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Anthropogenic impact on macrobenthic communities and consequences for shorebirds in Northern France: A complex response

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ABSTRACT

Shorebird populations are declining worldwide due to the combined effect of climate change and anthropogenic forcing, the ongoing coastal urbanisation amplifying the alteration of their habitat in both rate and magnitude. By focusing on a highly anthropogenically-influenced region in Northern France, we studied the impact of a seawall construction on wintering shorebird populations through potential alterations in the abundance and availability of their food resources. We concurrently investigated changes in the spatial distribution of muddy-sand beach macrobenthic communities between two periods of contrasting anthropogenic impacts and examined year-to-year trends of wintering shorebirds. Our study reveals that the seawall construction led to a major spatial reorganisation of the macrobenthic communities with a drastic reduction of the muddy-sand community. However, no relation between macrobenthic changes and shorebird abundances was detected. Fluctuations in shorebird abundances appeared to be congruent with flyway population trends. This result suggests that the response of shorebirds to human-induced perturbations is much more complex than expected. While an assessment of potential disturbances induced by coastal engineering constructions is needed, the pathways by which alterations could propagate through an ecosystem are not linear and as such difficult to determine. Ecosystems appear as complex adaptive systems in which macroscopic dynamics emerge from non-linear interactions at entangled smaller/larger scales. Our results confirm that an in-depth knowledge of the local, regional and global factors that influence trends of shorebirds and their habitat use is essential for accurate and effective management and conservation strategies.

1. Introduction

The world's ocean shores, mainly dominated by sandy beaches (Schlacher et al., 2008), represent an important component in processing large quantities of organic material and recycling nutrients back to coastal waters (McLachlan and Brown, 2006). These zones also provide permanent or transitory habitats for many invertebrates (zooplankton, benthic macro- and meiofauna and insects) and vertebrates (fishes, turtles and shorebirds) for reproduction, nurseries, migration or feeding (Schlacher et al., 2008; Defeo et al., 2009). In beach ecosystems, primary and secondary consumers, mostly represented by benthic organisms (Raffaelli and Hawkins, 1999), are consumed by top-predators such as shorebirds and fishes (Dugan et al., 2003; McLachlan and Brown, 2006).

Because of low food resources compared to estuarine and wetlands systems (Spruzen et al., 2008), sandy beaches are generally not considered as important feeding areas for shorebirds. Since coastal wetlands have become scarce (Hubbard and Dugan, 2003), some sandy beaches, especially those with muddy patches, may have become as attractive as estuaries and wetlands systems for foraging shorebirds (Burger et al., 1997; McLusky and Elliott, 2004; Van de Kam et al., 2004; Spruzen et al., 2008). However, previous studies have shown that birds are the most abundant and diverse vertebrate species encountered in these beaches (Burton, 2012). Buffer effect (Gill et al., 2001) and refuge during cold winter periods in north-western Europe (Camphuysen et al., 1996; Marzec

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and Luczak, 2005) have been suggested as potential factors influencing the use of these *a priori* low attractive habitats.

Beach areas provide a wide range of economical services for human settlements, development and local subsistence (Defeo et al., 2009). As a result, more than 60% of the world's population are currently living less than 60 km away from the sea (IPCC, 2007). Urbanisation is thus becoming increasingly important and the growing human pressure on beach ecosystems has significantly reduced both the number and the area of species habitats (Schlacher et al., 2008). Both engineering constructions (e.g. dykes, pipelines, harbours...) and recreational activities (e.g. swimming, camping, vehicles...) could induce drastic changes in the distribution, diversity and abundance of macrobenthic species (Lewis et al., 2003; Bertasi et al., 2007; Schlacher et al., 2008; Schlacher and Thompson, 2007, 2012). This human fingerprint could directly and indirectly influence shorebird species (Goss-Custard and Verboven, 1993) by disturbing their foraging behaviour (e.g. less time to feed; Thomas et al., 2003), their breeding success as well as their nesting behaviour (Lord et al., 1997, 2001). Global warming is another source of significant perturbation and climate-induced changes in the physiology, phenology and biogeography of species, leading sometimes to ecosystem reorganisations, have been already documented (Parmesan, 2006; Beaugrand et al., 2009; Luczak et al., 2012). Temperature is a cardinal factor governing changes in both biological and ecological systems from the individual to the community level (Goberville et al., 2014). Sea-level rise and extreme climatic events could alter marine habitats by modifying coastal landscapes and beach morphology (Harris et al., 2011).

Along the French coast of the Southern Bight of the North Sea, the "Hemmes de Marck" is the only major muddy-sand beach representing an attractive feeding area for shorebirds (Marzec and Luczak, 2005; Spilmont et al., 2009). However, the Calais harbour extension and a seawall construction in 1984 induced the destruction of two main habitats: a pond/marsh area and the aerial dunes as well as a high modification of the hydro-sedimentary dynamics and processes in this area (Richard et al., 1980; Hequette and Aernouts, 2010). In the present study, we investigated spatio-temporal changes in both muddy-sand beach communities and potential consequences on staging wintering shorebird populations. First, we compared the spatial distribution of the macrobenthic communities between the year 1982 (i.e. two years before the harbour extension) and the year 2010 (i.e. 26 years later). We then evaluated year-to-year changes in shorebird abundances from 1980 to 2012 to identify a possible relationship with changes in their food resources (i.e. macrobenthic communities). Finally, we discussed the implementation of management plans for effective shorebird conservation strategies.

2. Materials and methods

2.1. Study site

Highly impacted by anthropogenic activities, the French coast of the Southern Bight of the North Sea has three important harbours: Boulogne-sur-Mer (fishing activities), Calais (passenger travels) and Dunkerque (freight transport), constructions which have caused a decrease in habitat availability for many species (Richard et al., 1980). This part of the coast is mainly constituted by small estuarine areas and dissipative beaches (Rolet et al., 2014). Amongst these dissipative beaches, "The Hemmes de Marck" beach, located less than 5 kilometres east from Calais harbour (Northern France; Fig. 1), is of great importance for wintering and staging shorebirds because of its broad intertidal zone (up to 1500 m width), its muddy-sand patches and its location on the East Atlantic flyway, a biogeographic entity encompassing the Atlantic coasts of Europe (Greenland included) and West Africa (Marzec and Luczak, 2005; Delany et al., 2009). The tidal regime is semi-diurnal and macrotidal, the tidal range decreasing from 6.4 m in Calais to 5.6 m in Dunkerque (SHOM, 1968). Due to sand supply generated by the onshore migration and coastal welding of a nearshore sand bank, this site is the only in significant accretion in the region (Reichmüth and Anthony, 2007; Hequette and Aernouts, 2010).

Fig. 1. Location of the study site.

2.2. Sampling strategy

Sampling was carried out in autumn 1982 and 2010. To avoid potential biases due to any sampling changes, we used the same sampling strategy in 2010 than in 1982. For both periods, 17 stations (with three replicates per station) were sampled. Samples were collected with a corer (1/40 m^2 down to a depth of 0.25 m) and washed through a 1 mm mesh sieve. After sieving, all samples were immediately fixed and preserved in an 8% formaldehyde-seawater solution. At each station, one sediment core was sampled for granulometry analysis.

2.3. Laboratory work

In the laboratory, the sieved samples were sorted and macrobenthic organisms were counted and identified to the species level, except for Oligochaetes, Nematodes and some damaged amphipods (which represent 1% and 2% of the total abundance in both 1982 and 2010). Faunal densities were expressed as the number of individuals per m^2 (ind m^{-2}). Biomass was determined as ash free dry weight (g of AFDW m^{-2} after 6 h drying at 520 °C) for each station (ICES, 1986). Granulometry was analysed by dry sieving through a nested series of sieves with mesh sizes decreasing from 5 to 0.05 mm. Sediment grain size was grouped into six categories according to the Larsonneur (1977) classification: mud (<0.05 mm), fine sands (⩾0.05–0.2 mm), medium sands (⩾0.2–0.5 mm), coarse sands (⩾0.5–2 mm), fine gravels (⩾2–5 mm) and coarse gravels (⩾5–20 mm).