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FISH HABITAT MAPPING

Habitat discrimination of juvenile sardines in the Aegean Sea using remotely sensed environmental data

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Abstract Despite the importance of the recruitment process for small pelagic fish and the high economic importance of European sardine (*Sardina pilchardus,* Walbaum 1792) in the Mediterranean Sea, knowledge on the distribution and environmental characteristics of its nursery grounds is very limited. In the present study, we used pelagic trawl data collected during 1995–2006 to explore the spatial distribution of sardine juveniles in the Aegean Sea in early summer. Based on sardine abundance per length class, a cluster analysis was initially used to define hauls dominated by juveniles. In a subsequent step, Discriminant Function Analysis (DFA) was applied to discriminate stations with high relative abundance of juveniles using satellite environmental data and bottom depth. The parameters contributing mostly to the discrimination of juvenile grounds were sea level anomaly, photosynthetically active radiation, sea surface temperature, chlorophyll-α and bottom depth. The classification functions of DFA were finally used to post classify unsampled areas in the Greek Seas and the Mediterranean Sea in order to map grounds that meet characteristic environmental conditions for young sardine. Such areas were mostly located inshore, in semi-closed productive areas and often in proximity to river mouths, a pattern that is generally supported by existing information.

Keywords Small pelagic fish · Sardine's juveniles · Nursery grounds · Remote sensing · Aegean Sea · Eastern Mediterranean

Introduction

Knowledge on the distribution of the different life stages of a species is fundamental in ecology and conservation planning (Freon & Misund, 1999; Reynolds et al., 2001). Especially when it comes to decision making, as in the case of fisheries

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Essential Fish Habitat Mapping in the Mediterranean

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management, this knowledge almost constitutes a requirement. For several fish species, especially small pelagic, different patterns in the spatial distribution of juvenile and adult fish have been observed. Regarding the European sardine (*Sardina pilchardus*, Walbaum 1792), Porteiro et al. (1986) described a gradient in species distribution off Galicia, which was related to age classes. In the Gulf of Lions (Western Mediterranean—France), sardine juveniles are mostly located close to the coast (Bigot, 2007) while in the Tramontana region (Western Mediterranean—Spain) sardine juveniles are mainly located near the Ebro river delta (Giráldez et al., 2005). This differentiation in the spatial distribution of juveniles and adults is probably related to biological requirements, environmental conditions, hydrographic characteristics and biotic factors and may reflect the fish response to the gradient rather than to the absolute value of a parameter (Freon & Misund, 1999).

Sardine constitutes almost 20% of Mediterranean (Lleonard & Maynou, 2003) and 12% of the Greek annual landings (Stergiou et al., 1997). Despite its high economic importance and demand for effective management, the knowledge on basic aspects of juvenile sardine ecology, distribution and the environmental characteristics of nursery grounds is limited (Palomera et al., 2007). The growing availability and reliability of environmental information through remote sensing techniques during the recent years may serve as a tool to overcome these gaps of knowledge (Turner et al., 2003). This environmental information has the advantage that it can be obtained easily and almost in real time allowing its application in habitat modelling and the development of large-scale descriptive and predictive models for various time periods that field sampling is not necessarily available (Turner et al., 2003; Elith et al., 2006).

In the present work, we identify the grounds of sardine juveniles during June. Identification is based on the discrimination of environmental characteristics (i.e. satellite environmental data as well as bathymetry data) of certain areas in Aegean Sea (Eastern Mediterranean—Greece), which presented high relative abundance of sardine juveniles in experimental trawling. Results are applied to predict and map the areas characterized by environmental conditions that could serve as nursery grounds for sardine juveniles in Greek Seas and the entire Mediterranean Sea.

Materials and methods

Study area

The northern Aegean Sea is one of the most important fishing grounds for small pelagic fish (mainly anchovy and sardine) in Greek waters (Stergiou et al., 1997; Somarakis et al., 2006). Aegean Sea is generally characterized by a complex hydrography and diverse topographic characteristics (Lykousis et al., 2002; Somarakis et al., 2002). Surface water layers are influenced by nutrient rich, low saline, Black Sea Water inputs while water column is influenced by oligotrophic Levantine Intermediate Waters (Stergiou et al., 1997; Siokou-Frangou et al., 2002). The coastal zone of the Aegean Sea is influenced by river flows, enhancing the productivity of the area locally (Karageorgis et al., 2001; Isari et al., 2006). Certain gyre-eddy formations and thermal fronts increase the complexity of the water characteristics (Nittis & Perivoliotis, 2002; Somarakis et al., 2002; Zervakis & Georgopoulos, 2002). Moreover, the region is characterized by peculiar topography, with variable sized open areas (e.g. Thracian Sea) connected with semi-enclosed gulfs (e.g. North Evoikos, Strymonikos and Thermaikos gulfs) affecting the ecological features of the marine ecosystem and the spatial distribution of small pelagic fish (Giannoulaki et al., 2003, 2006).

Data collection

Data were collected on board R/V Philia in Aegean Sea (Greece) (Fig. 1) during six research surveys (1998–99 and 2003–06). All surveys were held during June of each year, which coincides with the recruitment period for sardine in the Greek Seas (Somarakis et al., 2006; Machias et al., 2007). Fish specimens were collected with experimental fishing in the framework of acoustic surveys. Hauls were mainly held on locations with high fish concentrations and were well distributed along the surveyed areas (Fig. 1). A pelagic trawl with 10 m opening and 8 mm codend mesh size was used. Trawl duration ranged between 37 and 151 min. For each haul, a representative sample of at least 150 specimens was used to measure the total length to the closest mm, and the length frequency distribution (numbers/hour weighted by the total catch of the haul) per 5 mm

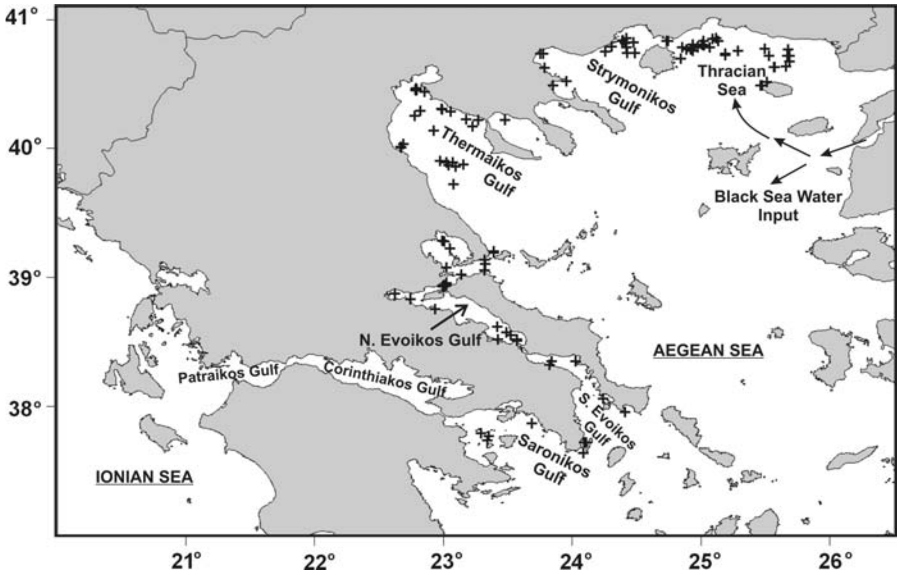

Fig. 1 Aegean (study area) and Ionian Seas. Major areas used in this work are indicated in the map. Cross symbols indicate the positions of the hauls held between 1998 and 2006

length classes was estimated. In total, data from 63 hauls with sardine catches were used.

Data analysis

In a first step of the analysis, we explored whether there were hauls dominated by juveniles or all hauls presented similar compositions. We therefore examined the similarity of the hauls based on the abundance per length class in each haul. The hauls were grouped by applying multivariate techniques using as variables the weighted abundance (fourth root transformation of numbers/hour) at each length class recorded in the haul. For this purpose, we applied cluster analysis using a Bray–Curtis similarity matrix (Field et al., 1982). The analysis was carried out using the Primer v.5 software (Clarke & Warwick, 1994).

Cluster grouping was subsequently examined in relation to the relative abundance of juveniles, i.e. fish smaller than 115 mm length, which approximates the length at first maturity for sardine in the Aegean Sea (Somarakis et al., 2006). Hauls with 100%, >75%, >50% and >25% contribution of juveniles to the total sardine catch were considered.

The second analytical step included the application of a stepwise backward Discriminant Function Analysis (DFA) in order to examine whether the dominance of juveniles could be explained in terms of certain environmental characteristics. We used relative abundance of juveniles (as described above) as classification factor and environmental satellite data and mean bottom depth at the haul route as explanatory variables. Bottom depth (D in m) was calculated through processing (kriging) of a point dataset derived from a blending of depth soundings collected from ships with detailed gravity anomaly information obtained from the Geosat and ERS-1 satellite altimetry missions (Smith & Sandwell, 1997). Concerning environmental data, we used mean weekly values of sea surface temperature (SST in °C) available through the German Aerospace Agency's (DLR) satellite data archive (EOWEB), chlorophyll-α (CHLA in mg/m^3) and photosynthetic active radiation (PAR in Ein/m^2/day) downloaded through Oceancolor Web (NASA's online Distributed Active Archive Center), sea level anomaly (SLA in cm) available through AVISO website using their Live Access Server, and mean monthly values of sea surface salinity (SSS in ppt) estimated from CMA BCC GODAS model, (Liu et al., 2005) available through the International Research Institute for Climate and Society (IRI—University of Columbia) online data distribution archive. The location (coordinates) of each haul was used to assign environmental variables using GIS techniques (for details see Valavanis et al., 2004). Through this procedure, we estimated the environmental parameters as well as the classification functions that discriminate areas where juveniles tend to concentrate. Cross-validation based on the leave-one-out method was used to evaluate the performance of the Discriminant function (McLachlan, 1992). Discriminant analysis was performed using the S-PLUS 2000 (MathSoft Inc, 1999) statistical software.

In the last analytical step, we used environmental satellite and bottom depth data to post classify areas based on the estimated classification functions of DFA. In this way, we mapped the regions, which were characterized by those environmental conditions that can likely support increased presence of juvenile sardine. Mapping was applied at 1.3 km (Aegean and Ionian Seas) and 4 km resolution (Mediterranean Sea) for June 2004–2006. The Surfer v8.0 software (Golden Software, 2002) was used for mapping.

Results

Seven hauls included 100% juveniles while 19, 23 and 32 hauls contained more than 75%, 50% and 25% juveniles, respectively. Hauls with juveniles were generally grouped together by the cluster analysis (Fig. 2), except those hauls containing 100% juveniles, which were very few in number. Best match with cluster grouping was observed for hauls containing 75% and 50% juveniles (Fig. 2B, C).

The results of the DFA (including classification function coefficients and cross-validation results) are shown in Table 1. The analysis for hauls with 100% juveniles is not shown due to low number of hauls as well as non significant results derived from discrimination. The high percentages of correct assignments (>77% and >66% for cross-validated values) denoted satisfactory results (Table 1), but the percentage of correctly classified cases was higher for the hauls containing more than 50% juveniles. The parameters mostly contributing to the aforementioned discrimination were D, SST, CHLA, PAR and SLA (Table 1).

Following the examination of cluster and DFA results, the classification factor ">50% juveniles" and the corresponding Discriminant Function were chosen as the most appropriate factors for mapping potential 'juvenile areas'. Maps indicate the spots that were post-classified as juvenile areas in the Greek Seas according to the included environmental parameters (Fig 3). Indicated areas, although exhibiting spatial variability across years, are mostly confined to the coastal waters

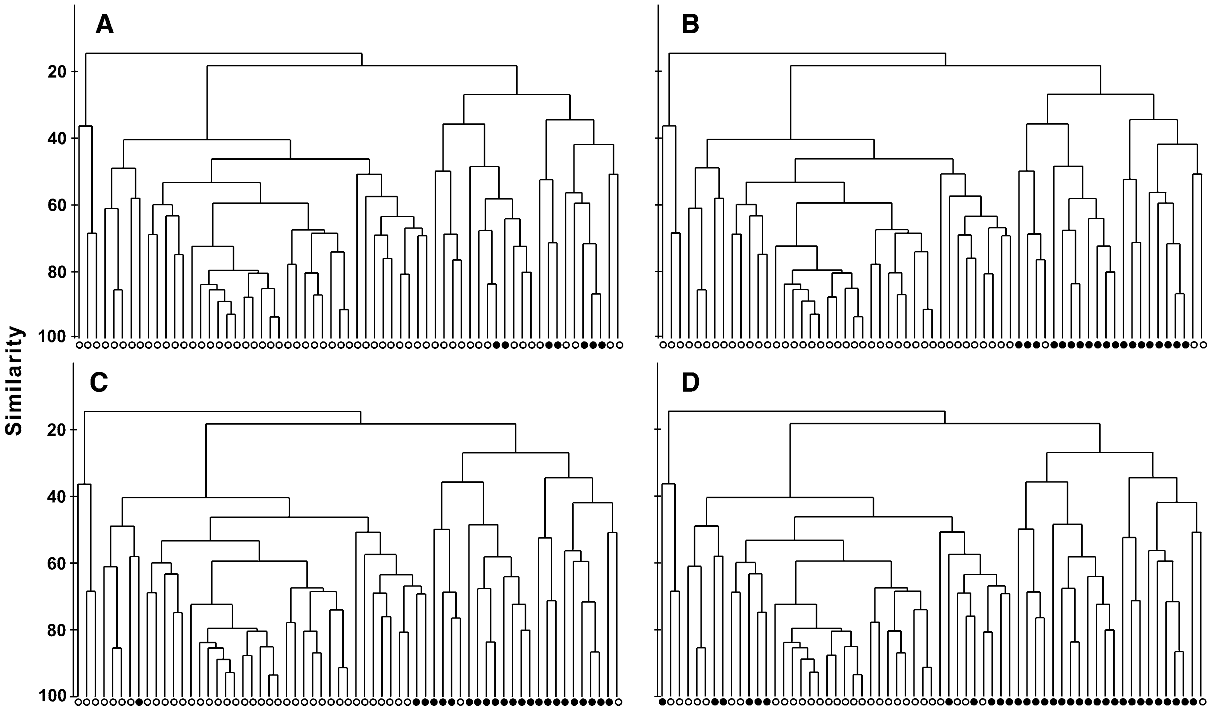

Fig. 2 Cluster analysis results. Black dots indicate hauls with relative abundance of juveniles (**A**) 100% (**B**) at least 75%, (**C**) at least 50% and (**D**) at least 25%

Table 1 DFA results. SLA: sea level anomaly, PAR: photosynthetic active radiation, SST: sea surface temperature, CHLA: chlorophyll-a, SSS: sea surface salinity. D: depth. Classification Function Coefficients for juvenile (A) and non juvenile (B) areas are shown. Cross validated assignments were based on-leave-one-out cross-validation

Factor	Wilks' λ	*P*-value	Variables	Classification function coefficients		Correct assignments (%)	Cross Validated assignments (%)
				A	B		
Over 75% juveniles	0.74	0.007	SLA	10.589	10.161	77.78	77.78
			PAR	11.294	11.380		
			SST	0.324	0.509		
			CHLA	63.368	62.726		
			SSS	376.580	375.964		
			D	−0.834	−0.815		
				Constant = −7534.360	Constant = −7521.920		
Over 50% juveniles	0.74	0.004	SLA	−1.583	−1.941	84.13	73.02
			PAR	6.515	6.723		
			SST	3.828	3.961		
			CHLA	74.159	75.418		
			D	0.245	0.265		
				Constant = −252.983	Constant = −270.723		
Over 25% juveniles	0.66	0.000	SLA	−0.925	−1.416	79.37	66.67
			PAR	6.013	6.042		
			SST	3.474	3.422		
			CHLA	72.984	77.160		
			D	0.208	0.237		
				Constant = −236.38	Constant = −242.01		

of Thracian Sea and Thermaikos Gulf, the northern part of North Evoikos Gulf, in almost the entire South Evoikos Gulf as well as in certain parts of the Saronikos, Corinthiakos and Patraikos gulfs.

Extrapolated mapping for the Western Mediterranean predicted areas located in the Adriatic Sea, the Sicily Channel, the Tyrrhenian Sea (northwestern Italy), and the Gulf of Lions, Catalan and Alboran seas (Fig. 4). In Eastern Mediterranean maps (Fig. 5), indicated areas in Turkish coastal waters of the Aegean Sea, along the Egyptian coastline (mainly off the Nile River Delta), coastal waters of Tunisia (Gulf of Gabes) and Libya.

Discussion

We propose a simple methodology for the discrimination of regions that could support the occurrence of sardine juveniles. The methodology allows (i) flexibility in setting the criteria to define the nursery grounds (because it is based on the relative abundance of juveniles), (ii) the selection of the most significant environmental parameters for the discrimination of the nursery areas and (iii) the mapping of regions that feature the predicted characteristics Furthermore, the main advantage of the proposed method is that it permits a definition and mapping of potential nursery grounds with relatively few data.

During early summer the population of sardine in the Greek Seas is characterized by high abundance of juveniles (Machias et al., 2007). Cluster analysis revealed the grouping of hauls with increased presence of sardine juveniles suggesting that, in the Aegean Sea, there are spatial differences in the relative abundance of juveniles and adults, which is very important for the management of the stocks. Furthermore, given that the horizontal distributions of juvenile and adult fish overlap at varying degrees, a criterion such as 50% or 75% of juveniles in the catch seems to be a reasonable cutoff point for the definition of nursery grounds.

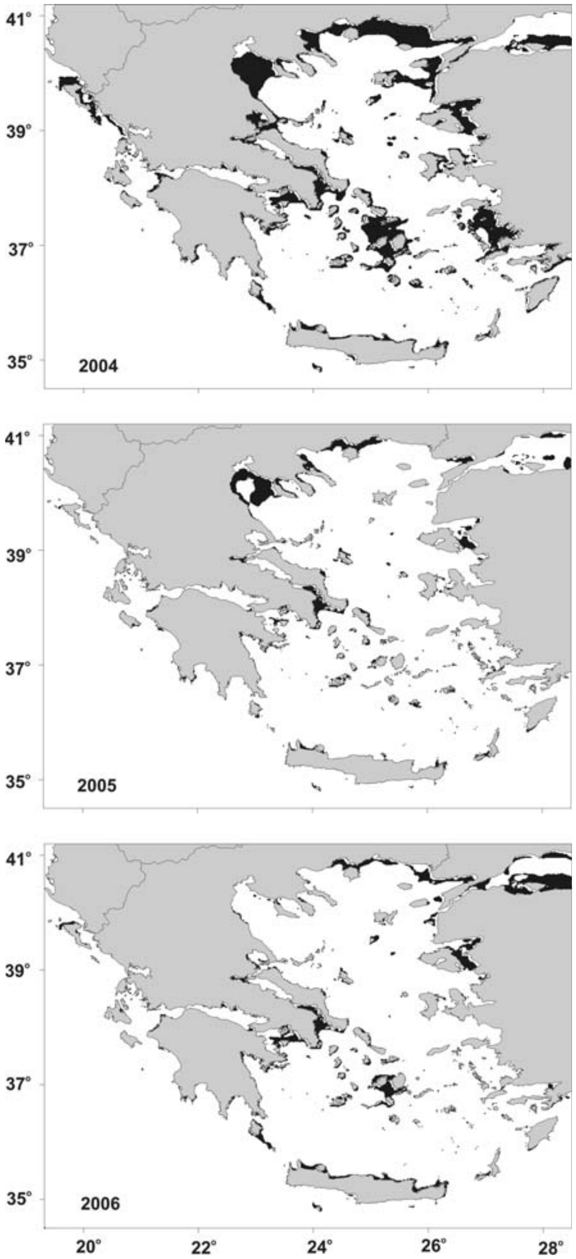

Fig. 3 Geographic distribution of regions post-classified as "juvenile" areas, by applying the DFA for a grid of spots within the Greek Seas, for June 2004–2006

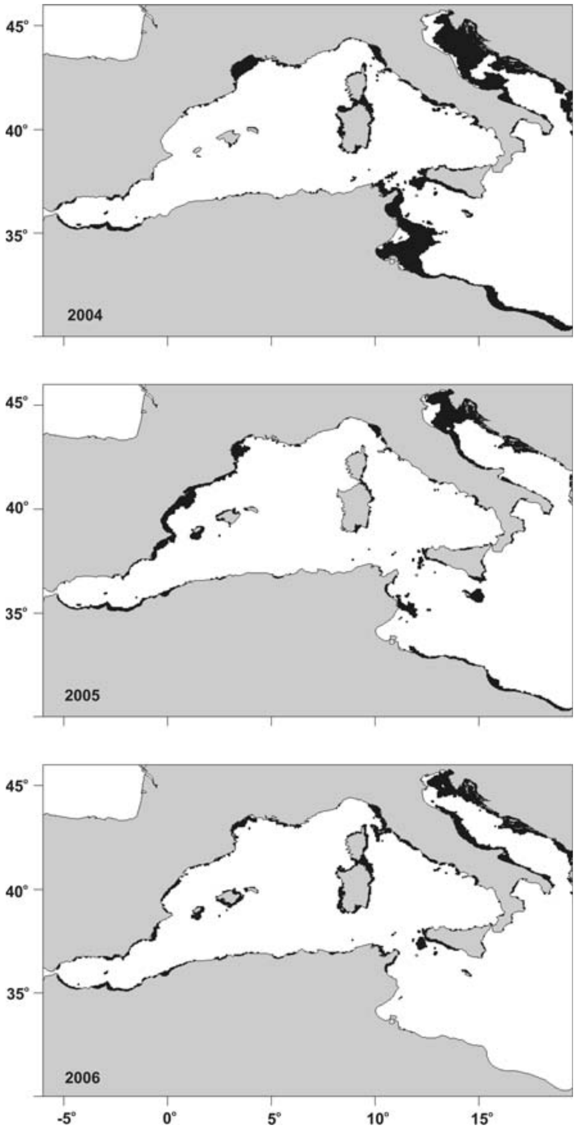

Fig. 4 Geographic distribution of regions post-classified as "juvenile" areas, by applying the DFA for a grid of spots within the Western Mediterranean Sea, for June 2004–2006

DFA indicated that areas with juveniles were adequately discriminated based on the values of certain satellite environmental parameters and bottom depth (SST, PAR, SLA, CHLA and D), probably reflecting differences in habitat preferences of juveniles. The use of satellite data has the advantage that it can be easily obtained for various years and areas, while they are available almost in real time. Although satellite data do not describe the actual conditions at sea, they seem to provide a general good description of the areas that sardine juveniles are concentrated during early summer.

Mapping for the Greek Seas, based on the classification functions estimated by DFA, indicated that juveniles are concentrated inshore, in semi-closed productive areas and often in proximity to river estuaries (Fig. 3). Despite the fact that our

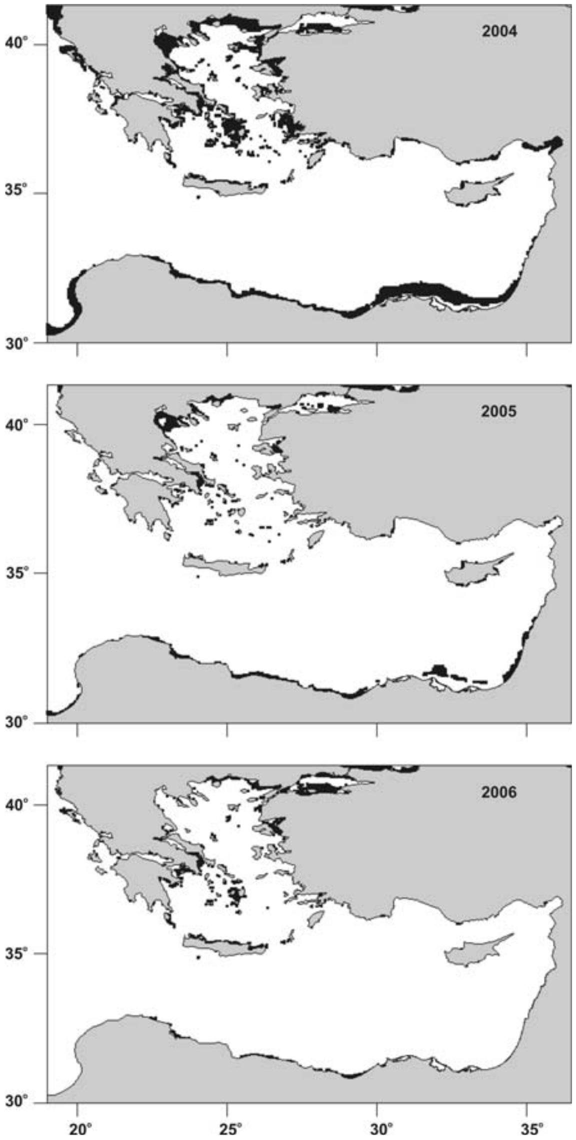

Fig. 5 Geographic distribution of regions post-classified as “juvenile” areas, by applying the DFA for a grid of spots within the Eastern Mediterranean Sea, for June 2004–2006

knowledge on the distribution of juveniles in Greek Seas is limited, certain areas known to serve as nursery grounds were post-classified as “Juvenile” areas, confirming the reliability of results. These areas include the coastal waters of the northern part of Corinthiakos and Patraikos gulfs (Anonymous, 2001), characterized by local, seasonal upwelling events and/or river outflow.

Results also agree with findings from other regions of the Mediterranean Sea. In the Gulf of Lions, nursery areas of sardine are known to be located in lagoons and close to the coast (Bigot, 2007) while in Tramontana region, the most important concentration area for juvenile sardines is located near the mouth of the Ebro River (Giráldez et al., 2005). Moreover, nursery grounds have also been reported in the North Alboran Sea (Alemany et al., 2006). Extended parts of these regions were consistently classified as sardine nursery grounds (Figs. 4, 5).

The size of the nursery areas as indicated by our mapping (Figs. 3–5), seems to present inter-annual variability depending on the environmental conditions. These fluctuations may also be related to the successful recruitment of sardine. The broad nursery areas of 2004 (Figs. 3–5) may be an explanation for the increase of Greek sardine landings (from 9,217 mt to 11,258 mt; Greek National Statistical Service) and Mediterranean sardine landings (from 181,738 mt to 203,541 mt; FAO) in 2005. The approach we follow here could be useful in justifying similar trends.

The absence of field data concerning the spatial distribution of sardine juveniles did not allow a quantitative evaluation of our predictions. The reliability of such maps should be checked by collecting appropriate field data. However, considering the lack of information regarding the spatial distribution of small pelagic juveniles, the proposed method might be particularly useful in mapping juvenile habitat across years and areas and may turn out helpful when addressing management issues and especially for precautionary measures (e.g. MPAs definition). In addition, the method could be a practical tool for sampling design through selection of survey areas for the study of juvenile fish. The use of data from additional years, seasons and areas will improve the identification of such areas while a regular field monitoring may track variations of juvenile fish habitat preferences due to large scale atmospheric, oceanic and climate change.

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