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Modeling sensitive elasmobranch habitats

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ABSTRACT

Basic information on the distribution and habitat preferences of ecologically important species is essential for their management and protection. In the Mediterranean Sea there is increasing concern over elasmobranch species because their biological (ecological) characteristics make them highly vulnerable to fishing pressure. Their removal could affect the structure and function of marine ecosystems, inducing changes in trophic interactions at the community level due to the selective elimination of predators or prey species, competitors and species replacement. In this study Bayesian hierarchical spatial models are used to map the sensitive habitats of the three most caught elasmobranch species (*Galeus melastomus*, *Scyliorhinus canicula*, *Etmopterus spinax*) in the western Mediterranean Sea, based on fishery-dependent bottom trawl data. Results show that habitats associated with hard substrata and sandy beds, mainly in deep waters and with a high seabed gradient, have a greater probability registering the presence of the studied species than those associated with muddy shallow waters. Temperature and chlorophyll-α concentration show a negative relationship with *S. canicula* occurrence. Our results identify some of the sensitive habitats for elasmobranchs in the western Mediterranean Sea (GSA06 South), providing essential and easy-to-use interpretation tools, such as predictive distribution maps, with the final aim of improving management and conservation of these vulnerable species.

1. Introduction

There is increasing concern worldwide over elasmobranch species because their K-selection life-history traits make them susceptible to population depletion as a result of anthropogenic activity, including unsustainable fisheries, by-catch, and habitat modification (Dell'Apa et al., 2012). Most elasmobranchs are predators at or near the top of marine food chains and thus, play an important role in marine ecosystems, potentially regulating the size and dynamics of their prey populations (Stevens et al., 2000). Their removal could affect the structure and function of marine ecosystems, inducing changes in trophic interactions at the community level due to selective removal of predators or prey species, competitors and species replacement.

In the Mediterranean Sea, this is of particular concern since sharks and rays make up an important percentage of the by-catch (Carbonell and Azevedo, 2003) and their mobile nature makes them potentially accessible to several fisheries at various bathymetric ranges (Ferretti et al., 2008). Bottom trawling is considered responsible for a large proportion of the by-catch of elasmobranch species in the Mediterranean Sea, and throughout the world in general (Maravelias et al., 2012). Evidence of changes in the number of elasmobranchs and the decrease in the abundance of several species (e.g. *Raja clavata* and *Dipturus batis*) over the last decade has been reported for the whole of the Mediterranean Sea and in particular, for the highly exploited area of the Gulf of Lions (Abdulla, 2004). As a result cartilaginous fishes can be used as ecological indicators and their study and monitoring are considered essential for the conservation of the marine ecosystem (Stevens et al., 2000).

In 2009 the European Commission adopted the first Action Plan for the conservation and management of elasmobranchs (EU, 2009) with the aim of rebuilding their stocks under threat, and of setting down guidelines for the sustainable management of the fisheries concerned. Moreover, the implementation of an ecosystem approach to fisheries management (EAFM) and marine spatial planning (MSP) contemplates the protection of priority habitats, a policy of reducing by-catches and the study of current and expected impacts with a view to preparing efficient strategies for the preservation of the marine environment and in particular its living marine resources (Katsanevakis et al., 2009).

In order to achieve these purposes the prerequisites are a solid knowledge of species–environment relationships and the identification of priority areas using robust analysis of existing information and databases (Massutı and Moranta, 2003). Habitat and species mapping is essential for conservation programs because it provides a clear picture of the distribution and extent of these marine resources, and thus facilitates managing the marine environment (Barberá et al., 2012).

Following Soberón and Peterson (2005) and Soberón (2010) these objectives can be achieved by either using Species Distribution Models

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(SDMs; models containing biotic or accessibility predictors and/or being limited in spatial extent) or Ecological Niche based Models (ENMs; for forecasting an approximation to the species' niche) (Guisan and Zimmermann, 2000; Wiens et al., 2009). On the one hand, the theoretical framework of ENMs is based on the ecological niche concept which identifies a niche as a subdivision of the habitat containing the environmental conditions that enable individuals of a species to survive and reproduce, based on broad-scale variables (climate) that are not affected by species density (Sillero, 2011). On the other hand, SMDs aim to predict quantities of interest at unsampled locations based on measured values at nearby sampled locations, within the range of environments sampled by the training data and within the same general time frame as that in which the sampling occurred.

In line with the SMD context, our study aims to identify sensitive habitats of elasmobranch species and develop probabilistic spatial scenarios as effective tools for supporting decision-making within the conservation framework. To this end we have analyzed a group of georeferenced data of the presence/absence of the most common demersal cartilaginous species collected from fishery-dependent bottom trawl sampling carried out along the continental shelf and slope of the Western Mediterranean Sea (GFCM Geographical Sub Area 06) during a six-year period of time. In particular, we have modeled the occurrence data of the three most frequently captured species: smallspotted catshark (*Scyliorhinus canicula*, Linnaeus, 1758), blackmouth catshark (*Galeus melastomus*, Rafinesque, 1810) and velvet belly (*Etmopterus spinax*, Linnaeus, 1758), which comprise more than 80% of the total demersal elasmobranch abundance caught during the period 2006–2011. Cluster Analysis (CA) and Multi Dimensional Scaling (MDS) techniques have been applied to observers' data in order to verify whether the three species studied are in fact representative of the whole elasmobranch community of this area.

To accomplish spatial prediction, ordinary kriging can be used to obtain the best linear unbiased predictor. However, accuracy is not always easy to achieve because there is often a large amount of variability surrounding the measurements of response and environmental variables, and traditional prediction methods, such as ordinary kriging, do not account for an attribute with more than one level of uncertainty. This variability leads to uncertain predictions, and consequently to uninformed decision making. In order to solve this problem, we have chosen to use hierarchical Bayesian spatial models and Bayesian kriging has been used.

In our approach, one of the additional advantages is the possibility of integrating current modeling approaches (such as GLM and GAM) and uncertainty analyses into a more general hierarchical framework. Within the Bayesian framework, full inference about uncertainty, given what we have observed (the data) and what we know or assume about the process (the model), comes free with the model predictions (Banerjee et al., 2004). Spatial autocorrelation can be incorporated into a regression model through random effects that capture spatial dependence in the data (Latimer et al., 2006). Since the random effects are model parameters, they also emerge with a full posterior distribution that allows quantification of uncertainty. Hierarchical stages can describe conceptual but unobservable latent processes that are ecologically important, as well as error in the observation process or gaps in the data (Gelfand et al., 2006).

However, until recently, it was computationally quite expensive to calculate these Bayesian hierarchical models with this spatial structure. In this study we overcome this problem by using the integrated nested Laplace approximation (INLA) methodology and software (http://www.r-inla.org). INLA provides accurate approximations to posterior distributions of the parameters, even in complex models, in a fast computational way (Rue et al., 2009). In addition, INLA can be used through R software, providing a familiar interface with the programming of the model.

But, more importantly to us, this methodology allows us both to estimate the processes that drive the distribution of elasmobranchs and also to generate predictive maps of the distribution of species in the study area, especially in non-observed locations.

The establishment of regional marine protected areas for protecting sensitive habitats would benefit from an improved understanding of the spatial distribution of vulnerable species, such as elasmobranchs, and could help towards the more efficient management and control of marine resources.

2. Material and methods

The study area was the Gulf of Alicante (Western Mediterranean), between 37° 15.6′ and 38° 30.0′ N, and 1° 0.0′ W and 0° 30.0′ E (Fig. 1). The Gulf of Alicante has a surface area of 3392 km^2 and an average shelf width of approximately 32 km. The largest fleet is the bottom trawl one, with 169 vessels landing an average of 8000 t per year. Seabed trawling usually takes place on the shelf, yielding a multispecific catch with European hake (*Merluccius merluccius*) as the main target species. The elasmobranch species most frequently caught are: *G. melastomus*, *S. canicula*, *E. spinax*, *R. clavata*, *Raja asterias* and *Squalus acanthias*. Their distribution and abundance vary according to depth.

2.1. Data

The data set includes 400 hauls of 25 different trawler vessels and has been provided by the Spanish Oceanographic Institute (Instituto Español de Oceanografía, IEO). The IEO provides the national input of the European Observers Programme for collecting fishery-dependent data. In particular, they collect samples from the commercial fleet with observers on board. This sampling has been carried out since 2003, usually involving about 2–3 observer samplings every month for the trawler fleet, accounting for an average of 10 hauls monthly. From this database we have used the geographical location and occurrence of the elasmobranch species for each haul. The fisheries were multispecies and none of the elasmobranchs were target species.

Extrinsic factors influencing the spatial distribution of elasmobranch species used were depth, which is often the main gradient along which faunal changes occur when analyzing shelf and upper slope assemblages (Kallianiotis et al., 2000), type of substratum (Demestre et al., 2000), slope of seabed and physical characteristics of the water masses (Maravelias et al., 2007).

For ocean processes, chlorophyll-α concentration and Sea Surface Temperature (SST) data can be used to locate thermal and productivity-enhancing fronts and marine productivity hotspots and thus determine the influence of such features on species distribution (Valavanis et al., 2008). In addition, SST and Chl-α are also strong functional links between surface primary productivity and biological activity at the sea floor through the episodic deposition of particulate material (Nodder et al., 2003, Leathwick2006). Previous studies have shown that the distributions of many demersal fish species are likely to be influenced by overall ecosystem productivity (Hopkins and Cech, 2003; Leathwick et al., 2006; Martin et al., 2012; Matern et al., 2000).

In particular, Chl-α concentration can be used as an index of primary production of an ecosystem (de Leiva Moreno et al., 2000). Obviously, primary production depends on a range of factors, including light, light penetration and temperature, which could not be taken into account here due to the absence of data. Nevertheless, the mean value of Chl-α concentration can be used as an independent index of primary production in the area of interest, since its variability could modify trophic conditions of the species' habitat from oligotrophic to mesotrophic (Katara et al., 2008).

Sea Surface Temperature (SST) is strongly related with primary productivity and is thus a possible candidate to explain the distribution of the species (Valavanis et al., 2004). Previous studies on