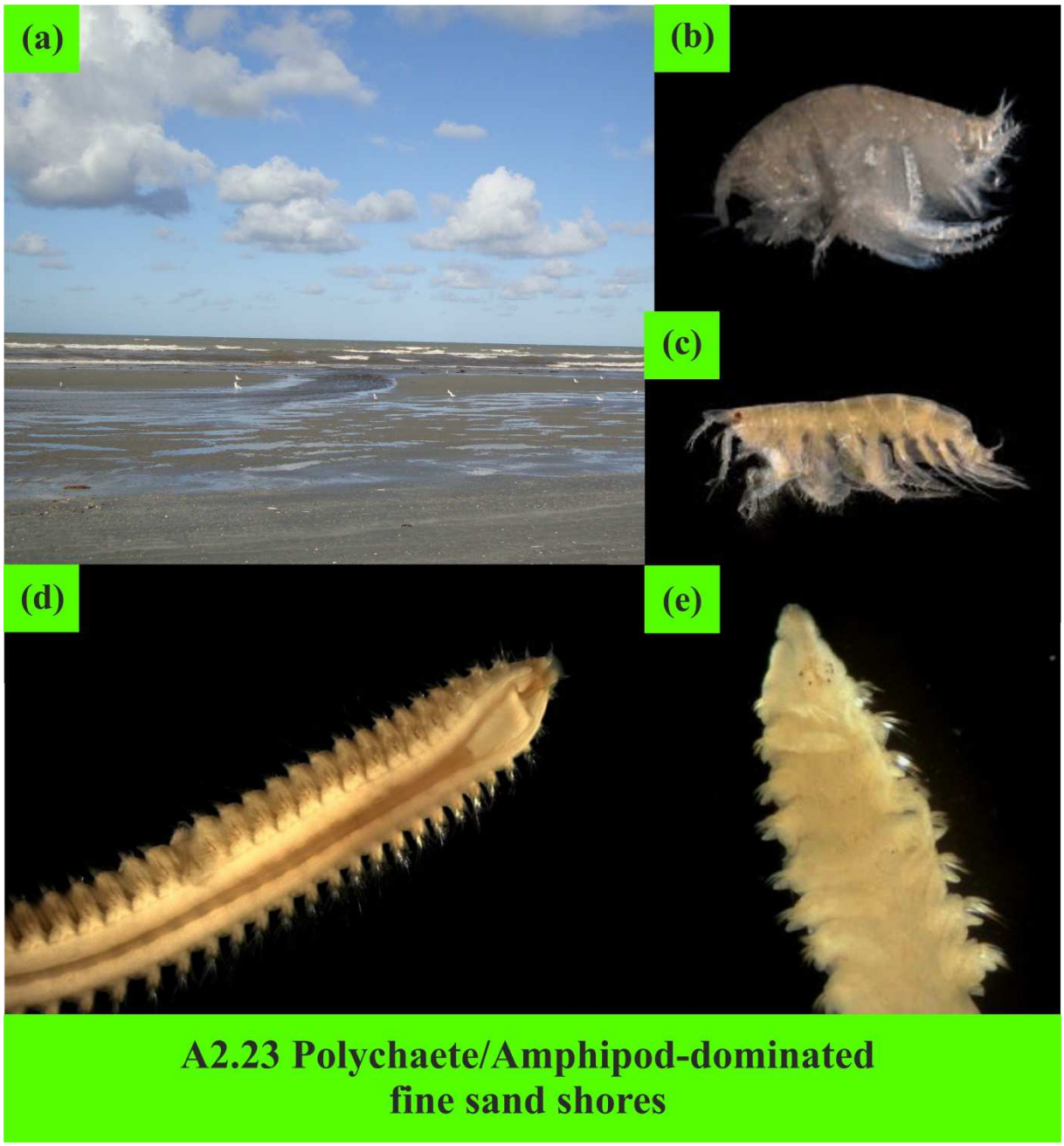

Figure 8. (a) The lower shore colonized by the Polychaete/Amphipod-dominated fine sand shores community A2.23 (picture from Merlimont, France; © Céline Rolet), (b) the Amphipod *Urothoe poseidonis* (height 6 mm; © Hans Hillewaert), (c) the Amphipod *Bathyporeia pelagica* (height 6 mm; © Hans Hillewaert), (d) the Polychaete *Nephtys cirrosa* (height 60-100 mm; © Hans Hillewaert) and the Polychaete *Spio martinensis* (height 30 mm; © Hans Hillewaert)

D- The Polychaete/Bivalve-dominated muddy sand shores community (A2.24)

The Polychaete/Bivalve-dominated muddy sand shores community (A2.24) was mainly located in the Canche and Authie bays, upstream and along the channels of both rivers. It was also located in the upper areas of two beaches: les Hemmes de Marck (East of Calais) and Gravelines (West of Dunkirk; see maps). It was characterized by medium sands (61%). fine sands (32%). coarse sands (3%) and a non-negligible proportion of mud (3%). Gravels were represented only in weak proportions (1%; Table 3 and Figure 9).

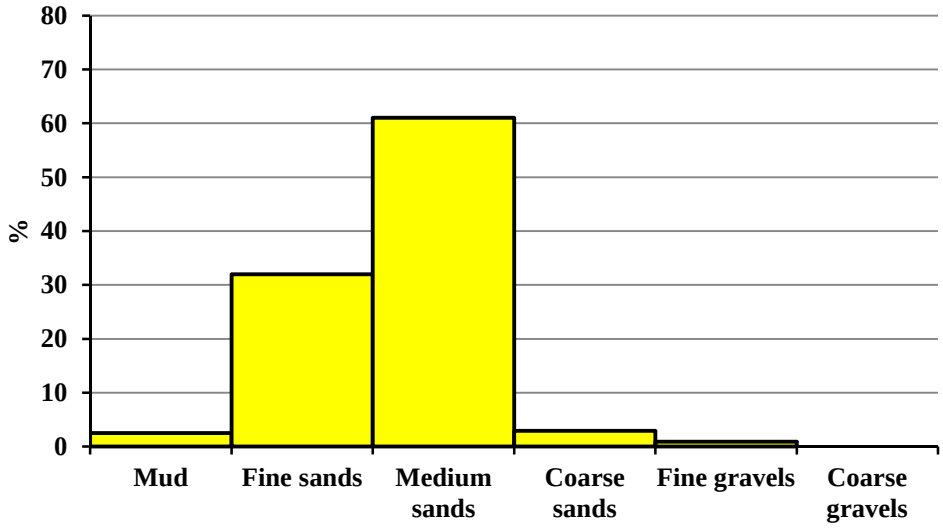

Figure 9. Characteristic granulometry of the Polychaete/Bivalve-dominated muddy sand shores community (A2.24)

The Polychaete/Bivalve-dominated muddy sand shores community had a similar species richness than the two other communities (i.e A2.223 and A2.23) with 6.3 ± 3.6 species, but with a smaller number of identified species (37 species). Mean densities and biomass were higher (respectively 6774 ± 11239 ind.m^{-2} and 21.59 ± 72.36 g.m^{-2}) and Shannon index and Pielou's evenness were lower (H = 1.33 ± 0.68 and E = 0.55 ± 0.25; Table 2) than those observed in A2.223 and A2.23 communities. This community was represented by species with a muddy-sand affinity: the Molluscs *Peringia ulvae*, *Cerastoderma edule* and *Macoma balthica*; the Crustaceans *Corophium arenarium*, *Bathyporeia pilosa*, *Eurydice affinis* and the Polychaetes *Pygospio elegans* and *Hediste diversicolor* (Figure 10).

This community covered 9.9% of the intertidal area of the Nord - Pas-de-Calais region, *i.e.* a total of 10.5 km^2.

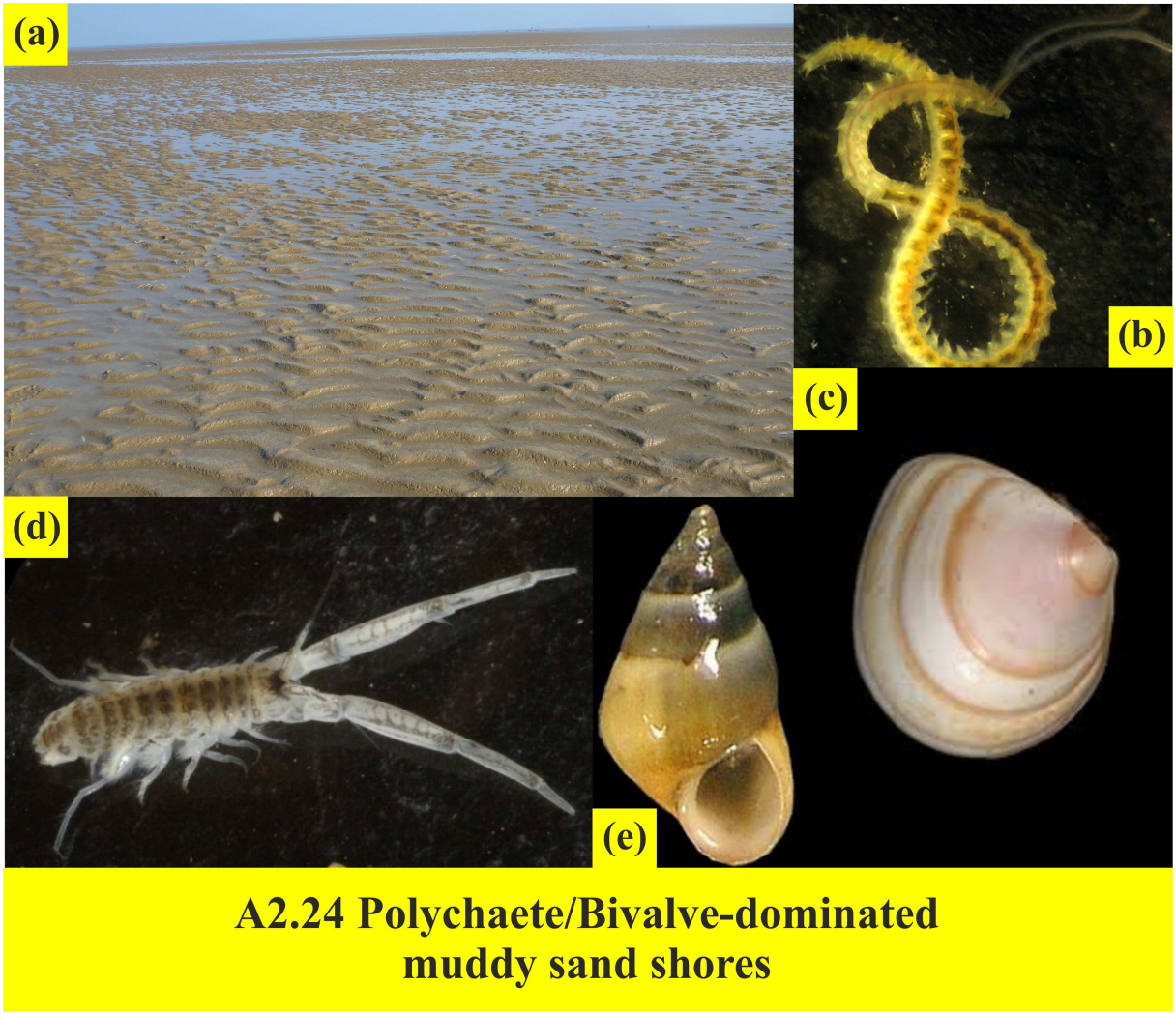

Figure 10. (a) The mid shore and/or the upstream of the bays colonized by the Polychaete/Bivalve-dominated muddy sand shores community A2.24 (picture from the Hemmes de Marck, France; © Christophe Luczak). (b) the Polychaete *Pygospio elegans* (height 10-15 mm; © fyu.fi), (c) the Bivalve Mollusc *Macoma balthica* (height 25 mm; © Hans Hillewaert), (d) the Amphipod *Corophium arenarium* (height 7 mm; © Marc Cochu), (e) the Gastropod *Peringia ulvae* (height 6 mm; © G & Ph Poppe)

The multivariate analysis highlighted the presence of three sub-communities (level 5 of the EUNIS classification) from the Polychaete/Bivalve-dominated muddy sand shores community (A2.24):

- The *Cerastoderma edule* and Polychaete in littoral muddy sand community (A2.242)
- The *Bathyporeia pilosa* and *Corophium arenarium* in littoral muddy sand community (A2.244)
- The *Lanice conchilega* in littoral sand community (A2.245)

E- The *Cerastoderma edule* and Polychaetes in littoral muddy sand community (A2.242)

The *Cerastoderma edule* and Polychaetes in littoral muddy sand community (A2.242) was located in a sheltered area of the western harbour of Dunkirk and colonized the mid shore of the intertidal area, *i.e* a total of 1.1 km^2 (1% of the study area; see map). Sediments were mainly composed by medium sands (77%), fine sands (18%), coarse sands (2%) and 3% of mud (Table 3 and Figure 11).

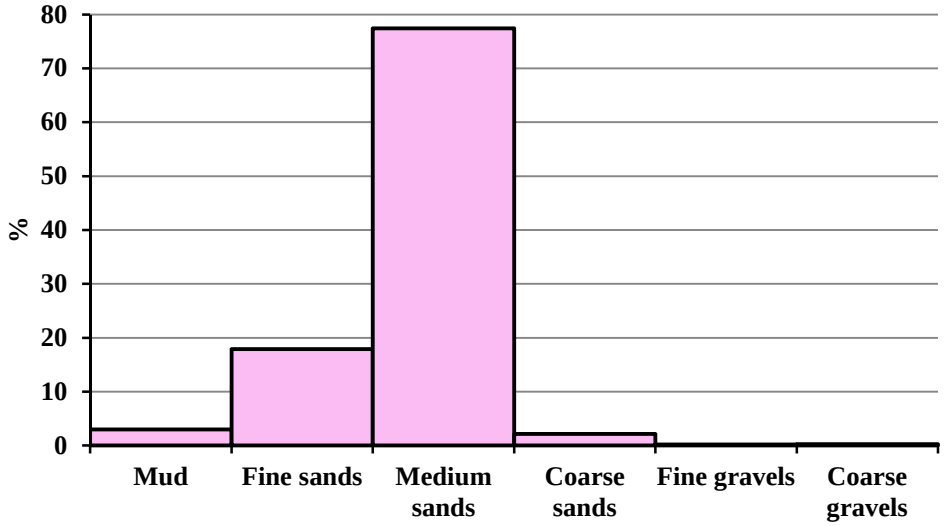

Figure 11. Characteristic granulometry of the *Cerastoderma edule* and Polychaetes in littoral muddy sand community (A2.242)

The species richness and Shannon index of this community were high compared to the other communities described here: 17.5 ± 4.9 species and 2.67 ± 0.08 respectively. Densities and biomass were also high with a mean of 4749 ± 3698 $ind.m^{-2}$ and 12.80 ± 10.80 $g.m^{-2}$ (Table 2). The *Cerastoderma edule* and Polychaetes in littoral muddy sand community was characterized by Bivalves Molluscs such as *Cerastoderma edule* and *Macoma balthica*, and Polychaetes such as *Eteone longa*, *Pygospio elegans*, *Phyllodoce mucosa* and *Capitella capitata* (Figure 12)

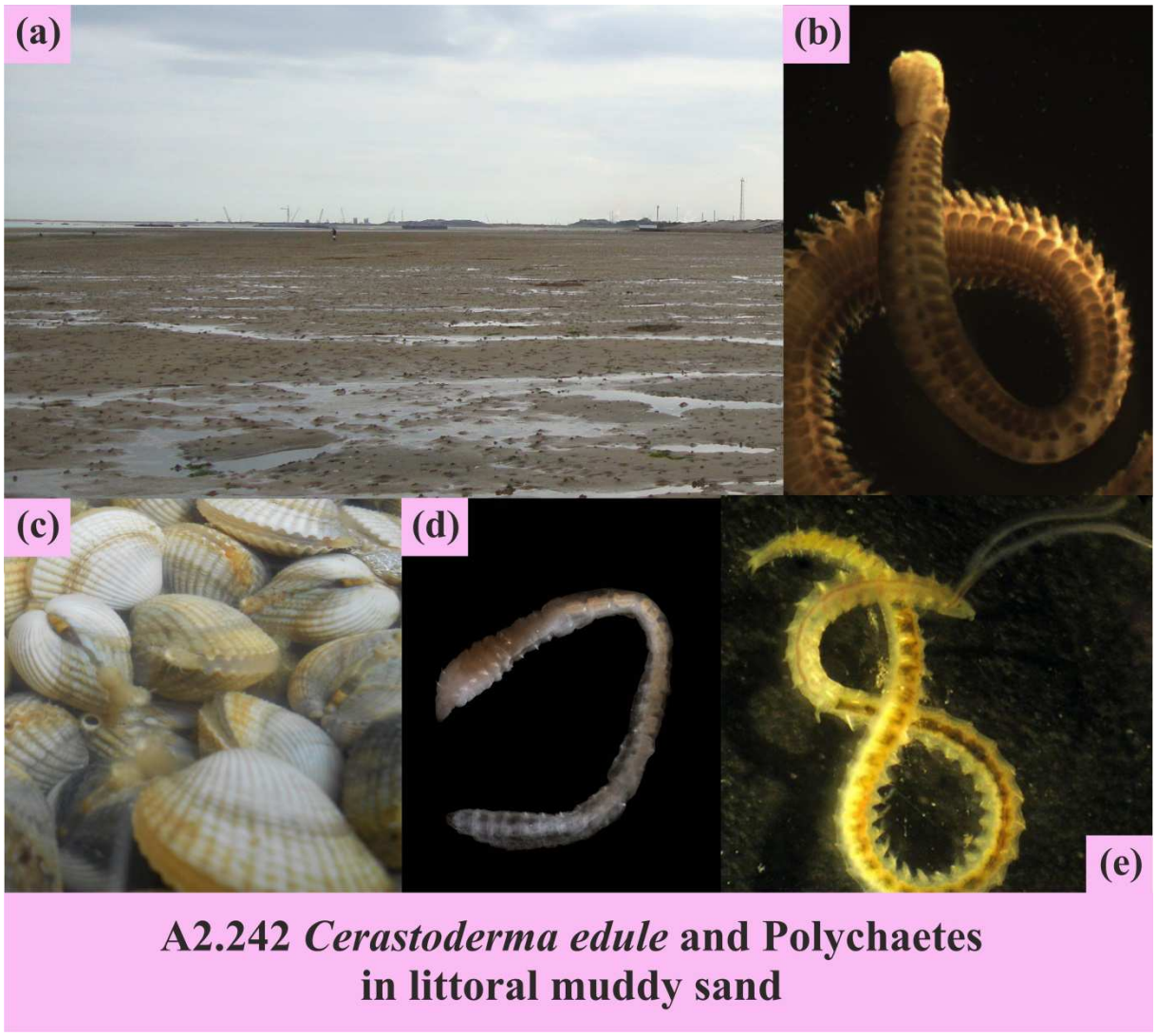

Figure 12. (a) The mid shore of the western harbour of Dunkirk colonized by the *Cerastoderma edule* and Polychaetes in littoral muddy sand community A2.242 (picture from the western harbour of Dunkirk, France; © Céline Rolet), (b) the Polychaete *Eteone longa* (height 25-60 mm; © Céline Rolet), (c) the cockle *Cerastoderma edule* (height 50 mm; © GEMEL Picardie), (d) the Polychaetes *Capitella capitata* (height 20-100 mm; © Hans Hillewaert) and (e) *Pygospio elegans* (height 10-15 mm; © fyu.fi)

F- The *Bathyporeia pilosa* and *Corophium arenarium* in littoral muddy sand community (A2.244)

The *Bathyporeia pilosa* and *Corophium arenarium* in littoral muddy sand community (A2.244) was located in a small area (0.3 km^2 or 0.3%) in the upper zone of the Platier d'Oye beach (between Calais and Dunkirk; see map). Sediments contained a more important proportion of coarse grains than in other communities: 54% of medium sands, 10% of coarse sands, 4% of fine gravels and 3% of coarse gravels. Fine sands represented 29% and muds were present in weak proportions (0.1%; Table 3 and Figure 13).

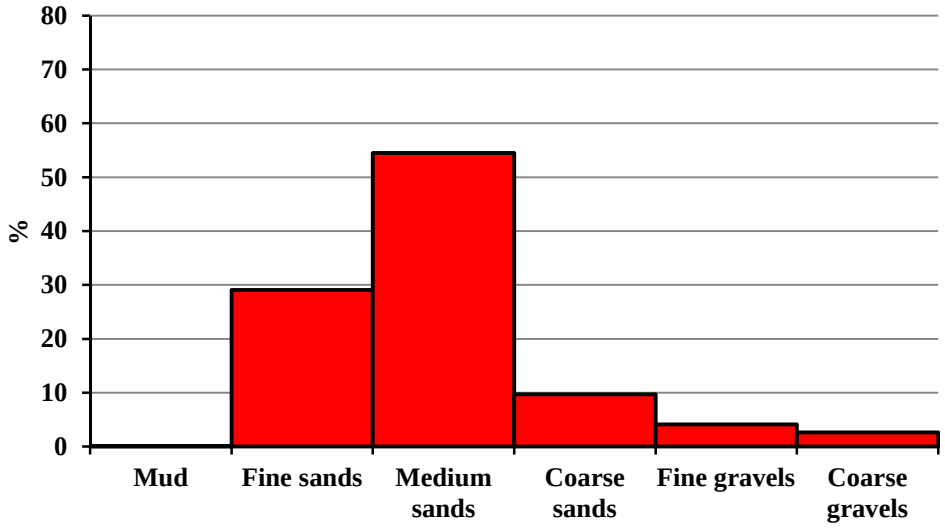

Figure 13. Characteristic granulometry of the *Bathyporeia pilosa* and *Corophium arenarium* in littoral muddy sand community (A2.244)

This community, as for the strandline (A2.21), exhibited a low diversity (Shannon index = 0.73 ± 1.03). Species richness, densities and biomass were also reduced (on average 2 species identified, 47 $ind.m^{-2}$ and 0.07 ± 0.09 $g.m^{-2}$; Table 2). A small number of species was encountered in this community located on the upper beach. The Amphipod Crustacean *Corophium arenarium*, the Gastropod *Peringia ulvae* and Dipteran larvae were sampled in this community (Figure 14). Although *Bathyporeia pilosa* was not sampled during the surveys, the presence of this Amphipod Crustacean in this community is confirmed (C. Rolet. personal observation).

Figure 14. (a) The upper area of the "Platier d'Oye" beach colonized by the *Bathyporeia pilosa* and *Corophium arenarium* in littoral muddy sand community A2.244 (picture from Oye-Plage, France; © Céline Rolet), characteristic Amphipods of this community with (b) *Corophium arenarium* (height 7 mm; © Marc Cochu), (c) *Bathyporeia pilosa* (height 6 mm; © Hans Hillewaert) and (d) the Gastropod *Peringia ulvae* (height 6 mm; © G & Ph Poppe)

G- *Lanice conchilega* in littoral sand community (A2.245)

The *Lanice conchilega* in littoral sand community (A2.245) was located in the Dunkirk and Boulogne-sur-Mer harbours and in the center of the Canche bay (see maps). It mainly colonized the lower shores and the sheltered areas. The sediment was mainly composed of fine sands (64%) and medium sands (30%). A proportion of coarse grains was also detected with 3% of coarse sands and 3% of fine gravels (Table 3 and Figure 15).

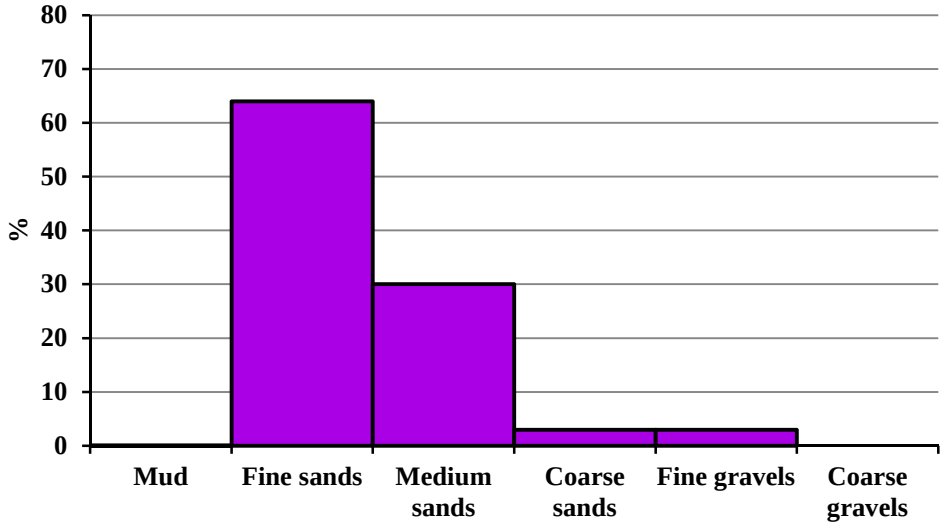

Figure 15. Characteristic granulometry of the *Lanice conchilega* in littoral sand community (A2.245)

Twenty-six (26) species were identified in this community (on average 7.1 ± 4.7 species). The diversity was relatively high (Shannon index = 1.48 ± 0.73). Densities were important with an average of 3132 ± 5565 ind.m^{-2}, as well as the biomass with 5.17 ± 8.27 g.m^{-2}. The main macrobenthic species encountered were the Polychaetes *Lanice conchilega*, *Capitella capitata* and *Notomastus latericeus*. The Bivalves Molluscs *Macoma balthica* and *Abra alba* and the brown shrimp *Crangon crangon* were also listed (Figure 16). The Polychaete *Lanice conchilega* may exhibit important densities; tubes formed by this worm are then visible at the surface of the substrate (Figure 17).

This community covered 0.85 km^2 at the scale of the Nord - Pas-de-Calais region (0.80% of the total area).

Figure 16. (a) The lower shore of harbours and/or the center of the Canche bay colonized by the *Lanice conchilega* in littoral sand community A2.245 (picture from the western harbour of Dunkirk, France; © Céline Rolet), (b) the Polychaete *Lanice conchilega* (height 250-300 mm; © Hans Hillewaert), (c) the brown shrimp *Crangon crangon* (height 90 mm; © Hans Hillewaert) and the Polychaetes (d) *Phyllodoce mucosa* (height 100 mm; © Hans Hillewaert) and (e) *Capitella capitata* (height 20-100 mm; © Hans Hillewaert)

Figure 17. Tubes of the Polychaete *Lanice conchilega*, representative species of the A2.245 community and may have important densities (© Christophe Luczak)

Littoral rock A1 in the Nord - Pas-de-Calais region represented 3.3 km^2 (or 3%). They were located on Equihen-Plage, Le Portel, from Wimereux to the Cape Gris-Nez and from the Cape Gris-Nez to the Cape Blanc-Nez.

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Christophe Luczak

Marc Cochu and Florence Gully

GEMEL Picardie

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ANNEX 1: Statistical analysis to highlight macrobenthic communities

To identify the macrobenthic communities, we used a coupling between a multidimensional ordination (defining gradients and groups) and a clustering (identifying groups and breaks between them; Clarke & Warwick, 2001; Legendre & Legendre, 2012).

A hierarchical clustering (represented as a cluster) and a non-metric multidimensional ordination (nMDS) were computed from a distance matrix using the Bray-Curtis metric. This matrix was calculated on density data (ind.m^{-2}) previously transformed by the fourth root function ($\sqrt{\sqrt{x}}$) to moderate the influence of dominant species.

Groups, from the average linkage method and projected on the 1-2 plane of the non-metric multidimensional ordination (nMDS), were used to identify the different macrobenthic communities living along the coast of the Nord - Pas-de-Calais region (Figure 1).

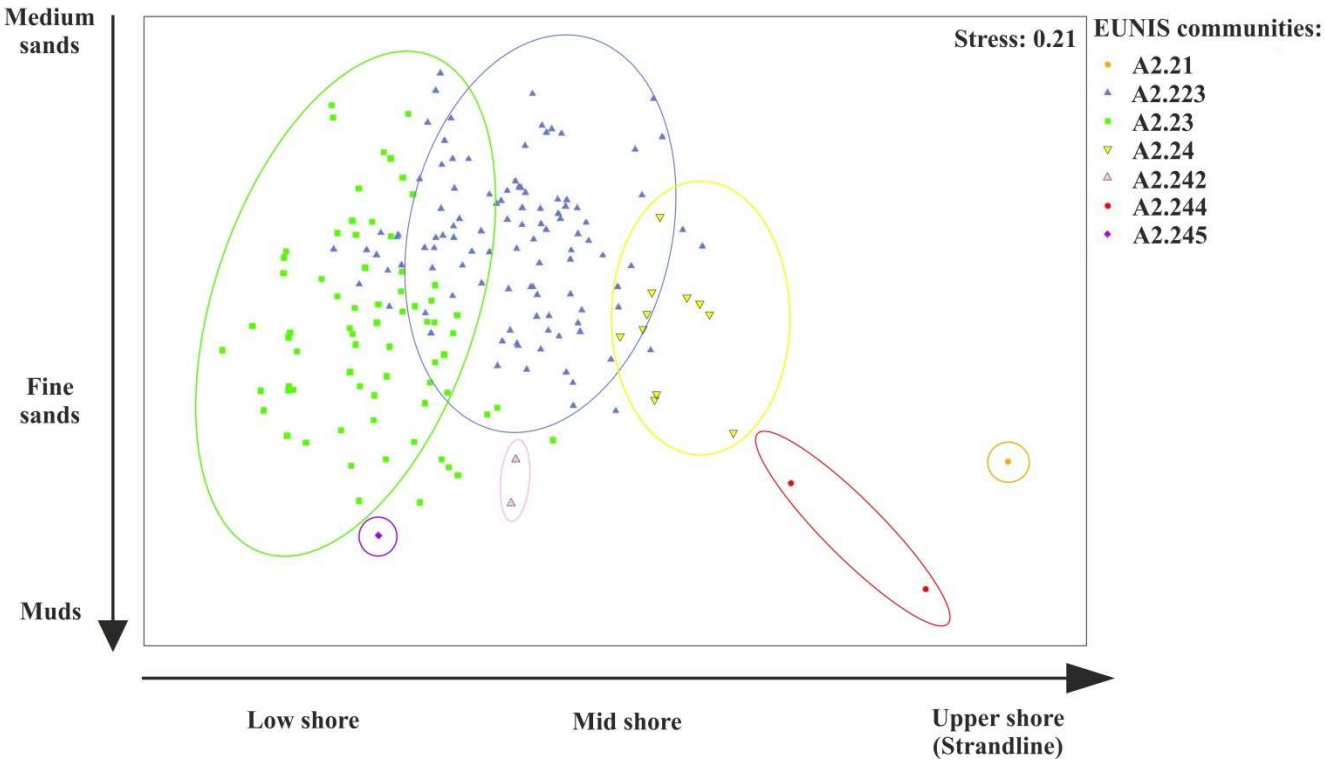

Figure 1. nMDS for the identification of the different macrobenthic communities and highlight gradients between upper shore/lower shore and medium sands/mud. Analysis realized on the macrofauna density data of the stations sampled on the beaches of the Nord - Pas-de-Calais region. Groups were delimited from the clustering based on the same distance matrix. All the analysis were performed with R® (R Core Team, 2013).

Annex 2: List of identified species for each macrobenthic communities encountered on the shores of the Nord - Pas-de-Calais region (France)

Identified species	A2.21	A2.223	A2.23	A2.24	A2.242	A2.244	A2.245
Annelids Polychaetes							
Aonides oxycephala		x					
Arenicola marina		x	x	x	x		x
Capitella capitata	x	x	x	x	xxx		x
Caulleriella alata		x	x				
Chaetozone christei		x	x				
Chaetozone gibber					x		x
Eteone longa		x	x	x	x		
Eumida sanguinea			x				
Eunereis longissima		x			x		x
Glycera tridactyla		x	x				
Hediste diversicolor	x	x		xx			
Heteromastus filiformis		x	x	x	x		
Hilbigneris gracilis			x				
Lanice conchilega		x	x	x	x		xxx
Magelona alleni			x				
Magelona johnstoni			x				
Magelona mirabilis		x	x	x			
Malmgreniella arenicolae							x
Nephtys assimilis			x				
Nephtys caeca		x	x				
Nepthys cirrosa		x	xxx	x	x		x
Nephtys hombergii		x	x	x	x		x
Notomastus latericeus					x		x
Ophelia celtica				x			
Ophelia rathkei		x					
Paraonis fulgens		x	x				
Phyllodoce laminosa			x				x
Phyllodoce mucosa		x	x		xx		
Poecilochaetus serpens							x
Pygospio elegans	xx	x	x	xxx	xxx		x
Scolelepis (Scolelepis) squamata	xx	xxx	xx	x			x
Scoloplos (Scoloplos) armiger			x				x
Sigalion mathildae			x				
Spio martinensis		x	xxx	x			x
Spiophanes bombyx		x	x	x	x		x
Syllidae spp.			x				

Identified species	A2.21	A2.223	A2.23	A2.24	A2.242	A2.244	A2.245
Bivalves Molluscs							
Abra alba		x	x				x
Angulus fabula			x				
Angulus tenuis		x	x				
Cerastoderma edule		x	x	x	x		x
Donax vittatus		x	xx				x
Ensis directus		x	x				
Ensis magnus			x				
Kurtiella bidentata					x		
Macoma balthica	x	x	x	x	xx		x
Mya arenaria				x			
Mya truncata				x			
Mytilus edulis		x					
Petricolaria pholadiformis				x			
Scrobicularia plana				x	x		
Spisula solida		x	x	x			
Tellimya ferruginosa			x				
Gastropods Molluscs							
Buccinum undatum							x
Nassarius reticulatus							x
Peringia ulvae	x	xx	x	xxx	x	xxx	
Crustaceans Amphipods							
Amphilochus neapolitanus			x				
Bathyporeia guilliamsoniana		x					
Bathyporeia pelagica		x	xx	x			
Bathyporeia pilosa		xxx	x	xx			x
Bathyporeia sarsi	x	xx	x	x	x		x
Calliopus laeviusculus		x					
Corophium arenarium		xx	x	xxx	xxx	xxx	
Corophium volutator				x			
Deshayesorchestia deshayesii	x						
Gammarus finmarchicus			x				
Gammarus zaddachi		x	x				
Haustorius arenarius		xx	xx	x			x
Leucothoe incisa			x				
Nototropis falcatus			x				
Nototropis swammerdamei	x	x	x				
Orchestia gammarellus	x						
Photis longicaudata			x				
Pontocrates altamarinus		x	x				
Pontocrates arenarius		x	x				
Talitrus saltator	x	x					
Urothoe brevicornis			x				
Urothoe poseidonis		x	xx	x	xx		

Identified species	A2.21	A2.223	A2.23	A2.24	A2.242	A2.244	A2.245
Crustaceans Isopods							
Eurydice affinis		x	x	x			
Eurydice pulchra	xx	xxx	x	x			
Idotea pelagica			x				
Lekanesphaera monodi		x					
Ligia oceanica	x						
Crustaceans Mysids							
Gastrosaccus spinifer	x	x	x				
Schistomysis spiritus			x				
Crustaceans Cumaceans							
Cumopsis goodsir		x	xx				
Cumopsis longipes			x				
Pseudocuma (Pseudocuma) longicorne			x				
Vaunthompsonia cristata			x				
Crustaceans Decapods							
Anapagurus hyndmanni			x				
Carcinus maenas		x	x	x	x		
Crangon allmanni			x	x			
Crangon crangon		x	x	x	x		x
Diogenes pugilator			x				
Liocarcinus depurator			x				
Liocarcinus holsatus			x				
Liocarcinus navigator			x				
Liocarcinus pusillus			x				
Palaemon serratus		x			x		
Pinnotheres pisum			x				
Portumnus latipes		x	x				
Echinoderms							
Ophiura albida		x	x				
Ophiura ophiura		x					
Sea Spiders							
Nymphon brevirostre			x				
Diverse							
Fish			x				
Insects	x	x		x		xxx	
Nematoda		x	x				
Nemerta		x	x	x			
Oligochaeta	xxx	x	x	x			
Total number of identified species	**16**	**60**	**80**	**37**	**24**	**3**	**26**

x: identified
xx: abundance > 5%
xxx: abundance > 10%
x: identified because sampling was realized at the junction between two macrobenthic communities