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Modelling spatial distribution of epibenthic communities in the Gulf of St. Lawrence (Canada)

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ABSTRACT

Correlative habitat models using relationships between marine organisms and their surrounding environment can be used to predict species distribution, and the results can assist management of human activities sharing the marine space (e.g. fisheries, MPAs, tourism). Here, epi-benthic megafauna was sampled at 755 stations in the Lower Estuary and Northern Gulf of St. Lawrence (EGSL) each summer between 2006 and 2009. We combined various types of multivariate analyses to 1) describe the structure and spatial distribution of benthic communities, 2) analyse the relationship between these communities and environmental parameters, and subsequently 3) build a community distribution model to predict the spatial distribution of the communities, creating community distribution maps covering the entire area to be used for marine management and conservation. We identified distinct benthic communities in the study area that closely correlate with the 200 m depth contour and with major environmental variables. A redundancy analysis revealed that communities were associated with depth, oxygen saturation, temperature, bottom current, seabed uniformity, distance to coast and type of sediment. Together these environmental descriptors explained 38% of the variation in megafaunal community composition. The environmental variables were used to build a community distribution model using generalized linear models to predict high and low suitability zones of each community in the EGSL.

1. Introduction

Species distribution models (SDMs) are used to provide guidance for conservation planning, for instance during the process of designing protected areas, in a context of ecosystem-based management of natural areas. These models focus on the habitat characteristics surrounding the species. According to Baretta-Bekker et al. (1992), a habitat is simply the distinctive space occupied by a population or a species. The set of conditions required for an individual to survive and reproduce constitutes the "ecological niche" within which a species may indefinitely maintain itself (Hutchinson, 1957), and the geographical projection of this fundamental niche corresponds to the habitat of the considered species (Chase and Leibold, 2003). Therefore, a habitat is an area with specific environmental conditions in which an organism, a population, or a community can survive (e.g. Eastern Channel Habitat Atlas for Marine Resource Management, Carpentier et al., 2009). In natural environments, most communities are associated with a recognisable suite of physical conditions, and some communities occur within a narrower physical habitat window than others (Urbanski and Szymelfenig, 2003). This relationship between physical characteristics of an area and biological composition of the associated communities can be assessed by SDMs, which was initiated in terrestrial ecosystems several decades ago and is still developing (Degraer et al., 2008; Guisan and Zimmermann, 2000; Hirzel et al., 2006), in particular to study the possible consequences of a changing environment on species distributions (Guisan and Thuiller, 2005). In marine ecosystems more specifically, a large number of studies have demonstrated the importance of environmental factors as driving forces of the distribution of benthic and fish communities (e.g. Carassou et al., 2008; Chouinard and Dutil, 2011; Glockzin and Zettler, 2008; McArthur et al., 2010; Rosenberg, 1995). From these analyses, full coverage spatial distribution maps of biological communities or biodiversity can be created (Degraer et al., 2008, Mellin et al., 2010).

Even though predicting species or community occurrence using modelling has become increasingly common in ecological conservation studies (Degraer et al., 2008; Martin et al., 2010, Mellin et al., 2012; Vaz et al., 2008), SDMs are often too simple scientifically speaking (they do not incorporate all ecological processes, Dormann et al., 2012) or too

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complex to be easily and safely transferred to decision makers and people responsible for natural-area management. With the higher number of management programmes for marine space planning throughout the world, it is necessary to provide simple but accurate tools such as high-resolution easy-to-read present and future biodiversity distribution maps derived from SDMs to be used in environmental policies.

The Gulf of St. Lawrence (Canada) is a good candidate area in which to develop SDMs for marine ecosystem planning. Due to the variety of hydrodynamic regimes and physical processes observed, the Lower Estuary and Northern Gulf of St. Lawrence (EGSL) is often divided into distinct oceanographic sub-regions (Brunel et al., 1998; Koutitonsky and Bugden, 1991). This high spatial heterogeneity is combined with high faunal diversity, which makes the EGSL a good area to evaluate the potential connections between environmental factors and marine communities. Notwithstanding a limited number of local or taxon-specific studies investigating diversity and distribution of benthic invertebrates (Belley et al., 2010; Bourque, 2008; Desrosiers et al., 2000; Massad and Brunel, 1979; Ouellet, 1982; Peer, 1963, Préfontaine and Brunel, 1962; Robert, 1979), benthic communities at the EGSL scale remain poorly known. Additionally, some of the ESGL oceanographic conditions have already noticeably changed due to global climate change (modification of water layer heights and increased hypoxia: Belley et al., 2010; Gilbert et al., 2005, 2007; acidification, Mucci et al., 2011), which generates a strong need for tools to predict present and future biodiversity distribution and aid conservation management. Because of the presence of several diversity conservation and fishery issues (such as fishery overlap or stock management, DFO, 2006, 2010), fishery managers, governmental organisations, and research institutes are working together to gather new methods and tools to predict species distribution and community structure (e.g. Canadian Fisheries Research Network: http://www.cfrn-rcrp.ca), and could therefore benefit directly from this study.

Since 1990, the Department of Fisheries and Oceans Canada (DFO-Quebec region) has been conducting annual groundfish and northern shrimp bottom trawl surveys in the EGSL. The main objective was to collect biological information related to commercially important groundfish (cod, Greenland halibut, redfish) and northern shrimp stocks exploited in the EGSL. Each summer 2006 to 2009, the effort was intensified for the identification of all benthic invertebrate taxa aboard the CCGS *Teleost* research trawler. In spite of this intensive sampling effort, the relative opacity of seawaters renders species community observation on a continuous large area impossible. In this case, community distribution models (CDMs) can be implemented to give a better picture of community composition in poorly-sampled areas of the EGSL. Given that correlations between environmental conditions and species distribution are known to exist, we assume that such relationships will also be detectable at the community level. We therefore hypothesise that temperature, depth, and oxygen will be strong determinants of community structure. Sediment type and other hydrodynamic-related variables are expected to have a weaker influence on community structure. The 2006–2009 dataset was therefore used to: (1) explore the composition and distribution of the epibenthic megafaunal communities using multivariate analyses; (2) correlate the communities' spatial distribution with the abiotic factors to determine which environmental parameters may drive diversity patterns; and (3) create high-resolution maps from a statistical CDM, describing megafaunal community affinities with significant environmental parameters.

2. Material and methods

2.1. Study area

The EGSL has two major connections with the Atlantic Ocean, through Cabot and Belle-Isle Straits, and receives important freshwater inflows, mainly from the St. Lawrence River. Consequently, estuarine circulation occurs by water flowing seaward in the surface layer and landward in the deep layers (Saucier et al., 2003). The topography of the northern part of the Gulf is distinguished by three deep channels: Laurentian, Anticosti, and Esquiman (Fig. 1).

2.2. Survey method and biological data collection

Megafauna was sampled from 755 stations in total during summers 2006 to 2009 (1–31 August each year), with sampling station depth spanning from 24 to 512 m, and minimal distance between two stations being 115 m (Fig. 1). The sampling strategy used consisted of a stratified random sampling following predetermined strata based on depth (Doubleday, 1981). All samples were collected with a four-sided shrimp bottom trawl (*Campelen 1800* type). The trawl was rigged with variable net mesh sizes (44 to 80 mm centre knot to centre knot) appropriate for each part of the trawl. The codend and the lengthening piece were also equipped with a 12.7 mm knotless nylon lining (McCallum and Walsh, 2002). The standard tow duration was 15 min on the bottom but was shorter in rare cases where the substrate was rougher. Among these cases, tows exceeding 10 min were retained in the analysis and tows below this threshold were removed (Archambault et al., 2012). The 15-minute duration was then used to calculate the biomass for all tows.

The catch from scientific surveys was sorted and identified to the lowest possible taxonomic level. Because colonial organisms such as bryozoans and hydrozoans were too abundant to be enumerated, the wet weight of each taxon was instead recorded. The sorted megafauna was photographed aboard, and images of total capture and of each identified taxon were recorded. Species not identified while at sea were preserved in 70% ethanol or frozen for later identification in the laboratory. Taxonomic names were verified using the Integrated Taxonomic Information System (www.itis.gov). Biomass estimates were standardized relative to catch per unit effort (CPUE) by dividing the mass of a taxon by the total area swept by the trawl. Biomasses in the database were therefore expressed in kg.km^{-2}.

2.3. Environmental variables and spatial distribution maps

Two sets of environmental variables characterising the EGSL were gathered from different sources, i.e. at the sampling stations and throughout the EGSL.

At each sampling station, a CTD Seabird™ apparatus (SBE911 Plus), combined with a SBE 43 dissolved oxygen sensor, measured the water column characteristics such as salinity (conductivity), temperature, and dissolved oxygen at predetermined depths, including the bottom. Titrations of water samples, collected with Niskin bottles fixed on a rosette, were carried out to corroborate the concentration of dissolved oxygen measured with the oxygen sensor. Geographical (e.g. distance to coast) and physical descriptors related to the underwater relief were also gathered for each sampling station (Dutil et al., 2011). Another extensive set of these water-column, geographic, and physical data, located all over the EGSL, was used (Dutil et al., 2011). Bottom current, included as an abiotic factor in the environmental dataset, was obtained using a three-dimensional coastal ice-ocean model with realistic tidal, atmospheric, hydrologic, and oceanic forcing (Saucier et al., 2003). At each sampling station, the maximum mean hourly bottom current value in cm.s^{-1} was obtained for August for each corresponding year (2006 to 2009), and, for the entire EGSL, maximal values per year, averaged over 2006 to 2009, were calculated and included in the EGSL environmental dataset. A digital map of seabed sediment types, derived from Loring and Nota (1973) and validated using sediment grabs by Bourque (2008) and pictures of the seafloor from Belley et al. (2010), was used to determine substratum type in the entire EGSL, including at each sampling station. The original sediment classification contained 46 substratum codes identified by textual analysis, and, for simplification, 14 groups were made from these and retained for subsequent analysis (Table 1).