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Modelling of European hake nurseries in the Mediterranean Sea: An ecological niche approach

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ABSTRACT

An ecological niche modelling (ENM) approach was developed to model the suitable habitat for the 0-group European hake, *Merluccius merluccius* L., 1758, in the Mediterranean Sea. The ENM was built combining knowledge on biological traits of hake recruits (e.g. growth, settlement, mobility and feeding strategy) with patterns of selected ecological variables (chlorophyll-a fronts and concentration, bottom depth, sea bottom current and temperature) to highlight favourable nursery habitats. The results show that hake nurseries require stable bottom temperature (11.8–15.0 °C), low bottom currents ($<0.034\ m\ s^{-1}$) and a frequent occurrence of productive fronts in low chlorophyll-a areas (0.1–0.9 $mg\ m^{-3}$) to support a successful recruitment. These conditions mostly occur recurrently in outer shelf and shelf break areas. The prediction explains the relative balance between biotic and abiotic drivers of hake recruitment in the Mediterranean Sea and the primary role of unfavourable environmental conditions on low recruitment in specific years (i.e. 2011). The ENM outputs particularly agree spatially with biomass data of recruits, although processes such as fishing and natural mortality are not accounted for. The seasonal mapping of suitable habitats provides information on potential nurseries and recruitment carrying capacity which are relevant for spatial fisheries management of hake in the Mediterranean Sea.

Introduction

Understanding spatial patterns in population dynamics is a necessary prerequisite to protecting critical habitats, and thus ultimately in ensuring sustainable management of fishery resources (Berkeley et al., 2004; Caddy, 2000). Reducing fishing effort on juveniles in particular is vital if populations are harvested at maximum sustainable yield, especially in areas where juveniles are vulnerable to unselective fishing gears (Caddy, 2009), as is often the case in the Mediterranean Sea (Colloca et al., 2013). Furthermore, information on critical reproductive habitats provides an insight into the likely spatial structure of population units or stocks, whilst an insight into environmental conditions required for successful recruitment allows scientists and managers to better depict the interaction between environmental parameters and stock recruitment relationships. Information on the spatial aspects of population ecology and interactions with relevant ecosystem components are needed to implement an Ecosystem Approach to

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Fisheries Management (Link, 2013; Pauly et al., 2011) that is required as part of the implementation of the Marine Strategy Framework Directive (European Commission, 2008) and is recognized as a fundamental principle underpinning the revised Common Fisheries Policy. As a matter of fact the Council Regulation (EC) 1967/2006, concerning management measures for the sustainable exploitation of fishery resources in the Mediterranean Sea, specifically requires the inclusion of spatial aspects such as the establishment of fishing protected areas in order to protect nurseries and/or spawning areas. Among the commercial species, the European hake (*Merluccius merluccius*, L. 1758) is one of the most important in the Mediterranean Sea with total landings of 22547 tons in 2011 (GFCM-FAO[1]). All the available assessments in the Mediterranean Sea have underlined that the status of hake stocks is characterised by high fishing mortalities on juveniles (Colloca et al., 2013). Considering the large size that hake can reach (more than 100 cm Total Length), coupled with a low size at first capture of the Mediterranean fine-meshed trawling (Bethke, 2004), the protection of hake nurseries has been proposed as an effective measure to improve size composition of catches (Caddy, 1999).

In order to identify appropriate areas to be closed to fishing, many authors have regionally studied the spatial distribution of the European hake juveniles and identified the main nurseries as areas where the highest concentrations of young-of-the-year remain remarkably stable over the years (Carlucci et al., 2009; Colloca et al., 2009; Lembo et al., 2000; Fiorentino et al., 2003; Lleonart, 2001; Murenu et al., 2010; Tserpes et al., 2008). Although the stability of the nurseries over time implies the existence of favourable habitats, only a few regional research initiatives have focused on the identification of the ecological factors which make some areas more suitable compared to others for hosting high concentrations of 0-group hakes in the Mediterranean Sea. These factors such as wind mixing, temperature, currents, fronts and primary production were identified independently in different Mediterranean regions (Abella et al., 2008; Bartolino et al., 2008a; Hidalgo et al., 2008; Lleonart, 2001) and no clear explanation of their role in the nurseries' functioning could be provided. In this paper, the underlying assumption for the feeding habitats of hake recruits in the Mediterranean Sea relies on the importance of productive fronts (chlorophyll-a fronts), by means of their long lifetime, to efficiently transfer the flow of energy along the food chain up to top predators. It is well known that productive oceanic features (chlorophyll fronts) are key vectors of the oceans' productivity along the food chain (Belkin et al., 2009; Druon et al., 2012, 2011; Kirby et al., 2000; Le Fèvre, 1986; Olson et al., 1994; Polovina et al., 2004, 2001). Bakun (2006) highlights the importance of frontal systems as sub-seasonal meso-scale environmental processes that may often be critical to regulating population-scale reproductive success, as in the Strait of Sicily with the semi-permanent eddies and fronts produced by the Atlantic Ionian Stream (see e.g. Fortibuoni et al., 2010; Garofalo et al., 2011). Very recently Alemany et al. (2014) showed that marine fronts represent important fishing areas even for demersal resources, as the distribution of fishing fleets and fishing effort are positively associated with frontal zones. In the case of hake juveniles, feeding on vertically migrating preys is an ecological characteristic that is presumably linked to the occurrence of chlorophyll-a fronts. Feeding intensity of hake was significantly correlated with major phytoplankton bloom events with a delay from one (Cartes et al., 2004) to two months (Hidalgo et al., 2008) presuming that most hake prey were pelagic (euphausiids, clupeids) and they may reach high densities after exploiting local phytoplankton blooms (Cartes et al., 2004).

[1] http://www.gfcm.org/gfcm/topic/17105/en.

Ecological niche models (ENMs), also termed Species distribution modelling (SDM) (Elith and Leathwick, 2009; Guisan and Thuiller, 2005; Peterson and Soberón, 2012) have become increasingly popular tools in the study of marine species distribution (Bentlage et al., 2013; Friedlaender et al., 2011; Tyberghein et al., 2012; Wiley et al., 2003). ENMs are spatially-explicit methods for modelling the ecological requirements of a given species and predicting its potential distribution in geographical space. They encompass numerous conceptual approaches and analytical tools, all underpinned by the niche concept formalized by Hutchinson (1957), i.e. the *n*-dimensional hypervolume formed by the environmental conditions a species can tolerate and within which populations can survive (Hirzel et al., 2002). ENMs basically work by distinguishing between ecological and geographical space. Given a set of species occurrence (or abundance) data across geographical space coupled with variations of a set of environmental factors in the same geographical space, ENMs are used to (i) explore the relationship between observed species occurrence and environmental variables, (ii) define, in the ecological space, the environmental variables that govern or limit the species distributional potential in the geographical space, (iii) predict, by projection back onto geographical space, the species occurrence also in areas where the distribution is unknown. Expected output of ENMs are maps of suitable or unsuitable habitats for studied species (Hirzel et al., 2002), which have many challenging applications in ecological studies (see Guisan and Thuiller, 2005 for a review) and are currently recognized as powerful tools for supporting appropriate management and conservation plans of marine resources. Despite these potentialities, to date few ENMs application have specifically addressed at a regional spatial level the Mediterranean Sea (Azzellino et al., 2012; Azzurro et al., 2013; Druon et al., 2012, 2011; Langer et al., 2012; Sarà et al., 2013) and those based on distributional information of demersal species are rare (Hattab et al., 2013).

Data collected of decadal scientific surveys in the Mediterranean Sea coupled with environmental data from remote sensing and circulation models were used to apply the ENM approach, with the aim of identifying the most suitable environmental conditions which could promote the aggregations of 0-group hake in nursery areas. It is important to note that the present modelling approach refers to potential – rather than effective – habitats since the identified environmental conditions of nurseries are projected back onto space and time. The distribution of the realized nurseries and the dynamics of recruitment should, at model level, include other factors such as spawning stock biomass, connectivity from spawning to nursery grounds, predation and/or fishery pressure. This work will nevertheless provide relevant information to explain and monitor the environmentally-driven variability of hake recruitment, as well as to identify priority protection areas of hake recruitment.

Materials and methods

The methodological approach used in our ENM is essentially composed of four main steps (Fig. 1), namely: (1) identify the main life-history and ecological traits of 0-group hake based on literature; (2) process biomass indices for hake recruits and environmental covariates; (3) identify a suite and relevant thresholds of environmental variables related to the recruits' lifetime to describe the nursery habitat characteristics and finally (4) develop a habitat model to classify on a daily basis the degree to which each portion of the study area (model grid cell) is either suitable or unsuitable for recruitment. All variables were projected on the finest horizontal grid of the satellite ocean colour data which was used (NASA MODIS-Aqua sensor), i.e. at the resolution of 1/24° (about 4.6 km).