The importance of a historical approach for the knowledge, management and protection of ecosystems

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Abstract: The impacts of various human activities on the European continental shelves are significant since about 150 years, long before sciences provided accurate "data" to describe the marine ecosystems. Therefore, efforts aimed at ecological restoration of heavily impacted areas will be meaningless if they do not take into account the real baseline situation through a labour-intensive but rewarding survey of the available historical information. We illustrate this statement with a case-study from Belgian waters, where the baseline biodiversity of a forgotten pebble and cobble ground as well as its environmental history is reconstructed to provide guidelines for future management of human activities.

Keywords: Baseline, Gravel, *Ostrea edulis*, *Clupea harengus*, Benthos

Introduction

The human pressure put on coastal and marine ecosystems considerably increased since the Second World War. However, the continental shelves of industrialized countries have been exposed to impacts by various human activities for more than 150 years, *i.e.* long before marine sciences really took off (Airoldi and Beck, 2007). Many of the early impacts have been forgotten. In particular, the overall effect of more than 150 years of bottom trawling in the North Sea fishing grounds is far from being understood because we lack data on the initial state of the ecosystem. Thus, management measures solely based on recent data will fail to identify the best locations to bring back some level of 'naturalness' in heavily impacted areas.

Through reprocessing a century-old benthos and sediment data-set and reviewing the historic literature (19th and 20th centuries), we partly reconstructed the baseline and environmental history of benthos in front of the Belgian coasts. In particular, we re-discovered the existence of forgotten species-rich pebble and cobble grounds in the Belgian part of the North Sea (BPNS). These habitats hosted wild beds of the European flat oyster *Ostrea edulis* prior to the 20th century. They were inaccurately documented since then and were therefore reinvestigated through a multidisciplinary field survey. The implications of our findings for the future management of human activities and marine biodiversity are discussed.

Materials and methods

Our investigation is based upon digitization and processing of the natural history collection acquired by Professor G. Gilson in the southern bight of the North Sea during the first decade of the 20th century, which is stored at the RBINS. This exceptionally large and old data-set addresses various compartments of the North Sea ecosystem (plankton, benthos, nekton) within a restricted area. It had never been analyzed holistically and remained to a large extent unpublished. So far, our investigations focused on sediments and benthic invertebrates sequentially collected within high resolution sampling grids along and off the Belgian and Dutch coasts (see figure 1). The detailed materials and methods of this research are published elsewhere (Houziaux et al, 2008). A reconstruction of the seafloor composition (average sand grain-size, relative mud content, relative shell content and occurrence of pebbles and cobbles) was carried out using sample descriptions performed onboard by Gilson at every sampling station. These data were used by Fettweis et al (2007) to reconstruct the fate of cohesive sediment in front of the Belgian coast. In this contribution, we will focus on pebbles and cobbles. A large part of the benthic invertebrates collected by Gilson was also digitized, focusing on epifauna collected with a specially designed dredge, and their taxonomy was verified. Doubtful data and stations were eliminated prior to preliminary spatial analysis of diversity indices. This task is still ongoing with further data acquisition on bivalves, polychaetes and amphipods in the framework of the projects 'Quest4D' (Belspo, SSD programme, 2007-2010) and "DIGIT05" (BELSPO, programme "digitization of collections", contract DI/00/05, 2007-2008).The information obtained from processing this historic data-set was supplemented by a thorough investigation of the historic literature (mainly 19th and 20th centuries) dealing with the local environmental history, fishing activities and the European flat oyster.

Certain historic stations of Gilson of the Westhinder area were re-sampled in 2005 using a 2m beamtrawl, a multibeam echosounder and underwater videos recordings. Methods as well as preliminary results are detailed in Houziaux et al (2007, 2008). The benthos data could not yet be fully processed. Long-term changes in the epibenthic community associated to pebble and cobble grounds were however explored through comparing the observed catch probabilities of some species formerly and/or nowadays abundant.

Results

1. Sandy pebble and cobble grounds: baseline benthic biodiversity of the Hinder banks

The reconstructed map of gravels (figure 1, left) matches the most recent maps (Van Lancker et al, 2007). The results suggest that the swale located along the south-eastern flank of the Westhinder sand bank hosted minimum amounts of sand. When epibenthic invertebrate biodiversity is considered (figure 1, right), the latter area displays the highest values of species richness and taxonomic breadth. The epifauna comprises more than 180 of the considered taxa, including a large array of branching epilithic taxa such as sponges, bryozoans and coelenterates not observed in the BPNS since Gilson's work except on shipwrecks (Zintzen et al, 2008). The mobile epifauna of this area is also characterized by many species typical of hard substrata not encountered in the neighbouring species-poor sandy areas. Gilson's data confirm earlier contributions which indicated the existence of such a species-rich „*cobble field*" in Belgian waters in the nineteenth century.

Through our literature review, we further discovered that wild beds of the European oyster *O. edulis* used to form biogenic reefs at the same location 40 years prior to Gilson's investigation (Houziaux et al, 2008; figure 2). These beds were destroyed by English 'deep-sea' oyster dredgers in the1860s. Fourty years later, recently settled larvae as well as large adults were yet collected by Gilson at the same locations. This observation fully confirms earlier descriptions on the occurrence of specimens from 2-3 to above 20 year old, which points at larvae settlement and survival as well as active reproduction in this habitat. The fact that oysters remained scarce decades after exploitation ceased also agrees with some former testimonies on the non-recovery of destroyed open-sea beds. It indicates that recovery of such open-sea bed was naturally very slow (> 50 years). The species has not been mentioned in the BPNS since Gilson's work (last sample: 1933) and can be considered 'virtually extinct' in this area. However, large isolated specimens are still accidentally collected by trawlers in the southern bight and the English Channel nowadays. The species thus forms a "cryptic" population in its former distribution range.

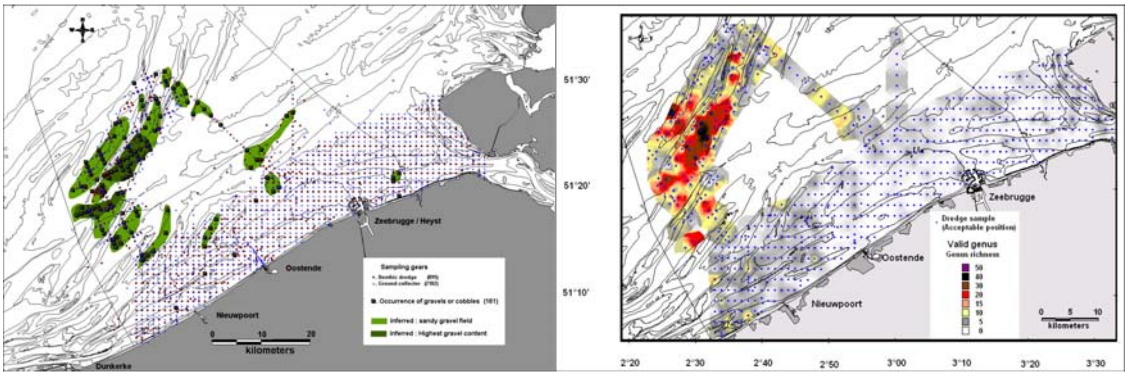

Figure 1. Left: Distribution of gravel in the surface sediment, based on Gilson's descriptions of sediment samples (blue dots) and the occurrence of cobbles in towed gears (dredges and trawls: red dots, median position), in the period 1899-1910. Gravel grounds are drawn manually (green). Areas where all samples contained gravels or cobbles are highlighted in dark green. Right: Interpolation map of epibenthos species richness (Inverse Distance Weighting, search radius: 2 km; taxonomic level: genus) within Gilson's sampling grid (1899-1908). Sampling stations with doubtful geo-referencing as well as non relevant taxa (e.g. infauna) were eliminated prior to analysis. Polychaetes, most bivalves and amphipods are not included in the analysis yet.

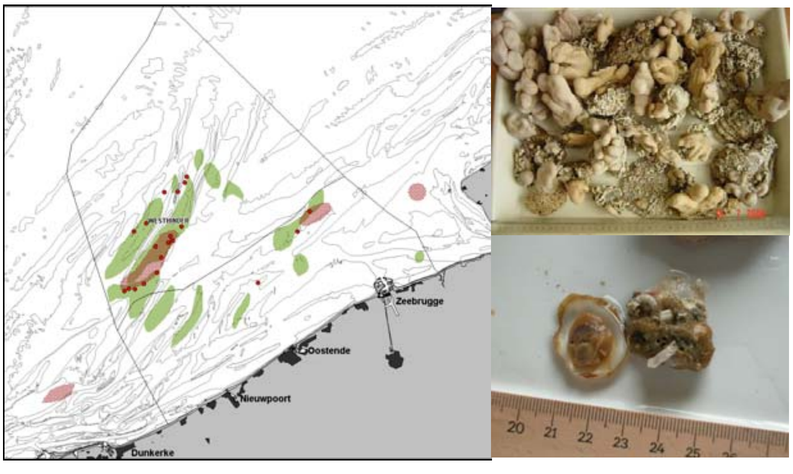

Figure 2. Left. Composite map of sandy gravels (Gilson's data, 1899-1910; green areas), oyster beds targeted by British oystermen in the 1860s (historical literature review; red area) and occurrences of living flat oysters in the first decades of the 20th century (Gilson's data, 1899-1933; red dots). Data are superimposed on the modern coastline and bathymetry. Right, above: oyster specimens and valves gathered by Gilson on the richest station, West of the Westhinder bank, together with some of the 250 large colonies of the dead-man finger *Alcyonium digitatum* collected along. Right, below: a young specimen collected by Gilson East to the Westhinder, showing early colonization by the tube-worms *Pomatoceros triqueter* and *Sabellaria spinulosa*.

2. Chronology of direct impacts of fishing activities to pebble and cobble grounds

On the basis of our literature review, we reconstructed the chronology of impacts caused by dredging and trawling activities to the seafloor of pebble and cobble ground of the Belgian part of the North Sea (see Houziaux et al, 2008). It can be divided into 8 distinct periods (figure 3).

Prior to the 1820s (period 1), the Belgian fishermen did not use trawls. Although it is not impossible that English trawlers were already active in the area of the Hinder banks, we can assume that these coarse deposits were not directly targeted with towed gears. Immediately after 1820, the beam trawl equipped with a wooden beam spread in the Belgian fleet. In the late 19th century, the Hinders ground was known as a good fishing spot, but sailing trawlers avoided stony grounds as much as possible; impacts must thus have remained very limited in these early days (period 2). In 1868, English oyster dredgers appeared in the area and remained active until 1873. They destroyed the biogenic reefs formed by the oysters within a short span of time, leaving a scattered population on the ground. This was the first major impact to the habitat integrity (from biogenic reefs to sandy gravels; period 3). Immediately afterwards, the ground must have been left at rest for a couple of decades, probably enabling a slow restoration of the oyster beds (period 4). The emergence of steam-trawling in the last decades of the nineteenth century probably led to first impacts by bottom trawls to such stony areas in the southern North Sea. They probably increased slowly as the fleet of steam-trawlers grew up (period 5). When G. Gilson sampled the area (1905-1907), the seafloor could be described as a sandy gravel with scattered specimens of flat oysters and many large colonies of branching species.

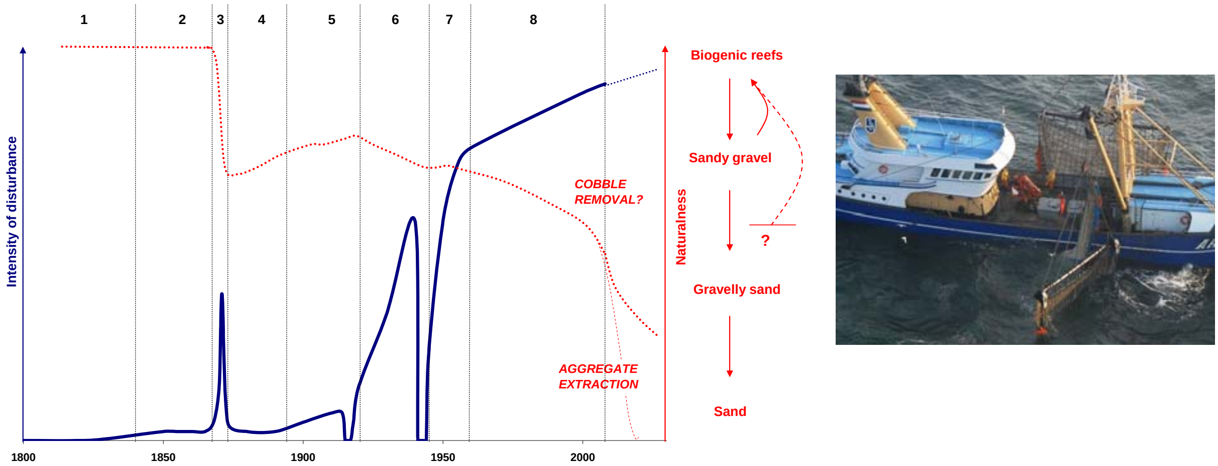

Figure 3. Left. Schematic representation of the chronology of impacts caused by towed fishing gears to pebble and cobble grounds of the Belgian part of the North Sea. The relative intensity of direct disturbance to the seafloor (blue line) and the evolution of the 'naturalness' of the benthic habitat (red line) is estimated on the basis of our literature survey and is divided into 8 distinct periods. The degree of 'naturalness' of the habitat is defined relatively to its baseline state, from biogenic reefs (top level) to bare sands (lowest level). The possible transitions from a state to another are represented by arrows. See text for details. Right. A large modern chain-mat beam trawler operating in the surroundings of the Westhinder area. Image: J. Haelters, MUMM, 2007.

After 1920, trawlers increasingly targeted pebble and cobble grounds (period 6). Indeed, by then, motorized trawling begun to replace the traditional drift-net herring fishery practised in the southern bight by North Sea fleets since the middle-ages. The trend to increasingly target these grounds was explicitly reported by Gilson (1921). After the Second World War, industrial trawlers of the North Sea fleets exploited spawning herring more intensively, among others in the gravels of the Hinder banks (period 7). In the 1960s, after depletion of herring stocks, the Belgian and Dutch fleets started to disturb gravels with chain-mat beam trawls, targeting flatfishes, with increasing ship power (period 8). The use of chain-mat beam trawls towed by increasingly powerful vessels is likely to have further altered the seafloor even if the trawling effort is assumed to have remained constant. Houziaux et al (2007, 2008) suggest that the pebble and cobble ground of the swale between the Westhinder and the Oosthinder sand banks is nowadays entirely trawled by powerful vessels every two years. This is probably an under-estimate of the real situation. Furthermore, cobbles gathered by the large Dutch chain-mat trawlers are kept and used for decorative purpose in gardens (Lindeboom, com.pers.), a practice inevitably leading to a progressive removal of the substratum. Indeed, In Dutch waters, some gravel grounds are nowadays definitely wiped out subsequently to this practice (Baretta, 2004).

We can thus consider the still ongoing human-induced habitat degradation path as an irreversible erosion process through which the pebble and cobble field is progressively replaced by a gravelly sand and finally a sandy area; the „no-return" point from which restoration of oyster beds becomes impossible can hardly be determined at this stage (see figure 3). Noteworthy, such an increase of sand content is observed in the adjacent pebble and cobble grounds of the French part of the North Sea since 30 years (Carpentier et al, 2005; De Warumez, *com.pers*.), but it remains yet unexplained. The immediate effect of enabling aggregate extraction on such gravels will be a considerable acceleration of the definitive biotope removal process at the extraction pits.

3. Present state of the pebble and cobble grounds: degraded benthic biodiversity

Gilson's historic stations located in the swale between the Westhinder and the Oosthinder sand banks were surveyed in 2005 within a multidisciplinary field survey (see Houziaux et al, 2007, 2008). The benthos samples collected with a 2 meter chain-mat beam trawl enabled us to confirm the occurrence of a typical epifauna of hard substrata in this swale. Based on these data, acoustic maps of the seafloor and underwater video footages, the seafloor can be descibed as a heterogeneous field of pebbles and cobbles partly covered with a thin layer of sand. Emerging pebbles and cobbles are often colonized by a wide variety of encrusting and branching epilithic species. When compared to the historical situation depicted by Gilson's data, long-term changes were observed, although the data are yet incompletely processed. Indeed, the relative abundance of species most sensitive to trawling activities is decreased, with in particular a virtual disappearance of the European flat oyster (figure 4). Species considered as opportunistic feeders as well as robust and short-lived species have increased their numerical abundance.

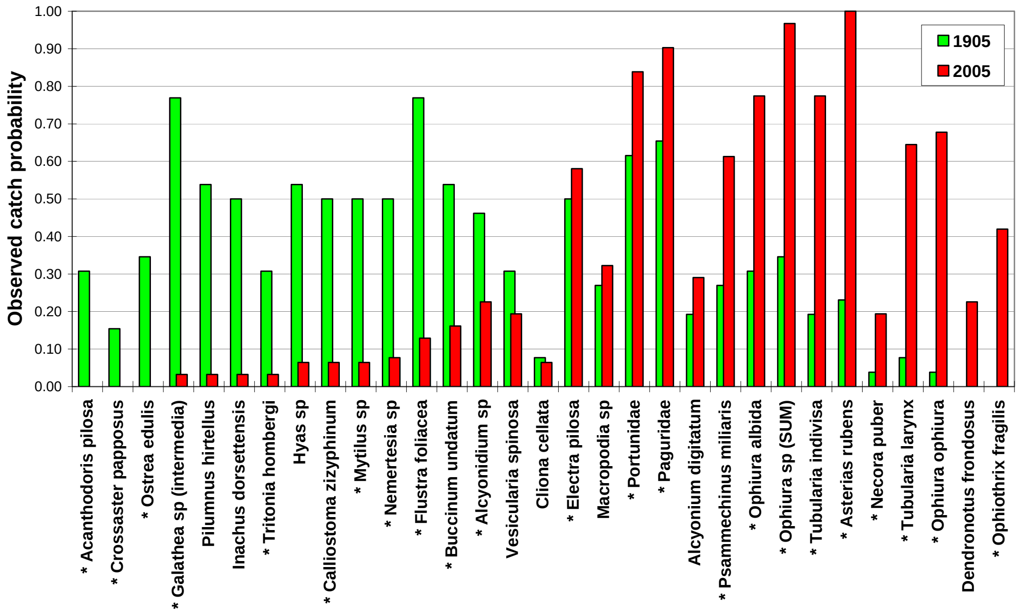

Figure 4. Comparison of catch probabilities in Gilson's survey (green bars; spring-summer1905; n=21 dredge tows) and our survey (red bars; spring 2005; n=31 beam trawl tows) for 30 species commonly encountered and accurately collected by both sampling gears. Densities are further aggregated for the genus *Ophiura*. Catch probabilities of species marked with an (*) are unlikely to change subsequently to further processing of samples from the survey of 2005. Source: Houziaux et al, 2008.

The size of the colonies of the soft coral *Alcyonium digitatum* also appeared as a good indicator of trawling impacts. Indeed, only three of the recent stations provided large colonies of this species, while tiny colonies were observed at all others. Furthermore, the proportions of damaged epilithic taxa (*e.g.* the tube worm *P. Triqueter*) were visibly lower at these stations. When the acoustic map of the seafloor obtained with the multibeam echosounder was examined, these samples originated from two gravel spots between large sand waves at the foot of the Oosthinder sand bank. There, the amount of trawl marks on the seafloor was lower than in the main swale (figure 5). These are undoubtedly natural refuges against bottom trawling.

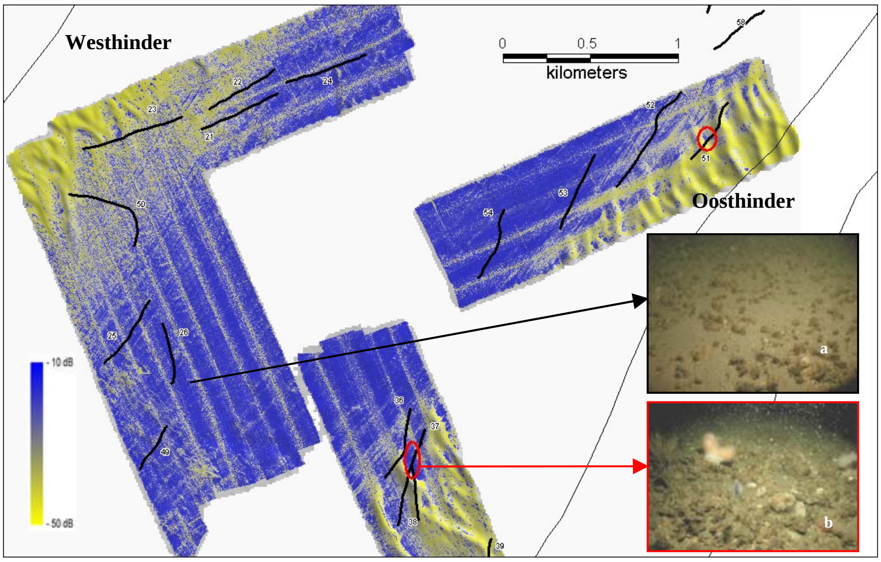

Figure 5. Distribution of backscatter intensity values provided by the multibeam echosounder (high values – gravel grounds: blue; low values – sand dunes: yellow) between the Westhinder and the Oosthinder banks. The black lines represent the 2m beamtrawl tows. *a*: typical aspect of the main swale (disturbed by trawling). *b*: typical aspect of the 'refuge' area discovered between transversal sand waves at the foot of the Oosthinder sand bank, bearing among others higher species diversity and larger colonies of sensitive species (*e.g. Alcyonium digitatum*). Two refuges were discovered (red circles). Underwater photographs: MUMM, A. Norro (2007).

Discussion

The investigated pebble and cobble grounds were yet poorly defined and their associated benthic biodiversity was undescribed prior to our survey of available historical data. The historic collection of Gilson fully confirmed statements expressed by former authors and enabled us to delimitate an area where epibenthic species richness and taxonomic breadth was maximum in the BPNS. The combined analysis of the historical literature and data evidences the former ecological importance of these habitats in the southern North Sea: they naturally hosted European flat oyster beds, which formed „biogenic reefs"; they hosted highest levels of species richness and taxonomic breadth, including large branching species, even after removal of the oyster beds; they hosted spawning of the herring *Clupea harengus*, another key-species of the North-Eastern Atlantic.

Although there are little published data on the micro-scale distribution of trawling activities through time, our survey of the literature as well as the field data gathered in 2005 leave no doubt on the fact that this fishing practice has exerted an increasing pressure on the considered grounds and its associated biodiversity since more than 80 years. When the historic literature about flat oysters and trawling activities is investigated on the larger scale, it clearly appears that our findings in the Belgian Part of the North Sea can be transposed to adjacent areas in the southern North Sea and English Channel. Indeed, such so-called 'deep-sea' wild oyster beds occurred in pebble and cobble habitats throughout the area prior to being targeted by English specialized oyster dredging fleets from Kent, Essex, the Solent and Jersey (see Houziaux et al, 2008). Thus, this was an important habitat for this species, and this fact has been forgotten since the late nineteenth century. We propose that the role played by bottom trawling in the fate of European flat oyster populations of the English Channel and the southern North Sea has been much underestimated so far because oyster researches historically focused on the (cultivated) coastal beds. On the other hand, as far as we know, the impact of chain-mat trawling activities ongoing since the 1960s on the reproductive success of herring is undocumented in the southern bight.

Apart from virtual extinction of the European flat oyster, the data gathered so far do indicate a significant shift in the composition of the associated benthic community over hundred years. However, the seafloor can still be described as a „sandy gravel" where many epilithic species can settle down and, for a part of them, grow up. There is no doubt that the present levels of beamtrawling dramatically alter the composition of benthic communities associated to these habitats through selective removal and non-reinstallation of sensitive (large, long-lived) species. Permanent degradation of the seafloor composition is also much likely to take place through continuous displacement and removal of cobbles. The latter practice will ultimately lead to definitive removal of these biotopes, as happened already in adjacent waters. The discovery of natural refuges for these sensitive taxa strongly supports our views but also provides a hopeful perspective for marine ecological restoration. If the seafloor of the main swale has not been permanently modified by decades of bottom trawling, we propose that these refuges could act as 'primers' toward a restoration of a more healthy benthic biodiversity where sensitive taxa can recolonize the habitat, provided a specific management of human activities is implemented in the area. Therefore, a new MPA was recently proposed on the basis of historical evidences partly presented here (Haelters et al, 2007). However, predicting the future evolution of this biotope and its impact on ecosystem functioning under various management scenarii will not be feasible unless further biological researches and monitoring are carried out.

Noteworthy, the European flat oyster is not 'extinct' in the area since it is yet occasionnally caught by bottom trawlers in the English Channel and the southern North Sea. Thus, despite its strongly reduced population, the species is still able to reproduce and maintain a „cryptic" population. It seems much likely that this population must survive in refuges similar to those discovered in the Westhinder area, disseminated accross the English Channel and the southern bight. A potential toward recovery of wild beds on offshore sandy gravels must exist indeed provided their habitats are still suitable. Their original role within the overall flat oyster meta-population remains to be investigated.

Conclusions

Our investigation of the baseline situation of the pebble and cobble grounds evidences biodiversity patterns forgotten in the most recent researches. No doubt, these discrete habitats exert important ecological functions in the southern North Sea through their natural species richness and the occurrence of some key-species. They are natural „hot-spots" for marine biodiversity in this predominantly sandy shallow region. We therefore advocate for strict protection measures against human activities likely to permanently alter these habitats, even though their present state is yet poorly documented, and for the implementation of specific biodiversity research and monitoring activities. No aggregate extraction should be permitted on such ground because the resource is not renewable at all and it plays an important role in ecosystem functioning. Similarly, trawling must be banned as well to ensure some level of ecological restoration to take place. In the absence of strict and urgent measures, irreversible losses will continue to take place throughout the area.

Marine biodiversity ignores administrative boundaries: our results can obviously be transposed to adjacent areas, and the implementation of protection measures should therefore be undertaken in the frame of a larger-scale approach, e.g. "coherent" networks of MPAs to be defined soon in the frameworks of OSPAR (target: 2010) or the Convention on Biological Diversity (target: 2012).

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