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Mapping benthic communities: An indispensable tool for the preservation and management of the eco-socio-system in the Bay of Seine

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HIGHLIGHTS

- The Bay of Seine is an area with an accumulation of human activities.
- Habitat mapping is an essential tool for managing coastal ecosystems.
- There is a balance between natural heritage conservation and economic development.
- Expert judgement is indispensable to represent the mosaic of habitats.
- Maps of benthic habitats of the Bay of Seine use different typologies.

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ABSTRACT

The establishment of benthic marine habitat maps plays an important role in the conservation and management of coastal ecosystems faced with the increasing impacts of human activities. The Bay of Seine, bordering the eastern part of the English Channel, is an area undergoing considerable cumulative impacts, and which consequently requires a synthesis of our knowledge of the ecological status of its benthic habitats. Fortunately, numerous benthic sampling campaigns have been carried out over the last two decades, mainly in the eastern and western shallow parts of the bay. These campaigns have led to the construction of a database, allowing statistical analyses at the scale of the whole area which are then used to produce maps. Nevertheless, it appears that maps constructed using existing Natura 2000, EUNIS (European Nature Information System), and French MNHN (Museum National d'Histoire Naturelle) typologies are not enough detailed to distinguish the mosaic of habitats of the Seine estuary. It is indispensable to add expert judgements concerning local areas to updated maps of the benthic communities in the Bay of Seine. Several Natural Zones of Interest for Ecology in terms of Flora and Fauna named 'ZNIEFF-Marine' areas have been identified, which could be useful in the future in the context of marine Natura 2000 sites for the management and conservation of endangered marine habitats in this maritime zone subject to highly conflicting interests.

1. Introduction

In the English Channel, a shallow megatidal and epicontinental sea, benthic studies began in the 1960s and 1970s with the work of teams led by Norman Holme (UK) and Louis Cabioch (F). The first

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maps of the subtidal benthic communities were drawn up in the western part of English Channel (Cabioch, 1968; Retière, 1975). In the eastern part, the map for the Bay of Seine published by Cabioch and Gentil (1975) was based on the Ph.D. studies of Gentil (1976), including 72 stations sampled with a "Rallier du Baty" dredge in 1971 and ~100 other stations sampled with the same type of gear in the period from 1972 to 1974. Later, Cabioch et al. (1978), Gentil and Cabioch (1997) published a synthesis of the above mentioned samplings in which they described seven main macrobenthic communities which were later classified following the EUNIS (European Nature Information System) habitat classification taking in account French contributions (FR) (Guillaumont et al., 2008) to the INTERREG-MESH (Mapping European Seabed Habitats) programme (http://www.emodnet-seabedhabitats.eu/): (1) the coarse gravel and pebbles community (A4.13_FR01: sessile fauna on circalittoral coarse gravels and cobbles) [*cf. Sparse sponges…on circalittoral mixed substrata (W13, W17 cited in* Lozach, 2008*), do not confuse with EUNIS habitat A4.13: mixed faunal turf communities on circalittoral rock*;], with three facies: type facies, pebble facies and impoverished facies on pebble gravels; (2) the sandy gravels and gravels community (A4.13_FR02: sandy gravels habitats; cf. EUNIS habitat A5.13: circalittoral coarse sediment); (3) the *Branchiostoma lanceolatus* coarse sand community (A5.135: *Branchiostoma lanceolatum* on circalittoral coarse sand with shell gravel); (4) the *Ophelia borealis—Nephtys cirrosa* fine and medium clean sands community (A5.251: *Echinocyamus pusillus*, *Ophelia borealis* and *Abra prismatica* in circalittoral fine sand); (5) the *Abra alba* muddy fine sand community (A5.244: *Spisula subtruncata* and *Nephtys hombergii* in shallow muddy sand), with two facies: types facies and *Abra alba—Lagis koreni* facies; (6) the heterogenous muddy mixed community (A5.43_FR03: *Pista cristata* in shallow subtidal mixed sediment), considered by Dewarumez et al. (1992) as an ecotone between the pebbles community and the *Abra alba* community and (7) the *Macoma balthica* community in estuarine muddy fine sand and mud (A5.222: *Nephtys cirrosa* and *Macoma balthica* in shallow subtidal mobile sand under variable salinity conditions). This pattern reflects the decrease in energy of the hydrodynamic regime from strong offshore tidal currents to slackened currents in the eastern and western shallow waters in front of the Seine and Veys estuaries, with superficial sediments ranging from pebbles in high-energy zones to sandy mud and mud in low-energy zones according to the sediment maps (Vaslet et al., 1979; Larsonneur et al., 1982; Lesourd et al., in press).

Nowadays, the establishment of benthic marine habitat maps plays an important role in the context of conservation and management of coastal ecosystems faced with the increase of human activities. These cumulative human activities involve harbour development, with dredging and sediment deposition operations to facilitate access for shipping, as well as fisheries, aquaculture, aggregate extraction, marine renewable energies and pollution, and mainly concern the continental shelves and shallow waters of the industrial developed countries. In their review, Halpern et al. (2008) pointed out that the North Sea and English Channel, especially its eastern Basin (Dauvin and Lozachmeur, 2006; Dauvin, 2012), which is among the coastal marine zones where cumulative human impacts have the greatest influence on the worldwide ocean.

The development of benthic mapping has been spurred by the European INTERREG programmes such as MESH and CHARM (), which included maps of benthic species, benthic communities and benthic habitats. The recent renewal of benthic mapping research in the Bay of Seine (see Dauvin, 2015) has been stimulated mainly by the increase of studies concerning human activities and the extension of the Natura 2000 network for marine areas (CARTHAM Programme: http://cartographie.aires-marines.fr/?q=node/43). The different goals of these programmes require precise descriptions of benthic habitats from small scales of observation (1–10 km^2) to more extended scales (10–100 km^2).

During the two last decades (1998–2014), numerous quantitative benthic sampling campaigns have been conducted mainly in the eastern and western shallow parts of the Bay of Seine (see Dauvin, 2015), which have led to the construction of the present database. Moreover, there has been an increase of sampling along the coast in the intertidal zone including soft-bottom and hard-bottom areas. These benthic data were obtained under two main types of scientific or operational programmes mostly conducted to study the impact of human activities in the Bay of Seine: (1) French National Scientific Programmes and the Regional Seine-Aval programme (http://seine-aval.crihan.fr/web/) and (2) impact studies for the two maritime harbours of the Seine estuary (Rouen and Le Havre) and work on the natural heritage of the Seine estuary from French government bodies. In this context, benthic studies and the resulting knowledge form the foundation of marine management for the French government and the mapping needs to be summarized and updated.

In this study, statistical analyses are applied to the recent available data at the scale of the whole of the Bay of Seine and expert judgement is also used in some local areas to produce updated maps of the benthic communities including intertidal and subtidal zones, soft-bottom and hard-bottom substrates, with zooms for the eastern and the western parts of the bay. The maps presented here use French national and European typologies including the EUNIS Classification (JNCC, 2015) of benthic communities, revealing a lack of scientific knowledge in some habitats of the Bay of Seine, as well as new benthic habitats that could be integrated later in a revision of the EUNIS classification. Finally, the present map and knowledge of benthic communities have been linked to management of an anthropic zone such as the Bay of Seine.

2. Main characteristics of the Bay of Seine

2.1. Oceanographic context

The Bay of Seine (Fig. 1) is the largest bay of the English Channel, covering a quadrilateral-shaped area of ~5000 km^2, i.e. 50 km from north to south and 100 km from west (eastern coast of Cotentin) to east (western extremity of the Pays de Caux) (Fig. 1). The offshore part of the bay does not exceed a water depth of 30 m. The maximum speed of the tidal currents is ~3 knots in the north of the bay, with weaker currents of less than 1.5 knots in the east near the Seine estuary and in the west near the Veys estuary. Added to the general drift of water masses from west to east, and the presence of an important gyre offshore from Barfleur, tidal currents play an essential role in the distribution of sediments and benthic communities, as well as in the dispersal of river input, especially from the Seine River (Gentil and Cabioch, 1997). The dominant offshore sediments are pebbles (mainly in the north-western part of the Bay off Barfleur), gravels and coarse sands, while the inshore sediments are mostly fine sands and silty/muddy fine sands in the Bay of Seine estuaries (Vaslet et al., 1979; Larsonneur et al., 1982). In the intertidal zone, mud flats are present in the estuaries and sheltered bays, where sandy and muddy beaches alternate with rocky substrates.

2.2. Human pressures

The Bay of Seine is affected by an accumulation of human activities, mainly in relation to the Seine estuary (in the eastern part of the bay) and to the presence of two large harbours (Le Havre at the mouth of the estuary and Rouen at 120 km inland from the sea) and their industrial-harbour developments (Dauvin,