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Improving marine habitat mapping using high-resolution acoustic data; a predictive habitat map for the Firth of Lorn, Scotland

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ABSTRACT

Habitat mapping is an important tool for marine spatial planning and is required for most ecosystem-based management approaches. The Firth of Lorn Special Area of Conservation (SAC), west Scotland, was originally designated for its rocky reef habitat but it is also an area of high importance for the Flapper skate (*Dipturus intermedius*) and Harbour porpoise (*Phocoena phocoena)*. Here we present an improved predictive habitat map for the SAC utilising multibeam backscatter and bathymetry data collected as part of the Ireland, Northern Ireland and Scotland Hydrographic Survey Project.

Backscatter, bathymetry and bathymetric derivatives were analysed using Principal Component Analysis (PCA) and acoustic signatures were created from drop-down video habitat location data. A predictive habitat map was created from Maximum Likelihood Classification using the PCA. Dominant habitat types identified included; moderate energy circalittoral rock (CR.MCR), sublittoral mixed sediment (SS.SMx) and sublittoral sand and muddy sand (SS.SSa). Drop down video showed variable accuracy with 0–100% correctly classified habitats due to the small sample size. The initial validation points were added and the model was rerun. In areas with no previous sea truthing points, some predictions changed to SS.SMx at depths > 100 m and SS.SSa in depths < 50 m, suggesting that the model can be improved with a greater depth-range of sea truthing data. Modern acoustic surveys undertaken for other purposes, such as navigational charting, can thus be used to generate broad-scale predictive habitat maps in a cost and time effective manner. Such maps have the potential for a wide range of use by marine stakeholders, in particular, for establishing environmental baselines for long term monitoring of benthic habitats. Given the high costs of surveying, such an approach supports the rationale of "Collect once and use many times".

1. Introduction

There is an urgent need to develop a standard and accurate method for mapping marine benthic ecosystems (Brown et al., 2011). It is estimated that only 5–10% of the seafloor has been mapped to a spatial resolution comparable to terrestrial studies (Brown et al., 2011). However baseline environmental data are required for long-term monitoring of environmental and biological conditions at an ecosystem level (Lundblad et al., 2006; Bianchi et al., 2012). Current conservation management and planning aimed to prevent further losses of marine biodiversity from various threats including pollution, resource extraction and climate change, as well as reporting on ecosystem health are also hampered by a lack of this information (Dunn and Halpin, 2009; Falace et al., 2015; Cánovas Molina et al., 2016a; Vassallo et al., 2018). Habitat maps have multiple uses as snapshots of environmental status including biological biodiversity and seafloor integrity and, when repeated over time, as indicators of changing pressures and impacts on the benthos (Bianchi et al., 2012; Galparsoro et al., 2012). Habitat mapping thus plays a vital role in marine (spatial) planning and in developing ecosystem-based approaches to management of marine resources (Connor et al., 2004; Holmes et al., 2008; Parravicini et al., 2012; Costa and Battista, 2013). Mapping the extent and status of protected, vulnerable or rare biotopes and how their distributions are changing over time is required for population assessments, measuring the effects of multiple pressures and establishing and monitoring Marine Protected Areas (MPAs) (Connor et al., 2004; Clark et al., 2008; Erdey-Heydorn, 2008; Parravicini et al., 2012; European Union, 2013; Lucieer et al., 2013). However, in the marine environment not only is collecting such data expensive but the mapping itself is usually difficult and time consuming suggesting there is a need for an automated

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method of classification that can be produced from merging historical and contemporary data sets (Degraer et al., 2007; McGonigle et al., 2009). Modern hydrographic surveys using multi-beam acoustics are often being conducted for other purposes, such as updating navigational charts. Such contemporary data could also be transformed into visualised or low dimensional maps that provide a broader picture of the marine habitat across large areas without the need for extensive additional surveys at sea (Marsh and Brown, 2009). In addition to an automated process, as the amount of mapping increases there is an important need for better standardisation of habitat classification, this increases the efficiency of habitat mapping and therefore the consistency of classification results (Ierodiaconou et al., 2007). Large-scale seabed mapping also strongly depends on having an agreed seabed habitat classification to ensure consistency throughout the project areas and allow for a stronger comparison between locations (Galparsoro et al., 2012). The use of a common method of classification is thus recommended so that habitat maps are comparable (Connor et al., 2004; Galparsoro et al., 2012). The common European standard for the classification of terrestrial and marine habitats is EUNIS (European Nature Information System) (Davies et al., 2004; Anderson et al., 2008; Clark et al., 2008; Foster-Smith et al., 2007; Ellwood, 2011; Galparsoro et al., 2012). EUNIS provides a reference set of habitat types within a hierarchical classification for reporting habitat data in a comparable manner throughout European seas (Galparsoro et al., 2012). EUNIS has been widely adopted both for direct mapping of observed habitats and for predictive habitat modelling (Galparsoro et al., 2012; Cánovas Molina et al., 2016a; Vassallo et al., 2018).

Traditional methods of collecting data for seabed habitat mapping include direct observations using drop-down or towed video and stills cameras. However, acoustic data can provide the basis for classifying and mapping ocean resources to allow for interpretation of the nature of the seabed surface over larger spatial areas (Anderson et al., 2008; Coggan et al., 2009). Modern Multibeam Echo Sounders (MBES) collect both direct bathymetry and backscatter whilst correcting for vessel movement and signal loss due to attenuation (Brown et al., 2004; Marsh and Brown, 2009; Simons and Snellen, 2009; Mitchell, 2009; Micallef et al., 2012; Calvert et al., 2015). MBES produces high resolution, high coverage data at relatively low cost, permitting off-the-shelf usability (Le Bas and Huvenne, 2009; McGonigle et al., 2009).

The strength of the sonar's acoustic returns is largely a function of seabed hardness with high signal strength associated with hard sediments such as gravel and boulders whilst low signal strength is associated with softer sediments such as sand and mud (Calvert et al., 2015). Thus one of the primary assumptions of acoustic-based habitat mapping is that there are links between substrate type and the benthic community structure (Brown et al., 2002; Brown and Blondel, 2009; Calvert et al., 2015). Seafloor geology, in particular topography and composition, are known to influence the benthic community structure and ecological processes at many spatial scales (Brown et al., 2004; Micallef et al., 2012). Harder substrates also tend to have higher biodiversity (Dunn and Halpin, 2009) but the complexity of the physical environment is also important as it controls the diversity of habitats for marine organisms (Degraer et al., 2007; Ierodiaconou et al., 2007; Lucieer et al., 2013). Therefore information on the physical nature of the seabed can provide indications about the associated biological communities.

Predictive habitat mapping using MBES combines the analysis of bathymetry and associated derivatives (Kostylev et al., 2001), including sediment type, benthic communities and bathymetric derivatives. Selecting the appropriate set of derivatives is important to optimise terrain information as their importance can vary depending on the complexity of the seabed feature (Lecours et al., 2017). Derivatives such as roughness and slope can be used to define similar areas of seabed morphology (Le Bas and Huvenne, 2009). Combined with backscatter data it assists in classifying the seafloor (Le Bas and Huvenne, 2009). Bathymetric derivatives are selected using Principal Component Analysis (PCA). PCA reduces the variation in data, therefore reducing dimensionality and allowing for a greater ease of analysis by removing highly correlated information (Van Lancker and Foster-Smith, 2007; Costa and Battista, 2013).

The aim of MBES-based predictive habitat mapping is to produce large spatial coverage maps of the seabed than has been directly observed i.e. to use the relationships observed between biological communities and physical seabed structure to interpolate the most likely habitat in areas lacking direct observations (Brown et al., 2011). The accuracy of the predictions of seabed habitat is thus reliant on integrating the broad-scale acoustic data with thorough sea truthing using drop-down video or stills photography, or physical sampling using grabs or cores. Additional methods for collecting sea-truth data include the use of imagery from autonomous or remotely operated vehicles and diver observations (Micallef et al., 2012). The recommended best practice for designing sea truthing surveys for habitat mapping is available from the development of a framework for Mapping European Seabed Habitats (MESH) programme, a European Union INRERREG IIIB funded marine habitat mapping programme (Coggan et al., 2007). It is important that sea truthing covers as wide a variety of habitats and biotopes in an area as possible in order that the habitats is mapped with a moderate to high degree of confidence (Mitchell, 2009).

To predict the habitat, characteristics from the sea truth data need to be linked to distinctive characteristics in the acoustic data (Clark et al., 2008; Brown et al., 2011). A widely used method of supervised classification is Maximum Likelihood Classification (MLC) (Van Lancker and Foster-Smith, 2007), which is a pixel-based supervised learning approach (Brown et al., 2005; Ierodiaconou et al., 2011). MLC calculates the probability that a given pixel belongs to a specific class and produces a grid of classes in the form of a raster thematic map (Ierodiaconou et al., 2011; Micallef et al., 2012).

Here we apply these techniques to a region of an established Marine Protected Area, in the Firth of Lorn located off the West Coast of Scotland (Fig. 1) in order to improve upon previous predictive benthic mapping undertaken by Scottish Natural Heritage (SNH) (Davies, 1999). This area is characterised by some of the strongest tidal streams in the UK and is one of the most species rich inshore areas of Western Scotland (Davies, 1999). Underlying geological formations and the retreat of glacial ice following the last ice age (< 20 ky) are responsible for most of the present seabed features (Davies, 1999; Howe et al., 2015). Rocky reefs extend from the shore into considerable water depths, up to 270 m encountered (Davies, 1999; Howson et al., 2006). It was designated a Special Area of Conservation (SAC) in 2005 to protect key features of interest; rocky reefs and the communities associated with them (Viana, 2008). As a continuing measure of conservation, in 2007 the area was closed to commercial scallop dredging until further studies could be performed to assess the potential impacts on the protected seafloor features (Viana, 2008). Since this legislation, studies conducted to address the recovery of habitat effected by dredging activity have yet to provide evidence that scallop dredging activities do not impact hard substrates in the SAC and the epibenthic communities that rely on them (Dale et al., 2011; Boulcott et al., 2014).

2. Material and methods

Insh Island is located in the Firth of Lorn SAC off the coasts of Seil and Easdale islands. It was chosen as the focus for this study as the surrounding waters contain abundant rocky reef habitat.

Multibeam bathymetry and backscatter data were collected from a hull mounted Reson Seabat 7125 dual frequency system using the R.V. Calanus between May and November 2012 as part of the Ireland, Northern Ireland, and Scotland Hydrographic Survey (INIS Hydro INTERREG IVA) Project. This project, which ran from January 2011 to September 2013, was coordinated by the Maritime and Coastguard Agency in association with the Scottish Association for Marine Science (SAMS). The main aim of the project was to generate modern