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RESEARCH PAPER

Environmental Influences on the Spatio-Temporal Distribution of European Hake (*Merluccius merluccius*) in Izmir Bay, Aegean Sea

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Abstract

In Izmir Bay, Aegean Sea, the influence of abiotic environmental factors besides depth and fishing pressure on the spatio-temporal distribution of European hake, *Merluccius merluccius* L. 1758, abundance were analysed using a Generalized Additive Model (GAM), with the Catch Per Unit Effort (CPUE) as the response-dependent variable and a Geographic Information System (GIS) software-based approach to display relationships. Data were collected on a monthly basis from 2007-2009 using a conventional bottom trawl net in Izmir Bay.
European hake is mostly abundant in Izmir Bay during summer and early autumn temporally (particularly during September) and spatially, in the region to the north of Uzunada Island and between the east coast of the island and the centre of the bay. GAM models also demonstrated that higher European hake abundances were located in waters of >50 m in depth with Sea Bottom Temperature (SBT) values ranging from 14.5-19 °C and Sea Bottom Salinity (SBS) values >38.55. In addition to this, the effects of fishing pressure were clearly evident throughout the area where bottom trawling is permitted. A better knowledge of the changes in spatio-temporal distribution of the species will allow the improved management of this important resource.

Keywords: European hake, Izmir Bay, spatio-temporal distribution, GAM, GIS.

Ege Denizi, İzmir Körfezi'nde Bakalyaro (*Merluccius merluccius*) Zaman-Mekansal Dağılımı Üzerine Çevresel Etkiler

Özet

Ege Denizi, İzmir Körfezi'nde bakalyaro *Merluccius merluccius* L. 1758, bolluğunun zaman-mekansal dağılımı üzerinde abiyotik çevresel faktörler, derinlik ve yanısıra balıkçılık baskısının etkisi, tepki-bağımlı değişken olarak birim av gücü (CPUE) ile birlikte Genelleştirilmiş Katkı Modeli (GAM) kullanılarak analiz edilmiş, ilişkileri açığa çıkarmakta yazılım tabanlı Coğrafi Bilgi Sistemi (CBS) kullanılmıştır. Veri İzmir Körfezi'nde geleneksel dip trol ağı kullanılarak 2007-2009 yılları arasında aylık olarak elde edilmiştir.

Bakalyaro, İzmir Körfezi'nde zamansal olarak; yaz boyunca ve sonbaharın başlarında (özellikle Eylül ayında), mekansal olarak; Uzunada Adası'nın kuzeyindeki bölgede ve adanın doğu kıyısı ile körfezin merkezi arasında en bol miktardadır. GAM sonucuna göre; yüksek değerdeki bakalyaro bolluğu >50 m derinlik ile birlikte 14,5-19°C arasındaki deniz tabanı sıcaklık ve >38,55 deniz tabanı tuzluluk değerlerine sahip sularda tespit edilmiştir. Buna ek olarak, balıkçılık baskısının etkisi dip trol avcılığının izin verildiği bölgede açık bir şekilde belirgindir. Türlerin zaman-mekansal dağılımındaki değişikliklerin iyi bilinmesi, bu önemli kaynakların yönetiminin geliştirilmesine imkan sağlayacaktır.

Anahtar Kelimeler: Bakalyaro, İzmir Körfezi, zaman-mekansal dağılım, GAM, CBS.

Introduction

The European hake *Merluccius merluccius* is one of the most economically important trans-boundary species in the Mediterranean and Atlantic. It constitutes the main target of small-scale fisheries and an important component of the fish assemblages exploited by bottom trawlers on the continental shelf in almost all Mediterranean countries (Abella *et al*., 2005). The species is fished with a variety of fishing gears (Stergiou *et al*., 2003) at depths from less than 50 m to more than 500 m (Erzini *et al*., 2001).

In Turkey, hake is of great commercial value and is one of the main target species of the commercial fisheries. The last Turkish official statistics (TUIK year?) showed that hake landings were 676 tons in 2013, of which 253.9 tons were harvested from the Aegean Sea. Hake is one of the most captured species in small-scale fishing fleets in the coastal side of the Aegean Sea. Izmir Bay is one of the most productive bays of the European hake fishery, however, there is a heavy fishing pressure on the European hake population, and the high exploitation rate appears to confirm this conclusion (Gurbet *et al*., 2013). Thus, hake plays an important role in the local micro-economy by the volume of catch and its high price.

The study area, Izmir Bay, is one of the most important fishing areas of the Aegean Sea (Figure 1). Studies on the European hake populations in Izmir Bay are relatively scarce while various aspects of their biology (Uçkun *et al*., 2000; Uçkun *et al*., 2006) and gear selectivity (Özbilgin *et al*., 2005; Aydın *et al*., 2007) have been documented. In Izmir Bay, all types of trawling are prohibited to the south-east of the line between Ardıç Cape and Deveboynu (Figure 1). It is becoming clear that studies on spatio-temporal fish distribution models must explicitly progress along with the increasing fishing pressure; particularly as environmental forecasts become increasingly accurate. Additionally, bottom trawling is prohibited from the 1st of April to the 15th of September to the north of the line where trawling is allowed (Anon, 2006). According to Turkish Fishery Regulations, the minimum landing size is 25 cm TL for European hake. However, the spatio-temporal distribution of the European hake has not yet been examined in relation to abiotic environmental factors (SBT and SBS), depth and fishing pressure.

Environmental influences are usually considered as the major factors that control the spatio-temporal distribution of fish populations. Once the environmental factors have been identified, the relationship between the environment and species needs to be specified (Planque *et al*., 2011). Environmental factors that vary according to the geographical location affect the water temperature, which may also be an indicator of other temperature-related environmental factors (for instance ocean circulation, which, in turn, determines food availability). Fish-environment interactions are complex and may be affected simultaneously by several conditions and variables. Thus, both free-ranging and experimental studies have shown that fish distribution is influenced by a variety of biotic and abiotic factors, such as temperature and food availability (Zheng *et al*., 2002). The distribution patterns of fish result primarily in the species' response to their physical environment (Laevastu and Hayes, 1982; Perry and Ommer 2003).

Knowledge of the environmental factors that influence the spatio-temporal distribution of fish can help to understand the ecological basis of adaptive behaviour, and it is critical to successful fisheries management since failure to recognize spatio-temporal complexity has resulted in stock collapses (Hilborn and Walters, 1992). An understanding of how the distribution of heavily exploited European hake within Izmir Bay is influenced by environmental factors and pressure is vital to the implementation of an ecosystem approach to fisheries management. In this study, we evaluated the results of the trawl surveys together with environmental data and questioned the effects of each of these factors in the spatio-temporal distribution of hake in Izmir Bay, Aegean Sea. The hypothesis that the spatio-temporal distribution of commercially important European hake is related to abiotic environmental factors, to bathymetry and to geographic location and associated variability within the Izmir Bay ecosystem is examined.

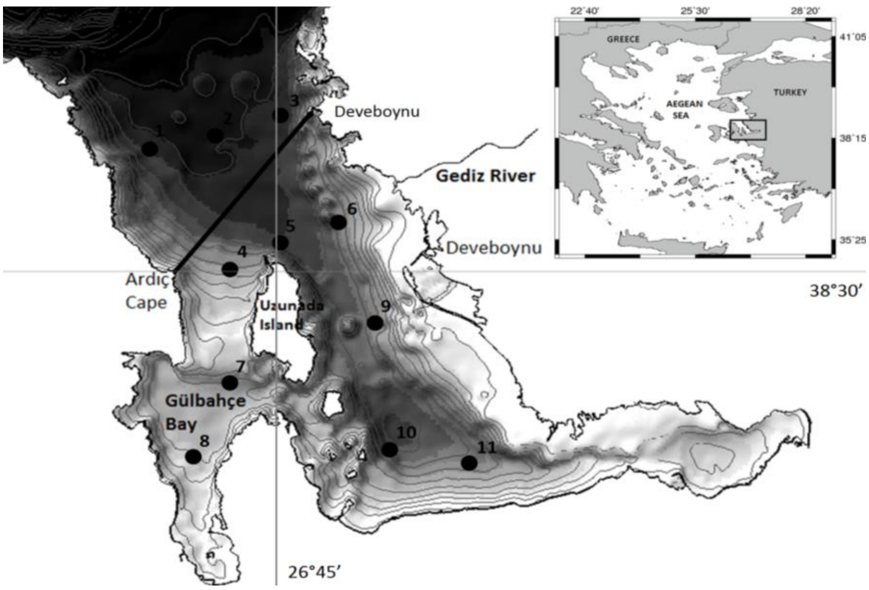


Figure 1. Studying area, Izmir Bay.

Materials and Methods

The study area, Izmir Bay, is one of the most important fishing areas of the Aegean Sea, which is a region of special interest for the oceanographic community (Figure 1). The analyses were based on sampling and conducted at fixed stations using CTD sensors, and individuals were collected during bimonthly experimental demersal trawling by '*R/V EGESUF*' between 2007 and 2009. Sampling was carried out using a conventional bottom trawl net with a 44-mm codend mesh size in both fishing prohibited/allowed areas for trawlers (Figure 1). The average width of the trawl mouth opening was 40 m, as standardized with a catch control system. A total of 11 fixed stations with depths from ~20 m to ~75 m were sampled according to their physical features (Figure 1). Sampling took place only during daylight hours. The duration of each haul was 1 h with a vessel speed of 2.5 knots. Fishing performance (CPUE) was defined as the number of individuals caught per hour (N h^{-1}) of trawling, and it was considered a relative measure of population density. All the individuals were measured to the nearest cm in TL.

ArcGIS has powerful functions for integrating and overlaying spatially referenced datasets for different variables from different time periods, potentially revealing relationships. In this study, GIS was used to display the relationships between the spatio-temporal patterns of European hake relative abundance data (CPUE) and abiotic environmental factors (SBT and SBS) by overlaying the different layers of information. Borders of fishing prohibited/allowed areas data were imported into the GIS as georeferenced data (Latitude and Longitude).

GAM-selected statistical models can serve as an indication of reference or association for the selected environmental variables (Austin, 2007; Dalamas and Megalofonou, 2012). The European hake predicted abundance indices from the GAM analysis were used to construct density distribution maps for the monthly abundance. It is a non-parametric method for determining the shape of the response curves from the data, instead of fitting a priori parametric model, which is widely applied in fisheries science (Zuur *et al.*, 2007).

The expected values of CPUE (values of response variable) in each haul were related to the spatio-temporal and environmental covariates, according to the following general formulation:

$$g(E[\mathrm{CPUE}_i]) = LP_i = \alpha + s_1(X_1) + s_2(X_2) + s_3(X_3) \ldots + \varepsilon_i$$

where each explanatory variable X_i, fitted by means of a smoothing function $s_i()$ is represented using penalized regression splines and where, g is the link function, LP is the linear predictor, α is the population intercept and ε_i is the residual or the information that is not explained by the model (Zuur *et al*., 2007). Dynamics of fish populations are complex ecological processes affected by a multitude of inter-connected factors, whose effects are often nonlinear (Bjørnstad and Grenfell, 2001). Thus, the main advantage of GAM over traditional regression methods is its capability to model nonlinearities using nonparametric smoothers (Hastie and Tibshirani, 1990). One such smoother is the cubic spline smoother, *s*, applied separately on each factors. A GAM is the addition of different functions fitted to the independent variables in order to predict CPUE values. CPUE distributions are usually skewed and far from conforming to the assumptions accompanying the Gaussian distribution (Katsanevakis *et al*., 2009), nonlinear relationships and violation of the normality assumption means a GAM with a Poisson distribution (Zuur *et al*., 2007). For count data that are not overdispersed, GAMs using the Poisson distribution with a log link function are used (Swartzman *et al*., 1992; Maravelias and Papaconstantinou, 2003; Maravelias *et al*., 2007; Zuur *et al*., 2007).

In the present study, the function pairs were drawn by pairwise scatterplots for each pair of columns in a matrix. The plot suggested a clear, non-linear pattern between European hake abundance and environmental factors. The first row shows the relationship between the European hake and each of the continuous explanatory factors. In the pairplot, the upper diagonal panel shows the (absolute) correlations coefficient and the lower diagonal part the pair-wise scatterplots with a smoothing line (Figure 2). Based on the diagnostic residual plots of preliminary runs, we assumed a Poisson distribution accompanied by its canonical log-link function.

Izmir Bay is an ideal region for the applicability of GIS- and GAM-based spatio-temporal modelling to reveal relationships between environmental factors and the distribution of the species. To aid this task, a GIS model incorporating the observed fish distributions and environmental pressures was constructed. GAM were then used to investigate the relationships of the CPUE of European hake with environmental factors with the main aim being to draw inferences for the mechanisms that give rise to the spatio-temporal distribution of European hake during the study period. Multiple Smoothing Parameter Estimation by Generalized Cross Validation (mgcv) package (Wood, 2000) implemented in R software (R Development Core Team, 2010) was used to fit the GAM. A series of GAMs of increasing complexity were constructed to model the distributional abundance of European hake using CPUE as a proxy for total fish biomass. Data were fitted with respect to the partial residuals (i.e., the residuals after removing the effect of all predictor variables). A detailed description of how GAMs are fitted to the data in relation to the algorithms used can be found in Hastie and Tibshirani (1987) and Wood (2006). All available environmental factors and their first order interactions were initially included in the model. Latitude and Longitude were used as a measure of spatial location. The explanatory variables

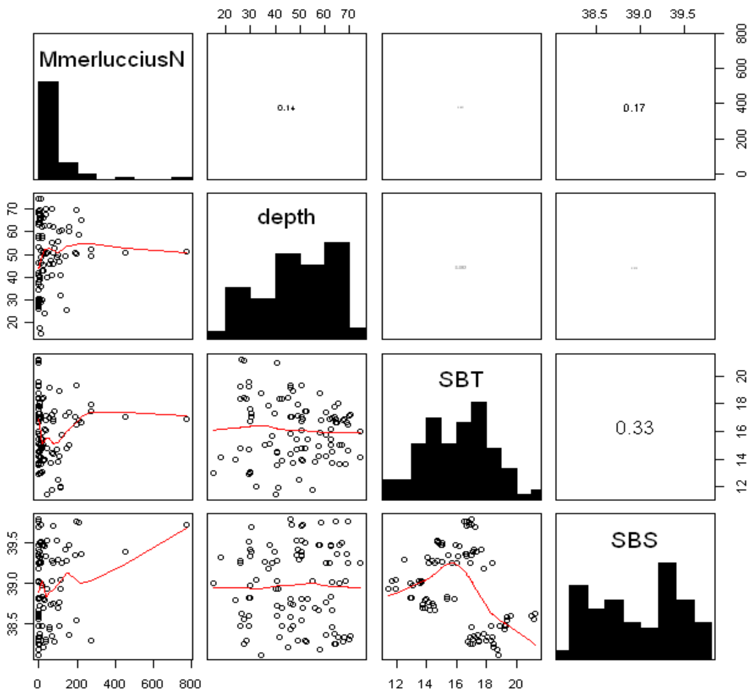


Figure 2. Pairplot of the European hake and selected explanatory variables. In the pairplot, the upper diagonal panel shows the (absolute) correlations coefficient and the lower diagonal part the pair-wise scatterplots with a smoothing line. The font size is proportional to the value.

included in the analysis were used (*i*) Latitude; (*ii*) Longitude; (*iii*) Depth; (*v*) SBT; and (*vi*) SBS. Apart from the fishing area (allowed/prohibited), fishing time (allowed/prohibited) and month were also considered as nominal (unsmoothed) variables. Stepwise model selection was used to select a set of significant variables. This process starts with an arbitrary object and takes a step by adding or removing that term from the current model that reduces the Akaike information criterion (AIC) the most (Hastie and Tibshirani, 1990).

The AIC statistic accounts simultaneously for the degrees of freedom used and the goodness of the fit (AIC = D + 2 * *df* * φ; where D is the deviance, *df* is the degrees of freedom in the fit and φ is an estimate of the dispersion parameter). The process stops when no step decreases the AIC criterion further (Chambers and Hastie, 1992; Planque *et al.*, 2007), indicating the best fitting model. The smooth terms can be functions of any number of covariates. By Poisson default, the smoothness selection for the model was performed using the Un-biased Risk Estimator (UBRE; Craven and Wahba, 1979; Wood, 2006). The degree of smoothness was determined on the basis of the observed data. The problem of smoothing parameter estimation was solved by the (mgcv) package using the UBRE, which is effectively just a rescaled AIC that is only used when the scale parameter is known (poisson or binomial families; Wood, 2006). The selected model has a slightly lower UBRE score, suggesting that it is to be preferred (Wood, 2006). The reduced computations allow fast automatic selection of the smoothing parameters using the UBRE criterion. Smoothing parameters were chosen to minimize the UBRE score, which is used to find the best model with the highest accounted deviance (0–100%) using the simplest splines. The UBRE criterion $d/n + 2*s*df/n - s$ where d is the deviance, n the number of data, s the scale parameter and df the effective degrees of freedom of the model. The environmental factors can be ranked according to the above criteria, so that the best model can be selected. The fitted models for European hake were again selected on the basis of level of deviance (the higher the better), UBRE (the lower the better) and AIC scores (the lower the better) explained.

In order to assess the effects of the explanatory variables on European hake abundance, the fitted contribution of each covariate of the GAM to species abundance were plotted against the value of the variable. In order to detect model misspecification, validation graphs such as residual plot vs. fitted values, Quantile-Quantile plot (QQ-plot) and residual plot against the original explanatory variables and histogram of residuals were checked.

Results

The results of the study supported the hypothesis that European hake distribution is related to abiotic environmental conditions, to bathymetry and to geographic location. The distribution maps of survey data sets were processed in the GIS database and mapped. In the bay, four distinct water masses with different features and classified as Aegean Sea water, Izmir Bay water and Izmir Bay inner water and Gülbahçe water were characterized. The spatial patterns of SBT and SBS showed seasonal changes and also showed a well-defined boundary between Aegean Sea water, Izmir Bay water and Gülbahçe water (Figure. 3 and Figure 4). Both increment and decrement of environmental factors first depended on the depth and water circulation. In the northern part of the bay including the Aegean Sea water, the SBT warmed up and there was an increase in SBS in the summer. Indeed, sea bottom temperature cooled and salinity decreased at slower rates in the winter compared to the water in the other regions. The SBT decreased in the summer throughout the eastern side from the south to north and vice versa in the winter, while the SBS increased in the summer throughout the eastern side from the south to north and vice versa

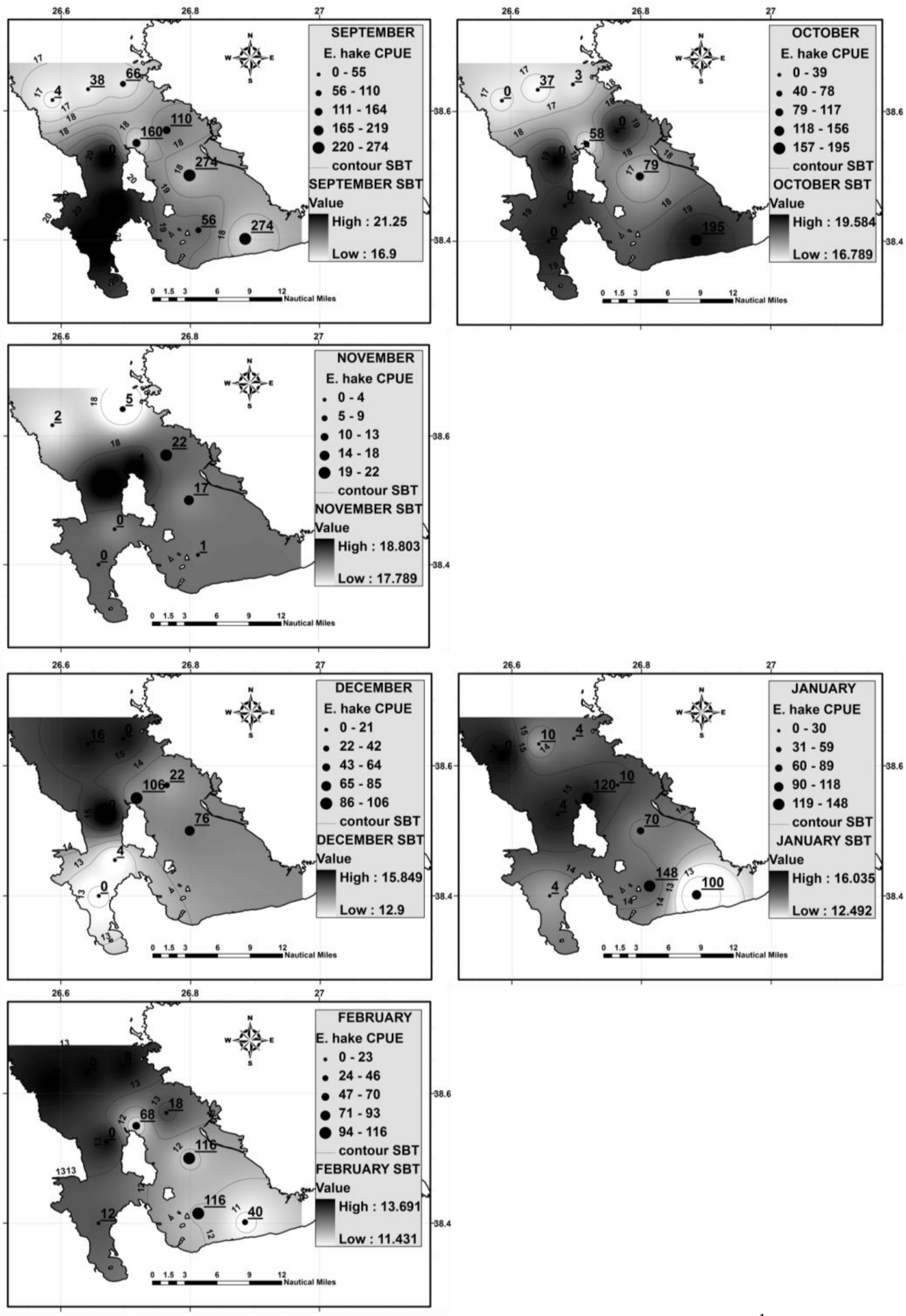
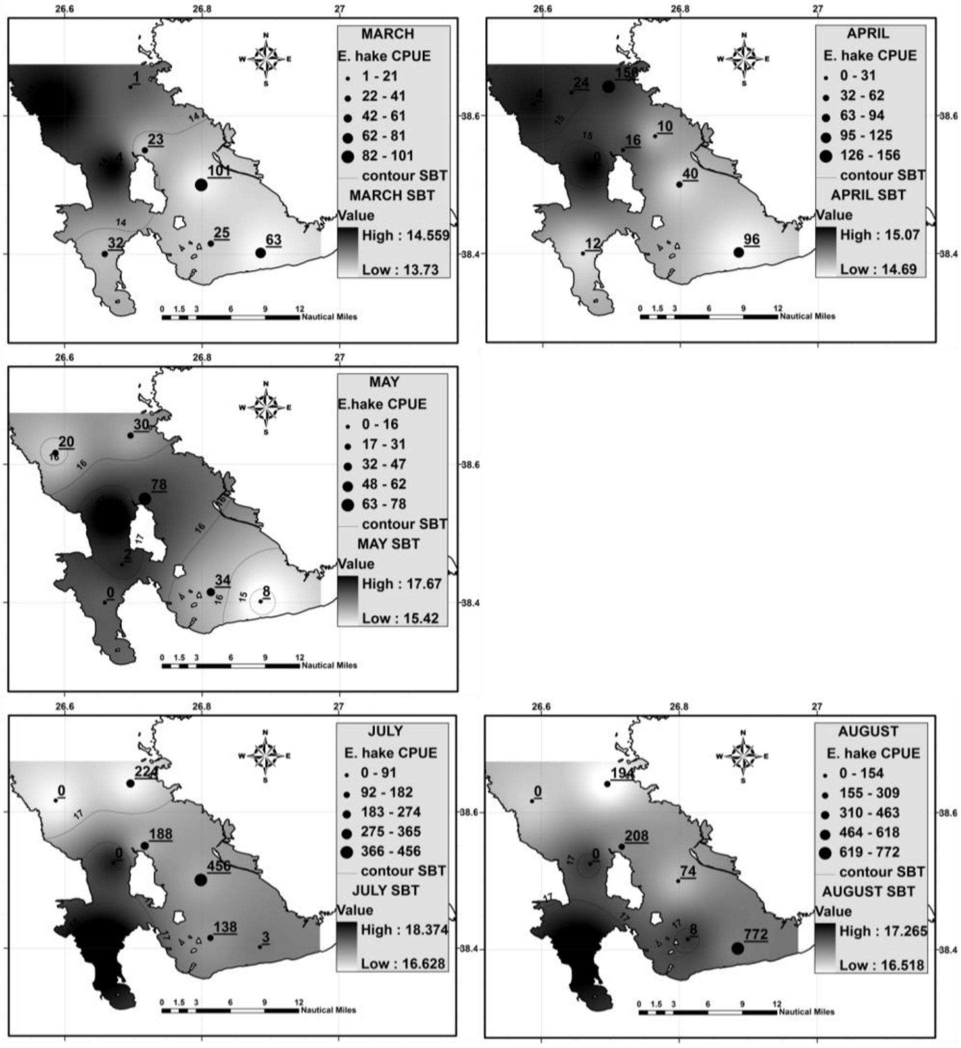


Figure 3. Monthly distribution of SBT, additionally European hake according to the CPUE (N h^{-1}).



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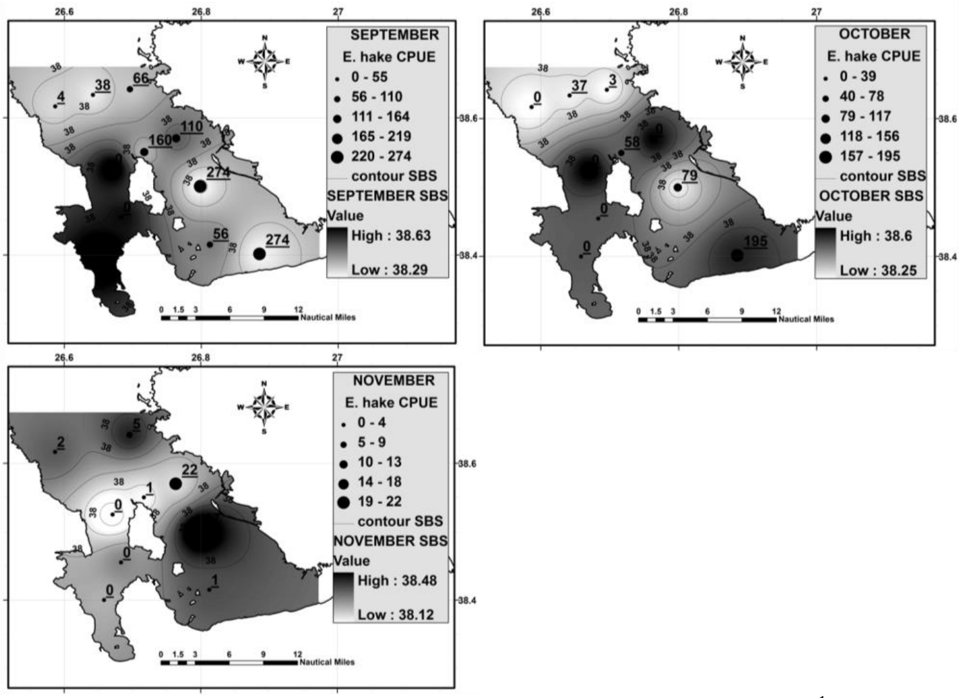

Figure 4. Monthly distribution of SBS, additionally European hake according to the CPUE (N h^{-1}).

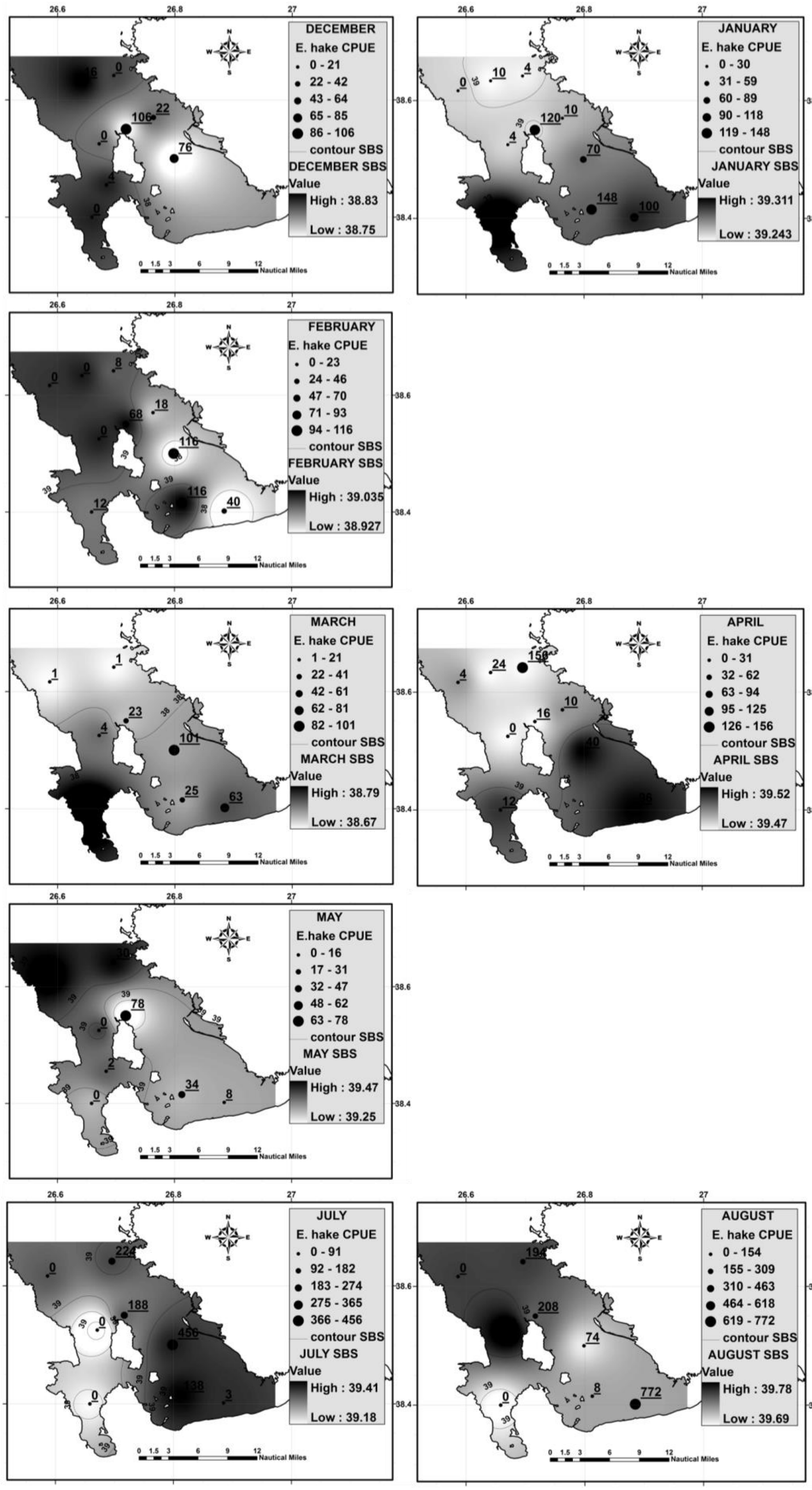

Figure 4. Continued.

in the winter (Figure. 3 and Figure 4). The seasonal variation of water properties in the Aegean Sea influenced the Izmir Bay water properties.

In summer and early autumn, the shallower Gülbahçe Bay was warmer and more saline than the other regions of the bay because of strong evaporation. While the colder and less saline Aegean Sea water had a greater influence in the northern part of the bay, other parts of the study area were dominated by Izmir Bay local water. Seasonal convective and turbulent mixing became important factors during the late autumn and winter and, thus, the northern part of the bay was warmer and less saline than Gülbahçe Bay and the rest of the study area. In the early spring, the bottom layer exhibited winter characteristics, while in the late spring it had summer characteristics (Figure 3 and Figure 4). April and October were characterized as transient months between winter and summer (Figure 3 and Figure 4).

The distribution and relative abundance of European hake (CPUE) is presented as seasonal clusters (Figure 5), and the distribution values of temperature and salinity over the bottom are shown in the raster maps (Figure 3 and Figure 4). The effect of temperature was pronounced in summer and autumn during periods of thermal stratification, whereas it was much less intense in winter when the thermocline was broken down (Figure 3). In a similar manner as the temperature patterns, the effect of salinity on European hake abundance was more intense during summer and autumn and much less intense in winter (Figure 4).

The highest abundance was detected along the east coast (except at the 6th station which is affected by the Gediz River) during summer and in early autumn. Abundances were lower during winter and even lower during the spring months. The lowest abundances were observed along the west coast (Figure 5) due to the shallow water depth (Figure 1) and prevalent water properties (Figure 3 and Figure 4). The size distribution of European hake caught in the bay in different seasons is shown in. In spring, the main peak was at 28–30 cm (>15%); however, the distribution also suggested a bimodal shape, with a first peak corresponding to the cohort reached around 6–8 cm (>5%) as observed in the figures. A unimodal distribution with a peak at 18–20 cm (>15%) was observed during the summer. In the autumn and winter, the distribution remained unimodal with the peaks shifting to 20–24 cm (>15%) and 28–30 cm (>15%), respectively.

In the spring, the main peak in size at 28–30 cm is also associated with a bimodal shape distribution, with a hinted first peak to the left of the main one corresponding to the main cohort reached around 6–8 cm. This may correspond to the beginnings of the recruitment of the individuals born in winter. In winter, smaller individuals were observed especially north of Uzunada Island (~60 m) and around station 3 (~75 m), while fewer larger individuals (30–34 cm; >15%) were observed in Gülbahçe Bay and also around stations 9–10 and 11 (28–30 cm; >15%) in the late winter and early spring. In Izmir Bay, Çoker (2003) reported that European hake eggs were

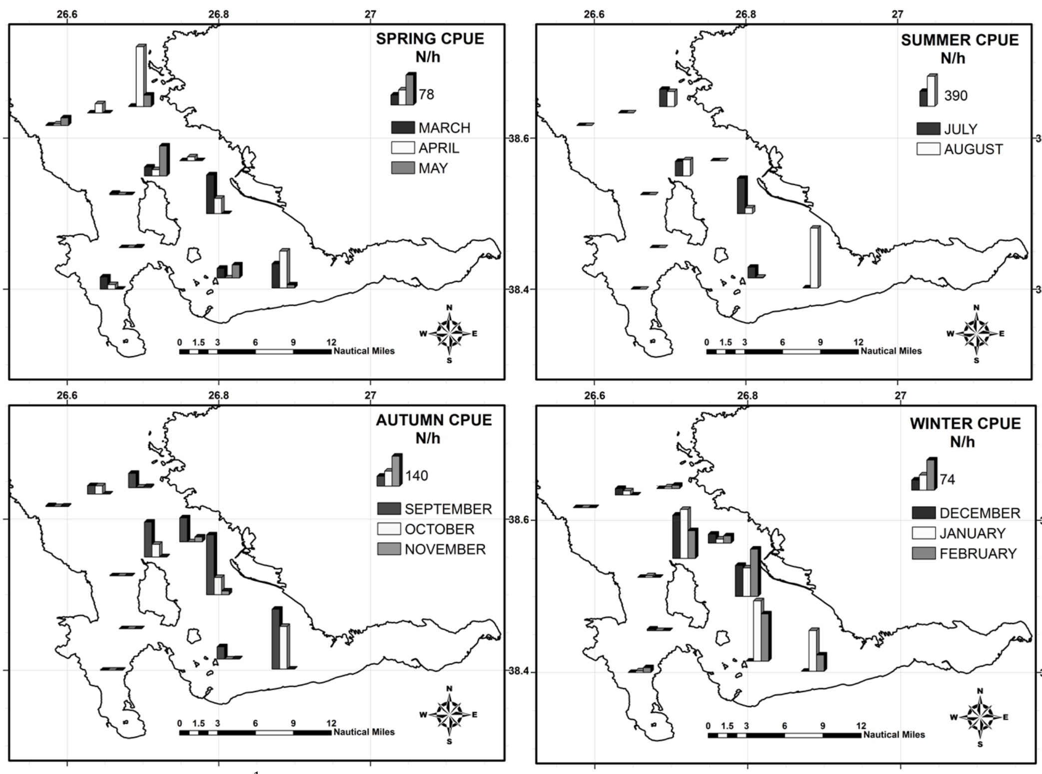

Figure 5. Observed CPUE (N h^{-1}) values present by seasonal clustering; (a) spring, (b) summer, (c) autumn and (d) winter.

obtained in the winter and summer, while larvae were attained in the spring, summer and autumn. Additionally, the depth of spawning and larval distribution has been reported between 45–75 m (Çoker, 2003). During the summer, the distribution is unimodal with a peak at 18–20 cm (>15%). In the autumn and winter, the distribution remains unimodal, with the peak shifting to 20–24 cm (>15%) and 28–30 cm (>15%), respectively. The shallower Gülbahçe Bay was associated with fewer but larger European hake in the late winter and early spring.

Fishing-prohibited time, which is a nominal explanatory variable, was found to be non-significant and it was removed from the model. The selected model with the best GAM and the lowest AIC, included the following parameters as the main effects: depth, geographical location (Latitude and Longitude), SBT and SBS as well as the month and fishing area (allowed/prohibited) as nominal (unsmoothed) explanatory variables described in Table 1. All variables selected in the model were statistically significant (P<0.000).

The best GAM with the lowest AIC for European hake was of the following form:

CPUE ~ α + s_1(depth) + s_2(SBT) + s_3(SBS) +

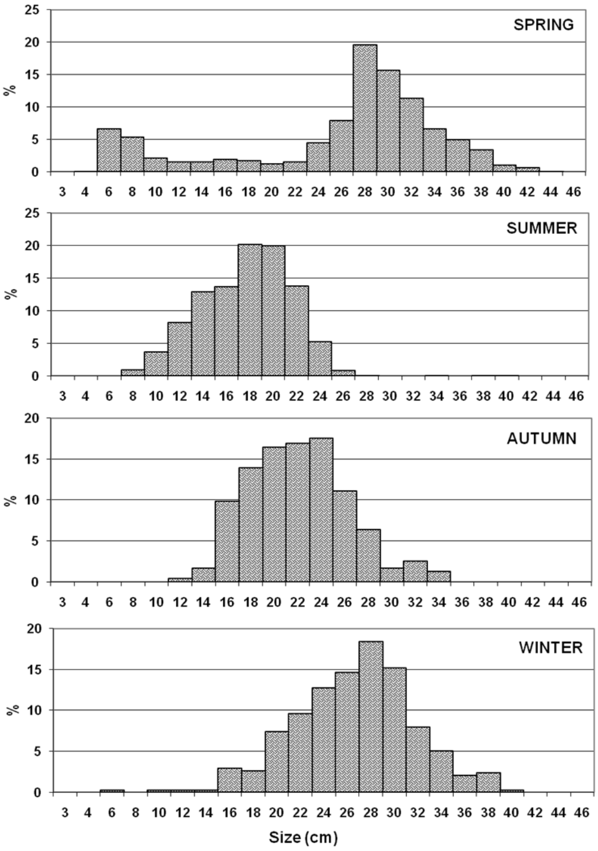

Figure 6. Size distributions of individuals present by seasonal in Izmir Bay; (a) spring, (b) summer, (c) autumn and (d) winter.

Table 1. Analysis of deviance for GAM covariates and their interactions of the best GAM fitted.

Parameter	Res. Df	Res. Deviance	Deviance explained %	UBRl
Null model	98	11807.2		118.2
s(Depth)	89.1	8001.7	32.2	80.02
s(Depth) + s(Lon)	80.37	4375.1	62.9	43.56
s(Depth) + s(Lon) + s(Lat)	71.71	3595.6	69.5	35.87
s(Depth) + s(Lon) + s(Lat) + s(SBT)	62.82	2831.9	76	28.33
s(Depth) + s(Lon) + s(Lat) + s(SBT) + s(SBS)	53.37	2009.7	83	20.22
s(Depth) + s(Lon) + s(Lat) + s(SBT) + s(SBS) + fishing area	52.09	1794.7	84.8	18.07
s(Depth) + s(Lon) + s(Lat) + s(SBT) + s(SBS) + fishing area + month	42.16	1246.6	89.4	12.74
Total variation % explained			89.4	

Level of significance was set at 0.05. Res. Df = residual d.f.; Res. Deviance = residual deviance; AIC = Akaike Information Crit
P-value (chi-square) = significance values

s_4(Lat) + s_5(Lon) + month + fishing area + ε_i

In the model, all smoothing functions s_1, s_2, s_3, s_4 and s_5 are penalized cubic regression splines. When two models were equivalent, the model with the fewest environmental factors was retained (Koubbi *et al*., 2006). Inference tests for the selection of variables that explain a significant portion of the variance, or deviance in the case of maximum likelihood estimation techniques, are similar for all regression models, mainly the Chi-square (χ^2) tests in the case of GAMs (Guisan *et al*., 2002; Cantoni and Hastie, 2002). Significant levels for the added predictors were estimated by means of the χ^2-test and the level of significance was set at 95%.

The statistical analyses suggested the following relationships for each factor examined. Cross-validation was used to estimate the optimal degrees of freedom. The 'best' model for European hake CPUE was again selected on the basis of level of deviance (89.4%) scores explained. The result of the GAM is presented in Figure 7. The spline GAM plots show that there are significant relationships demonstrated between explanatory variables and the European hake distributional abundance. The plot of location (Latitude and Longitude) revealed that the species abundance was highest to the south of ~38.6º N (Figure 7A) and to the east of ~26.7º E (Figure 7B) in Izmir Bay. The permitted use of bottom trawling for six months a year north of ~38.6º N may account for the low numbers of European hake in this area. Additionally, the location west of ~26.7º E is associated with low hake abundance due to depth factors. The plot of depth indicated a higher probability of European hake abundance in regions of Izmir Bay that are deeper than 50 m. Peak abundances occurred at 65 m and then gradually decreased below ~75 m and increased afterwards (Figure 7C). In the study area, deeper waters were found to be associated with high European hake abundances and vice versa for shallow waters. SBT effects on European hake distribution were clearly visible by their high abundance in waters of ~14.5–19 °C. For SBT, a multimodal response including peaks at 15, 16.5 and 19 °C was associated with high abundances. The lower SBT limit is evident, with a sharp decline in negative coefficient values beyond 19 °C (Figure 7D). In the study area, European hake perform seasonal and even monthly movements in search of more suitable environmental conditions. The SBT, which is one of the main and interactive effects on European hake distribution, was found to have highly significant covariates particularly in the late spring and summer. An influence of SBS on the potential distribution of European hake was also observed. The upper SBS limits could not be clearly defined as the coefficient did not decrease towards a value significantly less than zero. The lower SBS limit was evident with a decline in coefficient values below 38.25. For SBS, the response was bimodal with a main peak at 39 and the other at 39.5 (Figure 7E). In Izmir Bay, the lower European hake abundance was

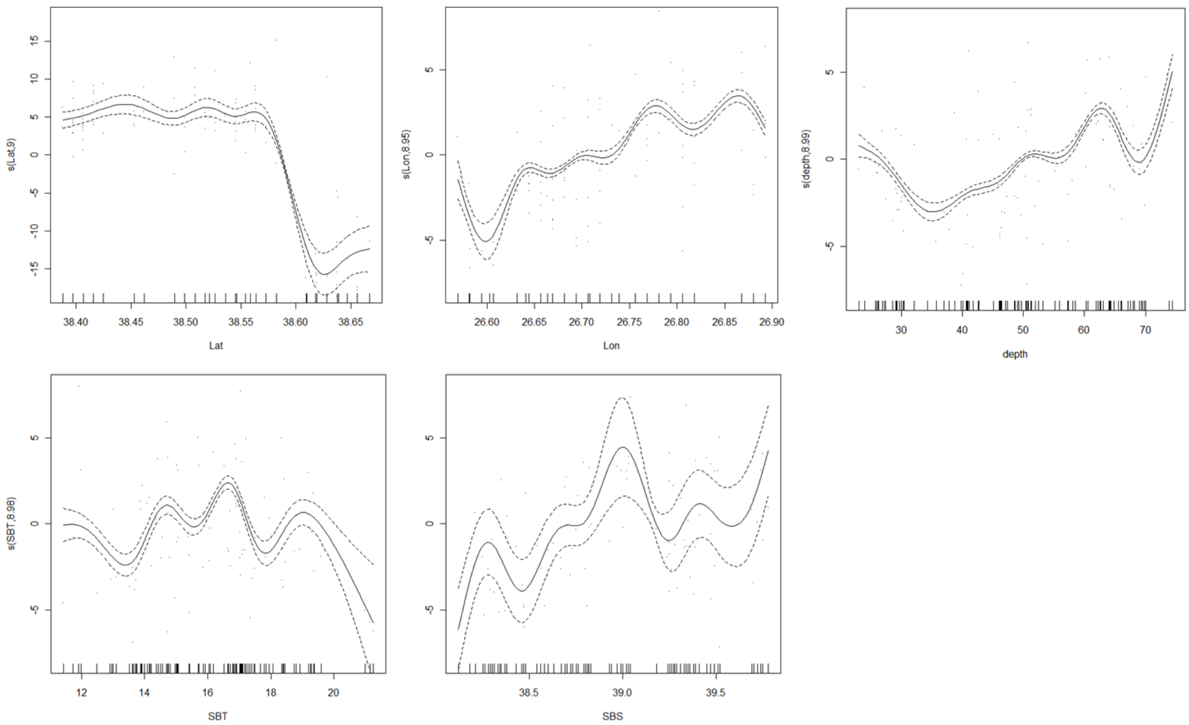

Figure 7. Coefficients of the Generalized Additive Model (GAM) for European hake against additive terms of Latitude (a) and Longitude (b), depth (c), SBT (d) and SBS (e). Dashed lines indicate the value of GAM coefficient, dotted line are the 95% confidence intervals at P<0.05.

associated with warm and less saline bottom waters.

The map of the spatial predictions showed that European hake were closely distributed with relation to explanatory variables. There were three distinct areas of high-CPUE (Figure 8), including the first on the northern side of the Uzunada Island, the second on the east coast of the island up to the centre of the bay and afterwards concentrated in the centre of the bay. Temporally, the species was found to be more abundant in the summer and early autumn mainly in September (Figure 8).

Discussion

Coastal habitats of fish are a combination of environmental factors that explain their distribution, with their presence linked to suitable conditions and density to optimum environmental conditions (Koubbi

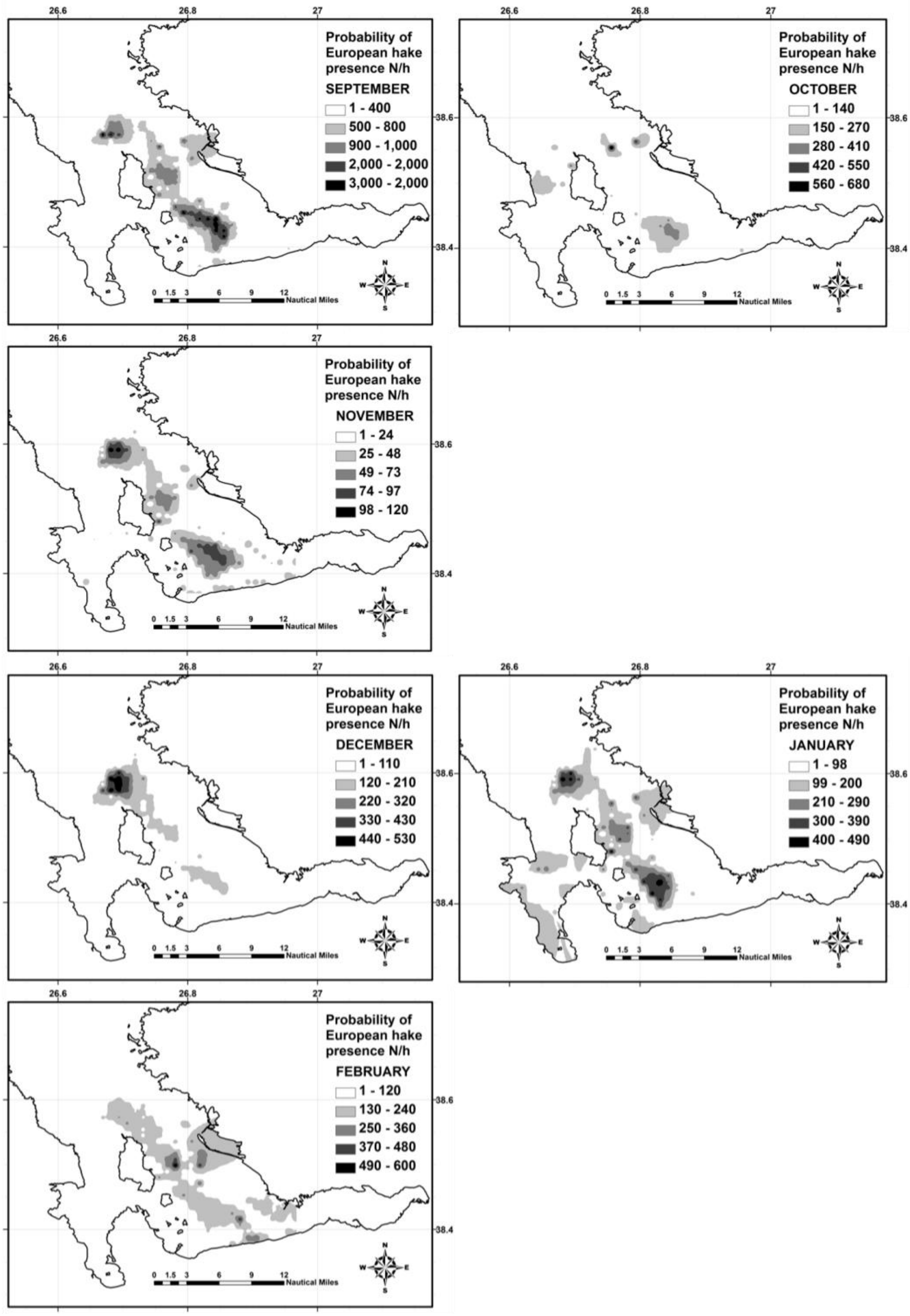

Figure 8. Monthly spatial distribution of predicted European hake CPUE based on the best GAM fitted.

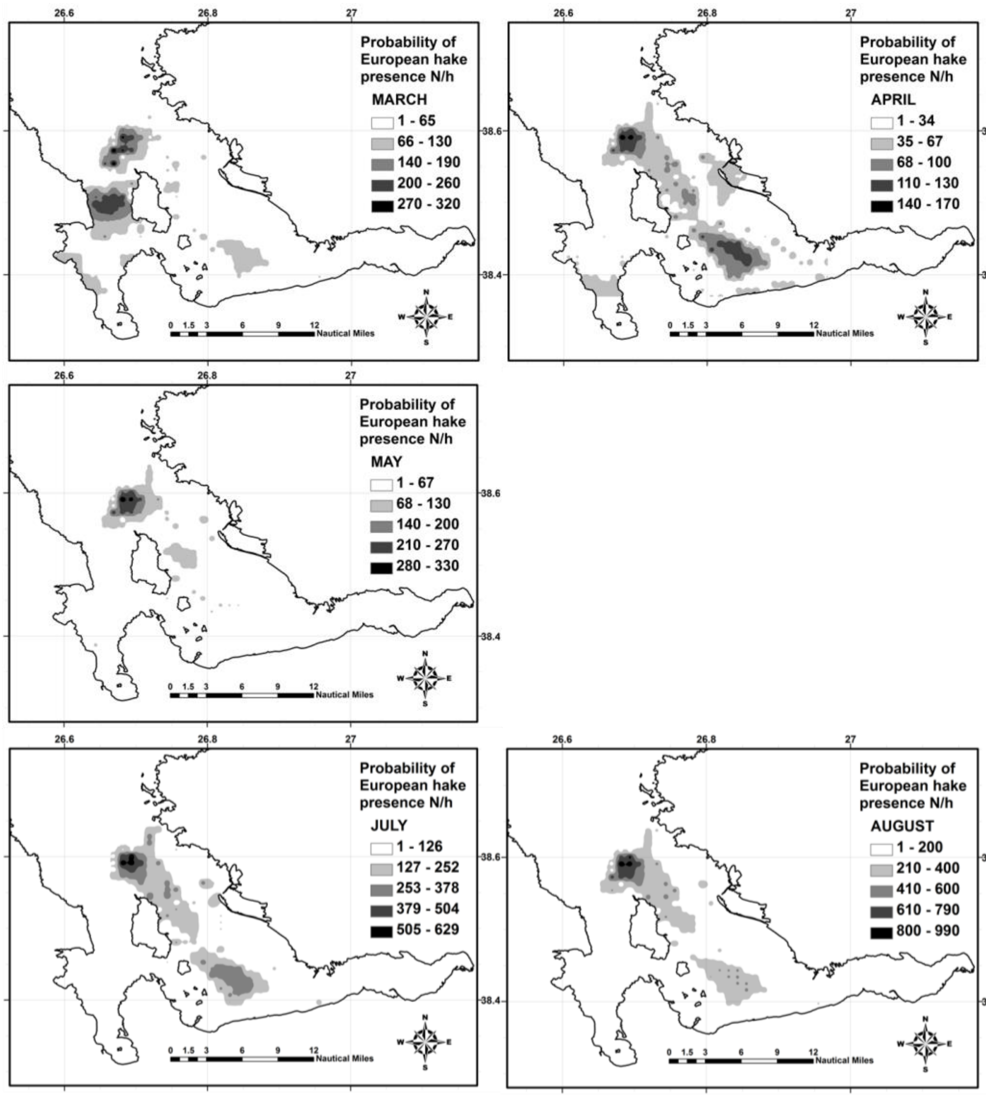

Figure 8. Continued.

et al., 2006). If European hake and abiotic environmental parameters are sampled simultaneously, they can provide information about the relationship between the distribution of fish and these parameters.

In Izmir Bay, throughout the year, the spatial distribution of the best GAM model predicted European hake abundances to be higher in transition zones between different waters and lower in stratified waters. It was predicted that the abundances of European hake first aggregated on the northern side of Uzunada Island. One possible explanation for the aggregation of European hake in the area could be the hydrological regime and the local anticyclonic eddies. Wind-driven circulation causes cyclonic or anticyclonic circulation movement on the eastern side in the middle of Izmir Bay (Sayin *et al*., 2006). These eddies affect water flow, increase the degree of mixing and are responsible for increased food availability in this region, resulting in the aggregation of the species throughout the year. On the other hand, winds from a southerly direction prevent the Aegean inflow into the bay and force upwelling conditions near the east coast of Uzunada Island (Sayin *et al*., 2006). Nutrient enrichment results in the presence of phytoplankton, and subsequent zooplankton growth provides feeding grounds for fish. It is assumed to be an important approach for the distributional abundance of European hake, which showed high concentrations on the east coast of Uzunada Island up to the centre of the bay.

Large-scale atmospheric cyclonic movements result in a water mass that has colder, less saline and less dense, and also oxygen-rich water, near the Aegean Sea boundary of Izmir Bay, particularly in the winter and summer (Sayin *et al*., 2006). In the boundary area, European hake abundance was low in the results of the model because of the fishing pressure, notwithstanding that the area is suitable for fish feeding and recruitment. It is necessary to consider all possible causes for the spatio-temporal distribution pattern of European hake, including the fisheries industry. Moreover, a river inflowing with cold and fresh water is one of the main sources of nutrients for the sea. Therefore, the highest abundance of the European hake was detected along the east coast, which is affected by the Gediz River during the summer and in early autumn.

The fish inhabit a depth range of ~20 to 75 m. In order to interpret the impact of environmental factors and fishing pressure on stock distribution within Izmir Bay, it is important to additionally consider the life stage of the fish, as sensitivity to environmental pressures may change accordingly. The GAM results could be used for selection and management of bottom trawling prohibited/allowed areas as stocks expand or contract in their distribution patterns. The present study also provides a useful management tool for local fishers and fisheries operations. In considering environmental factors, biotic factors (e.g., predator-prey interactions) are also important and should be evaluated together in future studies, which are required to confirm the consistency of the currently suggested distribution pattern throughout the year.

The bathymetry presumably exhibited both a main and an interactive effect on European hake abundance. The modelled potential distribution of the species is almost absent north of the ~38.6º N and west of the ~26.7º E due to the depth according to bathymetric structure. Our analysis shows that European hake are generally abundant at depths over 50 m, while they are rarely observed in shallower areas. Seasonal differences in the relative abundance of European hake were shown to be the same as in the model prediction map, which showed the highest hake abundance in the deeper regions and also in the fishing prohibited area. A common situation according to density peak throughout the time-series was that small European hake below a certain length were found in deeper water, and larger European hake preferred shallower water. The present study reveals that European hake actively seek more suitable environmental conditions in Izmir Bay. Additionally, there is a relationship between European hake length and depth of migration. The size distribution of European hake specimens caught in the bay in different seasons (Figure 6) implies that Izmir Bay provides favourable conditions for feeding and, presumably, spawning.

The Turkish Fishery Regulations have passed legislation on the trawl fishery in Turkey, which prohibits a variety of trawls to the south-east of the line between Ardıç Cape and Deveboynu in Izmir Bay (Figure 1). Additionally, bottom trawling is prohibited from the 1st of April to the 15th of September north of the line where trawling is allowed (Anonymous, 2006). GAM results indicated that the fishing prohibited/allowed time was not significant because illegal bottom trawling continues throughout the year. Smaller sizes than the legal minimum landing size of the species (<25 cm in TL) according to Turkish Fishery Regulations are permitted in fish markets during the prohibited time period. In this study, different life stages of European hake were found to inhabit Izmir Bay, ranging in total length (TL) from 6 to 30 cm (Figure 6).

Consequently, European hake spatio-temporal distribution generally follows the suitable environmental properties. Thus, establishing the process for the heavily exploited European hake population in Izmir Bay is a valuable tool for national fisheries management. The fisheries authority should make scientific preparations for the implementation of management measures including juvenile protection, area closures, square mesh and larger mesh sizes of trawl nets for this resource. Regulations on fishing area (allowed/prohibited) and fishing time (allowed/prohibited) should be redesigned based on this information.

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