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Linking macrobenthic communities structure and zonation patterns on sandy shores: Mapping tool toward management and conservation perspectives in Northern France

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ABSTRACT

In a context of intensifying anthropogenic pressures on sandy shores, the mapping of benthic habitat appears as an essential first step and a fundamental baseline for marine spatial planning, ecosystem-based management and conservation efforts of soft-sediment intertidal areas. Mapping allows representing intertidal habitats that are basically characterised by abiotic (e.g sediments, exposure to waves…) and biotic factors such as macrobenthic communities. Macrobenthic communities are known to show zonation patterns across sandy beaches and many studies highlighted the existence of three biological zones. We tested this general model of a tripartite biological division of the shore at a geographical scale of policy, conservation and management decisions (i.e. Northern France coastline), using multivariate analyses combined with the Direct Field Observation (DFO) method. From the upper to the lower shores, the majority of the beaches exhibited three macrobenthic communities confirming the existence of the tripartite biological division of the shore. Nevertheless, in some cases, two or four zones were found: (1) two zones when the drying zone located on the upper shore was replaced by littoral rock or engineering constructions and (2) four zones on beaches and estuaries where a muddy-sand community occurred from the drift line to the mid shore. The correspondence between this zonation pattern of macrobenthic communities and the EUNIS habitat classification was investigated and the results were mapped to provide a reference state of intertidal soft-sediment beaches and estuaries. Our results showed evidence of the applicability of this EUNIS typology for the beaches and estuaries at a regional scale (Northern France coastline) with a macroecological approach. In order to fulfil the requirements of the European Directives (WFD and MFSD), this mapping appears as a practical tool for any functional study on these coastal ecosystems, for the monitoring of anthropogenic activities and for the implementation of management plans concerning effective conservation strategies.

1. Introduction

The world's shoreline, interface between land and ocean, is dominated by sandy shores that are physically dynamic habitats (two-thirds of the world's ice-free coastlines according to McLachlan and Brown (2006)). These zones are of a prime importance for many animals since they provide permanent or transitory key habitats for zooplankton, macrofauna, insects, fishes, turtles or shorebirds for reproduction, nurseries, migration or feeding (Schlacher et al., 2008; Defeo et al., 2009; Schlacher et al., 2014a). Almost every beach on every coastline are threatened by some form of human activity (Brown and McLachlan, 2002); threats to sandy beach ecosystems range from the local spatio-temporal scale (e.g. weekly or seasonal recreational activities) to the global one (e.g. climate change; Defeo et al., 2009); as stressed by Schlacher et al. (2007), "sandy beaches are at the brink".

Because these unique ecosystems are facing intensifying anthropogenic pressures, Schlacher et al. (2007) stated that the continued existence of beaches as functional ecosystem is likely to

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depend on direct conservation efforts. The same conclusions were previously reached by McLusky and Elliott (2004) concerning the other major soft sediment areas in temperate regions, i.e. estuaries. In this framework, an ecological theory has to be developed and critical research directions required to improve sandy beach ecosystems management and conservation have been identified (Schlacher et al., 2007). Setting specifically-derived conservation targets for most ecosystems is a common practice; however, this has never been done for sandy shores (i.e. sandy beaches and estuaries; Harris et al., 2014a). Because of the complexity of ecosystems and hence biodiversity, surrogates approaches such as sub-sets of species, species assemblages and habitat typologies have to be used and plotted as measures of biodiversity (Pressey, 2004; Banks and Skilleter, 2007). Higher precision in the measurement and mapping of biodiversity across regions and biomes is an urgent need to improve systematic conservation planning (Margules and Pressey, 2000). In this context, species assemblages and/or habitat typologies appear as an appropriate surrogate for biodiversity estimation, but it needs to be mapped at a relevant scale that is sufficiently fine to be effective in a reserve design process and conservation (Harris et al., 2011). Mapping macrobenthic communities thus emerges as an essential initial step and a fundamental baseline for managing and conserving soft sediment intertidal areas (Shumchenia and King, 2010). As a prerequisite, multiple classification schemes have been developed internationally in an attempt to systematically classify habitats in different marine environments: e.g. NOAA (Allee et al., 2000) and CMES (Madden and Grossman, 2004) for the USA; the temperate benthic component of hierarchical classification scheme for Canada (Roff and Taylor, 2000); the national marine habitat classification scheme for Britain and Ireland (Connor et al., 2004); the EUNIS habitat classification for Europe (Davies et al., 2004) and the CSIRO Marine Research hierarchical scheme for habitat mapping and classification for Australia (CMR and DEP, 2002).

Intertidal soft-sediment macrofauna have long been known to show zonation patterns (Bally, 1983; McLachlan, 1990; Defeo et al., 1992; McLachlan and Jaramillo, 1995; Brazeiro, 1999; Raffaelli and Hawkins, 1999; Degraer et al., 2003; Rodil et al., 2006). The prime causes of zonation across a sandy beach are exposure, changing wave energy levels, sediment water content, grain size, beach slope and stability (Knox, 2001; Schlacher and Thompson, 2013a). These zones, with their associated fauna, shift with tides, storms and accretion/erosion cycles. Therefore, communities do not occupy fixed discrete area and/or time periods (Brazeiro and Defeo, 1996; Degraer et al., 1999). Thus, these areas are difficult to define in terms of tidal levels (Knox, 2001), notable exceptions being the sheltered shores and estuaries where zonation reflects biological responses to salinity gradient and its associated gradient of particle size (Raffaelli and Hawkins, 1999). Schlacher and Thompson (2013b), in a synopsis of the global literature, showed that most studies recognise a tripartite biological division of the shore, whereas Defeo and McLachlan (2005) characterised macroscale pattern (biogeographic pattern in community and populations) and mesoscale patterns (i.e. variations within a single beach). Thrush et al. (2005) stated that it is an issue of scale to represent all relevant habitats/communities in a meaningful way. A large scale analysis may not be suitable to describe habitats/communities efficiently in every regional area; a specific analysis at a regional scale is therefore necessary (Schiele et al., 2014) with temporal data on a large time window to get a full picture of zonation patterns (Haynes and Quinn, 1995; Defeo and McLachlan, 2005; Schlacher and Thompson, 2013b). In the present study, the existence of such a pattern in sandy beaches and estuaries communities zonation was therefore investigated at a regional spatial scale (coastline length: 140 kms) corresponding to a geographical scale relevant for policy, conservation and management decisions (i.e. French county coastline). A macroecological approach is required to achieve such a goal (Brown, 1995; Gaston and Blackburn, 2000). In a research programme perspective, Brown et al. (2003) emphasised the focus of macroecology on trying to describe and explain the statistical phenomenology of ecologically informative variables among large number of species abundances within communities. The basis of the macroecological approach is to develop an understanding of complex systems through the study of the emergent properties of such systems in their entirety (McArthur, 1972; Brown, 1995), but at the relevant spatio-temporal scales to reveal it (Luczak, 2012).

In order to fulfil the requirements of the European Marine Strategy Framework Directive (MSFD), each European Union member State has to identify its biotope within a common classification system (Schiele et al., 2014). A joint European reference set of habitat units with both a common description and hierarchical classification was therefore required to report habitat/community data in a comparable manner for use in nature conservation and management (Evans, 2012). The EUNIS habitat classification has been designed to achieve these purposes (Davies et al., 2004), although many studies faced difficulties with the applicability of the EUNIS system in the field (e.g. Galparsoro et al., 2012; Schiele et al., 2014). From the intertidal soft-sediment zonation and communities previously identified and described in the macroecological approach, it can be tested whether there is a reliable correspondence with the EUNIS habitats/communities.

Mapping intertidal macrobenthic communities based on the EUNIS habitat classification at a regional (or larger) spatial scale is a fundamental step and tool for managing and preserving intertidal areas in Europe. Traditional methods using macrofaunal and sediment sampling coupled, for instance, with a geostatistic method (Godet et al., 2009a; Defeo and Rueda, 2002) is unachievable at this scale; the number of samples needed to reliably apply spatial statistics is too huge and out of reach in this context. Furthermore, metrics concerning any type of invertebrate assemblage (meiofauna and macrofauna) are often expensive to use in modern environmental evaluations because of high labour costs incurred during sampling, sorting and identification (Schlacher et al., 2014b) and because of the time available to work in the field is limited to only a few hours during spring tides (Harris et al., 2011). Therefore, to map the macrobenthic communities (EUNIS habitat classification), the Direct Field Observation (DFO) method proposed by Godet et al. (2009a) can be used in combination with a classical macrofaunal and sediment analysis, since Godet et al. (2009a) demonstrated the consistency between the DFO method and the EUNIS classification scheme.

The aims of this paper, at a regional scale (Northern France), were: (1) to test the general model of beach zonation proposed by McLachlan and Jaramillo (1995), supported recently by Schlacher and Thompson (2013b) and to extent analysis to estuaries; (2) to search for a correspondence between the zonation observed and the EUNIS habitat classification (Evans, 2012; Galparsoro et al., 2012); and (3) to map the results to provide a reference state of intertidal soft-sediment beaches and estuaries at the spatial scale of Northern France using a combination of multivariate analysis and the'DFO method' proposed by Godet et al. (2009a).

Finally, we discussed the protection status of the defined EUNIS communities at the Northern France scale in the frame of a Marine Protected Area (MPA) of 2300 km² along 118 km of coastline created in December 2012 under the Water Framework Directive (WFD) and the Marine Strategy Framework Directive (MFSD).

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