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Predicting the occurrence of rocky reefs in a heterogeneous archipelago area with limited data

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ABSTRACT

The lack of spatial distribution data on marine habitats often presents an obstacle to their protection. The Annex I of the Habitats Directive (European Council Directive 92/43/EEC) lists habitats that are important in biodiversity protection and should be maintained (or restored) to a favourable conservation status. The habitats listed should be protected within an ecological network of protected areas, the *Natura 2000* network. However, in the past the establishment of the marine *Natura 2000* network has been largely based on insufficient knowledge on the distribution of the habitats. Annex I habitat type reefs are defined as formations of hard compact biogenic or geogenic substrata, which arise from the seafloor in the sublittoral and littoral zone. As obtaining marine data is time-consuming and costly, the bathymetric and substratum data needed for their identification on a larger scale are often scarce. Furthermore, the use of data may be limited due to e.g. national security reasons. This study identifies reefs in a complex archipelago area in the northern Baltic Sea using the best, although limited, data currently available. In the area reefs are elevated rocky outcrops and the associated algal communities and blue mussel beds are vital in maintaining biodiversity in the relatively species poor Baltic Sea. In addition to identifying the physical reef structures, an estimate of their ecological value is obtained by modelling the distribution of four key species occurring on reefs. The results are encouraging, as 55 out of 68 of the potential reefs ground-truthed were confirmed to be reefs. Furthermore the number of predicted species occurring on the reefs, correlated significantly with the number of species observed. The presented maps serve as a valuable background for more detailed mapping of the species diversity occurring on reefs as well as for monitoring their ecological status. Map-based information on important habitats is essential in conservation and marine spatial planning to minimize human impact on marine ecosystems.

1. Introduction

With the drive towards more responsible use of marine resources in the recent decades, the spatial element of marine management has become ever more important. Management strategies, including spatial zonation of activities, have become the preferred way to minimize human impact on marine ecosystems. One of the core tools of spatial management is the establishment of interconnected networks of marine protected areas (MPAs) to ensure that species and habitats are maintained within their natural range. In Europe, the protection of marine habitats and species is largely implemented under the Habitats and Birds directives (Council Directive 92/43/EEC and Directive 2009/147/EC, respectively), which stipulate the formation of an ecological network of protected sites encompassing the terrestrial and marine habitats occurring in Europe (*Natura 2000* network).

Annex I of the Habitats Directive lists habitats important in biodiversity protection but these are mainly large physical habitats, defined by topographical and geomorphological attributes, but some biological formations are also included (e.g. biogenic reefs). In addition, typical species and communities associated with the habitats in the different European seas have been identified to broaden the habitat descriptions (European Commission, 2007).

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Furthermore, national interpretations of the pan-European habitats provide additional specifications on the habitat characteristics, including lists of typical species (Airaksinen and Karttunen, 2001).

Effective reserve design and management policies depend on spatial data availability, enabling more direct management of human activities (Costello et al., 2012). However, obtaining spatial data on seabed habitats is challenging and costly, and consequently most of the seabed globally remains unmapped. The requirement for spatial data on marine Annex I habitats in the subtidal has led to various GIS and statistical modelling efforts on existing data. The primarily physical nature of the habitats enables the use of topographical and geological attributes to map potential habitats. GIS analyses based on bathymetry and coastal morphology have been used to identify e.g. potential reefs (Diesing et al., 2009) and Large Shallow Inlets and Bays (Bekkby and Isaeus, 2008). However, in many cases the datasets required for the analyses may be incomplete, lacking e.g. the accuracy needed for reliable analysis, or their use may be limited due to national legislation (e.g. the Territorial Surveillance Act in Finland).

As the diversity of species and communities occurring in Annex I habitats are key aspects contributing to their ecological value, incorporating species information to the habitat maps increases their usability from the management perspective. Species distribution modelling is a tool that is used in conservation and spatial planning, especially in the terrestrial environment (Elith and Leathwick, 2009), but also increasingly in the marine realm (Robinson et al., 2011). Species distribution models (SDMs) provide a means for linking full coverage environmental data to point data on species occurrence, producing probability maps of species distribution. In recent years, many extensive marine habitat mapping projects have been ongoing in European countries (e.g. Connor et al., 2006; Buhl-Mortensen et al., 2011; Dorschel et al., 2011), resulting in better data availability on marine biodiversity. Also the geographical cover and resolution of available GIS layers of the physical environment has improved due to e.g. remote sensing techniques and advanced modelling techniques (Brown et al., 2011; Micallef et al., 2012).

According to the habitat description, reefs are formations of hard compact biogenic or geogenic substrata, which arise from the seafloor in the sublittoral and littoral zone (European Commission, 2007). The Annex I reefs include a range of such different habitats as biogenic reefs constructed by polychaetes (Hendrick and Foster-Smith, 2006; Rabaut et al., 2008), corals (Howell et al., 2011) or bivalves on soft substrata, to outcrops of hard substrata formed by bedrock, cobbles and boulders. This study focuses on the reefs formed by hard substrata.

In terms of biodiversity, rocky reefs often support a zonation of benthic communities, important in maintaining marine biodiversity. This is also true in the northern Baltic Sea although the species diversity is lower in comparison to more marine environments due to low salinity (e.g. Nielsen et al., 1995; Rinne et al., 2011). In the Baltic Sea, the shallow sublittoral is dominated by ephemeral green and brown algae (e.g. Kiirikki, 1996). A key species on the reefs is the perennial brown algae *Fucus vesiculosus* L. that forms a belt below the ephemeral algae. It is an important food source for many invertebrates (Engkvist et al., 2000; Wikström and Kautsky, 2007) also creating refuge for many invertebrate and fish species (e.g. Kautsky et al., 1992). Occurring among the *Fucus* belt, but mainly below it, a variety of red algae are important habitat builders (Eriksson and Bergström, 2005) that may facilitate e.g. mussel colonization (Westerbom et al., 2008). Many of the perennial red and brown algae respond negatively to the eutrophication effects of the Baltic Sea (e.g. Kangas et al., 1982; Berger et al., 2003) and thus may be used as indicators of the ecological status of the reefs (Eriksson and Bergström, 2005; Carstensen et al., 2008). For example, the number of late-successional algal species has been found to correspond negatively to eutrophication (Carstensen et al., 2008). Also the bivalve *Mytilus edulis* L. is often found within the algal communities and attached to *Fucus*, but it also forms dense beds below the algal zone (optimally 5–8 m, Westerbom et al., 2002). The mussel beds have been found to support diverse communities of associated fauna (Koivisto and Westerbom, 2010) and they are also an important food source for diving birds (Nyström et al., 1991).

This study aimed to map the occurrence of the Annex I habitat reefs in a geographically complex area where detailed full-cover data on substratum are lacking and detailed information on bathymetry is unavailable due to national legislation. This is done by examining the link between geological features and bottom topography derived from an existing coarse resolution bathymetric model and using the observed linkages to identify potential rocky reefs outside the extent of existing geological data. As the species diversity occurring on a reef is a key aspect in defining its conservation value, an estimate of the ecological value of the reefs is produced by modelling the distribution of the key component species.

2. Material and methods

2.1. Study area

The study was carried out in the highly heterogeneous archipelago region in south-western Finland, northern Baltic Sea (Fig. 1). The Baltic Sea is non-tidal and the low salinity (varying between 4.0 and 6.2 within the study area) and the ice that covers the northern Baltic Sea in the winter create a challenging environment for the biota. The archipelago acts as a transition zone between the coast and open sea, creating gradients of wave exposure, salinity, water quality and clarity, all generally decreasing towards the mainland (Jumppanen and Mattila, 1994; Suominen et al., 2010). The outer archipelago is rocky and exposed, while the innermost parts are sheltered and shallow, and often have softer sediments in combination with reed vegetation. The resistant Precambrian crystalline rocks and fault tectonics create complex topographic features in the area (Winterhalter et al., 1981; Kaskela et al., 2012). Average depth is about 20 m, but deep elongated channels located in bedrock fracture zones can reach depths of 100 m, whilst small skerries and subsurface rock outcrops are scattered throughout the area. The patchy seabed substratum distribution, with rock outcrops, gravel, sand and clays of different ages, forms one of the most diverse seabed areas within the Baltic Sea (Häkkinen, 1990; Kaskela et al., 2012).

2.2. Identifying potential reefs

2.2.1. Data

Only 41% of the study area is covered by detailed (scale ≥1:20,000) seabed substratum survey data (Fig. 1), interpreted from acoustic-seismic survey lines situated approximately 500 m apart and verified by sediment sampling (e.g. Häkkinen, 1990). In the remainder of the study area a coarse scale (1:1,000,000) seabed substratum type data layer, covering the whole Baltic Sea (Winterhalter et al., 1981), was used for background information, but it does not capture the true heterogeneity of the study area. Both datasets were reclassified to the following marine geological categories: 1) Mud, 2) Clay and silt, 3) Hard clay (varved clay that is exposed, often a thin sand layer on top), 4) Sand and gravel 5) Complex seabed (till), 6) Rock and boulders.

As no detailed bathymetric data were available for the study area, 20 m cell size bathymetric model covering the extent of the geological and species distribution modelling area (Fig. 1) was