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Satellite remote-sensing observations for definitions of areas for marine conservation: Case study of the Scotian Slope, Eastern Canada

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ABSTRACT

Characterizing offshore areas for marine conservation faces impediment from logistics and costs of in situ data collection. This study leveraged the high spatial and temporal coverage provided by remote-sensing ocean colour products, and the concept of biogeographical classification to delineate areas in the pelagic environment with application to marine conservation. Satellite-derived and modelled biogeophysical data were used to delineate an area of biological and physical homogeneity spatially consistent with the static boundaries of the Scotian Slope Ecologically and Biologically Significant Area (EBSA), off eastern Canada. We used iterative cluster analysis applied to an archive (2004–2014) that consisted of remotely-sensed Chlorophyll *a*, sea-surface temperature, and primary production derived from the Moderate resolution Imaging Spectroradiometer (MODIS), and simulated mixed layer depth to define "dynamic" boundaries of the EBSA at bi-weekly, seasonal and annual resolutions. The final cluster extended further east than the static EBSA in summer and fall, indicating that characteristics of the static EBSA environment persist beyond the current boundaries in these seasons. In winter and spring, the final areas derived by our analysis was smaller than the static EBSA, but again showed extension beyond the current eastern boundary. Both ice and cloud cover affecting remotely-sensed data and the extent of water column mixing were important in determining the size of the final cluster. The dynamic cluster east of the original static boundary incorporated an area of lower Chlorophyll *a* and water column primary production in the spring, but higher values in the autumn relative to the static area. Overall physical and biological characteristics of the static and dynamic EBSA considered in this research were similar within and across years. This methodology incorporates ocean-colour data and modelled estimates of multiple biological and physical characteristics to objectively refine areas of ecological interest at a spatial scale relevant for the management of marine conservation areas.

1. Introduction

1.1. Integration of multiple biological and physical variables for delineation of pelagic conservation areas

Offshore marine ecosystems provide and support significant productivity and biodiversity throughout the oceans (FAO, 2012; Briscoe et al., 2016). In order to help maintain biodiversity, ecosystem functioning, and services provided by the ocean, significant effort has been dedicated to the development of Marine Protected Areas (MPAs, FAO, 2012; O'Leary et al., 2012). The majority of MPAs worldwide are located in coastal areas. Reasons for this include the biological, economic, and social importance of coastal habitats (Costanza et al., 1997; Orth et al., 2006), but additionally the relative ease of monitoring these ecosystems compared to offshore pelagic zones (O'Leary et al., 2012). There is, therefore, an increasing need for the establishment of more offshore marine conservation areas in addition to those established in coastal regions.

Categorization of the ocean based on physical and biological variables has and remains an active field of oceanographic research, with application to designating areas for conservation (e.g. Longhurst, 2006; Devred et al., 2007; D'Ortenzio and Ribera d'Alcali, 2009; DFO, 2009a; Reygondeau et al., 2013). It has been suggested that identifying places for conservation can be informed by boundaries of biogeographic areas and that this once primarily terrestrial concept is applicable to both the coastal and open oceans (Fox and Beckley, 2005; Briscoe et al., 2016). For instance, Longhurst (1995, 2006) used extensive data on physical oceanographic processes to delineate surface waters of the global ocean into 51 static biogeochemical provinces (BGCPs) to distinguish environmental conditions that are unique within a global geography. Further research into the spatial and temporal fluidity of BGCP boundaries in the Northwest Atlantic has been completed: Devred et al.

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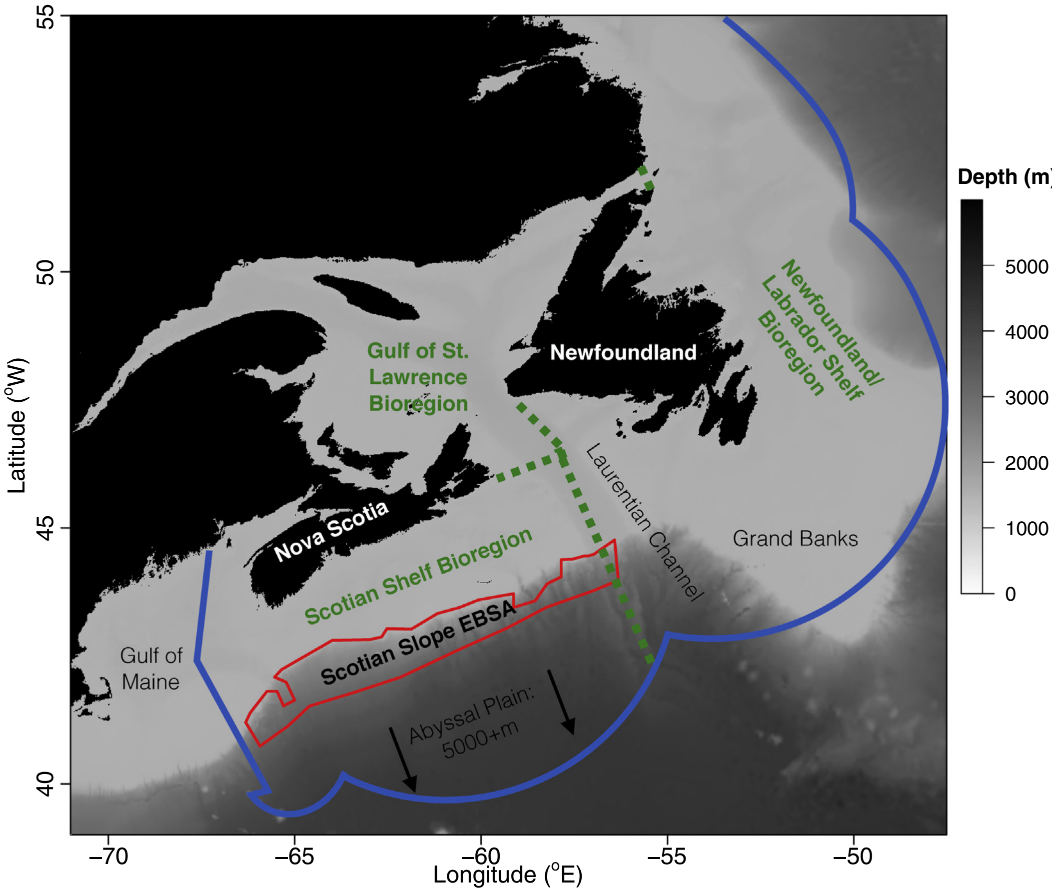

Fig. 1. The static Scotian Slope EBSA area (red boundary) overlaid on the bathymetric profile of the northwest Atlantic. The Scotian Slope EBSA sits on the edge of the Scotian Shelf, and includes a large portion of the dramatic increase in depth towards the Atlantic abyssal plain (see Fig. S.1). The red line indicates the boundary of Canada's Exclusive Economic Zone (EEZ), and the orange dotted lines and labels denote the bioregions identified by DFO in Canada's Atlantic region (DFO, 2009a, 2009b). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

(2007, 2009) integrated regionally specific remote sensing products with spatial and bathymetric data to delineate seven BGCPs in the Northwest Atlantic with dynamic boundaries. Using cluster analysis on the assemblage of data, they were able to objectively classify and identify regions therein, showing excellent agreement with Longhurst's BGCPs, but with fluid boundaries that reflected intra- annual (bi-weekly) and inter-annual temporal differences (Devred et al., 2007). Biogeographic classification at a regional level is also being conducted and applied for marine conservation objectives. For instance, Canada has defined bioregions in each of Canada's three oceans using existing biogeographic classification systems. Remote sensing data has been used to identify four regions within the Scotian Shelf bioregion based on their relative magnitude and persistence of phytoplankton biomass represented by Chlorophyll *a* (Chl*a*, Fuentes-Yaco et al., 2015). For scale comparison, the Northwest Atlantic Shelf BGCP produced by Longhurst/Devred incorporates two and a half Canadian bioregions in Canada's Atlantic Ocean jurisdiction (Fig. 1, DFO, 2009a, 2009b).

1.2. Region of interest: The Scotian slope EBSA

Canada has committed to protecting 10% of the ocean within its territory by 2020. Fisheries and Oceans Canada (DFO) is leading the process of identifying suitable sites for protection and developing MPA networks. As part of this work, experts identified Ecologically and Biologically Significant Areas (EBSAs): areas that have particular ecological or biological significance in Canadian waters (DFO, 2004; DFO, 2011; DFO, 2014). Identifying EBSAs is a tool to inform and facilitate a greater-than-usual degree of risk aversion in the management of activities in the area (DFO, 2011). DFO established criteria for identifying EBSAs (DFO, 2004); these criteria are consistent with those established later under the Convention on Biological Diversity (UNEP/CBD, 2008). The process by which these areas are identified requires integration of information from numerous types of assessments and monitoring from multiple sources (DFO, 2004). Ideally, data would be available at high spatial and temporal resolution and over large geographic areas, an objective that is more difficult to achieve in offshore areas given logistical and financial constraints of transport and sampling (DFO, 2004; O'Leary et al., 2012). In order to aid decision making regarding delineation of marine conservation areas a comprehensive method that integrates comprehensive biological and oceanographic variables to analyze pelagic regions is needed.

In the case study presented here, we applied a methodology based on advanced statistics applied to remote sensing and modelled environmental data to inform the biogeography and boundaries of the Scotian Slope EBSA, one of 18 offshore EBSAs identified in the Northwest Atlantic Scotian Shelf Bioregion (Fig. 1, Doherty and Horsman, 2007; DFO, 2014).

The Scotian Shelf bioregion (DFO, 2009a) within Longhurst's/Devred's Northwest Atlantic Shelf BGCP is a dynamic environment, exemplifying diverse geomorphic, oceanographic and biological characteristics and is inclusive of the Scotian Shelf, Slope and Rise (Stortini, 2015). It is a wide submerged portion of the continental shelf protruding 125–300 km from the Nova Scotian coastline, and runs > 700 km from George's Bank and the Northeast Channel in the southwest, to the Laurentian Channel in the northeast (Fig. 1). The shelf drops off precipitously from a depth of 200 m to > 3000 m over ~100–150 km,