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FISH HABITAT MAPPING

Modelling the presence of anchovy *Engraulis encrasicolus* in the Aegean Sea during early summer, based on satellite environmental data

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Abstract Acoustic and satellite environmental data as well as bathymetry data were used to model the presence of anchovy, *Engraulis encrasicolus* during early summer in the northern Aegean Sea (Eastern Mediterranean). Generalized Additive Models (GAMs) were used for modelling and subsequently applied in a predictive mode to identify those areas in the Greek Seas and the entire Mediterranean basin that could support species' presence. Model results were evaluated with the estimation of Receiver Operating Characteristic (ROC)-plots as well as qualitatively, based on (a) acoustic data from concurrent studies in certain areas of the northern Aegean Sea that were not included in the estimation of the GAM model and (b) historical acoustic data from the central Aegean and Ionian Seas. Mapping the estimated environmental conditions in the Mediterranean basin indicated areas that generally agree with the known distribution grounds of anchovy, such as the straits of Sicily and coastal waters of Tunisia, areas in the Tyrrhenian Sea, the Adriatic Sea, the Gulf of Lions and the Catalan Sea.

Keywords European anchovy · Habitat modelling · Potential habitat · Generalized Additive Models · Satellite environmental data · Aegean Sea

Introduction

European anchovy *(Engraulis encrasicolus*) along with sardine (*Sardina pilchardus)* are the two most important small-sized pelagic species in the Mediterranean (Lleonart & Maynou, 2003), representing almost 40% of the total annual landings. Regarding Greece, the two species comprise 18–25% of the total Greek landings and 60–70% of the total purse seine landings (Stergiou et al., 1997). Small pelagics like anchovy, present high fluctuations regarding their abundance and their distribution, largely depending on environmental conditions (Freon & Misund, 1999).

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Essential Fish Habitat Mapping in the Mediterranean

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The study of those environmental parameters that affect the spatial distribution of economically important stocks like anchovy, has gained particular attention lately due to the concern regarding the effect of climate change on fisheries resources (Cury et al., 2003). Habitat modelling of a species in relation to environmental parameters has expanded considerably in the last decade (Guisan & Zimmermann, 2000; Riou et al., 2001; Francis et al., 2005; Planque et al., 2007). It is increasingly becoming an effective tool for understanding the processes that affect the interannual variability in species distribution and provide essential information for ecological studies and management purposes. Defining the potential habitat of a species practically means determining the combination of those environmental factors that constitute suitable conditions for its survival (Guisan & Zimmermann, 2000; Planque et al., 2007).

Satellite environmental data are flexible allowing predictions in various years and regions and could be used as proxies to infer spatial variations of environmental factors and assess possible ecological relationships. In addition new powerful statistical techniques and Geographical Information Systems (GIS) tools have evoked during the last decade and are being widely adapted in the development of predictive habitat distribution models in ecology (Guisan & Zimmermann, 2000; Riou et al., 2001; Francis et al., 2005).

Habitat modelling can provide the basis for designing and executing intensive surveys in certain areas. Furthermore, sustainable management requires the knowledge of species habitat as well as how habitat area changes depending on environmental parameters. Thus, the development of large-scale descriptive and predictive models of fish presence and abundance is fundamental for effective management activities, such as placement of Marine Protected Area networks (Conover et al., 2000), spatial zoning of different permitted fishing activities (Rice & Cooper, 2003) and regulative use of the coastal environment (Coleman et al., 2004; Francis et al., 2005).

In the present study, the relationship of the adult anchovy, *Engraulis encrasicolus* presence during early summer was modelled with satellite environmental data and bathymetry data as proxies to infer spatial variations of environmental factors, in order to identify those areas in the Greek Seas and the Mediterranean basin that could serve as potential habitat for the species. Analysis was based on data obtained from acoustic surveys undertaken in the northern Aegean Sea during a 3-year period and statistical models (i.e. Generalized Additive Models) were used to model the relationship between anchovy presence/absence and environmental data.

Materials and methods

The study area

The northern Aegean Sea is characterized by high hydrological complexity mostly related to the Black Sea waters (BSW) that enter the Aegean Sea through the Dardanelles strait as a surface current (Zervakis & Georgopoulos, 2002). The area is characterized by the presence of two anticyclonic systems: one in the Samothraki plateau (the Samothraki gyre) and another one in the Strymonikos Gulf (Somarakis et al., 2002; Fig. 1B). These gyres are an almost permanent feature in the area during early summer and are coupled with a cyclonic system located south of the island of Thasos. The overall circulation is mainly determined by the presence of the Limnos-Imvros stream (LIS), which carries waters of Black Sea origin onto the Samothraki plateau (Somarakis et al., 2002, Fig. 1B). The outflow of BSW (salinity < 30) enhances local productivity and its advection in the Aegean Sea induces high hydrological and biological complexity (Isari et al., 2006, 2007; Somarakis & Nikolioudakis, 2007). This is further enhanced by the presence of a series of large rivers that end in semi-closed gulfs, such as Thermaikos and Strymonikos Gulfs (Stergiou et al., 1997; Isari et al., 2006).

Sampling

Acoustic data were collected on board the R/V Philia during June 2004, 2005 and 2006, in the framework of assessing anchovy stock biomass during the peak of the spawning season in northern Aegean Sea. Acoustic surveys were carried out along predetermined parallel transects in Thracian Sea and Thermaikos gulf, whereas, zigzagged transects were sampled in Strymonikos, North Evoikos and South

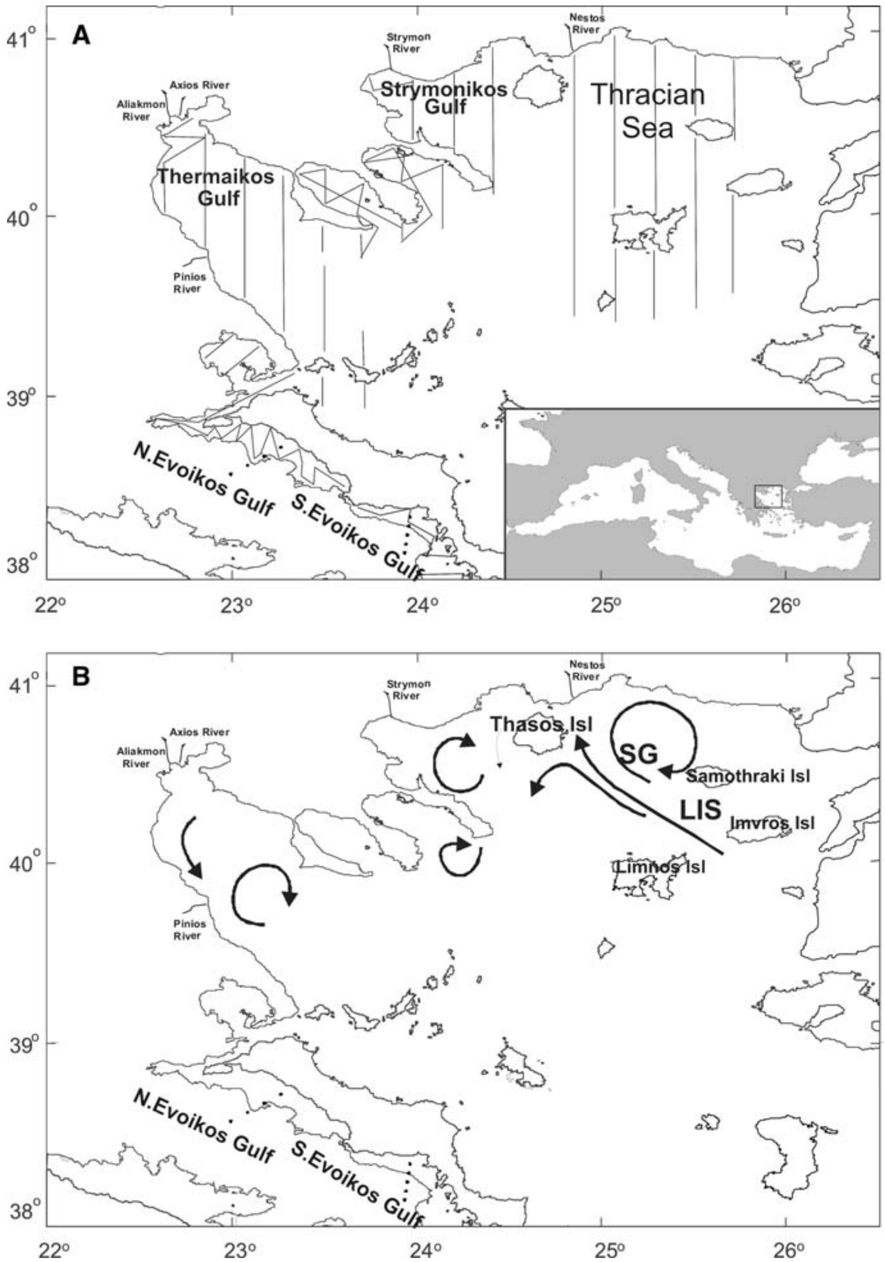


Fig. 1 (**A**) Map of the study area showing acoustic transects in June 2004, 2005 and 2006. (**B**) Map of the study area showing water circulation. Arrows indicate the presence of fronts and gyres (redrawn from Somarakis et al., 2002). LIS: Limnos–Imvos Steam, SG: Samothraki Gyre. Positions of the main rivers in the area are also shown. Toponyms mentioned in the text are also indicated. ——— Acoustic transect

Evoikos gulfs (Fig. 1A), by means of a Biosonic Split Beam DT-X echosounder at 38 kHz. The system was regularly calibrated using the standard sphere method (Foote, 1987). The distance between transects was 10 nautical miles (nm). The speed of the vessel was 8 nautical miles (nm) per hour. Anchovy echoes discrimination was based on the characteristic echogram shape of the schools and the catch composition of pelagic trawling held in the surveyed area (MacLennan & Simmonds, 1992). A pelagic trawl with a vertical opening of 10 m and an 8 mm codend was used to identify echo traces. Catch composition of a total of 109 hauls revealed that the main species in the study area were *Engraulis encrasicolus*, *Sardina pilchardus*, *Sardinella aurita* and *Trachurus* spp. The size of the Elementary Distance Sampling Unit (EDSU) was one nautical mile. The EDSU is the length of the cruise track along which the acoustic measurements are integrated to give one sample (MacLennan & Simmonds, 1992). Acoustic data

Table 1 Environmental satellite parameters and their characteristics

Parameter	Sensor/Model	Range/Mean	Resolution	Source
Sea surface chlorophyll-*a* (CHLO)	MODISA	0.07–24.62/0.32 mg/m^3	4 km	oceancolor.gsfc.nasa.gov
Sea surface temperature (SST)	AVHRR	18.5–28.9/22.9 °C	1.1 km	eoweb.dlr.de:8080
Photosynthetically active radiation (PAR)	SeaWiFS	20.3–64.7/57.8 Einstein/m^2/day	9 km	oceancolor.gsfc.nasa.gov
Sea level anomaly (SLA)	Merged Jason-1, Envisat, ERS-2, GFO, T/P	−12.3 to 0.7/−5.3 cm	0.25°	www.jason.oceanobs.com
Sea surface salinity (SSS)	CARTON-GIESE SODA and CMA BCC GODAS models	38.3–38.9/38.6 psu	0.5°	iridl.ldeo.columbia.edu

analysis was performed using the Sonardata Echoview software v3.30.

Furthermore, acoustic data from past surveys that were held in central Aegean and Ionian Seas (July 1998; June 1999) with a Dual Beam Biosonic echosounder at 120 kHz and the same acoustic methodology (acoustic sampling is described in detail in Giannoulaki et al., 2006), were used for model evaluation purposes.

Environmental data

The area is well monitored in terms of monthly satellite imagery (summarized in Table 1). Specifically, the sea surface temperature distribution (SST in °C), the sea surface chlorophyll concentration (CHLO in mg/m^3), the Photosynthetically Active Radiation (PAR in Ein/m^2/day), the sea surface salinity distribution (SSS in psu BCC GODAS model, Liu et al., 2005) and the sea level anomaly (SLA in cm) were downloaded from respective databases (see Table 1) and used. SLA describes ocean processes, such as gyres, meanders and eddies (Larnicol et al., 2002; Pujol & Larnicol, 2005), which enhance productivity and often function as physical barriers differentiating the distribution of species or species life stages. These aforementioned parameters might be important either as a direct influence on the distribution of anchovy or as a proxy for other factors (Bellido et al., 2001), for example PAR which is defined as the quantum energy flux from the sun in the spectral range 400–700 nm at the surface, representing the amount of solar radiation useable for plants to photosynthesize (Frouin et al., 2003), might be indicative of the extent of the euphotic zone, with its lower limit defined as the depth to which PAR values are reduced to 0.1% of the surface measurements (Hader et al., 1994). Bathymetry was also 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). All monthly averaged satellite images were processed as regular grids under a Geographic Information Systems (GIS) environment using ArcInfo GRID software (ESRI, 1994). The mean environmental monthly values for June 2004, 2005 and 2006 were estimated for all surveyed points of acoustic data based on the available spatial resolution of satellite data (Valavanis et al., 2004).

Model estimation

Generalized Additive Models (GAMs) were used in order to define the set of the environmental parameters that describe areas of anchovy presence in Northern Aegean Sea. A GAM (Hastie & Tibshirani, 1990) is a generalized linear model with a linear predictor involving a sum of smooth functions of covariates (Wood, 2006). The main advantage of GAMs over traditional regression methods is their capability to model non-linearities using non-parametric smoothers (Hastie & Tibshirani, 1990; Wood, 2006).

The selection of the GAMs smoothing predictors followed the method proposed by Wood & Augustin (2002), using the 'mgcv' library in the R statistical software (R Development Core Team, 2005). The output of the GAMs is smoothed fits for each environmental variable. The individual models cannot be tested for significance using the *P*-values provided by 'mgcv' library since the true number of degrees of freedom is unknown. However, each fit was analysed with regards to the level of deviance explained (0–100%; the higher the better), the Unbiased Risk estimator (UBRE, the lower the better), the Akaike's Information Criterion (AIC, the lower the better) and the confidence region for the smooth (which should not include zero throughout the range of the predictor). The degree of smoothing was also chosen based on the observed data and the Generalized Cross Validation method suggested by Woods (2006) and incorporated in the MGCV library. Because collinearity in the independent variables is a crucial problem in GAMs application, associated with stepwise model selection (Guisan et al., 2002, Wood, 2006), the best model was chosen based on a stepwise forward selection method that reduces the collinearity problem starting from a simple initial model with few explanatory variables (Sacau et al., 2005; Zuur personal communication). Specifically, models were compared using the estimated AIC, UBRE and deviance, the environmental variables were ranked and selection of the final model was based on the minimization of the above criteria.

As response variable (y), we used the presence/absence of anchovy. As independent variables we used: the cubic root of the bottom depth (to achieve a uniform distribution of bottom depth), the natural logarithm of CHLO (to achieve a uniform distribution of CHLO), the SST, the SSS, the SLA and the PAR. Bottom depth and CHLO presented high variability in their original values, thus transformation was necessary in order to achieve uniform distribution for GAM application (Hastie & Tibshirani, 1990). The appropriate type of transformation was based on the inspection of Quantile-Quantile plots (QQ-plots) to check if variables under certain transformations follow the normal distribution.

For the construction of such a model data collected over a wide range of environmental conditions should be collated. Therefore, pooled data from all three examined years deriving from both Thracian Sea and Thermaikos Gulf (two areas that vary highly in respect to environmental conditions and water circulation) were used, in order to obtain more possible observed conditions and ensure potentiality (ICES, 2005).

The binomial error distribution with the logit link function was used. Also the natural cubic spline smoother that applies splines with knots at each distinct value of the variable, (Hastie & Tibshirani, 1990) and minimizes the *penalised residual sum of squares* (Wood, 2006) was used for the independent variables smoothing and fitting GAM. Following the selection of the main effects of the model, all first order interactions of the parameters included in the final model were tested (Wood, 2006). Validation graphs (e.g. residual plot vs. fitted values, QQ-plot and residual plot against the original explanatory variables) were plotted in order to detect model misspecification.

Model validation

Furthermore, a GAM model was applied for the estimation of the probability of anchovy presence to each point of the area used for modelling, based on the available mean monthly values of satellite data (i.e. of the parameters incorporated in the final model). Therefore a specific set of satellite conditions was attributed to a specific probability of finding anchovy present. In a next step, the GAM model was applied in a predictive mode using as prediction grid the mean monthly satellite values measured for the Greek Seas as well as the entire Mediterranean basin, at a GIS resolution of 4 km in June 2004, 2005 and 2006. The areas with a specific set of satellite conditions corresponding to different probabilities of anchovy presence were plotted.

The predictive accuracy of the final model was tested and evaluated with the estimation of Receiver Operating Characteristic (ROC)-plots (Fieldings & Bell, 1997; Guisan & Zimmermann, 2000) and the estimation of the area under the Receiver Operating Characteristic curve (AUC) for (a) the Thracian Sea and Thermaikos gulf for each examined year, (b) North Evoikos and South Evoikos gulfs, areas that were surveyed concurrently in June 2004, 2005 and 2006 but they were not included in the estimation of the GAM model and (c) for past acoustic data from central Aegean and Ionian Sea in July 1998 and June 1999. AUC has been used extensively in the species' distribution modelling literature, measuring the ability of a model to discriminate between those sites where a species is present, versus those where it is absent (Hanley & McNeil, 1982). It provides an indication of the usefulness of the models for indicating areas in terms of their relative importance as habitat for the particular species. The values of AUC ranges from 0 to 1, where a score of 1 indicates perfect discrimination, a score of 0.5 implies predictive ability that is no better than a random guess, and values <0.5 indicate performance worse than random (Boyce et al., 2002; Elith et al., 2006). ROC and AUC estimation was made with the presence/absence library of the R statistical software. Model results were also evaluated qualitative by comparing the obtained maps with the anchovy's known distribution (a) from the concurrent acoustic surveys in North Evoikos and South Evoikos Gulf and (b) from acoustic data obtained at central Aegean and Ionian Seas in July 1998 and June 1999. The Surfer v8.0 of the Golden Software Inc. software was used for mapping.

Results

Anchovy distribution in northern Aegean Sea

The distribution of anchovy in northern Aegean Sea is shown in Fig. 2. Although its abundance and distribution shows a large degree of interannual variability, the highest abundances were observed in the northern part of Thermaikos gulf, the coastal waters of Thracian Sea and the inner part of Strymonikos gulf where large rivers outflow (Figs. 1B, 2). For example, the spatial distribution of anchovy in Thermaikos gulf in June 2005 and 2006 was patchy compared to June 2004, where anchovy was distributed over most of the shelf (Fig. 2). A more consistent pattern was observed in North Evoikos gulf during all years, where the main concentrations were generally confined in the northwest part and in the south most part of the gulf.

Model estimation

The final selected GAM model based on satellite data included as main effects: PAR, Depth as well as the interactive effect of SST and SLA, and it is described in Table 2. All variables selected in the final model were statistically significant. Inspection of the validation graphs (not shown) indicated a distinct pattern regarding the plot of residuals versus fitted values which is because of the presence–absence nature of the data and does not indicate a lack of fit. The plots of residuals of the model against the original explanatory variables did not show any apparent trend.

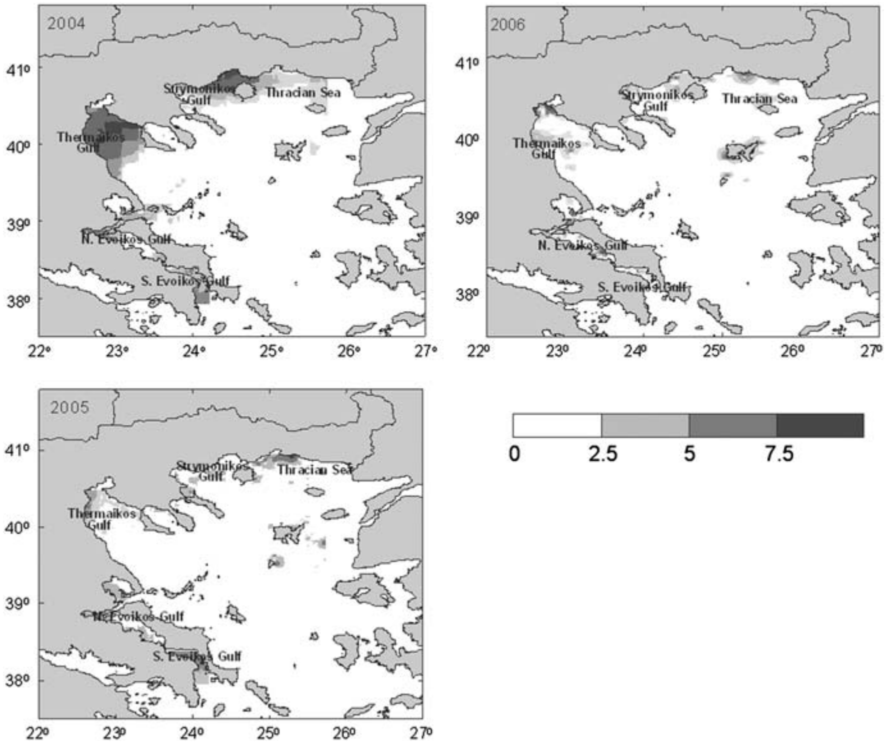


Fig. 2 Distribution maps of anchovy according to the ln of NASC (Nautical Area Scattering Coefficient in m^2/nm^2) for June 2004, 2005 and 2006, respectively. Kriging was used as the interpolation method (spacing 1 nm, spherical variogram model and anisotropy)

Table 2 Analysis of deviance for GAM covariates and their interactions of the final model fitted

Parameter	Res. Df	Residual deviance	Deviance explained (%)	AIC	*P*-value
Null model	2126	2321.669		2323.669	
s(Depth)	2120.93	1652.656	28.8	1664.796	<<0.000
s(Depth) + s(PAR)	2119.27	1616.155	30.4	1631.605	<< 0.000
s(Depth) + s(PAR) + s(SST:SLA)	2103.74	1495.933	35.56	1542.452	<< 0.000
Total variation % explained			35.56		

Level of significance was set at 0.05. The ":" sign denotes interaction. Res. d.f = residual d.f.; Res. Deviance = residual deviance; AIC = Akaike Information Criterion value; *P*-value (chi-square) = significance values

The results of the final GAM model are shown as plots of the best-fitting smooths for the effect of the environmental parameters on anchovy presence (Fig. 3). The 95% confidence intervals were also plotted around the best-fitting smooths for the main effects. Interaction effects are shown as a perspective plot (Fig. 3) without error bounds. The *y*-axis reflects the relative importance of each parameter of the model, and for the interaction effects, this is presented on the *z*-axis. The rug under the single variable effects plots indicates the density of points for different variable values (Fig. 3). It should be noted that the effect of each variable is the conditional effect, i.e. the effect that this variable has, given that the other variables are included in the model. Plots indicated a higher probability of finding anchovy present in shallow waters (less than 140 m depth) and PAR values less than 56 Ein/m^2/day. The interaction plot between SST and SLA also indicated higher probability of finding anchovy present in the lower available values of SST (<22°C) when co-existing with the lower available values of SLA (less than −6 cm) (Figs. 3, 5).

Model validation

The estimated values of AUC for each ROC plot for each year incorporated in the model indicated good

Fig. 3 Coefficients of the Generalized Additive Models (GAMs) for anchovy against Bottom depth and PAR. The interaction plot of SST and SLA is also shown. Black thick lines indicate the value of GAMs coefficient, dotted lines represent the confidence intervals at $P = 0.05$

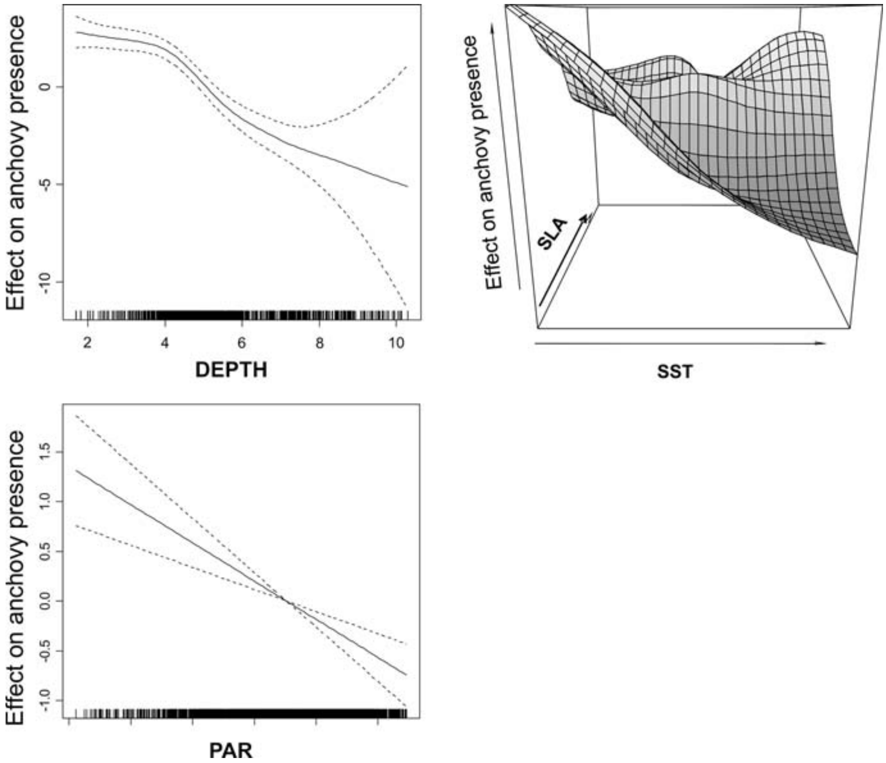


Table 3 Estimated area under the ROC curve (AUC) for anchovy per area and year

Year	Area	*N*	AUC	Sensitivity = Specificity threshold
2004	Thracian Sea & Thermaikos Gulf	697	0.87	0.27
2005	Thracian Sea & Thermaikos Gulf	698	0.86	0.28
2006	Thracian Sea & Thermaikos Gulf	729	0.88	0.34
2004	North & South Evoikos Gulf	203	0.82	0.43
2005	North & South Evoikos Gulf	195	0.67	0.37
2006	North & South Evoikos Gulf	189	0.68	0.42
1998	Central Aegean & Ionian Sea	675	0.58	0.20
1999	Central Aegean & Ionian Sea	725	0.70	0.23

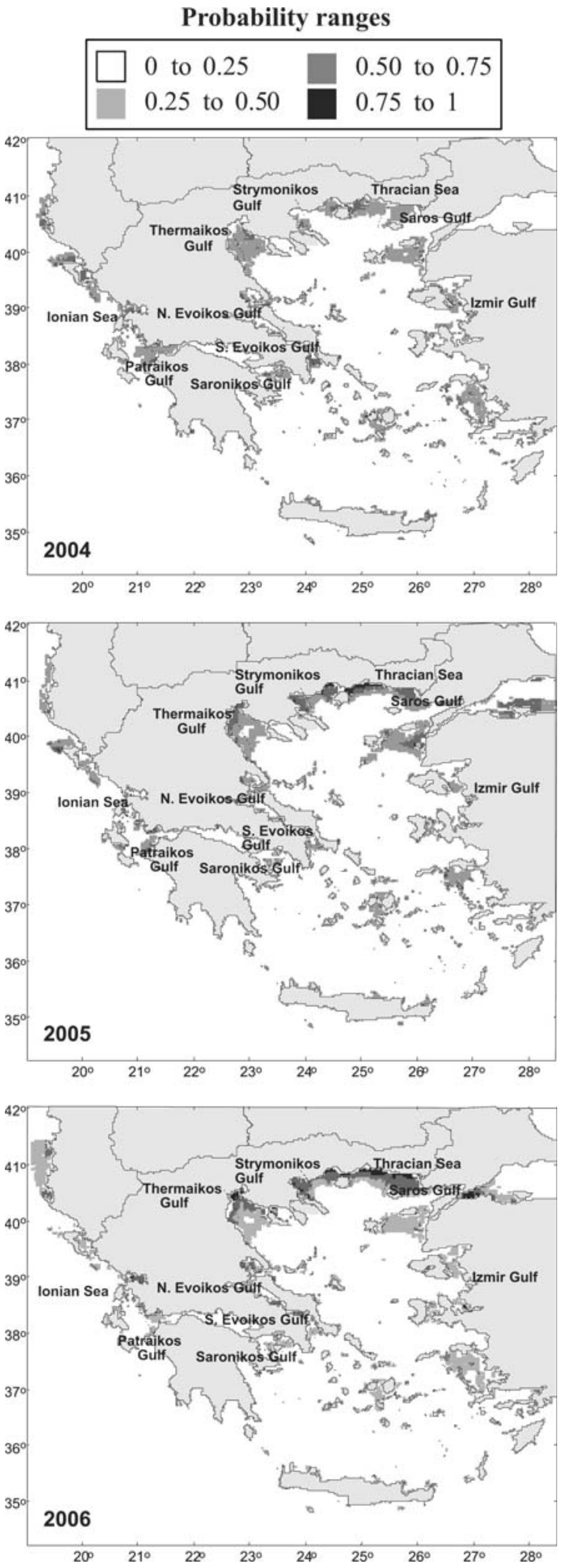
N: number of observations. Sensitivity equal specificity threshold is also shown. Sensitivity is defined as the probability that a model yields a positive prediction where species actually occurs (i.e. 1), whereas, specificity is the probability that the species is absent (i.e. 0). The threshold that sensitivity equals specificity, coincides with the optimum probability threshold for model performance

prediction ability of the model for the surveyed area according to Elith et al. (2006), since it exceeded 0.85 in all cases (Table 3). Regarding the prediction ability of the model for North Evoikos and South Evoikos Gulf, the central Aegean and Ionian Seas in 1998 and 1999, the estimated AUC values varied from 0.58 to 0.82. The lowest values were observed when both the area and the period highly diverged from the ones used for modelling for (i.e. central Aegean and Ionian Seas in July 1998). However, the comparison of maps for the entire Greek seas revealed a general good agreement between the predicted areas based on the measured satellite conditions (i.e. areas with a specific set of satellite parameters associated to specific probability of anchovy presence, e.g. 50%) and the observed distribution of anchovy (Machias et al., 2000; Figs. 2, 4, 6). Areas have been indicated in the most productive waters of the northwest part of Saronikos gulf which is under strong urban influence, in Patraikos gulf and in the inner part of the Ionian Sea between the islands and the mainland. These areas generally agree with the species actual distribution during early summer (Figs. 4, 6).

Furthermore, similar maps were also obtained for the entire Mediterranean Sea to indicate areas, where the specific set of satellite conditions associated with specific probability values, e.g. 50% of finding anchovy present, is met (Figs. 7, 8). In the western Mediterranean Sea areas, such as the Adriatic Sea, the Straits of Sicily, the Catalan Sea, the Gulf of Lions and the gulf of Gabes, where the presence of anchovy distribution grounds is known, have been indicated. In the Eastern Mediterranean Sea, areas have been indicated in the Turkish coastal waters of Aegean Sea, the Mersin gulf and the Nile Delta area. However, in these areas the distribution of anchovy is generally unknown.

Discussion

Satellite data although they do not describe the actual conditions at sea, they seem to provide a generally good description of the areas that anchovy distributes during early summer. Specifically, results indicated a higher probability of finding anchovy present at <140 m depth and at PAR values less than 56 Ein/m^2/day, which are both indicative of the shallow coastal waters of the studied area. In addition, the higher probability of finding anchovy present in areas characterized by the interaction of SST (values between 20 and 22°C) and the lower available values of SLA implies the association of anchovy with an anticyclonic system in the Samothraki plateau (i.e. the Samothraki gyre; Figs. 1B, 5). This is a downwelling water formation that is related to the inflow of BSW from the Dardanelles and is a permanent feature in northern Aegean Sea during early summer (Zervakis & Georgopoulos, 2002; Somarakis et al., 2002; Somarakis & Nikolioudakis, 2007). Anchovy association with anticyclonic systems during early summer in the studied area has also been shown, based on field measurements of environmental data (Giannoulaki et al., 2005). Early summer is the peak of the spawning season for anchovy in northern Aegean Sea (Stergiou et al., 1997; Somarakis, 2005), therefore a large



◀**Fig. 4** Map of the probability for anchovy potential presence in the Greek region, based on GAM model from Aegean Sea. GIS resolution used for prediction was 4 km of mean monthly satellite values from June 2004, 2005 and 2006

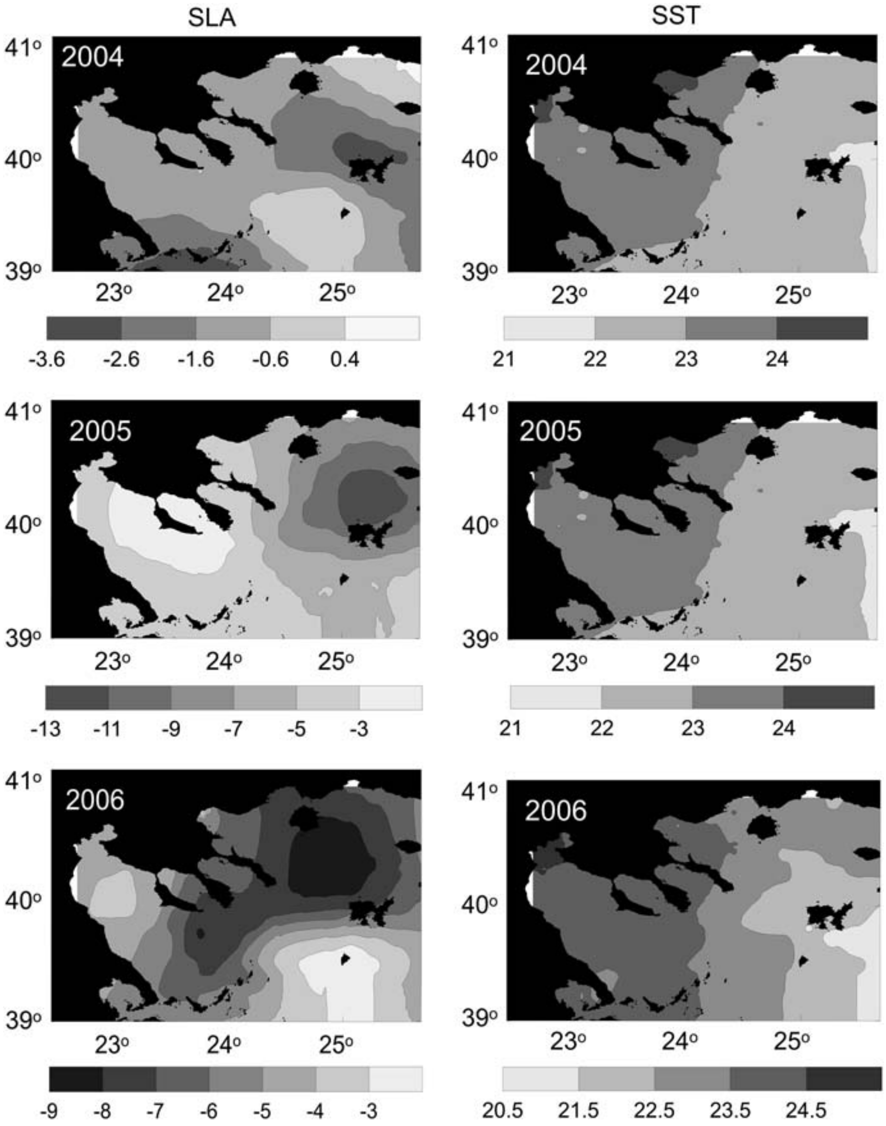
fraction of adult anchovy population is associated with spawning grounds. Anchovy spawning grounds are known to be highly dependent on surface water dynamics in areas like the Catalan sea, the Gulf of Lions and the Straits of Sicily (Giráldez & Abad, 1995; García Lafuente et al., 2002; Cuttitta et al., 2003; Sabates et al., 2007; Palomera et al., 2007).

Furthermore, the coastal waters of Thracian Sea, Strymonikos gulf and Thermaikos gulf, areas indicated by the model results, are under the influence of rivers runoff (Fig. 1). European anchovy spawning areas and juvenile grounds are also related to the influence of river outflow as shown in the Bay of Biscay, the Adriatic Sea, the Bay of Tunis (Motos et al., 1996; Agostini &Bakun, 2002; Zarrad et al., 2006), in the Catalan Sea and the Gulf of Lions (Palomera et al., 2007; Sabates et al., 2007). However, SSS did not enter the final model most likely because the given range of values of SSS at the best available resolution is very small and insufficient to capture and describe the river influence (Table 1).

The evaluation of the model outcome using acoustic observations of anchovy in the Thracian Sea and Thermaikos gulf (areas used for modelling), the North and South Evoikos gulfs (data from concurrent surveys in 2004, 2005 and 2006) and in central Aegean and Ionian Seas (July 1998 and June 1999) offered satisfactory results (i.e. estimated AUC values and map comparisons). Results were less satisfactory in the case of the central Aegean and Ionian Seas in July 1998, but the range of available values for the satellite parameters was highly divergent from the ones used for modelling because of the different survey period. However, in this case predicted areas also coincide with the most productive waters that are influenced either by urban runoffs like the northwest part of Saronikos gulf or by freshwater runoffs like Patraikos gulf and the inner part of the Ionian Sea. These results generally agree with the species' actual distribution during early summer and indicate that the model could generally describe it quite well (Figs. 4, 6).

Maps for the entire Mediterranean Sea (Figs. 7, 8) indicated areas with a certain set of environmental conditions as estimated by the model. These areas are

Fig. 5 Distribution maps of SST and SLA in northern Aegean Sea per year. Arrow indicates location of the Samothraki gyre

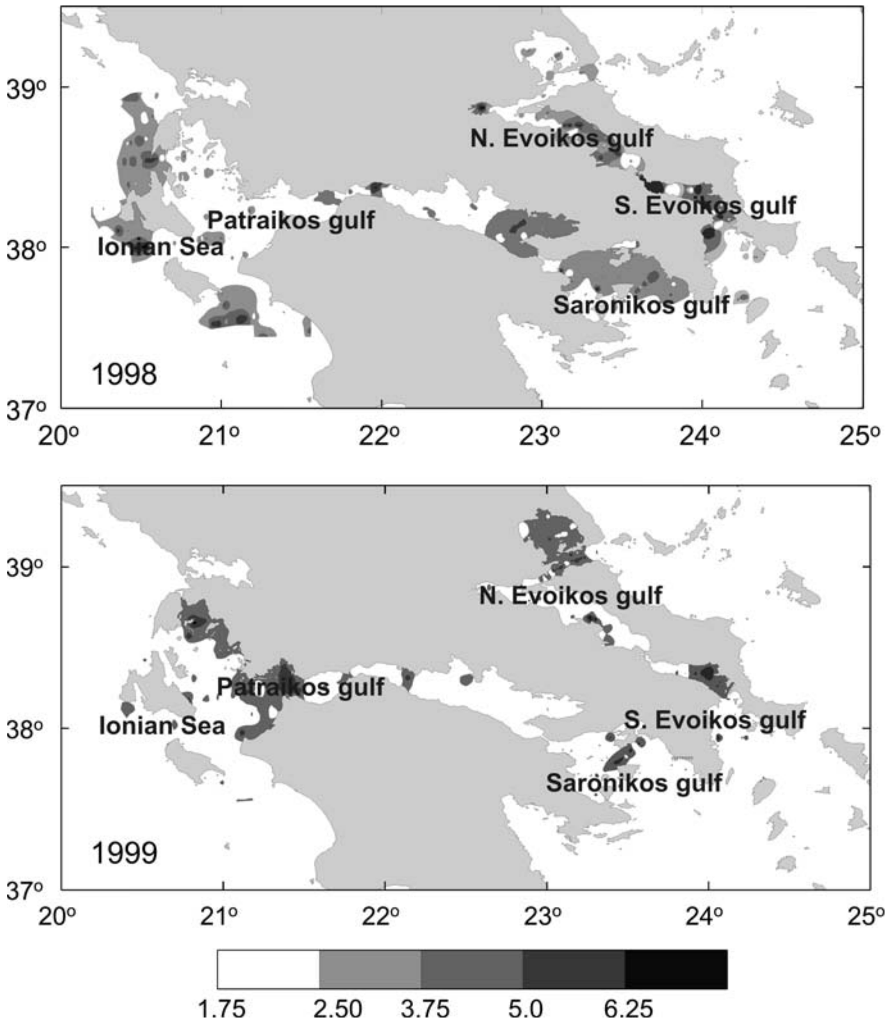


discussed in respect to known anchovy distribution grounds based on literature (areas summarized in Table 4). Specifically, in the eastern part, areas have been indicated in the Turkish waters of the Aegean Sea such as the Saros bay and the gulf of Izmir, the gulf of Mersin in the Levantine Sea, the coastal Syrian and Lebanese waters and the coastal waters of the Nile Delta region (Fig. 7). Anchovy presence in the Turkish coastal waters is known (Aka et al., 2004; Turan et al., 2004) and there is an established purse seine fishery in the region (Lleonart & Maynou, 2003), however, species spatial distribution is largely unknown. An established fishery for anchovy has also been reported in the Lebanese coastal waters (Bariche et al., 2006, 2007) but concerning the Nile Delta area there is no published information.

The related information is generally very scarce regarding the northern African waters. However regarding the Gulf of Tunis published work based on acoustic and egg surveys (Ben Abdallah & Gaamour, 2005; Zarrad et al., 2006) refers that the higher anchovy abundances are mostly located in the south part of the gulf, such as the inshore waters of the gulf of Gabes and the gulf of Sousse, areas that coincide with the locations characterized of high probability of finding anchovy present (>0.5) based on model results.

In the western Mediterranean basin the indicated areas generally agree with the major grounds of

Fig. 6 Distribution maps of anchovy according to the ln of NASC (Nautical Area Scattering Coefficient in m^2/nm^2) for June 1998 and 1999, respectively. Kriging was used as the interpolation method (spacing 1 nm, spherical variogram model and anisotropy)



anchovy's known distribution (Table 4) like the straits of Sicily, the Adriatic Sea, the gulf of Lions and the Catalan Sea (Abad et al., 1998; Guennegan et al., 2000; Patti et al., 2000; Alemany et al., 2002; Giraldez & Alemany, 2002; Cuttitta et al., 2003; Patti et al., 2004, 2005; Bonanno et al., 2005; Palomera et al., 2007; Giraldez et al., 2007). In the Adriatic, results from acoustic and trawl surveys (Cingolani et al., 1996; Azzali et al., 2005; Leonori et al., 2007a, b) have shown that anchovy's shows a patchy spatial distribution that covers the coastal waters of the northern part in association with the Po delta (Leonori et al., 2007a), the southwest part of the Adriatic (Leonori et al., 2007b) and to a lesser extent the Croatian coastal waters in the east part (Ticina et al., 2005), higher anchovy densities were generally observed within the bathymetric range of 60–200 m (Azzali et al., 2005; Leonori et al., 2007a, b). Anchovy distribution in the Straits of Sicily and the Catalan Sea has been associated with surface waters dynamics (Cuttitta et al., 2003; Palomera et al., 2007) and the presence of river outflow (García Lafuente et al., 2002; Palomera et al., 2007; Giraldez et al., 2007).

The aim of this article was to (a) construction of a general model that describes these areas that could potentially but not necessarily, support anchovy presence and (b) examine if this could be applicable over larger areas. The use of data from additional areas as well as pooled data from several years could better define the set of the environmental parameters that characterize the areas of anchovy's distribution and improve the application of the model over a wider range of areas. This kind of a general model

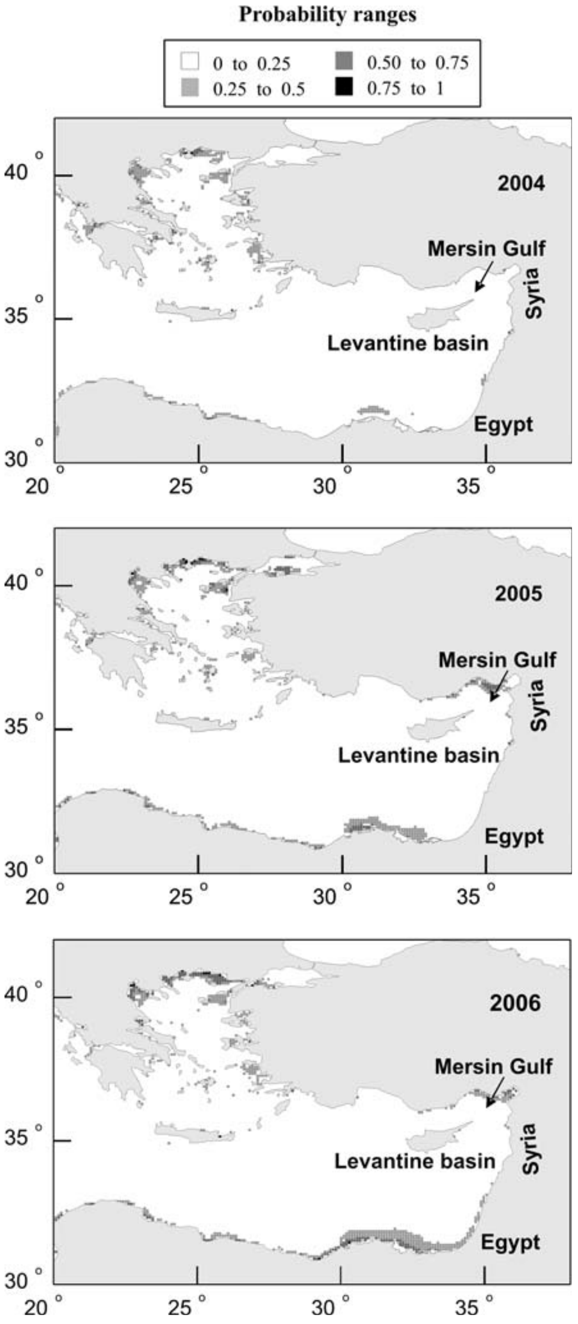


Fig. 7 Eastern Mediterranean Sea: Map of the probability for anchovy potential presence based on GAM model from Aegean Sea. GIS resolution used for prediction was 4 km of mean monthly satellite values from June 2004, 2005 and 2006

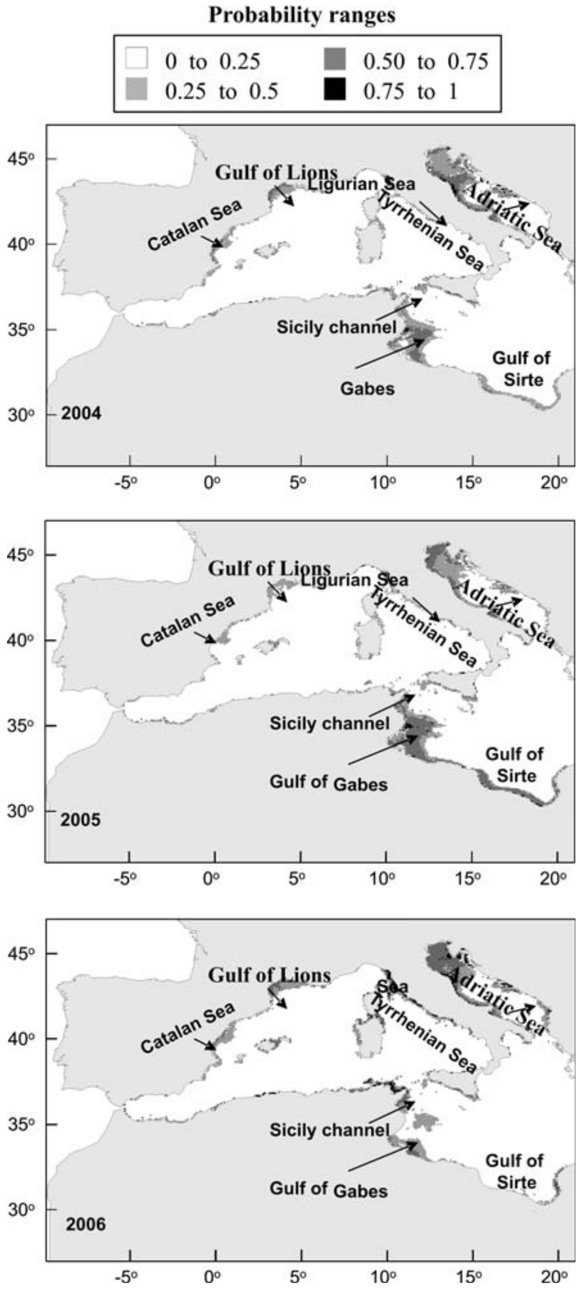


Fig. 8 Western Mediterranean Sea: Map of the probability for anchovy potential presence based on GAM model on records from Aegean Sea. GIS resolution used for prediction was 4 km of mean monthly satellite values from June 2004, 2005 and 2006

presents special interest from a managerial perspective. Small pelagics like anchovy are highly exploited species, characterized by large fluctuations in abundance and spatial distribution that are largely depending on environmental parameters. Regions assigned as potential habitat for such species could be used to define suitable areas for scientific purposes like ecological studies, e.g. estimation of spawning or

Table 4 Areas in the Mediterranean Sea with known anchovy distribution grounds

	Region	Area	Type of data	Source
Eastern Mediterranean	Aegean Sea	Greek coastal waters	Acoustic surveys data	Present paper; Machias et al. (2000)
	Ionian Sea	Greek coastal waters	Acoustic surveys data	Machias et al. (2000)
	Aegean Sea	Turkish coastal waters	Landings data	Turan et al. (2004); Aka et al. (2004)
	Levantine	Lebanese coastal waters	Landings data	Bariche et al. (2006, 2007)
	Gulf of Tunis	Inshore waters of the Gulf of Gabes and the Gulf of Sousse	Acoustic & Egg Surveys data	Ben Abdallah & Gaamour (2005); Zarrad et al. (2006)
Western Mediterranean	Straits of Sicily		Acoustic surveys, ichthyoplankton surveys	Patti et al. (2000); García Lafuente et al. (2002); Cuttitta et al. (2003); Patti et al. (2004, 2005); Bonanno et al. (2005)
	Adriatic Sea	Italian part	Landings data, Acoustic Surveys data	Cingolani et al. (1996); Azzali et al. (2005); Leonori et al. (2007a, b)
		Croatian part	Acoustic Surveys data	Ticina et al. (2005)
	Gulf of Lions	Gulf of Lions	Acoustic surveys	Abad et al., 1998; Guennegan et al. (2000); Alemany et al. (2002); Palomera et al. 2007;
	Catalan Sea	Catalan Sea; Ebro shelf	Acoustic surveys, ichthyoplankton surveys	Abad et al. (1998); Giraldez & Alemany (2002); Giraldez et al. (2007); Palomera et al. (2007)

nursery grounds. Furthermore, regions assigned as potential habitat could be used in adapting management decisions such as spatial zoning, defining and delimiting Marine Protected Areas (MPAs). Improvement of such a model with data from other areas, along with the availability of satellite data from international databases, can allow the historical or real time estimation of anchovy potential distribution grounds, the estimation of spatialized indicators (Freon et al., 2005; Babcock et al., 2005) and the implementation of a precautionary ecosystem approach to fisheries management (i.e. the estimation of spatial interactions between small pelagics, top predators and fisheries).

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