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FISH HABITAT MAPPING

Identification of deep-water pink shrimp abundance distribution patterns and nursery grounds in the eastern Mediterranean by means of generalized additive modelling

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Abstract Generalized Additive Modelling (GAM) techniques were used to model the time series of abundance data of deep-water pink shrimp, collected during the MEDITS bottom trawl surveys carried out in the Greek seas from 1996 to 2006, as functions of the sampling location (longitude–latitude), depth and year. The life stages of the species were taken into account. All variables were highly significant, although latitude and depth had always the highest explanatory power. The total abundance was higher between 100 and 400 m of depth, with juveniles and adults being more abundant in the 100–200 m and 200–400 m depth strata, respectively. GAM prediction maps showed high abundance concentration areas for all life stages mainly in the Aegean Sea. The most important nursery ground identified was located in the Saronikos Gulf and a secondary in the Thracian Sea. Concerning the concentration areas of the adult specimens, they are located mainly in the Saronikos Gulf, the Thracian Sea, the Thermaikos Gulf, the Cretan Sea and the eastern part of the Aegean.

Keywords Deep-water pink shrimp · Mediterranean · Distribution · Nurseries · Generalized Additive Models

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Essential Fish Habitat Mapping in the Mediterranean

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Introduction

The deep-water pink shrimp *Parapenaeus longirostris* (Lucas, 1846) is a species of wide geographical distribution extending from the eastern Atlantic, in the north of Spain to the southern waters of Angola, to the whole of Mediterranean and its adjacent seas (Sea of Marmara) (Holthuis, 1980; Pérez Farfante & Kensley, 1997; Sobrino et al., 2005).

In the Mediterranean Sea, the bathymetric distribution of the deep-water pink shrimp ranges from 20 to 840 m (Tom et al., 1988; Politou et al., 2005). However, sandy-muddy bottoms between 100 and 400 m constitute the main distribution areas of the species (Holthuis, 1980; Sobrino et al., 2005). A size-related bathymetric distribution was observed for the deep-water pink shrimp, with juveniles (<20 mm Carapace Length) settling at shallower waters (mostly around 100–200 m) and larger individuals moving towards deeper waters (Mori et al., 1986; Ardizzone et al., 1990; D'Onghia et al., 1998; Politou et al., 2000; Abelló et al., 2002).

This species is the main target of a large fishing fleet operating in the eastern Atlantic. In the Mediterranean Sea, it is the fifth crustacean species in biomass landed and it is fished almost exclusively by trawl (Stamatopoulos, 1993). In Greece, it is widely fished in all the country and it presents the highest mean annual crustacean landings (1227 t) (Kapiris et al., 2007).

Due to its high commercial importance, a lot of information exists on its biology and ecology, which is summarized in Sobrino et al., 2005. However, there is a great lack of knowledge on the biological, ecological and exploitation aspects of the species in the Greek waters. Some information comes from experimental trawl surveys and it concerns its abundance, distribution, size structure, growth and mortality (MEDITS 1994–2006, INTERREG II Italy-Greece 1999–2001 and RESHIO 2000–2002 projects reports; Politou et al., 2000; Abelló et al., 2002) as well as its feeding habits (Labropoulou & Kostikas, 1999; Kapiris, 2004). The deep-water pink shrimp is a short-living epibenthic species with high abundance in the Greek waters (mainly in 100–500 m depth), and biomass usually higher in the 200–500 m depth stratum than in the 100–200 m stratum, in accordance with its depth related size trend. Its growth is fast, although comparatively slower to other Mediterranean areas (Sobrino et al., 2005), and its total mortality rate high. The presence of younger individuals in almost all seasons reinforces the hypothesis of continuous reproductive activity. Its diet is characterized by a large variety of preys, mainly small fishes, cephalopods and crustaceans. An evaluation of the exploitation state of this resource in the Greek waters indicates a general over- or full-exploitation (Kapiris et al., 2007; MEDITS, 2007). In order to contribute to a sustainable exploitation of the resource, the identification of its main nursery areas was recently attempted, based on nominal values obtained from a series of experimental bottom-trawl surveys (Fiorentino et al., 2002; Politou et al., 2006).

Within the same context and aiming to better understand the factors that might determine the spatial distribution and abundance of the deep-water pink shrimp, the present article focuses on the identification and analysis of the quantitative relationships between the abundance/distribution data time series and abiotic factors in the totality of the Greek waters, using Generalized Additive Modelling (GAM) techniques. The different life stages of the species are taken into account, and potential nursery grounds and adult concentration areas are mapped using the GAM estimates.

Materials and methods

Data were collected in the frames of the MEDITS program (International bottom trawl survey in the Mediterranean) carried out in the Greek seas (Aegean and Ionian Sea) from 1994 to 2006 (with the exception of 2002) and included density indices (DI) per trawling station expressed in terms of number of animals per square km (n/km^2). The first 2 years were not included in our analysis, since the sampling methods were not completely standardized. The MEDITS survey is accomplished once per year (summer) and covers all trawlable areas from 10 to 800 m of the Aegean and Ionian Sea with pre-defined sampling stations. Further details on the sampling protocol can be found in Bertrand et al. (2000, 2002). Based on literature information on size at first maturity (Sobrino et al., 2005), density indices were also estimated separately for adults (>20 mm CL) and juveniles.

The effects of trawling location and depth on DI (total, adult and juveniles) were examined by means of Generalized Additive models (GAMs). GAMs, which are able to deal with non-linear relationships between a dependent variable and multiple predictors in the same model, are non-parametric generalizations of multiple linear regression that are less restrictive in assumptions about the underlying distribution of data (Hastie & Tibshirani, 1990). In GAMs, a pre-defined link function is related to predictor variables by scatter-plot smoothers in lieu of least-squares fits.

In the present case, our non-linear components were fitted with a locally weighted regression scatterplot smoother (*loess* smoother, Cleveland & Devlin, 1988) by means of the S-PLUS software package following Venables & Ripley (1997). Based on the diagnostic residual plots of preliminary runs we assumed a Poisson distribution accompanied by its canonical log-link function. Apart from trawling location and the depth, the year parameter was also modelled as a categorical variable. Hence, four variables were included in the analysis: Year, Latitude (Lat), Longitude (Lon) and Depth. The GAM model was of the form:

$$DI = a + Year + lo_1(Lat) + lo_2(Lon) + lo_3(Depth) + e,$$

where a is a constant, lo_i is the *loess* smoother function of the corresponding independent variable and e is a random error term.

Variable selection proceeded by a stepwise forward entry and the Akaike Information Criterion (AIC) (Akaike, 1978) was used to detect the relative importance of each variable in explaining variations and determine the order of those that should be included in the final model. This approach resulted in parsimonious models that included only the most important variables, in terms of explanatory power. In addition, collinearity problems were avoided, as correlated variables were not included in the final models (Crawley, 2005). The AIC statistic accounts simultaneously for the degrees of freedom used and the goodness of fit. A smaller AIC statistic corresponds to a better model in the sense of smaller residual deviance penalized by the number of parameters that are estimated in fitting the model. At each stage of the forward entry, the AIC was computed for every candidate predictor not yet entered. The variable resulting in the highest AIC decrease was entered into the model. Forward entry continued until additional variables no longer yielded reductions in the AIC statistic. Significant levels for the added predictors were estimated by means of Chi-square tests and the level of significance was set at 95%.

The predicted DI values from the GAM analysis were used to construct density distribution maps for the pink shrimp in the Greek seas. Maps were generated using the SURFER software (Golden Software, 2002) and interpolation was made by means of the "inverse distance to a power" gridding method (Davis, 1986).

Results

Data from 1716 hauls were analyzed (Fig. 1). The three stepwise GAMs (total, adult and juveniles)

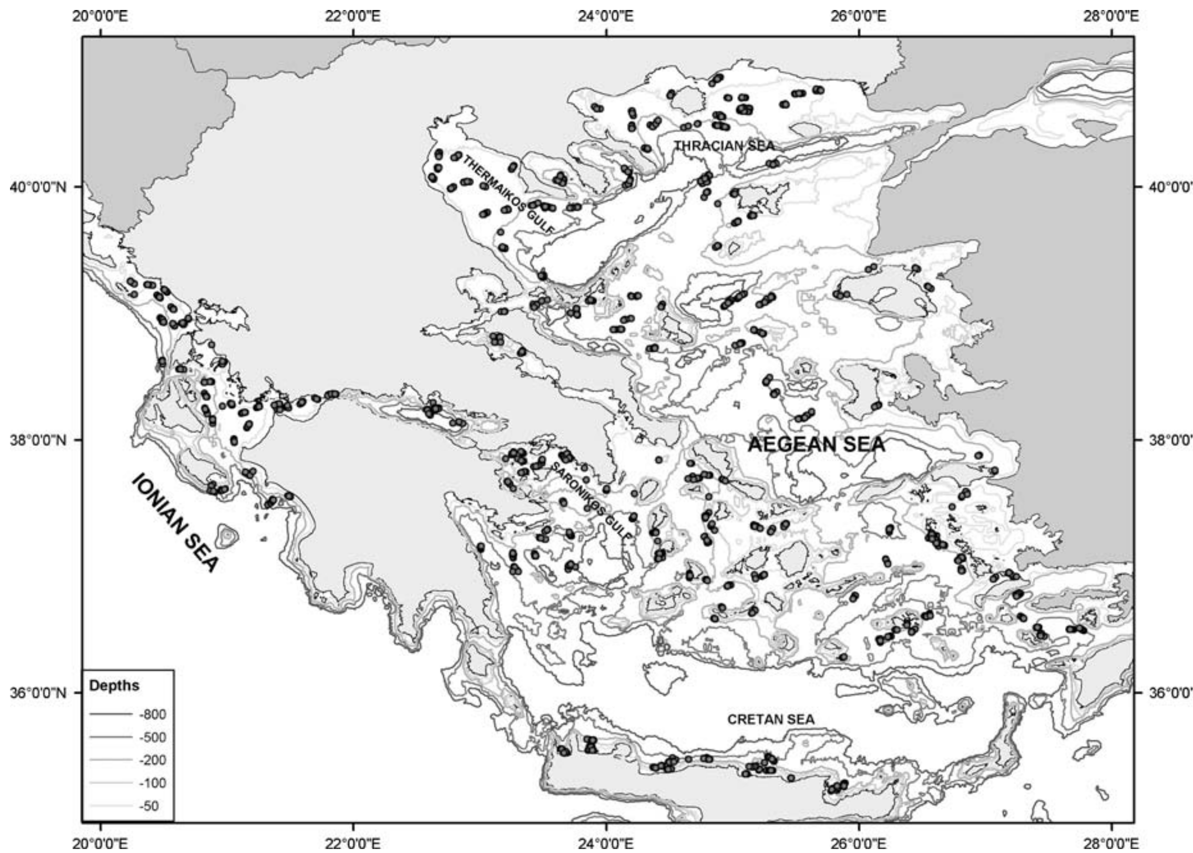

Fig. 1 Map showing the distribution of the sampling stations of the MEDITS surveys 1996–2006 in the Greek waters

Table 1 Analysis of deviance for the GAMs fitted to the pink shrimp DI data

Explanatory variable	Residual d.f.	Residual deviance	Cumulative variance explained DI
Total			
Mean	1715.00	13982750	
Latitude	1705.27	10998030	21.35
Depth	1696.33	8340559	40.35
Longitude	1686.41	7531263	46.14
Year	1677.40	7270476	48.00
Adults			
Mean	1715.00	7015614	
Depth	1706.01	5687683	18.93
Latitude	1696.44	4181988	40.39
Longitude	1686.45	3816384	45.60
Year	1677.45	3768221	46.29
Juveniles			
Mean	1715.00	8853561	
Latitude	1705.11	6622754	25.20
Depth	1696.14	5417116	38.81
Longitude	1686.28	4870400	44.99
Year	1677.22	4400700	50.29

explained 46–50% of the total variation (Table 1) and all variables were highly significant ($P < 0.0001$). Latitude and depth had always the highest explanatory power ranging from 38 to 40%.

The effect (loess plot) of the predictors on DI is shown on the *y*-axis for different values of the predictor (*x*-axis) (Figs. 2–4). The zero line indicates mean DI estimated by the model, while the *y*-axis is a relative scale where the effect of different values of the predictors on the response variable is shown. Hence, negative values on the *y*-axis indicate that at the corresponding levels of the predictor (*x*-axis), the model estimates that DI is lower than the mean, while the opposite holds for positive values on the *y*-axis. In that sense, loess plots did not reveal any trend in the yearly abundance variations, mostly referring to the adults. Yearly fluctuations in juvenile abundance, however, were much higher than those of the adults, probably reflecting recruitment variations. These were more limited after 2001 with the abundance remaining at a relatively higher lever than previously. This change can also be observed, in a lower degree, in the total population. All abundances decreased sharply below 400 m and adult abundance had an increasing trend up to 200 m. In general, the highest adult abundance occurred in depths from about 200 to 380 m, while juveniles seemed to prefer shallower waters. Juvenile abundance decreased after 200 m with the decrease being more abrupt after 400 m. In all cases, the graphs of latitude suggested that, with the exception of a peak around 38°N, abundances were higher in the southern and northern parts of the examined area. Longitude graphs had several local peaks with the highest ones around 23 and 28°E.

The density distribution maps that were built based on the GAM estimates indicated that relatively higher abundances, both for totals and juveniles, are expected in the Saronikos Gulf and the Thracian Sea. Adult distribution pattern was rather patchy with several local abundance maxima. Apart from the aforementioned locations, there were additional areas, mostly in the Cretan Sea, the eastern part of the Aegean and the outer part of Thermaikos Gulf, with relatively high adult densities (Figs. 5–7).

Discussion

Our results reveal a wide bathymetric distribution (from 26 to 757 m) for *P. longirostris* in the Greek waters, with a higher abundance from 100 to 400 m. This observation is in agreement with previous findings for the Mediterranean area, which are summarized in Sobrino et al. (2005).

On the other hand, our results confirm the primordial role that depth plays in the distribution of the different life stages of the deep-water pink shrimp. The shallower distribution of juveniles (<20 mm CL), mostly in 100–200 m with their abundance decreasing deeper, and the preference of large individuals to depths of about 200–400 m is in accordance to earlier observations for the Greek waters (Politou et al., 2000) and other Mediterranean areas (e.g. central Tyrrhenian Sea: Ardizzone et al., 1990).

Concerning the year effect, there was indication of an amelioration of the recruitment during the last years, whereas no high variation or time trend was observed for the abundance of the adult population. Recent analyses of MEDITS data using population and community indicators have shown an increasing

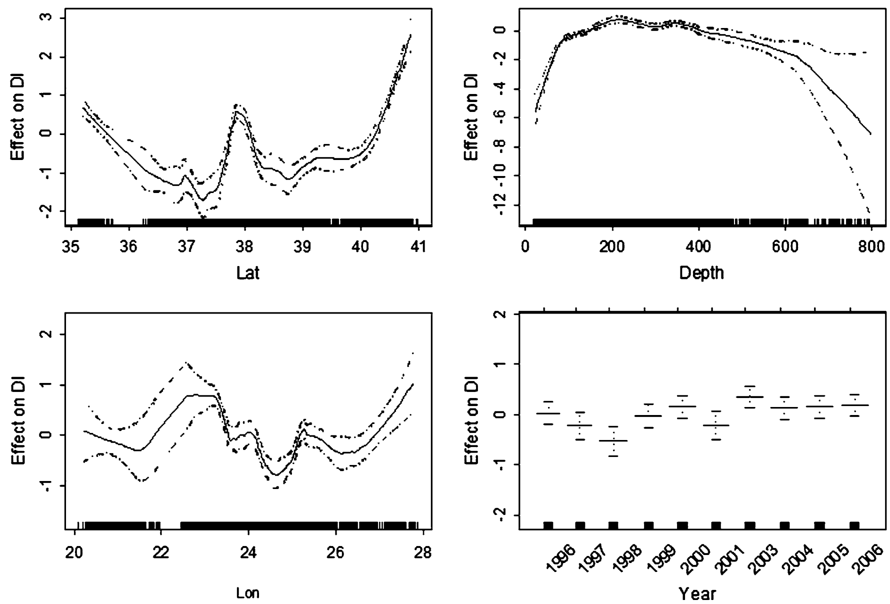

Fig. 2 GAM derived effects on the total pink shrimp DI. Each plot represents the contribution of the corresponding variable to the fitted predictor. The fitted values are adjusted to average zero and the broken lines indicate two standard errors. The relative density of data points is shown by the "rug" on the *x*-axis

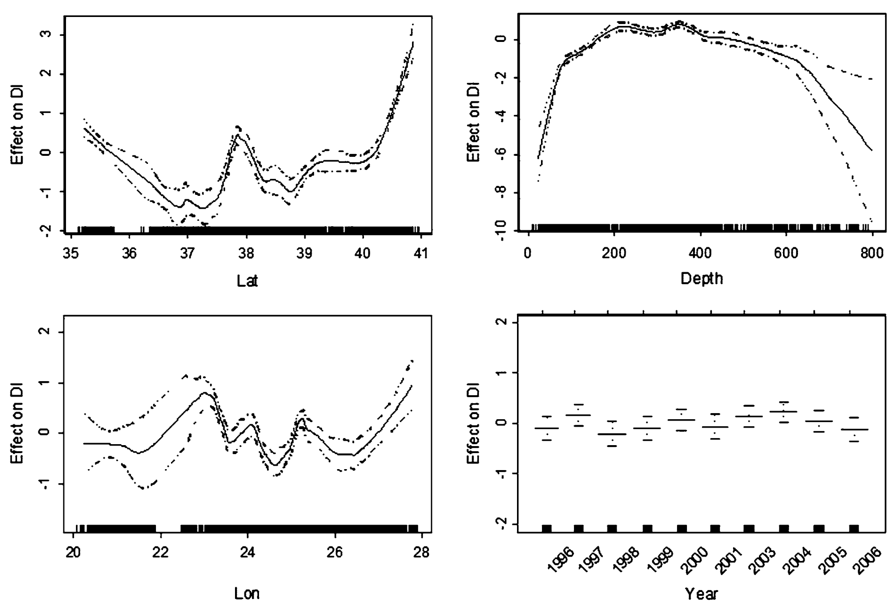

Fig. 3 GAM derived effects on the adult pink shrimp DI. Each plot represents the contribution of the corresponding variable to the fitted predictor. The fitted values are adjusted to average zero and the broken lines indicate two standard errors. The relative density of data points is shown by the "rug" on the *x*-axis

trend in the abundance of the deep-water pink shrimp in the Greek Ionian Sea for the period 1994–2004. No changes in abundance were found for the Aegean Sea during the same period, however, an increasing trend was observed after 2000 (MEDITS, 2007). The fisheries management measures imposed in the Greek waters (reduction of the fishing effort, increase of cod-end mesh size) during the last years could have decreased the fishing impact on the species and led to an increase of abundance, observed mainly in the Ionian Sea. However, environmental changes are also susceptible to be the factor that has affected the fisheries production. According to Rochet et al. (2007), an increased recruitment was detected at both population and community levels of demersal species in the Eastern Ionian. This was attributed to the recent changes in the water circulation in the area (Klein et al., 1999; Manca et al., 2002) that have contributed to an increase in biological production (Souvermezoglou & Krasakopoulou, 2005)

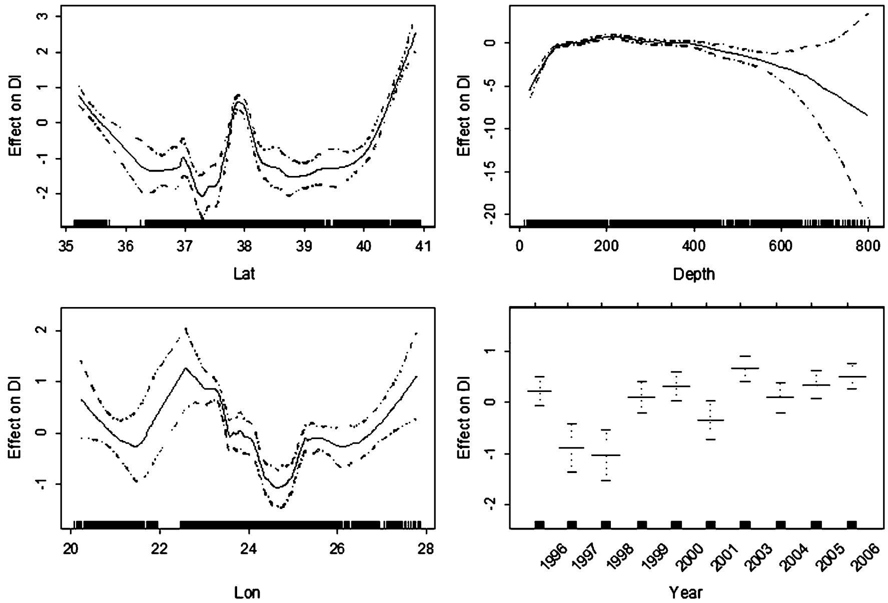

Fig. 4 GAM derived effects on the juvenile pink shrimp DI. Each plot represents the contribution of the corresponding variable to the fitted predictor. The fitted values are adjusted to average zero and the broken lines indicate two standard errors. The relative density of data points is shown by the "rug" on the *x*-axis

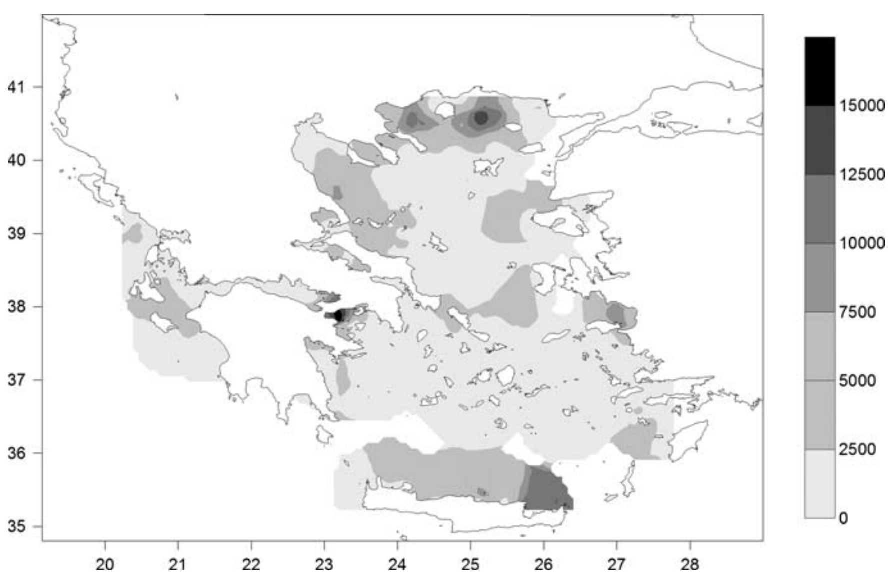

Fig. 5 Map of the total pink shrimp distribution. DI is expressed in terms of n/km^2. Interpolation was made by means of the "inverse distance to a power" gridding method

The geographical location (latitude, longitude) also had a consistent effect on the abundance of the different life stages of the deep-water pink shrimp. The maps built, based on the GAM predictions, showed high abundance concentration areas for all life stages mainly in the Aegean Sea. The most important nursery ground identified was located in the Saronikos Gulf and a secondary in the Thracian Sea. According to Fiorentino et al. (2002), the Aegean Sea was one of the areas where the main nursery grounds of the species, in terms of abundance of juveniles, were encountered in a Mediterranean level. Politou et al. (2006) identified the nuclei stations of its nursery grounds, which were found to occur mainly in the Saronikos Gulf and also in the Thracian Sea and the northern-eastern part of Crete. These findings are in general accordance with our results. Concerning the concentration areas of the adult specimens of the pink shrimp, according to our maps, they are located mainly in the Saronikos Gulf, the Thracian Sea, the Thermaikos Gulf, the Cretan Sea and the eastern part of the Aegean. These results

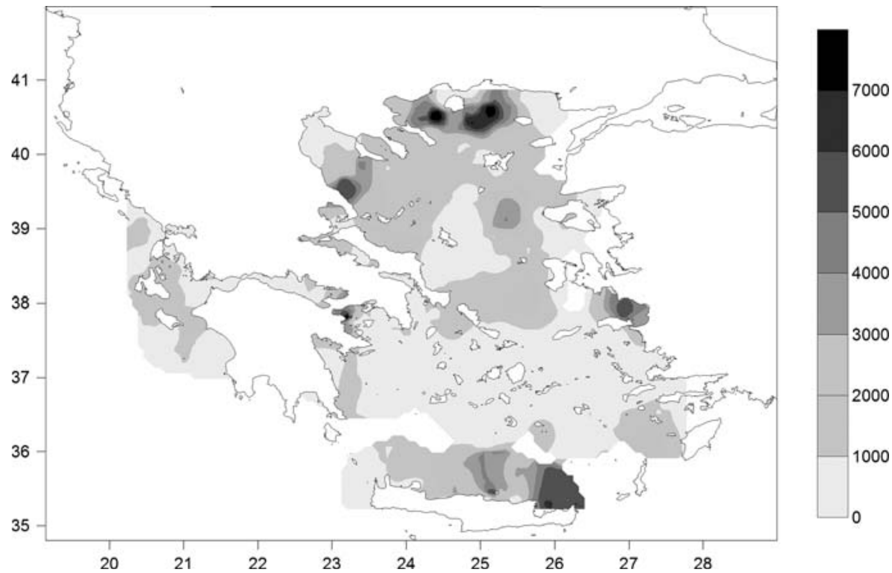

Fig. 6 Map of the adult pink shrimp distribution. DI is expressed in terms of n/km^2. Interpolation was made by means of the "inverse distance to a power" gridding method

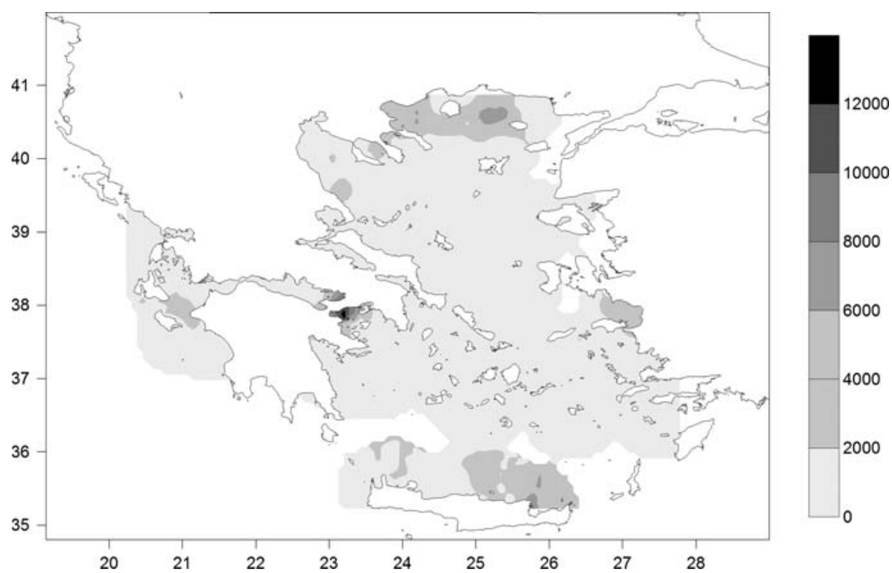

Fig. 7 Map of the juvenile pink shrimp distribution. DI is expressed in terms of n/km^2. Interpolation was made by means of the "inverse distance to a power" gridding method

are in good agreement to the pink shrimp catch data reported by the National Statistical Service of Greece (Kapiris et al., 2007). The density distribution map of the total population was more similar to that of the juveniles, which seems natural for a short-living species with a lifespan of 2–3 years and high mortality.

Over the last years, GAM techniques have been repeatedly used for the examination of marine species abundance in relation to environmental and spatio-temporal variables (e.g. Bigelow et al., 1999; Daskalov, 1999; Walsh & Kleiber, 2001; Maravelias & Papaconstantinou, 2003). In the current study, GAMs explained a relatively high percentage of abundance variations and allowed direct spatiotemporal comparisons by removing effects that could bias nominal indices.

Mapping of the spatial distribution of the different life stages of the species using the GAM estimates gave reasonable results and the predicted abundance variations were in good agreement with already existing observations. The performance of the models could be without doubt improved by including more parameters, which were not currently available, such as bottom type and temperature, water circulation and productivity. Nevertheless, the present approach gave a quantitative basis for the identification of the essential habitats of the pink shrimp in the Greek waters. Taking into account that the management of the demersal fisheries resources in the Mediterranean is based on technical measures, such as licence limitations, gear restrictions and closed seasons/areas, this information may contribute to the sustainable exploitation of the resource. Further research programs are clearly needed in order to investigate seasonal variations or to obtain results in a finer-local scale.

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