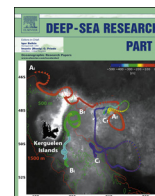




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# The distribution of deep-sea sponge aggregations in the North Atlantic and implications for their effective spatial management



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## ABSTRACT

Sponge aggregations have been recognised as key component of shallow benthic ecosystems providing several important functional roles including habitat building and nutrient recycling. Within the deep-sea ecosystem, sponge aggregations may be extensive and available evidence suggests they may also play important functional roles, however data on their ecology, extent and distribution in the North Atlantic is lacking, hampering conservation efforts. In this study, we used Maximum Entropy Modelling and presence data for two deep-sea sponge aggregation types, *Pheronema carpenneri* aggregations and ostur aggregations dominated by geodid sponges, to address the following questions: 1) What environmental factors drive the broad-scale distribution of these selected sponge grounds? 2) What is the predicted distribution of these grounds in the northern North Atlantic, Norwegian and Barents Sea? 3) How are these sponge grounds distributed between Exclusive Economic Zones (EEZs) and High Seas areas? 4) What percentage of these grounds in High Seas areas are protected by the current High Seas MPA network? Our results suggest that silicate concentration, temperature, depth and amount of particulate organic carbon are the most important drivers of sponge distribution. Most of the sponge grounds are located within national EEZs rather than in the High Seas. Coordinated conservation planning between nations with significant areas of sponge grounds such as Iceland, Greenland and Faroes (Denmark), Norway (coastal Norway and Svalbard), Portugal and the UK, should be implemented in order to effectively manage these communities in view of the increasing level of human activity within the deep-sea environment.

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## 1. Introduction

Sponges are a key component of marine benthic ecosystems from shallow tropical coral reefs to deep-sea systems, providing a number of important functional roles. Studies in shallow waters have suggested sponge communities create complex habitats supporting high biodiversity, provide refuge for fish, are a source of novel chemical compounds, and have an important role in biogeochemical cycling (Bell, 2008; Maldonado et al., 2016). Deep-sea sponge aggregations, although less studied than their shallow water counterparts, show evidence of having similar important functional roles.

Within the North Atlantic there are three widely accepted and clearly defined deep sea sponge habitat types, *Pheronema carpenneri* (Thomson, 1869) aggregations (Rice et al., 1990), boreal ostur, and cold water ostur (Klitgaard and Tendal, 2004). While

there is no doubt other sponge aggregations do exist, these have not yet been defined in the peer reviewed literature. *P. carpenneri* is a hexactinellid (glass sponge) that can form aggregations on fine sediments with densities of up to 1.53 individuals/m<sup>2</sup> as seen on the Goban Spur (Hughes and Gage, 2004). These aggregations are associated with an increase in abundance and richness of macrofauna within spicule mats and sponge bodies providing habitat complexity and a hard substrate for epifauna colonization, (Rice et al., 1990; Bett and Rice, 1992). They are thought to be associated with areas of high productivity, and possibly proximate to regions of enhanced bottom tidal currents which aid in resuspension of organic matter (Rice et al., 1990; White et al., 2003).

Another widely recognised deep-sea sponge aggregation is 'ostur' or 'cheese bottom' as defined by (Klitgaard and Tendal, 2004). These authors recognise two main types of ostur: a boreal ostur, which occurs around the Faroe Islands, Norway, Sweden, parts of the western Barents Sea and south of Iceland; and a cold water ostur, which is found north of Iceland, in most of the Denmark Strait, off East Greenland and north of Spitsbergen. Both

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ostur types are characterised by sponges of the genus *Geodia* Lamarck, 1815. Boreal ostur consist of *Geodia barretti* Bowerbank, 1858, *Geodia macandrewii* Bowerbank, 1858, *G. atlantica* (Stephens, 1915) and *G. phlegraei* (Sollas, 1880), whilst cold water ostur is formed by *G. hentscheli* Cárdenas et al., 2010 (referred to as *G. mesotriaena*) and *G. parva* (Hansen, 1885) (referred to as *Isops phlegraei pyriformis* but identified as *G. parva* in Cárdenas et al., (2013)). Maps of the distribution of ostur, determined largely from fisheries trawl samples, were compiled by (Klitgaard and Tendal, 2004), while more recently Cárdenas et al., (2013) have summarised known locations of characterising geodid species on maps.

Deep sea sponge habitats are also thought to play a key role in nutrient recycling as a result of the large quantities of water they filter (Reiswig, 1971; Reiswig, 1974). Sponges are suspension feeders and recent studies have demonstrated the importance of sponge feeding to benthic-pelagic coupling in the deep sea (Pile and Young, 2006; Yahel et al., 2007), with sponges representing an important link between carbon in the water column in the form of ultraplankton and picoplankton (Reiswig, 1975), dissolved organic carbon (Yahel et al., 2003) and viral particles (Hadas et al., 2006), and the benthos. Sponges may enable carbon flow to higher trophic levels through predation (Wulff, 2006) and respiration rates are 9 times higher on sponge grounds than surrounding sediments (Cathalot et al., 2015). In addition, areas of high sponge abundance may play a key role in global Silicate cycling (Maldonado et al., 2005) the importance of which might be geographically variable (Bell, 2008). Further, Hoffmann et al., (2009) postulated that all sponge aggregations may function as so far unrecognised sinks for inorganic nitrogen.

The range of ecological functions provided by deep-sea sponge aggregations has resulted in these habitats being considered of conservation importance under United Nations General Assembly Resolution 61/105 and under Annex V of the Oslo-Paris (OSPAR) Convention for the Protection of the Marine Environment of the North East Atlantic. Thus stakeholders are required, in respect of areas where vulnerable marine ecosystems (VMEs) are known to occur or are likely to occur based on the best available scientific information, to close such areas to bottom fishing and ensure that such activities do not proceed unless conservation and management measures have been established to prevent significant adverse impacts on VMEs (UNGA 61/105).

Despite these policy provisions, progress in the protection of deep-sea sponge aggregations is slow. Several nations and the Northwest Atlantic Fisheries Organization (NAFO) have recently recommended or implemented area closures for the protection of sponge habitats in response to UNGA Resolution 61/105. To date however, no OSPAR marine protected areas (MPAs) have been designated specifically for the protection of these habitats. Part of the reason for the slow progress is likely to be the more limited spatial location data for deep sea sponge habitats (Rodríguez et al., 2007), although indicative maps of the distribution of some types of sponge grounds have existed for some time (Klitgaard and Tendal, 2004).

While the production of point based distribution maps are a critical first step in developing environmental management strategies, predictive habitat modelling provides a means to produce full coverage spatial data where distribution information is lacking (Elith and Leathwick, 2009; Galparsoro et al., 2009; Dambach and Rodder 2011; Robinson et al., 2011). The resulting predictions may then be used to support conservation management decisions (Kenchington and Hutchings, 2012).

Predictive modelling of the distribution of a biological 'habitat' such as a deep-sea sponge aggregation may be achieved in a variety of ways. Where the habitat is formed by a single dominant species, two different approaches have been used. The first models

the distribution of the species (Davies et al., 2008; Dolan et al., 2008; Guinan et al., 2009), the second models the distribution of the habitat (Ross and Howell, 2013; Ross et al., 2015). Where both approaches have been used results suggest that predicted habitat distribution is a highly restricted subset of predicted species distribution (Howell et al., 2011; Rengstorf et al., 2013). Where a 'habitat' is composed of a distinct assemblage of species, the distribution of that assemblage may be modelled (Degraer et al., 2008; Gonzalez-Mirelis and Lindegarth, 2012; Piechaud et al., 2015), alternatively the distribution of key indicator species may be modelled and the resulting maps overlaid highlighting areas of overlap as potential habitat distribution (Ferrier and Guisan, 2006; Rinne et al., 2014).

This study uses Maximum Entropy Modelling, considering both species and habitat based approaches, to address the following questions:

- 1) What environmental factors drive the broad-scale distribution of ostur and *Pheronema carpenneri* sponge grounds?
- 2) What is the predicted distribution of these grounds in the northern North Atlantic, Norwegian and Barents Sea?
- 3) How are these sponge grounds distributed between EEZ and High Seas areas?
- 4) What percentage of these grounds in High Seas areas are protected by the current High Seas MPA network?

## 2. Methods

### 2.1. Study area

The study is focused on the North Atlantic deep sea areas (200–5000 m deep) off the Canadian coast, the Azores and the Iberian Peninsula to Baffin Bay, Greenland and Iceland, the Greenland Sea and western part of Barents Sea off the coasts of Spitzberg (Fig. 1). This region was chosen to encompass an area where sufficient data are available on presence and absence of ostur, geodids, and *P. carpenneri*. Although geodid sponges are very common in fjords (Klitgaard and Tendal, 2004), coastal regions were not included as a result of both the resolution and coverage of some of the environmental layers.

### 2.2. Biological data

Presence data were compiled for each of six geodid sponge species *Geodia barretti*, *G. macandrewii*, *G. atlantica*, *G. hentscheli*, *G. phlegraei* and *G. parva*, for ostur habitat, and for *P. carpenneri*. All geodid presence data was derived from the same dataset as used in Cárdenas et al. (2013) and recovered from the Dryad Repository (<http://www.datadryad.org>) where it is recorded under the Dryad package identifier: <http://dx.doi.org/10.5061/dryad.td8sb>. Ostur presence data was compiled from experts identifications of the habitat (Klitgaard and Tendal, 2001, Klitgaard and Tendal, 2004), unpublished sample data held by Plymouth University and data from the NAFO NEREIDA research programme which receives support from EU, Canada, Spain, UK, Russia, Portugal. Ostur presence in the NEREIDA dataset was determined based on agglomerative clustering with average linkage on a subset of data records, with abundance values for selected VME indicator species. A group dominated by a high biomass of geodids was identified as ostur. *P. carpenneri* presence records were those used in Ross and Howell (2013) with additional data compiled from various literature sources (Table 1).

In order to control for sample bias in the model (Phillips and Dudík 2008) a background dataset was compiled from all presence data and 'apparent absence' data. 'Apparent absence' data was

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