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FISH HABITAT MAPPING

Identifying essential fish habitat for small pelagic species in Spanish Mediterranean waters

Jose M. Bellido · Alex M. Brown · Vasilis D. Valavanis · Ana Giráldez · Graham J. Pierce · Magdalena Iglesias · Andreas Palialexis

Abstract Populations of small pelagic fish support important fisheries in Spanish Mediterranean waters, particularly sardine (*Sardina pilchardus*) and anchovy (*Engraulis encrasicolus*), and are distributed along the entire length of the Spanish continental shelf. Using annual acoustic survey data for the years 2003–2005, a GIS-based environmental modelling approach was used to investigate the distribution and abundance of small pelagic fish in relation to environmental variables. Multivariate analysis was applied to provide a preliminary picture of relationships between fish and environmental conditions, followed by application of Generalised Additive Models (GAMs). GAMs showed the presence/absence of fish to be related to bathymetry, sea surface chlorophyll-a concentration and sea surface temperature (SST). The strength and significance of these relationships varied spatially and temporally. High resolution Essential Fish Habitat (EFH) maps were generated for sardine and anchovy, based on the predicted probability of presence of each species. Substantial inter-annual variability in the distribution and quality of EFH was observed, particularly for anchovy. Identification of EFH is of great importance to assess and manage sardine and anchovy resources as it provides a natural link between population dynamics features and geographical scenarios.

Keywords Anchovy · Sardine · Essential fish habitat · Environment · Mediterranean

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Essential Fish Habitat Mapping in the Mediterranean

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Introduction

Small pelagic fish are predominantly confined to coastal regions, with the largest populations occurring in regions of upwelling. The spatial heterogeneity of the physical characteristics of the coastal pelagic environment, and the high mobility of small pelagic fish, generally leads to their distribution being concentrated within areas which they find most favourable (Massé et al., 1996; Fréon et al., 2005). To a certain extent, fish show the ability to alter their behaviour in response to environmental variation (Agenbag et al., 2003). However, all populations and species have an affinity for environmental conditions most favourable to their survival, growth and reproduction (review in Blaxter & Hunter, 1982).

Environmental variability can result in shifts in fish distributions over relatively short time-scales, with considerable fishery implications (Fréon et al., 2005). Rapid horizontal and vertical migrations can be induced, altering the distribution of fish and therefore their availability to fishing. While such shifts in distribution are often relatively local and temporary, they have been observed to persist for several months and over large areas, greatly influencing the exploitation of populations (Schwartzlose et al., 1999; Binet et al., 2001; Boyer et al., 2001; Bertrand et al., 2004).

An association between greater presence and/or abundance of fish, more mixed waters and thermal fronts has been observed for a number of species, including herring (*Clupea harengus*) in the northern North Sea (Maravelias & Reid, 1995); anchovy (*Engraulis ringens*) and sardine (*Sardinops sagax*) off the coast of Chile (Castillo et al., 1996); and sardine (*Sardina pilchardus*) and anchovy (*Engraulis encrasicolus*) in the northern Aegean Sea (Giannoulaki et al., 2005). However, such associations are commonly weak, and more direct relationships may be found between plankton abundance and fish distribution. Associations between high concentrations of plankton and fish have been observed for *C. harengus* in the northern North Sea (Maravelias, 1999) and anchovy (*Engraulis mordax*) in the eastern Pacific (Robinson, 2004).

The identification of Essential Fish Habitat (EFH) may be regarded as an application of studying fish–environment relationships. The term EFH has been defined by the EU Scientific, Technical and Economic Committee for Fisheries (STECF) in the Mediterranean as "a habitat identified as essential to the ecological and biological requirements for critical life history stages of exploited fish species, and which may require special protection to improve stock status and long term sustainability" (STECF, 2006).

A wide range of techniques is now available to model habitat requirements and these have been extensively reviewed (e.g. Guisan & Zimmermann, 2000; see also Redfern et al., 2006 for a particular review on marine species). Studies of habitat requirements of exploited marine fish have been driven both by the need to support management actions (e.g. to identify candidate Marine Protected Areas) and the increasing availability and accessibility of suitable tools. These include readily available remotely sensed data on a variety of surface oceanographic parameters, Geographic Information Systems (GIS) and powerful statistical modelling tools such as generalised additive models (GAM), which allow modelling of non-linear relationships, and generalised additive mixed models (GAMM), the latter allowing explicit consideration of spatial autocorrelation, particularly through the development of the "R" programming language (see Pierce et al., 2001, 2002; Valavanis et al., 2008, 2004; Zuur et al., 2007).

Valavanis et al. (2004) adopted a GIS-environmental modelling approach to identify EFH for short-finned squid (*Illex coindetti*) in the eastern Mediterranean Sea. Koubbi et al. (2006) reported an application on habitat modelling for flatfish larvae in the eastern English Channel. Both approaches aimed to model and predict fish distribution by using environmental relationships. An alternative approach was taken by Friedlander et al. (2007) and Le Pape et al. (2007), who examined the community assemblage and interactions between species and substrate in order to identify EFH.

Identifying EFH for highly mobile adult small pelagic fish presents different challenges to those associated with modelling habitat requirements of less mobile demersal species, which may for example be associated with particular seabed substrates. The environmental conditions which have been shown to influence the distribution of pelagic species are intrinsically spatially and temporally variable, therefore the corresponding EFH will show similar variability in predicted distribution.

This study aims to use a GIS and statistical modelling-based approach to investigate relationships between small pelagic fish and environmental conditions in Spanish Mediterranean waters. Small pelagic fish, in common with other short-lived species such as squid, are liable to show high variability in abundance year to year. This year to year fluctuation reflects variable recruitment strength and is thought to be strongly related to oceanographic conditions (temperature, salinity), e.g. due to their effect on juvenile growth and survival, as well as static ecogeographic variables such as bathymetry. Generalised Additive Models were applied to test the hypotheses suggested by initial data exploration using multivariate methods and GIS.

A further aim is to extend this approach to identify EFH and its temporal variability in sardine and anchovy. GAM predictions were used to reveal areas of high probability of presence and thus to identify EFH for both species.

Materials and methods

Species and study area

A variety of species of small pelagic fish are present in Spanish Mediterranean waters. Sardine (*Sardina pilchardus*), anchovy (*Engraulis encrasicolus*), Mediterranean horse mackerel (*Trachurus mediterraneus*), Atlantic horse mackerel (*Trachurus trachurus*), round sardinella (*Sardinella aurita*), bogue (*Boops boops*), chub mackerel (*Scomber japonicus*) and Atlantic mackerel (*Scomber scombrus*) are all encountered on the continental shelf (Giráldez & Abad, 2000). Although all of these species are caught by commercial fisheries, sardine and anchovy have traditionally been the most economically important (Pertierra & Lleonart, 1996), and have therefore been the main focus of scientific studies.

The study area comprises the entire Mediterranean coast of Spain (Fig. 1). A boundary is defined to encompass the continental shelf environment (from coastline to 200 m isobath) and a small area immediately offshore of this. The study area was considered both as a whole and as the following 3 separate zones:

Zone 1: Southern Gulf of Lyon and Catalan coast

The Gulf of Lyon is a well documented region of high productivity, characterised by a combination of a fairly wide continental shelf, considerable river run-off from the Rhône and a high degree of wind-induced mixing and upwelling from strong, predominantly north-westerly winds (Estrada, 1996; Salat, 1996; Agostini & Bakun, 2002). This is an important spawning area for anchovy and sardine (García & Palomera, 1996; Olivar et al., 2001). The Catalan

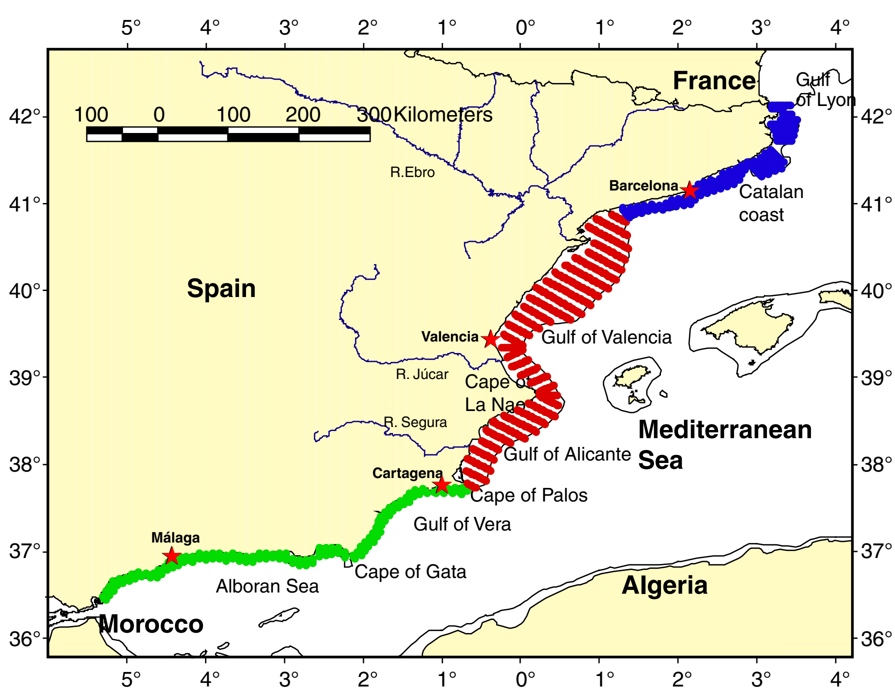

Fig. 1 Area of study, including the acoustic transects locations for zone 1 (north), zone 2 (center) and zone 3 (south). Black line is 200 m isobath

coast is characterised by a relatively narrow shelf and deep slope canyons. Catalan coastal waters are influenced by the transport of nutrients from the north, with additional fertilization caused by local vertical mixing and intrusions of slope waters onto the shelf through submarine canyons (Salat et al., 2002).

Zone 2: Gulfs of Valencia and Alicante

In the Gulf of Valencia, the coastal waters over the wide Iberian shelf are influenced by local meteorological events and freshwater input from the River Ebro (Salat, 1996). Meteorological events include strong north-westerly winds, causing intense water mixing around the Ebro delta (Estrada, 1996; Salat, 1996). The Iberian shelf provides important spawning grounds for anchovy and sardine (García & Palomera, 1996; Olivar et al., 2001).

Zone 3: Gulf of Vera and northern Alboran Sea

The input of Atlantic surface water through the Strait of Gibraltar dominates the hydrographic characteristics of the northern Alboran Sea. A 'jet' of Atlantic water causes turbulent mixing in the Strait, and creates two anticyclonic gyres with associated upwelling along the Spanish coast of the Alboran Sea (Tintorè et al., 1991; Vargas-Yañez et al., 2002). This area has been described as favourable for reproduction and growth of coastal pelagic fishes (Bakun, 1998).

GIS development

Fish data were obtained from the annual acoustic survey ECOMED, carried out by the Instituto Español de Oceanografía (IEO) during November–December. This coincides with the recruitment of anchovy to the fishery, and the earliest signs of spawning activity in sardine (Palomera, 1992; Pertierra & Lleonart, 1996; Olivar et al., 2001). A systematic design covering 128 transects perpendicular to the coastline provides 1290, 1292 and 1268 records for 2003, 2004 and 2005 respectively, with almost exact spatial overlap between years. Transects cover the continental shelf approximately between the 30 m and 200 m isobaths. Local fish abundance is quantified at each sampling point using the Nautical Area Scattering Coefficient (NASC, m^2 of cumulative backscattering cross-section per nmi^2). Routine experimental fishing determined the species composition of the NASC.

Monthly average environmental data were collated from internet-based sources and then processed into files suitable for use in a GIS (Table 1). GIS point layers of fish survey records were combined with environmental grids of 1 square nautical mile (nm^2) to extract the environmental values associated with each location of the fish survey record. Care was taken to ensure that the temporal resolution of the environmental grid matched with that of the survey sampling time. Maps were produced to visualise the distribution of fish and, after fitting of models, the probabilistic predictions of EFH for sardine and anchovy throughout the study area.

Multivariate analysis and GAM modelling for EFH identification

Multivariate analysis was applied in order to reveal plausible relationships between species and environmental variables. Correlation analysis and Redundancy Analysis (RDA) were applied to fishery and environmental data. RDA is a constrained ordination method which represents the relationships between two matrices: one dependent matrix of response variables (i.e. the species variables) and the other independent matrix of explanatory variables (i.e. the environmental variables). The ordination seeks the combination of explanatory variables that best explain the variation of the response variables and, using Monte Carlo permutation tests, determines the statistical significance of the effects of each of the suite of explanatory variables.

RDA graphic results are presented in the form of a correlation biplot, showing the response and explanatory variables on the same diagram. The length and angles in the RDA correlation biplot reflect correlations between response and environmental variables, and between response or environmental variables themselves. Since a limitation of this technique is that effects are assumed to be linear, most of the explanatory variables were log-transformed. The multivariate analysis results were also utilised as an exploratory analysis prior to GAM modelling. A high degree of co-linearity existed between several of the variables.

Table 1 Sources and descriptions of environmental data used in the GIS

Variable	Units	Source	Sensor/Model	URL
Photosynthetically active radiation (PAR)	($E/m^2/d$)	Oceancolor WEB, GSFC/NASA, USA	SeaWiFS	http://oceancolor.gsfc.nasa.gov
Sea level anomaly (ALT)	cm	Live Access Server	Merged (TOPEX/Poseidon, Jason-1, ERS-1/2, Envisat)	http://www.aviso.oceanobs.com/
Sea surface temperature (SST)	°C	DLR EOWEB, Germany	AVHRR SST	http://eoweb.dlr.de:8080/
Sea surface chlorophyll-a concentration (Chl-a)	(mg/m^3)	Oceancolor WEB, GSFC/NASA, USA	SeaWiFS	http://oceancolor.gsfc.nasa.gov
Sea surface salinity (SSS)	psu	IRI/LDEO, USA	CARTON-GIESE SODA and CMA BCC GODAS	http://ingrid.ldeo.columbia.edu/
Wind speed (WS)	(m/sec)	RS Systems, USA	QuikSCAT	http://www.ssmi.com/
Wind direction (WD)	(° from N)	RS Systems, USA	QuikSCAT	http://www.ssmi.com/
Bathymetry (depth)	m	NGDC, NOAA, USA	Geostat ERS-1 satellite & ship depth echosoundings	http://www.ngdc.noaa.gov/mgg/image/2minrelief.html

Finally SST, Chlorophyll-a concentration (Chl-a) and depth were selected for GAM models as they showed considerable variability throughout the study area and were believed to be easier to interpret biologically than some other variables available. The use of GAM allows for non-linear relationships between response and explanatory variables.

Binomial GAMs were developed for sardine and anchovy. Local occurrence (presence = 1 and absence = 0) was modelled against environmental variables for all zones and all years combined. GAMs were also developed for individual zones. Step-wise selection and cross-validation were applied to select the best models (based on the lowest AIC). The constructed models, from all years and all zones combined, were then used to predict the probability of sardine and anchovy presence in each year at the resolution of the environmental grids, i.e. 1 nm^2. The mean probability for each grid square over the period 2003–2005 was calculated and mapped to represent the average EFH distribution over the study period. The differences between this average EFH and probabilities for individual years were also calculated and mapped to show inter-annual variations in the distribution and quality of EFH, for instance $Dev_{2003} = EFH - Prob_{2003}$.

Results

General patterns in the distribution of small pelagic fish

High concentrations of anchovy were found in zone 1, near the Spanish–French border in the southern Gulf of Lyon (Fig. 2). This pattern was consistent throughout the 3 years analysed. In 2003 anchovy was almost absent from the northern Catalan coast to Barcelona whilst it was present at a low level during 2004 and 2005. The most consistent high concentrations of fish were located in zone 2, particularly around the mouth of the river Ebro. These were also areas of high Chl-a (Fig. 2). Anchovy showed reduced abundance and occurrence further south as far as the Gulf of Alicante. In zone 3, anchovy was concentrated around Málaga during 2003 to 2005, being totally absent in the Gulf of Vera. The Málaga area was also characterised by high concentrations of Chl-a.

The patterns of distribution and abundance of sardine (Fig. 3) were rather similar to those of

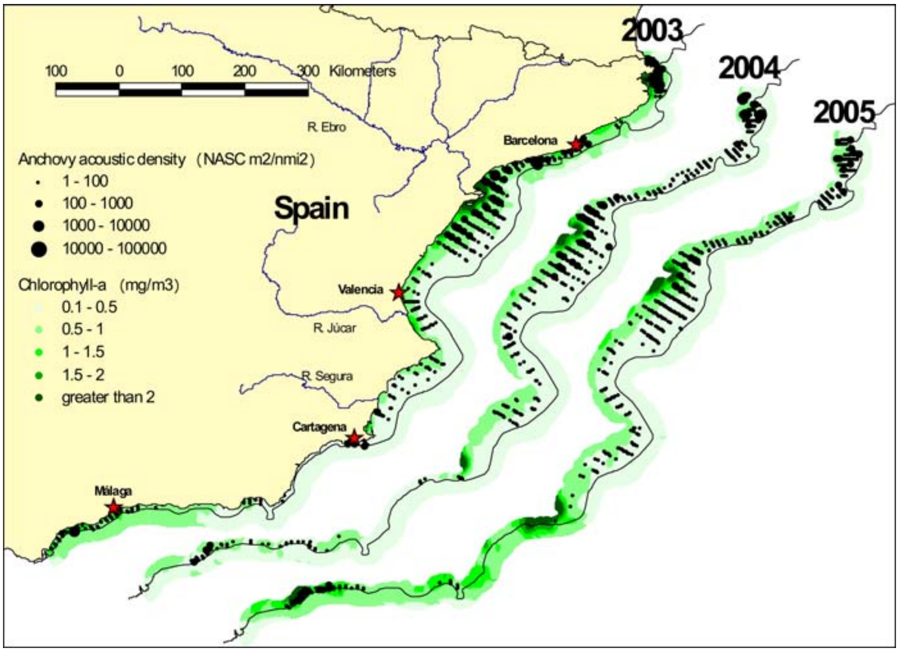

Fig. 2 Chlorophyll-a distribution and anchovy abundance for 2003, 2004 and 2005 throughout the study area

anchovy, although sardine appeared to be more widespread and abundant. The pattern was quite consistent for all years, the River Ebro delta being the area with highest sardine concentration. Abundance and occurrence both declined towards the Gulf of Vera, where sardine was practically absent. The northern Alboran Sea showed intermediate levels of sardine abundance, although an important increase is apparent in 2005.

Multivariate analysis

P-values from Monte Carlo tests show the significance of the RDA ordination method both for the first canonical axis and all canonical axes (Table 2). The first axis comprised up to 97.3% of the cumulative variance of species–environment relationships, reaching up the 100% in the third axis. The first axis accounted for a species–environment correlation of 0.275, whilst the second and third axes accounted for 0.174 and 0.157 respectively (Table 2).

Chl-a, longitude, latitude, depth, SSS and SST appeared to be the most important variables (Fig. 4). Chl-a showed a positive effect on anchovy and sardine occurrence. Depth and SST had an important negative effect on all species variables. Additionally SSS seems to have a notable negative effect. SSS may become more important in estuarine areas and river plumes, such as the River Ebro outflow. Latitude and longitude are considered secondary variables, as their effect can be hidden in other environmental variables. Other environmental variables such as altimetry, wind speed and wind direction seemed to be less important or at least not to have an apparent effect on the species variables.

Generalised additive models

The model for presence/absence of anchovy, for all years and all zones combined, explained 27.3% of the deviance (Table 3). Separate models for each zone explained 26.5, 37.2 and 33.6% of the deviance for zones 1, 2 and 3, respectively. For sardine, the presence–absence model explained 30.7% of the deviance for all years and all zones combined. For separate-zone models the deviance explained was 23.9, 36.3 and 40.3% for zones 1, 2 and 3, respectively (Table 3). All models included effects of depth, SST and chlorophyll, except the model for anchovy in zone 3, which did not include SST. Some common trends in these results were apparent. With the exception of zone 1, models for individual zones

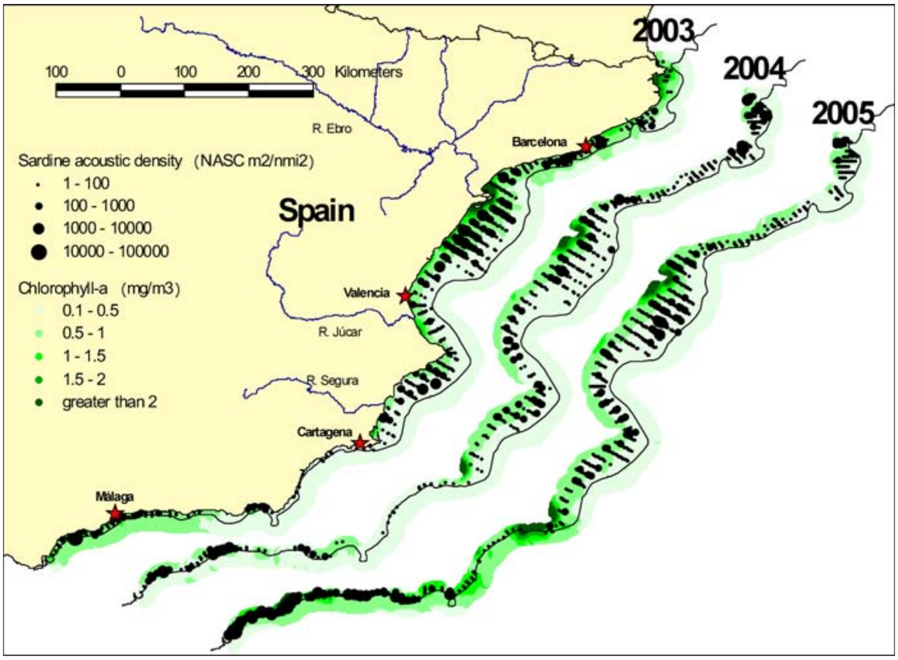

Fig. 3 Chlorophyll-a distribution and sardine abundance for 2003, 2004 and 2005 throughout the study area

Table 2 Species–environment RDA correlations and Monte Carlo tests of significance of canonical axes

	1st Axis	2nd Axis	3rd Axis
Eigenvalues	0.070	0.001	0.001
Species–environment correlations	0.275	0.174	0.157
Cumulative percentage variance of species data	7.0	7.2	7.2
Cumulative percentage variance of species–environment relation	97.3	99.2	100.0
	Sum of all Eigenvalues 1.000		
	Sum of all canonical Eigenvalues 0.072		
Monte Carlo test of significance (999 permutations)		*F*-ratio	*P*-value
First canonical axis	Eigenvalue = 0.070	290.014	0.0010
All canonical axes	Trace = 0.072	29.871	0.0010

explained a greater proportion of the deviance than models for all zones combined.

Relationships between fish presence/absence and environmental variables were quite similar for both species (see Fig. 5 for anchovy and Fig. 6 for sardine). In all models, depth was highly significant and the most important variable. The relationship between fish presence/absence and depth was generally negative, with a strong negative effect at depths in excess of approximately 100 m (4.6 on natural log scale, Figs. 5a and 6a). Chl-a was generally the second most important explanatory variable and its effect was significant for all models. The relationship between fish presence/absence and Chl-a was generally weakly positive, with wide confidence limits at very high Chl-a due to limited data (Figs. 5b and 6b). SST was generally the least important explanatory variable. A slight peak of positive influence on anchovy presence was apparent between approximately 15.5 and 17.5°C (2.74 and 2.86 on natural log scale, see Fig. 5c). However it seems that SST has little effect on sardine presence (Fig. 6c).

Essential fish habitat mapping

The areas of higher probabilities for EFH of anchovy were located in the vicinity of the River Ebro Delta and the southern Gulf of Lyon (Fig. 7). Other coastal

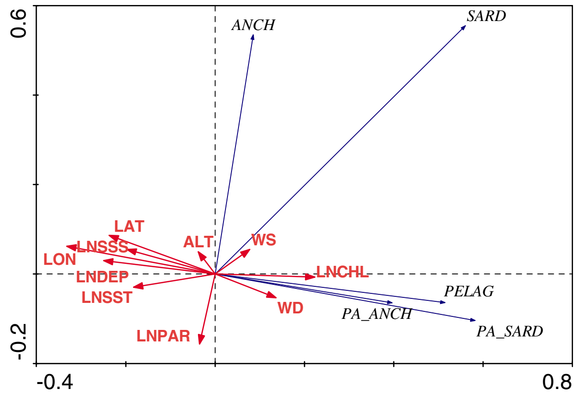

Fig. 4 RDA correlation biplot. Species variables are PELAG: Small pelagics acoustic abundance; ANCH: Anchovy acoustic abundance; SARD: Sardine acoustic abundance. PA_ANCH: Presence/Absence of Anchovy; PA_SARD: Presence/Absence of Sardine; Environmental variables are LAT: Latitude; LON: Longitude; PAR: Photosynthetically Active Radiation (Natural Log); ALT: Altimetry (or Sea Level Anomaly); SST: Sea Surface Temperature (Natural Log); CHL: Sea surface Chlorophyll-a concentration (Natural Log); SSS: Sea Surface Salinity (Natural Log); WD: Wind Direction; WS: Wind Speed; DEP: Depth (or Bathymetry) (Natural Log); See Table 1 for Units

areas of high EFH were north of Valencia and some local areas of the northern Alboran Sea. Unsurprisingly, the areas of highest predictions were very similar to the areas of higher anchovy abundance identified in Fig. 2.

Year deviation is a measure of how far the average anchovy EFH deviates from the EFH of a particular year at every predicted point. The years with higher deviations were 2003 and 2004. Along the Catalan Coast and Ebro Delta, average EFH showed a positive deviation with respect to 2003 whilst EFH-2004 showed a negative trend, i.e. 2003 was a worse year than average EFH and 2004 was a better year than average EFH. Further south along the Gulf of Vera, EFH-2003 showed a negative trend and EFH-2004 showed slight positive deviations. It is important to note that for both the years the higher deviations were located around the middle shelf and generally around the areas of higher EFH probabilities, for example the northern Catalan coast and the River Ebro Delta. In contrast to 2003 and 2004, 2005 did not exhibit high deviations from the average anchovy EFH.

For sardine, high probabilities of presence are more extensive and of a greater magnitude than those of anchovy. The coastal area from Valencia to the northern Catalan coast showed an almost continuous high probability of sardine presence (Fig. 8). This was particularly true for the River Ebro Delta, Valencia and Barcelona area, and the southern Gulf of Lyon (Cape of Creus). Moving south from Valencia towards the Strait of Gibraltar there was an intermediate level of EFH, exhibiting a patchy distribution of some local areas with higher probability of presence.

For sardine, inter-annual deviation in EFH was quite similar to that of anchovy (see Figs. 8 vs. 7). The area of highest deviations was located in the northern Catalan coast; they are also located in the middle shelf, which is the area with more variability. Years 2003 and 2004 were the most different to the general EFH sardine pattern, following the same

Table 3 Sardine and anchovy presence/absence GAM results, showing the best model for each zone using data from all years combined

Species	Zone	*n*	Variables (*P*-value)	Deviance explained (%)
Anchovy	All	3849	Depth (<0.01), Chl-a (<0.01), SST (<0.01)	27.3
	1	893	Depth (<0.01), SST (<0.01), Chl-a (<0.01)	26.5
	2	1973	Depth (<0.01), Chl-a (<0.01), SST (<0.01)	37.2
	3	983	Depth (<0.01), Chl-a (<0.01)	33.6
Sardine	All	3849	Depth (<0.01), Chl-a (<0.01), SST (<0.01)	30.7
	1	893	Depth (<0.01), SST (<0.01), Chl-a (<0.01)	23.9
	2	1973	Depth (<0.01), Chl-a (<0.01), SST (<0.01)	36.3
	3	83	Depth (<0.01), Chl-a (<0.01), SST (<0.01)	40.3

Variables are ordered according to their importance in the model, based on results from classification trees. The order runs from left (most important) to right (least important)

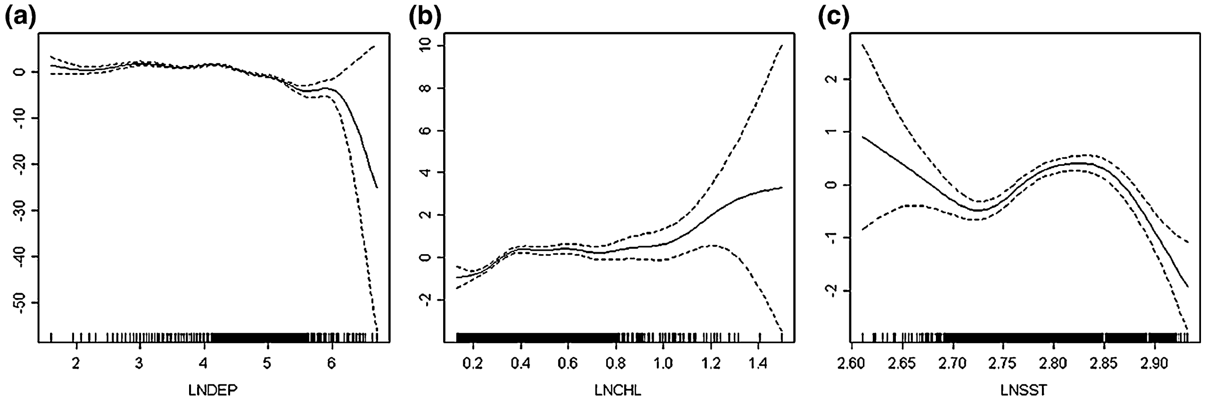

Fig. 5 GAM plots for anchovy presence/absence (all years all zones combined) showing the effect of every environmental variable on fish presence. (**a**) (left): depth (natural log). (**b**) (centre): chl-a (natural log). (**c**) (right): SST (natural log)

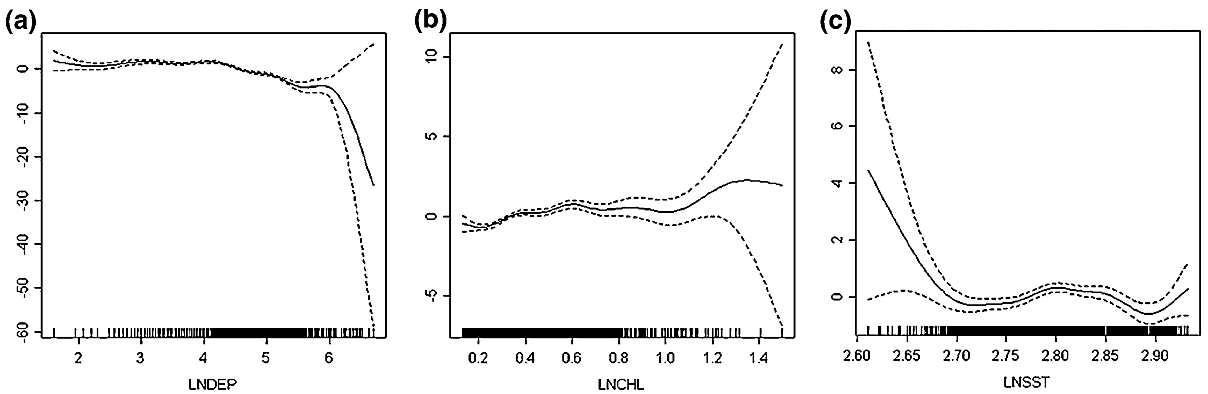

Fig. 6 GAM plots for sardine presence/absence (all years all zones combined) showing the effect of every environmental variable on fish presence. (**a**) (left): depth (natural log). (**b**) (centre): chl-a (natural log). (**c**) (right): SST (natural log)

pattern as anchovy, i.e. a positive trend was apparent in EFH-2003 and a negative trend was apparent in EFH-2004. In contrast, 2005 seemed to be a year rather similar to the general EFH sardine pattern.

Discussion

Environmental influences on the distribution of small pelagic fish

While the studied fish were distributed throughout Spanish Mediterranean waters, several areas were identified where fish could be found in high concentrations. The southern Gulf of Lyon, the Catalan coast around Barcelona, the vicinity of the Ebro delta and some local areas of the western Alboran coast all showed high concentrations of fish. Previous studies have documented the productivity of these areas, where oceanographic processes such as mixing by river flow and upwelling cause the nutrient enrichment of surface waters (Estrada, 1996; Salat, 1996; Agostini & Bakun, 2002). Nutrient enrichment results in phytoplankton, and then zooplankton growth—providing feeding grounds for fish.

The strong relationship between presence/absence of anchovy and sardine and depth showed a preference for depths shallower than 100 m. This is consistent with previous studies which have investigated the distribution of small pelagic fish in relation to depth (e.g. Giannoulaki et al., 2005). The distribution of Chl-a suggested higher levels of nutrient enrichment in shallower waters and close to the coastline. It is likely that fishes select these areas due to the higher concentrations of food associated with these productive waters.

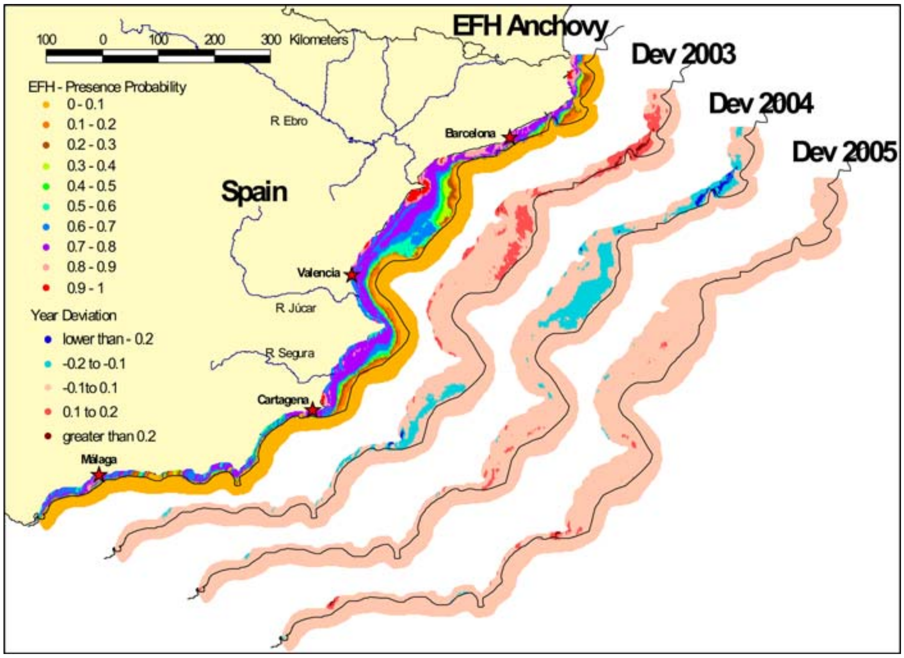

Fig. 7 EFH maps showing the predicted probability of presence of anchovy and inter-annual deviation from the general EFH model

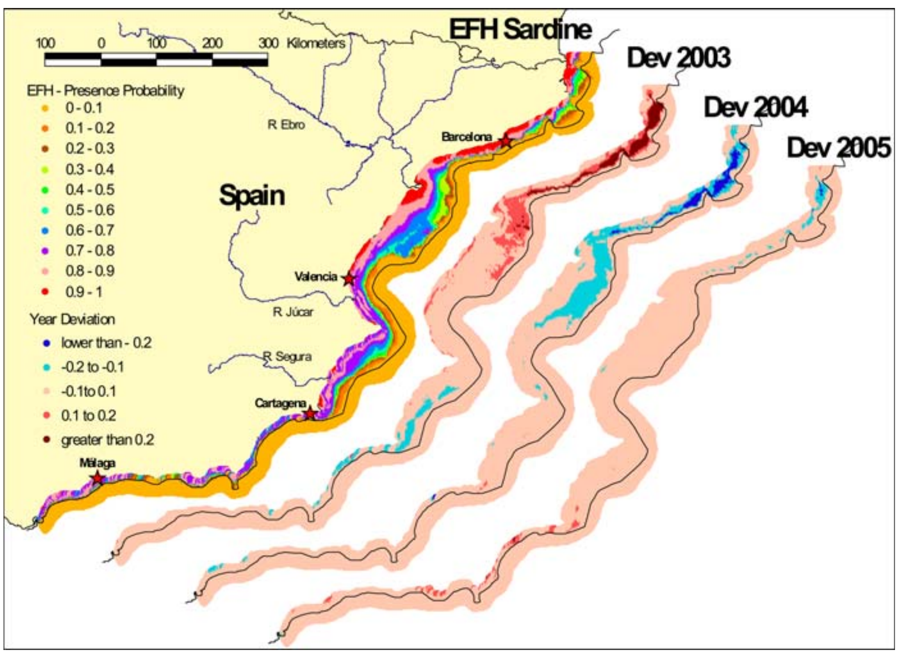

Fig. 8 EFH maps showing the predicted probability of presence of sardine and inter-annual deviation from the general EFH model

The results indicate that two main areas of fish distribution can be described, following a north–south axis. The first area extends from the Gulf of Lyon to the Cape of Palos, in the vicinity of Cartagena. This was an area of widespread occurrence and high abundance for the two studied species. Most of this area is characterized by a wide continental shelf, with important inputs from fluvial currents, particularly from the river Rhône and the Ebro. This area is considered a separate Management Unit by the General Fisheries Commission for the Mediterranean (GFCM) and it is named as Geographical Sub-Area 06—Northern Spain (GSA-06). Then a transition zone is apparent after Cape of Palos, occupying the Gulf of Vera. This is a hydrodynamic border, usually named the Almeria-Oran front, where the Atlantic Jet bifurcates into two currents, the Algerian current to the east and the Septentrional current to the northeast. This Septentrional current completes a cyclonic gyre through the Ligurian Sea, Gulf of Lyon and Catalan Sea (Millot, 1999; Pinot et al., 2002).

West of the Gulf of Vera, the Northern Alboran Sea is characterised by a very narrow shelf, where submarine canyons create a dynamic topography which direct many fish assemblages and delineate fish habitats, particularly important at a local scale. This area is also considered a separate Management Unit by the GFCM, named as Geographical Sub-Area 01—Northern Alboran Sea (GSA-01). GSA-01 extends from the Strait of Gibraltar to the Cape of Palos.

Both multivariate analysis and GAMs show a significant positive relationship between the distribution and abundance of fish and Chl-a. Although significant, these relationships are relatively weak. This suggests that Chl-a and fish are not directly related, but that higher Chl-a is an indicator of conditions favouring fish. Chl-a is a measure of the standing stock of phytoplankton in surface waters, therefore higher concentrations are likely to be associated with productive feeding grounds for planktivorous fish such as small pelagics.

Relationships between fish and SST were typically weaker and less significant than those with Chl-a. SST is likely to be less direct in its relationship with fish than Chl-a. Cooler SST can be indicative of nutrient enrichment processes such as wind mixing, upwelling and river-run off, which are associated with favourable conditions for fish.

Using Chl-a and SST with a time lag of several weeks may produce stronger relationships with fish distribution and abundance. Thus enrichment events indicated by high Chl-a and low SST may be more associated with fish after sufficient time has passed for both zooplankton abundance to rise, and fish to locate the area.

Essential fish habitat mapping

EFH maps showed the predicted probability of anchovy and sardine presence. Predictions were made according to the environmental conditions at a specific time, based on modelled relationships between environmental conditions and fish presence over 3 years of survey data. In this study, EFH was not defined as habitat with a predicted probability of presence above a specific threshold value. Instead, all areas within the study area were treated as EFH, with comparisons based on the pattern of predictions. The pattern of predictions can be considered a measure of the quality of EFH. Higher predicted probability of occurrence clearly indicate better quality habitat, in terms of the environmental variables considered in the model on which the predictions are based. The EFH maps act as a tool for identifying areas where environmental conditions are favourable or less favourable for fish to occur.

Results showed the EFH of anchovy to be concentrated in specific areas of more favourable conditions, such as the Ebro Delta and southern Gulf of Lyon. However, EFH of sardine showed a more widespread distribution, occupying most of the Cataluña and Valencia coasts as well as some local areas of the northern Alboran Sea.

Quality of EFH showed large inter-annual variation, particularly in the southern Gulf of Lyon and the Catalan coast. The most notable difference was a sharp decline of predicted presence for sardine in the southern Gulf of Lyon in 2003. A similar, but less extreme, trend was observed for anchovy. The same area in 2004 showed high predicted presence for both species. Chl-a was very similar in both 2004 and 2005, but SST was much cooler in 2004 (by around 2°C). This suggests that cooler SSTs in the southern Gulf of Lyon present more favourable conditions for sardine and anchovy.

Large inter-annual variations in the characteristics of predictions reflect substantial temporal variation in the distribution of areas which can be considered EFH. This could have considerable implications for both the ecology and management of the populations.

A management implication of substantial inter-annual variations in EFH could be the influence of these variations on the catchability of fish. Changes in catchability (the ease with which fish can be caught) are likely to arise when environmental conditions cause an expansion, contraction or shift in distribution of fish (Fréon et al., 2005). EFH maps reflect such changes in fish distribution (albeit with some degree of uncertainty). For example, a reduction in the distribution and quality of EFH, such as was seen in 2003, may cause fish to concentrate in remaining areas of favourable habitat. This should increase the efficiency of fishing activities due to less time spent searching for fish. Alternatively, an increase in the distribution and quality of EFH, such as was seen in 2004, may cause fish to disperse over a larger area. This should reduce the efficiency of fishing activities due to greater time spent searching for fish. Large-scale shifts in the distribution of EFH might bring fish within range of different fishing fleets, with different exploitation capacities.

Monitoring the catchability of fish is particularly important in the Mediterranean Sea as the fishing industry is regulated by effort and gear restrictions, not quotas. Fishing is not required to cease once a certain weight of fish are landed. Therefore, an increase in the catchability of a stock will cause a persistent rise in fishing mortality. If patterns in catchability are not taken into consideration, increasing commercial landings may give the false impression that fish are becoming more abundant, when they are only becoming more available to fishing.

Future work

Predictions for EFH mapping are only as accurate as the models they are based on. The use of different environmental variables at different temporal resolutions should be investigated, with a view to explaining a greater proportion of the deviance in fish distribution and abundance. Another logical step forward is to produce predictions of abundance in addition to presence. However, this task is reliant upon finding sufficiently strong relationships between environmental conditions and fish abundance.

Survey data of the quality used in this study are not readily available for many areas which support similar assemblages of fish. The spatial transferability of models developed in this study should be tested to see if models based on fish in Spanish Mediterranean waters can predict the distribution of fish in other areas. Temporal transferability can also be tested by using models based on data from 2003 to 2005 to predict fish distribution in other years.

Conclusions

Anchovy and sardine in Spanish Mediterranean waters are predominantly distributed in coastal areas, with a strong preference for waters shallower than 100 m; the most persistent areas of occurrence and higher abundance are located along the northern Catalan Coast and around the Delta of the River Ebro.

Environment and topography plays an important role in directing local distribution and variability of these EFH. However, the underlying relationships between oceanographic conditions and fish require further investigation. Spatial transferability of this modelling should be tested to see if models based on fish in Spanish Mediterranean waters can predict EFH of anchovy and sardine in other areas.

Size and shape of EFH can also have important effects on the fishing pattern as catchability of fish could be affected by schools gathering or fish dispersion. This is particularly important in the Mediterranean Sea as its fishery management system is based on effort and gear restrictions, not quotas. It is highly recommended to monitor these plausible interactions between environment and fishery, particularly in relation to the recently worldwide agreed framework of an ecosystem-based approach for the management of fisheries.

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