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Contrasting habitat selection amongst cephalopods in the Mediterranean Sea: When the environment makes the difference

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ABSTRACT

Conservation of fish habitat requires a deeper knowledge of how species distribution patterns are related to environmental factors. Habitat suitability modelling is an essential tool to quantify species' realised niches and understand species-environment relationships. Cephalopods are important players in the marine food web and a significant resource for fisheries; they are also very sensitive to environmental changes. Here a time series of fishery-independent data (1998–2011) was used to construct habitat suitability models and investigate the influence of environmental variables on four commercial cephalopods: *Todaropsis eblanae*, *Illex coindetii*, *Eledone moschata* and *Eledone cirrhosa*, in the central Mediterranean Sea. The main environmental predictors of cephalopod habitat suitability were depth, seafloor morphology, chlorophyll-a concentration, sea surface temperature and surface salinity. Predictive maps highlighted contrasting habitat selection amongst species. This study identifies areas where the important commercial species of cephalopods are concentrated and provides significant information for a future spatial based approach to fisheries management in the Mediterranean Sea.

1. Introduction

Knowledge of the spatial distribution of species in relation to the environment is an essential requirement for their sustainable exploitation and the conservation of their habitats (where habitat is defined as the set of environmental factors defining the conditions of presence, survival, growth, and reproduction of a given species). The need to integrate this aspect into marine resource management of commercial or conservation interest species has been highlighted in the latest European policies (European Marine Strategy Framework Directive and Common Fisheries Policy; EU, 2010, 2013).

Habitat suitability modelling is an important tool to quantify a species' realised niche (sensu Hutchinson; Araújo and Guisan, 2006) and understand species-environment relationships (Elith and Leathwick, 2009). Their application to fisheries management has been facilitated by the latest developments in statistical modelling, remote sensing and Geographic Information System (GIS; Guisan et al., 2013; Valavanis et al., 2008). Habitat suitability models *sensu lato* can be applied to support the conservation of fishery-sensitive species (Lauria et al., 2015; Morfin et al., 2012) and the identification of spawning and nursery areas of commercially important species (Lauria et al., 2011; Druon et al., 2015), as well as to climate change research (Guisan and Thuiller, 2005). These models are widely used in marine ecology research and can inform the application of an ecosystem-based approach to fisheries (EAF) management as well as conservation plans (Guisan et al., 2013).

Cephalopods are an important component of marine assemblages and play an essential role in marine food webs as they transfer energy from the lower to the higher trophic levels up to apex predators (e.g. fish, turtles, dolphins, whales; ICES, 2014; Valavanis et al., 2008). Cephalopods are highly sensitive to changes in environmental conditions at a range of spatial and temporal scales (Pierce et al., 2008), due to their specific biology (e.g. rapid growth rates, short lifespan and little generation overlap). The effect of environmental factors on cephalopod habitat selection varies amongst species as function of their biology and ecology: oceanographic conditions are more relevant for pelagic species while the typology of substrata and bathymetry can affect demersal and benthic species (Bakun and Csirke, 1998; Pierce et al., 2008; Smith et al., 2013; Wright et al., 2012). Cephalopods represent a significant fishery worldwide that has been increasing over the last decades (Boyle and Rodhouse, 2005; FAO, 2012), with some European fisheries contributing substantially to the economic benefits of the global fishing industry (ICES, 2014). However,

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because of their peculiar life cycle (semelparous short lived species that die after reproduction) the most appropriate methods to manage cephalopod fisheries are still being debated (Keller et al., 2015), and specific management measures, such as quotas or minimum legal sizes, are lacking. In the Mediterranean Sea the overall trend in cephalopod landings has shown a marked decline since 1990 (Fig. S1; FAO, 2011), however in some regions a positive trend in biomass has been observed (i.e. Strait of Sicily, Ionian Sea; Mannini and Sabatella, 2015).

Fisheries seem to have a contrasting effect on cephalopods (i.e. both negative and positive spatial correlations between fishing effort and cephalopod abundance have been observed; Boyle, 1990; Caddy, 1983; Maiorano et al., 2010; Navarro et al., 2015; Quetglas et al., 2016). However some studies have suggested that cephalopods are favoured by fishing activity due to a reduction in predation pressure resulting from predator release and a decrease in their competitors for prey (Coll et al., 2013). Also because of their specific biology (i.e. short life cycle, high population growth and turnover, lack of overlapping generations) cephalopods are less sensitive to long-term moderate disturbances such as fishing while more vulnerable to short-term perturbations, such as seasonal environmental changes (Quetglas et al., 2016). In the Mediterranean Sea cephalopods have a high socio-economic importance, especially for local fisheries. They are mainly caught by bottom trawl and artisanal fleets (Cabanellas-Reboredo et al., 2011; Keller et al., 2015; Sartor et al., 1998), although only few stocks have been assessed so far (Keller et al., 2015; Mehanna and Haggag, 2011). As a consequence a characterisation of cephalopod habitats and their relationship to environmental factors is needed (Perdichizzi et al., 2011; Puerta et al., 2015, 2014; Regueira et al., 2014) in order to promote the sustainability of Mediterranean cephalopod fisheries.

Using spatio-temporal dataset (14 years) of fishery-independent bottom trawl surveys in the central Mediterranean Sea we modelled the relative density of four commercially important cephalopod species (*Todaropsis eblanae*, *Illex coindetii*, *Eledone moschata* and *Eledone cirrhosa*) (Norman et al., 2014; Roper et al., 2010; Sartor et al., 1998) as a function of environmental variables, in order to identify the factors that drive their habitat selection. Oceanographic variables (i.e. sea surface temperature, chlorophyll-a concentration, surface salinity and photosynthetic active radiation), physical variables (i.e. depth, slope and rugosity) and a temporal variable (year) were used. Density distribution maps were produced in order to identify species-specific spatial patterns in the central Mediterranean Sea. This study contributes significantly to the knowledge of the species-environment relationship of commercially important cephalopod species, and can support future spatial based approach to fishery management in the Mediterranean Sea.

2. Materials and methods

2.1. Study area

The study area is located in the central Mediterranean Sea and comprises the northern side of the Strait of Sicily between 34°59′–38°00′N and 10°59′–15°18′W (Fig. 1A). This area corresponds to the Geographic Sub Area (GSA) 16 of the General Fisheries Commission for the Mediterranean (GCFM, 2007) and extends for about 34,000 km^2. It is characterised by complex seafloor morphology and hydrodynamic processes (Béranger et al., 2004), with a wide range of depths, including a shallow bank (Adventure Bank) in the western part (about 100 m) and deeper areas in the southeast (about 1800 m; Fig. 1A). In the Strait of Sicily a number of hydrodynamic processes and overlapping water layers occur (Fig. 1B; Lermusiaux and Robinson, 2001). In the upper layer, the Modified Atlantic Water (MAW) generates a meandering stream along the Sicilian shore called the Atlantic Ionian Stream (AIS) that determines the incidence of upwelling over the eastern Sicilian shelf- (Lermusiaux and Robinson, 2001; Robinson et al., 1999). The upwelling along the southern coast of Sicily is a persistent feature of the area (Bonanno et al., 2014), which is linked to the AIS meanders and cyclonic vortices and probably to westerly winds that can reinforce the coastal upwelling (wind-driven upwelling) (Robinson et al., 1999). This circulation pattern is further modified by the formation of mesoscale eddies that, together with the effect of AIS, have been suggested to drive the spatial distribution of cephalopod nursery and spawning grounds in the Strait of Sicily (Fig. 1B; Jereb et al., 2001; Garofalo et al., 2010). This very complex topography and circulation patterns make the Strait of Sicily a highly productive area (Agostini and Bakun, 2002) and a biodiversity hotspot (Garofalo et al., 2007, 2010, 2011; Gristina et al., 2013). This area is intensively exploited by many demersal fisheries (mainly bottom trawlers) operating along the southern coast of Sicily, including the Mazara del Vallo fleet, one of the largest and most active fleets in the Mediterranean (Fiorentino et al., 2004; Russo et al., 2014). The Strait of Sicily makes the highest contribution to the total Italian cephalopod landings, where cephalopods are caught by both industrial trawlers and artisanal fisheries (Garofalo et al., 2010; Jereb and Agnesi, 2009).

2.2. Survey data

Since 1994 the area has been investigated under the Mediterranean International Trawl Survey program (MEDITS; Bertrand et al., 2002). This survey is carried out annually in late spring/early summer, and takes place in several areas of the Mediterranean Sea using a standardised sampling methodology (Anonymous, 2013). It provides a spatio-temporal dataset of fishery-independent indices relating to demersal species abundance, demographic structure and spatial distribution. In GSA16, sampling stations are fixed and replicated each year according to a stratified random sampling design based on five depth strata: 10–50 m, 51–100 m, 101–200 m, 200–500 m, 500–800 m, where the number of hauls is proportional to the area of each stratum (Fig. 1A). A total of 55–120 stations (haul duration = 30–60 min hauls; trawl speed = 3 knots) was sampled each year (Fig. 1A) on board the commercial trawler Sant'Anna. The gear was the bottom trawl net (GOG 73) with a high (2.5–3 m) vertical opening and 20 mm side diamond stretched mesh in the cod-end. At each trawl station, collected species were sorted, weighed, counted and measured. Cephalopod density was calculated as the number of individuals per km^2 (Nkm^{-2}) for a total of 1186 trawl hauls covering the period 1998 to 2011. Habitat models were built for the commercial cephalopod species best represented in the survey (in terms of percentage occurrence) in particular *Todaropsis eblanae* (40.89%), *Illex coindetii* (49.49%), *Eledone moschata* (23.94%) and *Eledone cirrhosa* (27.99%). Information about cephalopod biology and fisheries is provided in Table 1.

2.3. Environmental data

Environmental predictors included three physical descriptors: depth, slope and rugosity; and four oceanographic variables: Sea Surface Temperature (SST), Chlorophyll-a concentration (Chl-a), Sea Surface Salinity (SSS) and Photosynthetic Active Radiation (PAR). Information on the ecological relevance of these variables for cephalopod habitat selection is provided in Table 2. A digital continuous map of depth was derived from a re-projection of the MARSPEC database (Sbrocco and Barber, 2013) using the ArcGIS's