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Collaborative approach for the management of harbour-dredged sediment in the Bay of Seine (France)

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ABSTRACT

Dredged material dumping is one of the most important human activities to be considered in coastal zone management. Searching for a new site for depositing the sediment dredged from the entrance of the navigation channel of Rouen harbour in the Seine estuary is complicated because of the combined natural heritage and anthropogenic constraints. This paper presents the intricate background and the collaborative efforts of the Seine estuary tripartite authority (National Government-Rouen Harbour-Scientific Committee) to initiate an ecosystem approach for managing waste. The selection of a future potential dumping area stems from a consideration of economic and logistic factors, both marine and environmental, as well as various natural and anthropogenic constraints in the complex ecosystem of the Seine estuary. It appears that a site with fine-to-medium clean sand situated offshore from the mouth of the Seine estuary would be a good candidate from the biological and economic points of view. Additional procedures on two experimental sites will be necessary before the French government can give a final decision to authorize the Rouen harbour to exploit this new deposit location.

1. Introduction

The English Channel (EC) is a natural passage between the Atlantic Ocean and the North Sea, representing one of the busiest routes used by shipping of all kinds transiting through the Dover Strait in the eastern sector of the Channel. It is a main route for the major North-European Harbours (e.g., Antwerp, Amsterdam, Bremen, Bremerhaven, Hanover, London and Terneuzen). The EC is "*the umbilical cord between the world and Europe, whose history and prosperity have been built around this sea*" (Buléon and Shurmer-Smith, 2007). The density of maritime traffic is nearly 20% of world traffic. With an especially dense west-east movement, there are also numerous transverse north-south movements between France and the UK.

The EC's maritime traffic is very intense, with about 500 vessels entering and leaving the Channel every day, plus between 90 and 120 daily ferry trips between the European continent, the United Kingdom and the Channel Islands (Buléon and Shurmer-Smith, 2008). There are a large number of vessels transporting hazardous cargoes, with oil tankers representing about 75% of this traffic. The increased human pressure on this maritime territory has created many conflicts of interest (Dauvin and Lozachmeur, 2006; Dauvin, 2012). Like other regional seas of the world, traditional activities (e.g., fisheries, shellfish farms, continental discharges, the presence of cables, urbanisation of tourist and harbour zones, and harbour infrastructure development) are omnipresent (Buléon and Shurmer-Smith, 2008).

On the route towards the North Sea, two main French harbours – Le Havre and Rouen – are located near the mouth of the Seine estuary, the latter port being situated 120 km from the open sea. In France, these harbours are economically major sites, mainly because they are situated on the Paris-Sea corridor linking through to Paris and its agglomeration (>16 million inhabitants), which concentrates most of the French economy. The development of both of these estuarine harbours remains very important, not only for access to the sea but also for fluvial French and European transport of merchandise from France to the rest of Europe.

The permanent accessibility of both the Le Havre and Rouen seaports (respectively Grand Port Maritime du Havre and Grand Port Maritime de Rouen, i.e. GPMH and GPMR) remains a

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permanent challenge in the context of the increasingly large capacities of cargo ships, which require the maintenance and dredging of deep channels to ensure access to the loading platforms at all times. Because of the GPMR operations, the main navigation channel of the Seine is used on a daily basis as a route for several cargo tankers and container ships. Thus, dredging and managing considerable quantities of dredged sediments have to reconcile these harbour requirements with the high quality natural heritage of the estuarine ecosystems. In fact, since the end of the 1990s with the construction of the new container platform called "Port 2000" for GPMH, it appears necessary to have a global management plan of the Seine estuary taking into account the sustainable development of the area involving many conflicts of interest (Desroy et al., 2006; Dauvin, 2006a, 2011).

Under European Union pressure, the French administration and non-governmental environmental protection organizations require both harbours to integrate their project into an Integrated Coastal Zone Management (ICZM) of the Seine estuary. In 1999, a Scientific and Technical Council of the Estuary was created; under the National Harbour Law of 4 July 2008, this body was changed into the Scientific Committee of the Seine Estuary (SCSE). All environmental questions about estuarine planning are submitted to the SCSE, which is the scientific reference to the prefect of the Haute-Normandie region, who represents the French national government. Among recent questions, there is the issue of depositing sediment dredged from the navigation channel of GPMR. The current dumping site (*Kannik*, situated inside the estuary) is known to have contributed over the last decades to maintaining the silting up of the northern bank of the estuary (i.e. the northern mudflat and associated channel, Cuvilliez et al., 2009). For that reason, the SCES has recommended that GPMR should locate a new sediment deposit area outside the Seine estuary. There are collaborative efforts from the National Government, GPMR and SCSE to find a less detrimental dumping area to minimise the ecological footprint of dredged sediment deposition. From the SCES study, it appears that a site with fine-to-medium clean sand offshore from the mouth of the Seine estuary would be a good candidate in view of the biological and economic perspectives. Dumped material come from the navigation channel is composed of fine sand containing a significant proportion of shell debris. The fine fraction (<63 μm) makes up between 30% and 50% of the bulk sediment. Thus, the similarity between dredged material and sediments in the dumping area will play an essential role in controlling the type and severity of the impact on the marine environment.

The aims of this paper are: 1) to summarize the main natural and anthropogenic constraints in the complex ecosystem of the Seine estuary, 2) to present the collaborative efforts of the National Government, GPMR and SCSE, and 3) to propose a feasible sediment dumping site that takes into account the sediments and the characteristics of benthic communities as biological indicators of ecosystem health in the marine environment. This paper also illustrates how European, National and Regional harbour regulations – both GPMR and GPMH – have provided new knowledge about the structure and functioning of benthic ecosystems in the eastern sector of the Bay of Seine.

2. Sea-bottom characteristics of the eastern sector of the Bay of Seine and the Seine estuary

Geographically, the EC is a shallow epicontinental sea, extending over an area of more than 77,000 km^2 and bordered by two maritime countries: the United Kingdom and France. Its main general characteristics have been recently described in studies that highlight the particular features of the western and eastern basins, showing the existence of two distinct management-based ecosystems and the importance of tidal currents in the structure and functioning of this tidal sea (Reid et al., 1993; OSPAR, 2000; Paphasis et al., 2010; Dauvin, 1997, 2012).

As a part of the eastern basin, the Bay of Seine forms an approximate quadrilateral with an area of 5000 km^2, never exceeding a water depth of 30 m. In this macrotidal setting (tidal range up to 7.5 m at Le Havre), with tidal currents averaging between 1 and 2 knots in the southern sector of the bay, and their intensity gradually decreasing toward the eastern Bay of Seine (Salomon and Breton, 1991, 1993). These currents play an essential role in controlling the distribution of both sediments (Larsonneur et al., 1982) and benthic communities (Cabioch and Gentil, 1975; Gentil and Cabioch, 1997). The Bay of Seine is sheltered from the action of western high-energy oceanic swells, and is only affected by wind-induced waves formed on the central part of the EC, with periods of 4–5 s and a decennial maximum significant wave height about 9 m; waves are known to be efficient in water depths of less than 10 m (Larsonneur et al., 1982; Avoine, 1987).

Lesourd (2000) carried out the most recent mapping of sedimentary facies across the eastern Bay of Seine, before the construction of "Port 2000". A sedimentary gradient is present from offshore to inshore: offshore sediments generally consist of pebbles, gravel and coarse sand, while sediments just at the mouth of the Seine estuary are mainly fine sand and silty/muddy fine sands. The main part of the tidal ebb delta is formed of fine sands resulting from the Holocene transgression (i.e. during the last 6500 years), which introduced large volumes of shelf sands and silts into the lower valley of the Seine River (Lesueur et al., 2003; Tessier et al., 2012) under the combined influence of waves and dominant flood tidal currents. Since the mid-19th century, sediment distribution has changed from a sand/gravel system to the muddy deposit system prevalent at the end of the 20th century (Lesourd et al., 2001). Seasonal variations in the sedimentary regime in the mouth of the macrotidal Seine estuary, were described in Lesourd et al. (2003).

In the eastern sector of the Bay of Seine, Gentil and Cabioch (1997) identified four main macrobenthic communities: 1) a medium-to-fine sand *Ophelia borealis* community linked to hydrodynamic sand dunes; 2) a muddy-fine sand *Abra alba-Pectinaria koreni* community; 3) a heterogeneous muddy community, especially along the Pays de Caux coast between the Hève and Antifer capes (Fig. 1); and 4) a muddy *Macoma balthica* community in the Seine estuary in both the north and south channels. The navigation channel, which is dredged continuously, shows a very poor benthic compartment (Dauvin and Desroy, 2005). In parts of the eastern sector of the Bay of Seine, both *Abra alba-Pectinaria koreni* and heterogeneous muddy communities show very high abundances and biomasses, being among the highest observed in analogous north-eastern Atlantic benthic communities (Thiébaut et al., 1997), which ensures a high trophic transfer in fish (Dauvin and Desroy, 2005). The Seine estuary and the eastern sector of the Bay of Seine remain important flatfish nurseries for the EC (Le Pape et al., 2003, 2007), despite the poor environmental quality (Cachot, 2009) and the great reduction in the estuarine surface-area (Dauvin, 2006a). Nevertheless, Le Pape et al. (2007) have highlighted several signs of degradation.

The Seine River has a mean annual discharge of around 410 m^3 s^{-1}, with peak flows exceeding 2200 m^3 s^{-1} and a minimum of 40 m^3 s^{-1} (Guézennec et al., 1999). The mean annual transport of suspended particulate matter (SPM) at the upper estuary boundary is estimated at around 6×10^5 t year^{-1}, with marked variations over the years, and extreme values of 1.3×10^5 and 1.7×10^6 t year^{-1}