Investigating the distribution of small pelagic fish in Spanish Mediterranean waters using environmental modelling and essential fish habitat mapping

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Abstract

Populations of small pelagic fish form important fisheries 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. Generalised additive models showed bathymetry, sea surface chlorophyll-a concentration and sea surface temperature to be related to both the presence/absence and relative abundance of fish. The strength and significance of these relationships varied spatially and temporally. An extension of the same modelling procedure was applied to sardine and anchovy specifically. Models were used to produce high resolution essential fish habitat (EFH) maps, 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. Shifts in fish distribution associated with variability in EFH could affect the catchability of fish with considerable fishery implications.

Keywords: pelagic, environment, distribution, GIS, essential fish habitat

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1. Introduction

This study presents a multidisciplinary approach to investigating the distribution of small pelagic fish. For clarity and ease of reading, the study is presented in two main themes:

environmental influences on the distribution of small pelagic fish, and essential fish habitat (EFH) mapping.

1.1 Environmental influences on the distribution of small pelagic fish

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 (hereafter referred to only as 'fish'), generally leads to their distribution 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 order to adapt to such a variable environment (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).

Using SST, an association between greater presence and abundance of fish and 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).

At short time scales, environmental variability can change fish distributions 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 many of these shifts in distribution may be 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).

1.2 EFH mapping

The identification of EFH may be regarded as an application of studying fish-environment relationships. The term EFH has been defined as 'those waters and substrate necessary to fish for spawning, breeding, feeding, or growth to maturity, including the physical, chemical and biological properties of the marine environment which support fish populations throughout their life cycle' (DOC, 1997). Valavanis *et al*. (2004) adopted a GIS environmental modelling approach to identify EFH for short-finned squid (*Illex coindetti*) in the eastern Mediterranean Sea. This approach is currently being developed in the EC project EnviEFH[1], where a combination of GIS and modelling tools are employed to map EFH for a number of species in the Mediterranean.

Identifying EFH for highly mobile adult small pelagic fish presents different challenges to that of less mobile demersal species with important substrate requirements. The environmental conditions which have been shown to influence their distribution are spatially and temporally variable, therefore the corresponding EFH will show similar variability in distribution.

1.3 Species and study area

A variety of species of small pelagic fish are present in Spanish Mediterranean waters. They include 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*) (Giráldez, 2005). 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.

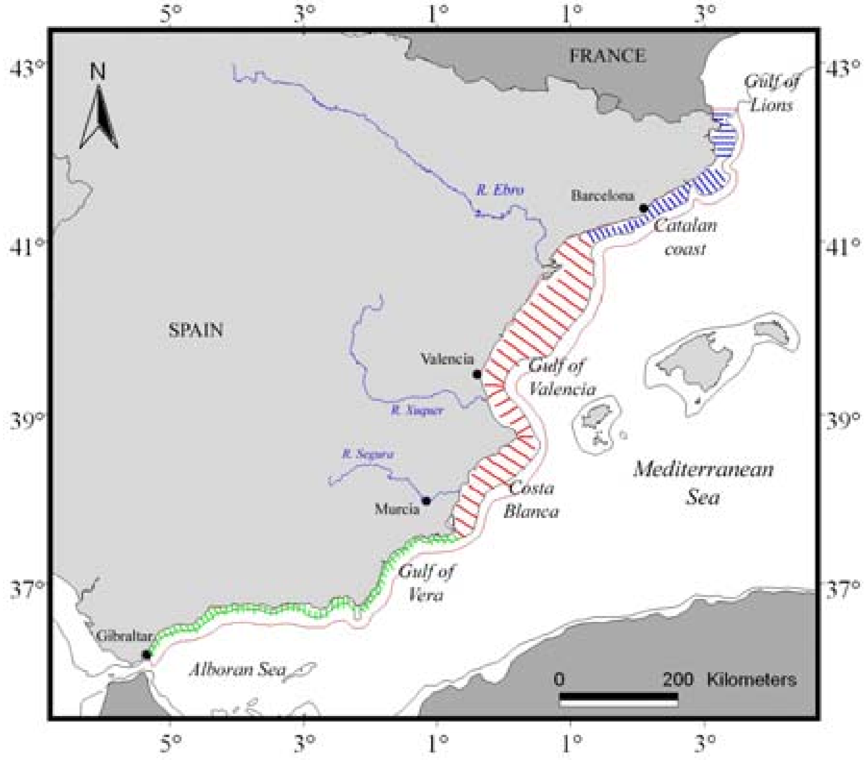

Figure 1. Study area boundary (red polygon), including the transect locations for zone 1 (blue lines), zone 2 (red lines) and zone 3 (green lines). Blank line over white is 200m isobath.

The study area comprises the entire Mediterranean coast of Spain (figure 1). A boundary is defined to encompass the continental shelf environment (coastline to 200m isobath)

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[1] EnviEFH (Environmental Approach to Essential Fish Habitat Designation) (http://arch.imbc.gr/envi efh/)

and a small area immediately offshore of this. The study area is divided into the following 3 zones:

Zone 1: Southern Gulf of Lions and Catalan coast

The Gulf of Lions is a well documented region of high productivity, caused 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). 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: Gulf of Valencia and Costa Blanca

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 cooler, less saline, nutrient rich Atlantic surface water at 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 the development of two anticyclonic gyres in the Alboran Sea with associated upwelling on the Spanish coast (Tintorè *et al*., 1991; Estrada, 1996). This area has been described as favourable for reproduction and growth in coastal pelagic fishes (Bakun, 1998).

1.4 Aims

This study aims to use a GIS-based environmental modelling approach to investigate relationships between small pelagic fish and environmental conditions in Spanish Mediterranean waters. A further aim is to apply an extension of this approach to sardine and anchovy specifically, in order to identify EFH and its temporal variability.

2. Materials and methods

2.1 GIS development

Fish data was provided by 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 30m and 200m isobaths. Fish are quantified at each record by a value of Nautical Area Scattering Coefficient (NASC), describing m^2 of cumulative backscattering cross section per nmi^2.

Environmental data were collated from internet-based sources by the Hellenic Centre for Marine Research, and then processed into files suitable for use in a GIS (table 1). Point covers of fisheries records were combined with environmental grids to extract environmental values for each fisheries record. Care was taken to ensure the temporal resolution of the environmental grid matched that of the fisheries sampling date. Maps were produced to visualise the distribution of NASC values throughout the study area.

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

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

2.2 GAM procedure

A high degree of co-linearity existed between several of the variables. SST, Chl-a and depth were selected for models as they showed considerable variability throughout the study area and were believed to be easier to interpret biologically than some other variables available. A two-stage GAM process was used to separately model relationships between fish presence/absence, then NASC (given fish presence) and environmental variables. Relationships were modelled for each separate zone, all zones combined, each separate year and all years combined. Step-wise selection and cross-validation were applied to select the best models (based on the lowest AIC). Classification and regression trees verified the relative importance of each variable in the models.

2.3 EFH mapping

Based on species compositions of experimental fishing during the survey, the presence/absence of sardine, then anchovy was modelled in relation to environmental variables. This followed the same procedure as in section 2.*2*, but was only carried out for all years combined. The best models were then used to predict the probability of sardine and anchovy presence in each year at the resolution of the environmental grids. Predictions were mapped to visualise their distribution. Inter-annual variations in the characteristics of predictions were analysed by cumulative frequency plots, scatterplots and Kolmogorov-Smirnov (KS) tests.

3. Results

3.1 Environmental influences on the distribution of small pelagic fish

Maps of NASC and Chl-a show the distribution and concentration of fish and Chl-a (figures 2-4). 2003 is used as an example. In zone 1, the highest concentrations of fish were near the Spain-France border in the southern Gulf of Lions, and along the Catalan coast near Barcelona (figure 2). These were also areas of high Chl-a. In zone 2, the most consistently high concentrations of fish were on the Iberian shelf, particularly close to the coast south of the River Ebro delta (figure 3). Some isolated high concentrations of fish were present further south, along the Costa Blanca. Chl-a was highest around the Ebro delta and along the Gulf of Valencia coast. High concentrations of fish were present along the majority of the coast of the northern Alboran Sea in zone 3 (figure 4). Some high concentrations also existed in the Gulf of Vera. Chl-a appeared to decrease from west to east with increasing distance from the Strait of Gibraltar.

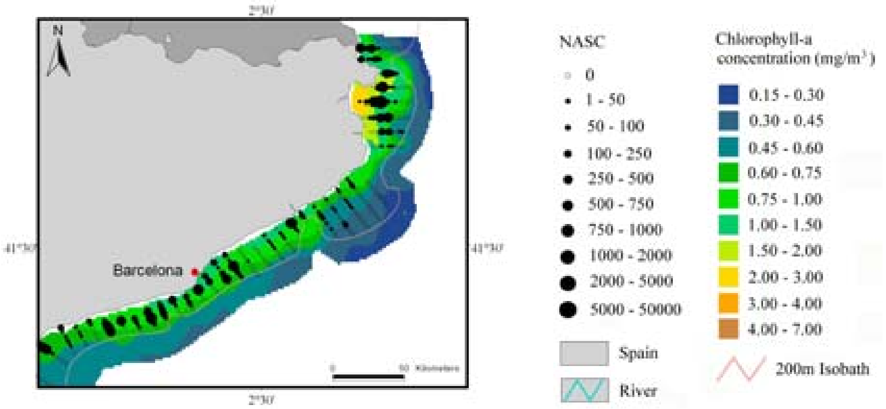


Figure 2. Zone 1, 2003. NASC and Chl-a

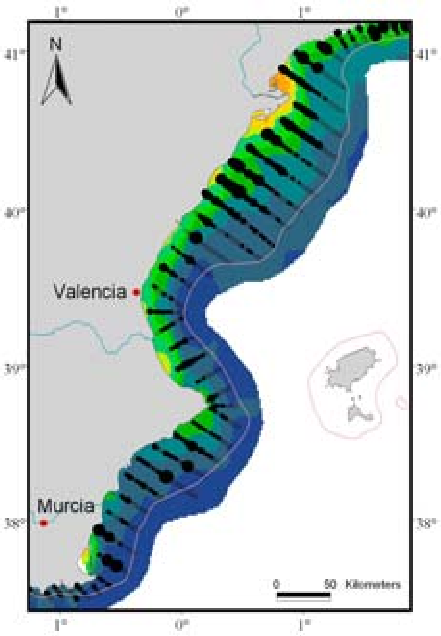


Figure 3. Zone 2, 2003. NASC and Chl-a

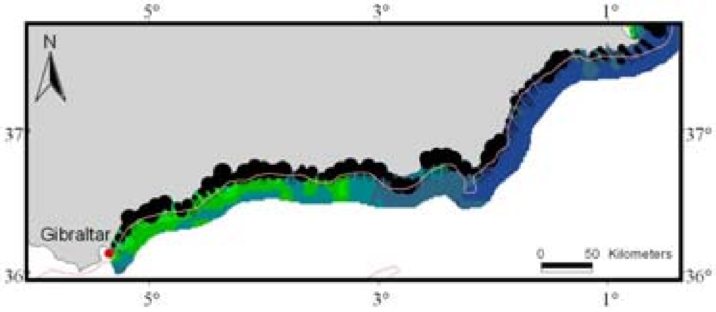


Figure 4. Zone 1, 2003. NASC and Chl-a.

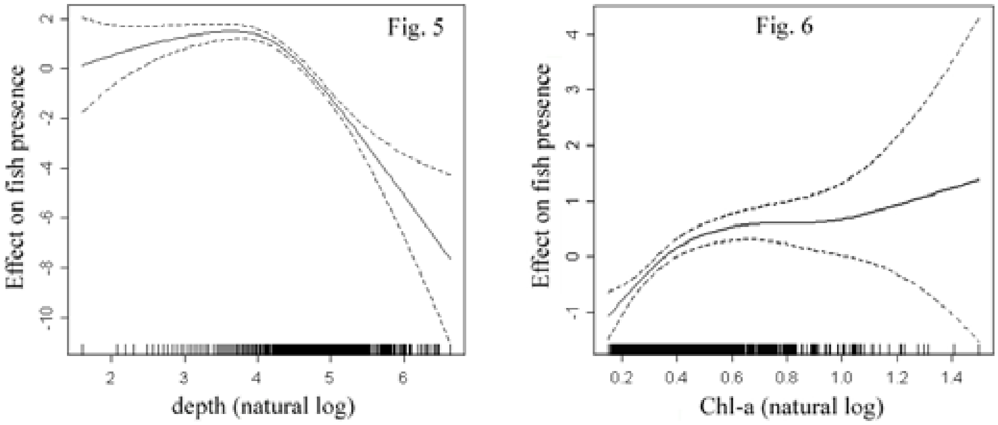
Presence/Absence models

Presence/absence models explained between 21.3% (2003: zone 1) and 51.5% (2005: zone 2) of deviance in the presence/absence of fish (table 2). Some common trends in these results were apparent. When considering all zones combined, the greatest proportion of deviance was explained by the model for 2005, followed by 2003, then 2003 – 2005, then 2004. With the exception of zone 1, models for individual zones explained a greater proportion of the deviance than all zones combined.

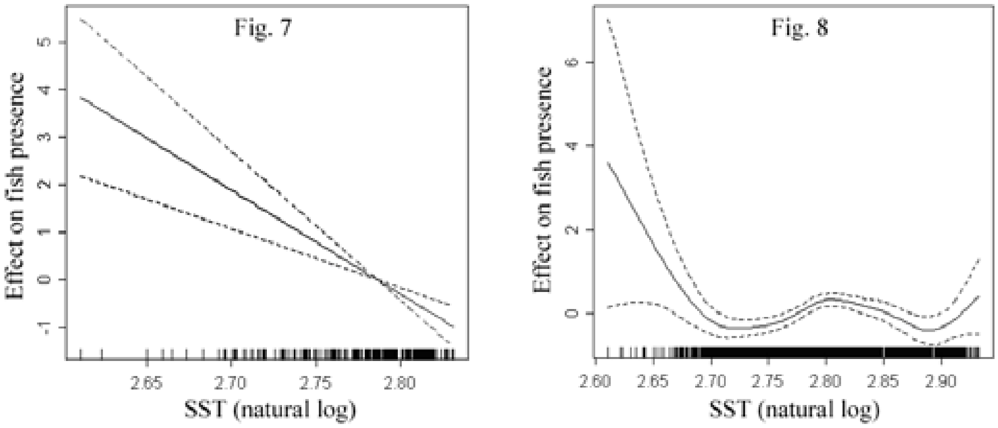
In all models, depth was highly significant and the most important variable. The relationship between depth and fish presence/absence was generally negative, with a strong negative effect at depths in excess of approximately 100m (4.6 on natural log scale) (figure 5). Chl-a was generally the second most important variable, and was only non significant in 2004: zones 1 and 2. The relationship between Chl-a and fish presence/absence was generally weakly positive with considerable uncertainty at very high Chl-a due to a low number of values (figure 6). SST was generally the least important variable, and was non-significant in 2003: all zones combined and zone 2, and 2005: zone 3. The relationship between SST and fish presence/absence showed considerable spatial and temporal variation. Identifying general trends were further complicated by SST not being used in several models. However, in zone 3 the relationship was consistently negative (figure 7). In the model for all years combined: all zones combined, a peak of positive influence on fish presence was apparent between approximately 16°C and 17°C (figure 8).

Year	*Zone*	*n*	*Variables (p-value)*	*Deviance Explained (%)*
2003	All	1290	depth (<0.01), Chl-a (<0.01), SST (0.23)	32.6
	1	292	depth (<0.01), Chl-a (<0.01),	21.3
	2	661	depth (<0.01), Chl-a (<0.01), SST (0.40)	35.7
	3	337	depth (<0.01), SST (<0.01)	50.1
2004	All	1292	depth (<0.01), Chl-a (<0.01)	29.3
	1	301	depth (<0.01), Chl-a (0.08), SST (<0.01)	26.5
	2	662	depth (<0.01), Chl-a (0.07)	30.6
	3	329	depth (<0.01), Chl-a (<0.01)	44.1
2005	All	1268	depth (<0.01), SST (<0.01)	39.7
	1	300	depth (<0.01), Chl-a (<0.05)	33.4
	2	650	depth (<0.01), Chl-a (<0.05), SST (<0.01)	51.5
	3	318	depth (<0.01), SST (0.78), Chl-a (<0.05)	48.7
All	All	3849	depth (<0.01), Chl-a (<0.01), SST (<0.01)	32.3
	1	893	depth (<0.01), Chl-a (<0.01), SST (<0.01)	24.5
	2	1973	depth (<0.01), Chl-a (<0.01), SST (<0.01)	36.3
	3	983	depth (<0.01), SST (<0.01), Chl-a (<0.01)	45.3

Table 2. Fish presence/absence GAM results, showing the best model for each zone and year. 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). Non-significant variables are highlighted in red. SST and Chl-a were co-linear in the models: 2003: zone 1, 2004: all zones combined.



Figures 5 and 6. GAM plots for fish presence/absence showing the effect of the environmental variable on fish presence. **Fig. 5** = 2004: all zones combined, depth (natural log). **Fig. 6** = 2003: all zones combined, Chl-a (natural log).

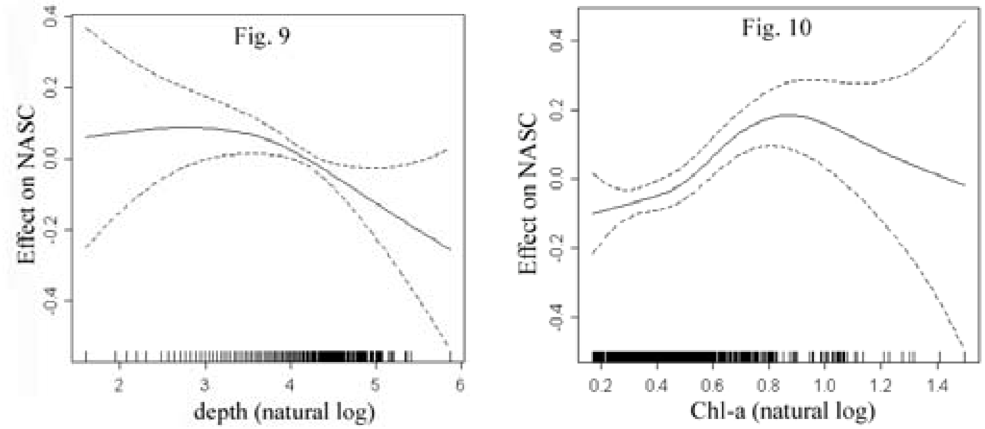


Figures 5 – 8. GAM plots for fish presence/absence showing the effect of the environmental variable on fish presence. **Fig. 7** = 2003: zone 3, SST (natural log). **Fig. 8** = all years combined: all zones combined, SST (natural log).

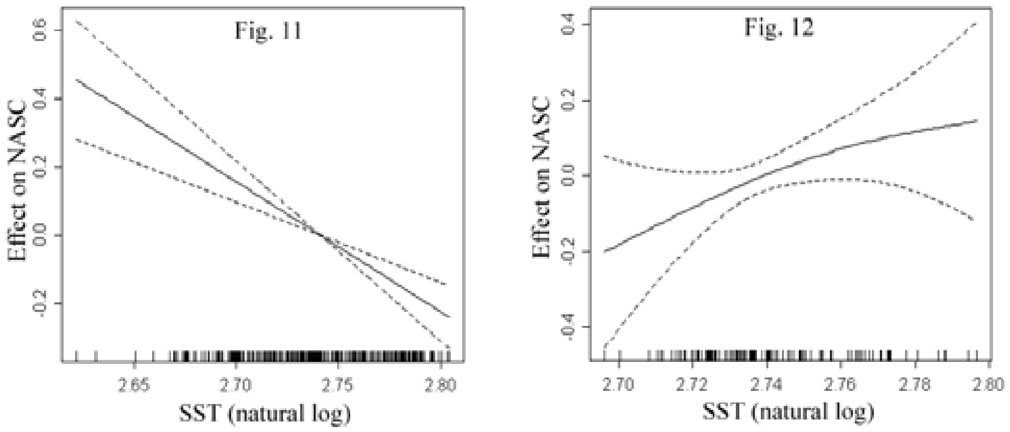
NASC models

NASC models explained between 2.03% (2005: zone 1) and 16.2% (2005: zone 2) of deviance in the presence/absence of fish (table 3). When considering all zones combined, the greatest proportion of deviance was explained by the model for 2005, followed by 2003, then all years combined, then 2004. However, when considering individual zones, models for zones 1 and 2 in 2005 explained the least deviance of all years, whereas zone 3, 2005 explained the most.

Where depth was used, it showed a negative relationship with NASC, similar to that between depth and fish presence/absence, although weaker (figure 9). The influence of depth on NASC became negative at depths in excess of approximately 60m (4.1 on natural log scale). The relationship between Chl-a and NASC was similarly weak and positive to that of Chl-a and fish presence/absence (figure 10). The character of the relationship between SST and NASC varied spatially and temporally, and was often weak. In all zones combined and zone 3, there was a negative relationship between SST and NASC (figure 11). For zone 1, there was a weak positive relationship between SST and NASC (figure 12), although this was non-significant in all years.



Figures 9 and 10. GAM plots for NASC showing the effect of the environmental variable on NASC. **Fig. 9** = 2003: all zones combined, depth (natural log). **Fig. 10** = 2003: all zones combined, Chl-a (natural log).



Figures 11 and 12. GAM plots for NASC showing the effect of the environmental variable on NASC. **Fig. 11** = 2003: zone 3, SST (natural log). **Fig. 12** = 2003: zone 1, SST (natural log).

Year	*Zone*	*n*	*Variables (p-value)*	*Deviance Explained (%)*
2003	All	658	Chl-a (<0.01), depth (0.09), SST (<0.05)	11.3
	1	137	Chl-a (<0.01), SST (0.15)	12.6
	2	360	SST (<0.01) , depth (0.46)	14.1
	3	161	depth (0.07)	2.81
2004	All	603	depth (<0.05), Chl-a (<0.05)	6.13
	1	152	depth (<0.01), SST (0.56)	14.1
	2	310	Chl-a (<0.01)	5.65
	3	141	SST (0.26)	2.83
2005	All	778	SST (<0.01), depth (0.20)	16.2
	1	201	depth (0.35)	2.03
	2	414	depth (<0.01)	4.16
	3	163	depth (<0.01)	5.43
All	All	2039	Chl-a (<0.01), depth (<0.01), SST (0.12)	7.65
	1	490	depth (<0.01)	4.89
	2	1084	depth (<0.01), Chl-a (<0.05), SST (0.15)	7.46
	3	465	SST (<0.01), depth (0.15)	10.3

Table 3. NASC GAM results, showing the best model for each zone and year. Variables are ordered according to their importance in the model, based on results from regression trees. The order runs from left (most important) to right (least important). Non-significant variables are highlighted in red. SST and Chl-a were co-linear in the models: 2004: all zones combined, 2004: zone 1.

3.2 EFH mapping

The models used to predict the probability of presence used data from all years combined. For sardine, models explained 23.9%, 36.3% and 40.3 % of the deviance for zones 1, 2 and 3 respectively (table 4). For anchovy, models explained 26.5%, 37.2% and 33.6 % of the deviance for zones 1, 2 and 3 respectively (table 4). All models used depth, SST and chlorophyll, except anchovy: zone 3, which did not use SST. Relationships between environmental variables and sardine and anchovy presence/absence were very similar to those described for small pelagic fish in general.

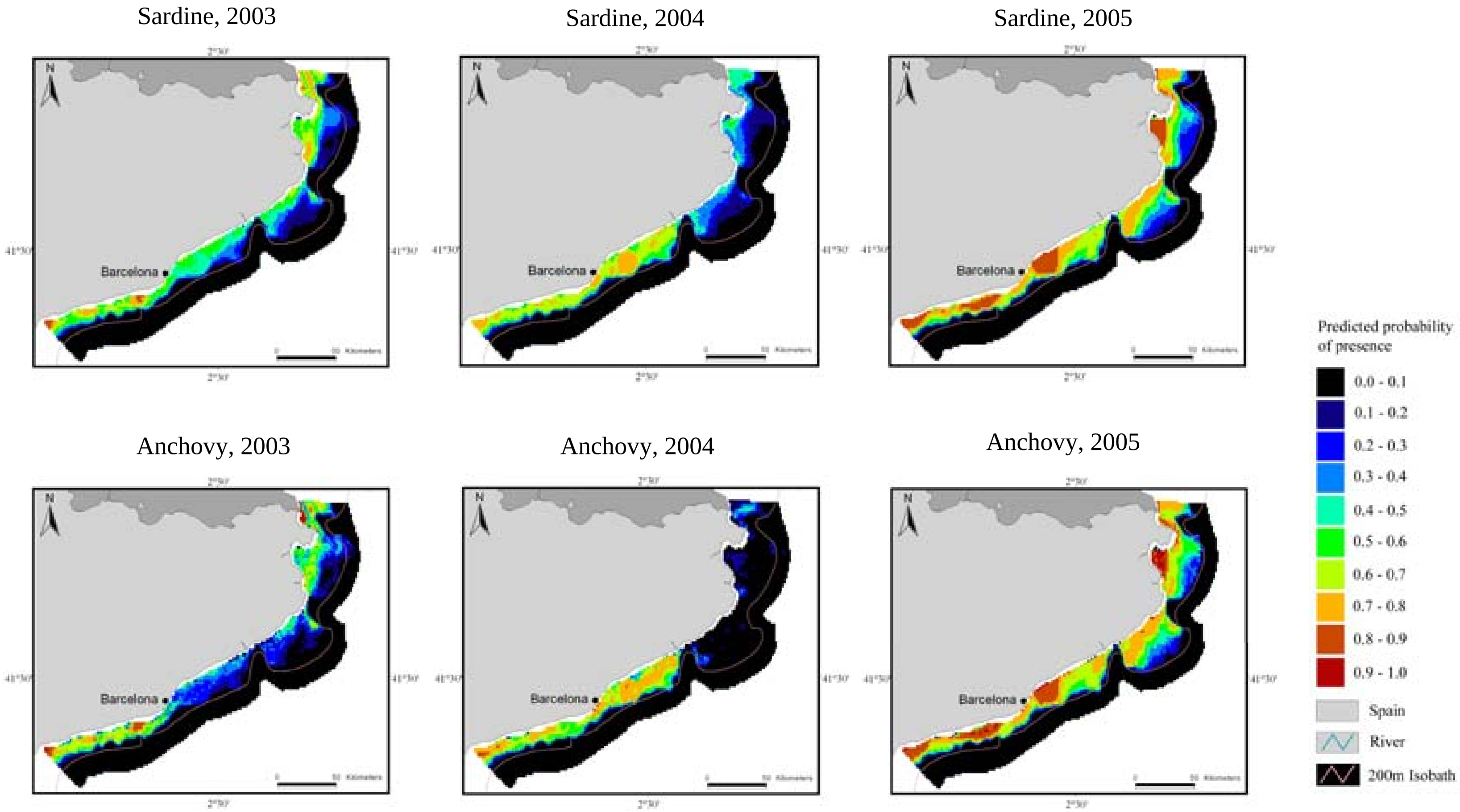
Species	*Zone*	*n*	*Variables (p-value)*	*Deviance Explained (%)*
Sardine	All	3849	depth (<0.01), Chl-a (<0.01), SST (<0.01)	30.7
	1	893	depth (<0.01), SST (<0.01), Chl-a (<0.01)	23.9
	2	1973	depth (<0.01), Chl-a (<0.01), SST (<0.01)	36.3
	3	983	depth (<0.01), Chl-a (<0.01), SST (<0.01)	40.3
Anchovy	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

Table 4. Sardine and anchovy presence/absence GAM results, showing the best model for each zone using data from all years combined. 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).

Predictions were mapped to allow visual analysis of the distribution of predicted presence. KS tests revealed the greatest inter-annual variation in the frequency distribution of predictions to occur in zone 1 (table 5). For conciseness, results are presented using only zone 1 as an example.

Zone 1

Mapping revealed considerable inter-annual variation in the distribution of predictions (figure 13). Unsurprisingly, the areas of highest predictions were very similar to the areas of higher NASC identified in section 3.1. For both species, 2005 showed the highest predictions, followed by 2003, then 2004. In 2004, the southern Gulf of Lions showed very low predictions, particularly for anchovy. The Catalan coast north of Barcelona also showed an area of very low predictions in 2003, again, particularly for anchovy.



Sardine, 2003

Sardine, 2004

Sardine, 2005

Anchovy, 2003

Anchovy, 2004

Anchovy, 2005

Figure 13. EFH maps showing the predicted probability of presence of sardine and anchovy in zone 1 for 2003, 2004 and 2005.

Cumulative frequency plots presented the differences in predictions in graphical form (figure 14), clearly showing the presence of higher predictions in 2005 over zone 1 as a whole. KS tests quantified these differences, and identified predictions for sardine to be most different between 2003 and 2005, and between 2004 and 2005 for anchovy (table 5). Inter-annual differences were of a greater magnitude for anchovy.

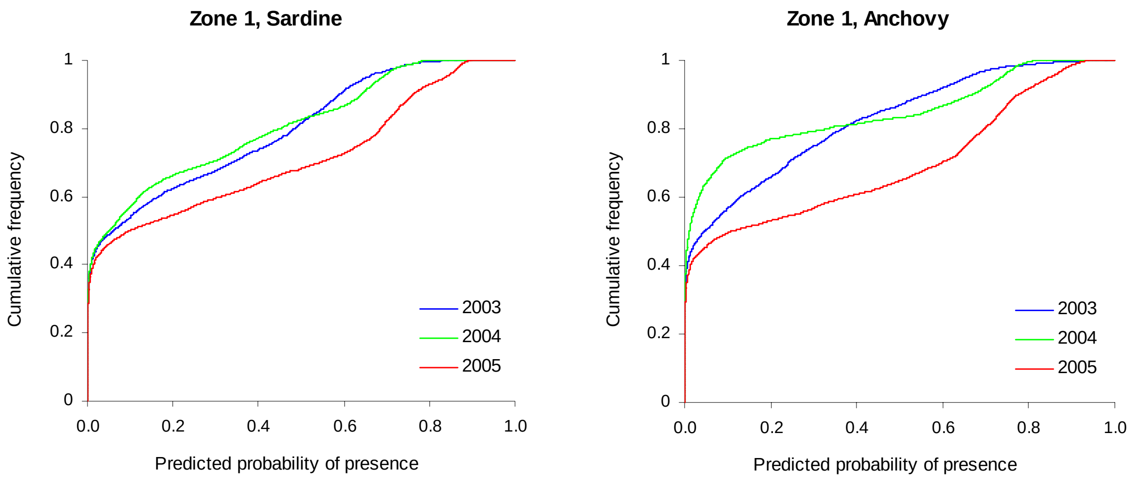


Figure 14. Cumulative frequency of predicted probability of presence for sardine (left) and anchovy (right) in zone 1.

Zone	*n*	*Years compared*	*Sardine KS value*	*Anchovy KS value*
1	5137	2003 vs 2004	0.0493	0.1513
		2003 vs 2005	0.1901	0.2251
		2004 vs 2005	0.1551	0.2391
2	16702	2003 vs 2004	0.0808	0.1011
		2003 vs 2005	0.0752	0.0868
		2004 vs 2005	0.0743	0.0743
3	7013	2003 vs 2004	0.0503	0.0627
		2003 vs 2005	0.0884	0.1636
		2004 vs 2005	0.1199	0.1439

Table 5. Results of KS tests. The number of values in each zone (in any one year) is given as *n*. KS values provide a measure of the maximum difference between frequency distributions of predictions between years. All values were significant ($p=<0.05$).

While cumulative frequency plots showed differences in predictions for the entire zone as a whole, scatterplots (figure 15) showed differences in predictions by comparing values at exact locations within each zone.

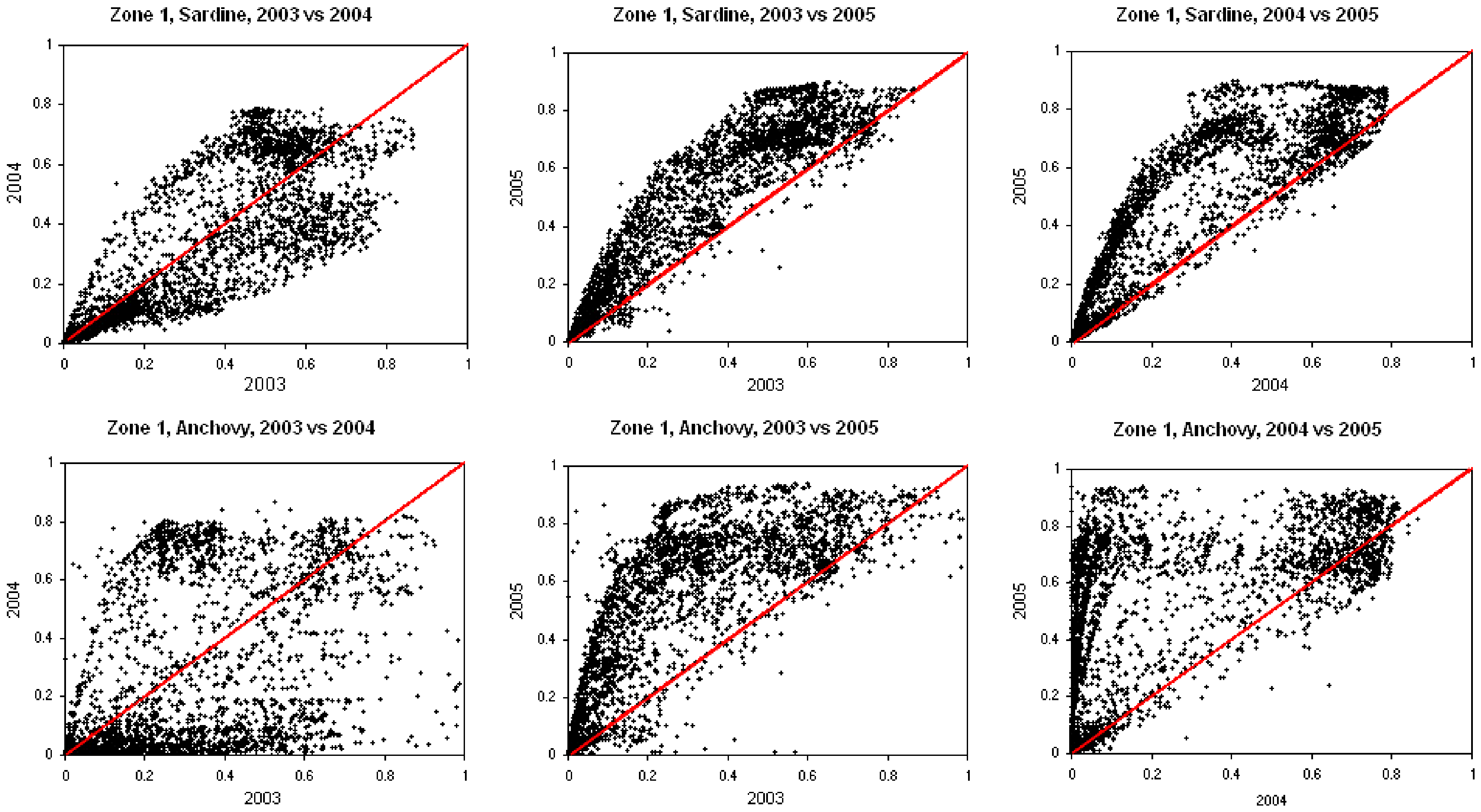


Figure 15. Scatterplots comparing predicted probability of presence between years. Both axis show the predicted probability of presence for the year they are labelled with. The red line is drawn manually for visual reference purposes only – it is not a trend line.

In the scatterplots, the magnitude of inter-annual differences in predictions at individual locations are represented by the distance of points from the red line. An even spread of points above and below the red line for 2003 vs 2004 shows an approximate overall balance in predictions between the two years. For 2003 vs 2005 and 2004 vs 2005, most points are above the red line, revealing that the majority of locations have higher predictions in 2005 than 2003 or 2004. Variability around the red line is generally lowest at very low and very high predictions. This suggests that areas of very high and low predicted presence show less inter-annual variability than areas of mid-range predicted presence.

4. Discussion

4.1 Environmental influences on the distribution of small pelagic fish

While fish were distributed throughout Spanish Mediterranean waters, several areas were identified where fish could be found in high concentrations. The southern Gulf of Lions, the Catalan coast around Barcelona, the Iberian shelf (particularly in the vicinity of the Ebro delta), and the majority 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 cause the nutrient enrichment of surface waters (Estrada, 1996; Salat, 1996; Agostini & Bakun, 2002). Nutrient enrichment results in phytoplankton, then zooplankton growth – providing feeding grounds for fish.

The strong relationship between fish presence/absence and depth shows a preference for depths shallower than 100m. 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 close to the coastline. It is likely that fish were selecting these areas due to the higher concentrations of food associated with these productive waters.

GAMs showed a significant positive relationship between the distribution and abundance of fish and Chl-a. Although frequently significant, these relationships were weak .This suggests that Chl-a and fish were not directly related, and that higher Chl-a was 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 even 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 1 – 2 weeks may produce stronger relationships with fish distribution and abundance. 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.

Spatial variation in the characteristics of relationships between the environment and fish are likely to be a result of differences in the species composition of the pelagic community. Relationships between fish and the environment are likely to vary with species. Therefore, grouping all fish together is likely to obscure some relationships, particularly those of less abundant species.

4.2 EFH

EFH maps showed the predicted probability of fish 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 made in the characteristics of predictions. The characteristics of predictions can be considered a measure of the quality of EFH. Higher predictions clearly indicate better quality habitat, in terms of the environmental variables considered in the model on which the predictions are based. The EFH maps presented in this study do not accurately predict all areas where fish will be present. They do, however, act as a tool for identifying areas where environmental conditions are suitable or unsuitable for fish to be present.

Using the southern Gulf of Lions and Catalan coast as an example, the quality of EFH showed significantly large inter-annual variation. The most notable difference was an almost complete absence of predicted presence for anchovy in the southern Gulf of Lions in 2004. A similar, but less extreme, trend was observed for sardine. The same area in 2005 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 Lions present unfavourable 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 fishery implications through altering the catchability of fish. Changes in catchability 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 error).

For example, a reduction in the distribution and quality of EFH, such as was seen in 2004, 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 2005, 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 actually only becoming more available to fishing.

4.3 Future work

Predictions for EFH mapping are only as accurate as the models they are based on. The use of different environmental variables and 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 stronger relationships between environmental conditions and fish abundance than were revealed in the current study.

Survey data of the quality used in this study is 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 – 2005 to predict fish distribution in other years.

Acknowledgements

This work was funded by a studentship from the Natural Environment Research Council (NERC). The authors thank Dr Colin MacLeod and Andreas Palialexis for their technical contributions and comments.

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