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# Nursery areas of red mullet (*Mullus barbatus*), hake (*Merluccius merluccius*) and deep-water rose shrimp (*Parapenaeus longirostris*) in the Eastern-Central Mediterranean Sea

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A B S T R A C T

The spatial pattern of the nursery areas of red mullet (*Mullus barbatus*), hake (*Merluccius merluccius*) (Linnaeus, 1758) and deep-water rose shrimp (*Parapenaeus longirostris*) (Lucas, 1846) was studied in the South Adriatic and North Ionian Seas (Eastern-Central Mediterranean) applying geostatistical techniques and data from time series trawl surveys conducted in the area. The analysed variables were: *R* (number of recruits/km$^2$) and *R*/Tot (fraction of recruits on the total sampled population). The structural analysis showed a spatial pattern of both variables characterized by continuity on a small scale. Predictions of nursery area localization with probability of finding recruits at different threshold values were obtained through median indicator kriging. For the red mullet the nurseries were mainly identified in the South Adriatic Sea off the Gargano peninsula and between Molfetta and Monopoli within 50 m in depth. The main concentration of hake juveniles was found to be between 100 and 200 m in depth along the Gargano peninsula and between Otranto and Santa Maria di Leuca, where a nursery of deep-water rose shrimp was also detected. An overlapping depth, between 100 and 200 m, was identified for hake and deep-water rose shrimp nurseries. Protection of these areas through limitations of fishing pressure is discussed.



## 1. Introduction

The red mullet *Mullus barbatus* (Linnaeus, 1758), hake *Merluccius merluccius* (Linnaeus, 1758), and the deep-water rose shrimp, *Parapenaeus longirostris* (Lucas, 1846), represent important commercial demersal resources sought on the shelf and upper slope in the Mediterranean Sea. In the last two decades there has been an increasing number of studies on the abundance and population dynamics of these species (e.g. Levi et al., 1995; Oliver and Massutì, 1995; Papaconstatinou and Stergiou, 1995; Recasens et al., 1998; Relini et al., 1999; Abelló et al., 2002; Orsi Relini et al., 2002 and references therein; Tserpes et al., 2002; Ungaro et al., 2003; Sbrana et al., 2006). Despite most of the Mediterranean stocks of *M. barbatus*, *M. merluccius* and *P. longirostris* exhibiting overfishing conditions (e.g. Abella et al., 1999; Lleonart and Maynou, 2003), these species do not show declining trends either in biomass or in average individual size (Orsi Relini et al., 2002 and references therein; Tserpes et al., 2002; Ungaro et al., 2006). However, the catches of hake and deep-water rose shrimp mostly consist of young individuals impairing the fishing sustainability in the long-term (Caddy, 1993; Bombace, 1995; D'Onghia et al., 1997; Orsi Relini et al., 2002 and references therein). Besides the pattern of the fishing pressure, an additional threat to the *M. barbatus*, *M. merluccius* and *P. longirostris* stock renewal might be due to environmental changes at the ecosystem level (Ungaro and Gramolini, 2006; Abella et al., 2008). In such a situation, action to protect recruits becomes quite urgent in order to prevent further stock depletion. This can be achieved through season and/or area closure and/or applying larger mesh size in the cod-end of the trawl net, or nets with different geometry (square *vs.* diamond). Considering the uncertainty in survival of escaped individuals, the former management measures in particular might prove more

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robust for the stochastic variability of the environment and include multi-species objectives (Cochrane, 1999).

In the Italian seas the protection of recruits has mainly driven the choice of a trawl fishing "closed season". This measure could generate potential benefit to the resources, if adopted in the suitable period and followed by limitations to avoid the concentration of catches on restarting fishing activity. The "area closure", where sensitive habitats/population life stages have been localised, might be an effective complementary management option. Areas identified as nurseries can be protected through limitation of the fishing pressure throughout the year ("no-take zones") or in defined periods, reducing the recruit fishing mortality. In this way catches will be indeed delayed until the fish grow up and spread out into the adjacent areas (Lauck et al., 1998; Lundberg and Jonzén, 1999), which is likely to produce similar effects on the population to those of the increased mesh size. Thus, the study of spatio-temporal distribution of recruits with identification of the nursery areas is fundamental for the institution of "closed area" measures.

Geostatistical tools have proved to be very useful in fishery science, allowing the understanding of the spatial structure of fish populations and their key life stages (e.g. recruits) (Petitgas and Poulard, 1989; Petitgas, 1993, 2001; Fariña et al., 1994; Maynou et al., 2003). Several experiments have been carried out in the Italian seas (Lembo et al., 1996, 1998a,b, 1999, 2000a,b; Ardizzone and Corsi, 1997; Fiorentino et al., 2003). However, no comprehensive studies on the young-of-the-year aggregations of *Mullus barbatus*, *Merluccius merluccius* or *Parapenaeus longirostris* have previously been carried out in the South Adriatic or North Ionian Sea (Eastern-Central Mediterranean). Hence, this study aims to assess the spatio-temporal distribution of the recruits of these highly valuable demersal species in these two border geographical areas of the Eastern-Central Mediterranean Sea and to localize their nurseries using the prediction tools of geostatistics.

## 2. Materials and methods

The spatial distribution of the young-of-the-year abundance of *Mullus barbatus*, *Merluccius merluccius* and *Parapenaeus longirostris* was investigated by applying geostatistical techniques on the data collected along the Apulian coasts in the South Adriatic and North Ionian Seas (Eastern-Central Mediterranean Sea) during experimental trawl surveys carried out from 1996 to 2003 as part of national (Relini, 1998, 2000) and international (Bertrand et al., 2000, 2002) assessment studies in the Mediterranean Sea (Fig. 1).

A random stratified sampling design was adopted during each survey and the investigated depth range was between 10 and 800 m. A commercial and an experimental otter-trawl net, respectively with a 40 and 20 mm stretched mesh size in the cod-end, were used in the different studies. The horizontal net opening was measured using a SCANMAR sonar system (Fiorentini et al., 1994) and the swept area was estimated according to Pauly (1983), hence data were standardised to the surface unit. Each haul was characterized by geographical position (latitude and longitude) and depth (m).

For each specimen, the total length (TL in mm) in both *Mullus barbatus* and *Merluccius merluccius* and the carapace length (CL in mm) in *Parapenaeus longirostris* were measured. In order to identify the modal components the length–frequency distributions (LFDs) were analysed using the Modal Progression Analysis procedure reported in FiSAT II (Gayanilo et al., 2006). For each survey the average length ($\bar{l}$) of the first modal component and the relative standard deviation (sd) were computed in order to calculate the size of cut-off ($\bar{l} \pm$ sd) in LFDs. All the specimens with TL (red mullet and hake) or CL (deep-water rose shrimp) less than the cut-off size were considered recruits.

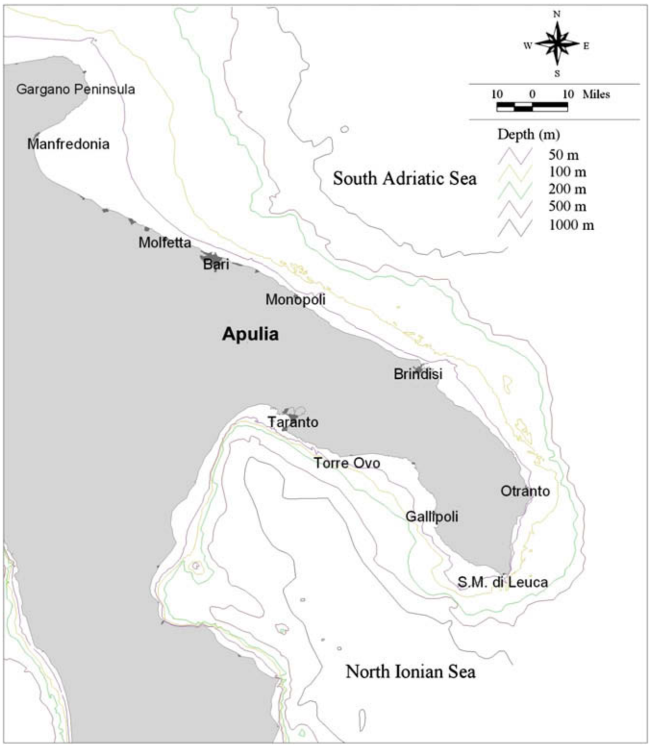


**Fig. 1.** Map of the Apulian coasts (Eastern-Central Mediterranean Sea) with indication of the main fishing ports.

The density index of recruits ($R$ in N/km$^2$) and the ratio between the number of recruits and the number of all sampled specimens ($R$/Tot) were calculated for each haul and survey.

Among the data series the years analysed were ranked using a combination of the following criteria in both geographical subareas: total number of hauls, percentage of positive hauls, species abundance, and ratio between the number of recruits and the total number of individuals ($R$/Tot). Only those years with high scores were analysed in more depth.

The knowledge on the recruitment pattern, growth and migration of red mullet, hake and deep-water rose shrimp during their first year of life (Orsi Relini et al., 1988, 1989; Lembo et al., 1998a, 2000a,b; Fiorentino et al., 2003; Abella et al., 2005), and the daylight time of hauls all support the stationary hypothesis (no drift) in this study.

The conventional statistical analyses (base map, scatter diagram, H-scatter plot and Q-Q plot) and the geostatistical study (variography, variogram cross-validation, kriging and indicator kriging) were carried out on the spatial variables $R$ and $R$/Tot using the ISATIS 5.0.3 (Geovariances) software package. Experimental variograms were constructed and a theoretical model fitted determining its parameters (Matheron, 1971; Journel and Huijbregts, 1978). In addition, the possible directionality of the variables (anisotropy) was investigated in the 45° (from the coast to offshore) and 135° (along the coast) directions.

The model best describing the spatial continuity was cross-validated by the jackknife technique (Miller, 1974). The local estimates of variables were carried out by means of the non-linear and non-parametric indicator kriging (Journel and Huijbregts, 1978; Isaaks and Srivastava, 1989). This approach has the advantage of both not operating under the binormality assumption and working with thresholds to create binary data (0 or 1 values, indicator data). Spatial predictions from indicator kriging are thus interpreted as the probability of exceeding the specified threshold, and in our study related to the young-of-the-year abundance. In particular, the non-parametric median indicator kriging was applied (Journel, 1983; Bierkens and Burrough, 1993; Deutsch and Journel, 1993; Goovaerts, 1997; Webster and Oliver, 2001; Chica-Olmo and Luque-Espinar, 2002), establishing *a priori* the probability that the variable $R$ (N/km$^2$) exceeded some threshold values of recruits (cut-off). In particular, for *Mullus barbatus* the indicator kriging was applied on the $R$ (N/km$^2$) variables with cut-offs of 500, 2000, 5000 and 10 000 N/km$^2$ (years: 1997, 1998, 2000, 2001 and 2002), whilst for *Merluccius merluccius* the indicator kriging on $R$ was carried out using the cut-offs of 100, 2000, 4000 and 6000 N/km$^2$ (years: 1997, 1998, 2001 and 2002). Regarding *Parapenaeus longirostris*, the threshold values 100, 1000, 2000 and 5000 N/km$^2$ were chosen in the selected years (2001 and 2002).

A grid with mesh size of 500 m was generated using ARCVIEW GIS 3.2 (Esri) and different maps were plotted for both species and each cut-off representing the localization of the nursery areas with the relative probability of finding recruits at different threshold values.

## 3. Results

### 3.1. Mullus barbatus

Juveniles of red mullet were mainly distributed in the South Adriatic Sea where they were more abundant off the Gargano peninsula and along the coast of Bari. The $R$/Tot variable was more homogeneously distributed but were more intense in the Gulf of Manfredonia and along the coast between Brindisi and Otranto. However, the correlation ($p \cong 0.5$, for the selected years) between the two variables showed that generally a higher number of recruits corresponded to increasing $R$/Tot ratios, and in particular for $R$ values greater than 5000 N/km$^2$ this ratio was almost always between 0.7 and 1. The Quantile-Quantile Plot indicated that $R$ significantly shifted from a theoretical Gaussian distribution, whilst the variable $R$/Tot approximated a normal distribution in 1997 ($p < 0.05$).

The experimental variograms of the indicator median $R$ showed that the spatial continuity in the distribution of recruits was generally described by a spherical model, typical of phenomena continuous on a short spatial scale (Table 1). An exponential model was adopted to describe the higher spatial continuity of the $R$ variable in 2000 and 2002. Both the spherical and exponential models indicated a variability higher on a short spatial scale (nugget effect), a correlation with short distance with a range between 23 000 and 33 842 m, and a variability (sill) between 0.05 and 0.09, generally greater than the sample variance. The spherical model was applied to describe the spatial continuity of $R$/Tot variable in 2000, 2001 and 2002. In particular, with exception of 2000, no nugget effect was detected. In addition, the range parameter was between 9716 and 38 940 m and the sill was between 0.10 and 0.13, generally more than the sample variance.

**Table 1**
Variogram parameters (range, nugget and sill) calculated for *M. barbatus* with indication of the investigated variable, variogram model, number and value of the lag.

| Year | Variable | Model | N. lag | Lag (m) | Range (m) | Nugget | Sill |
|---|---|---|---|---|---|---|---|
| 1997 | Indicator $R$ (100) | Spherical | 8 | 10 000 | 32 000 | 0.027 | 0.061 |
| 1997 | Indicator $R$ (100) | Spherical | 8 | 10 000 | 23 000 | 0.027 | 0.061 |
| 1998 | Indicator $R$ (500) | Spherical | 8 | 10 500 | 33 842 | 0.088 | 0.074 |
| 2000 | Indicator $R$ (500) | Exponential | 9 | 10 500 | 30 516 | 0.019 | 0.087 |
| 2000 | $R$/Tot | Spherical | 10 | 7500 | 9716 | 0.020 | 0.103 |
| 2001 | Indicator $R$ (500) | Spherical | 9 | 11 600 | 25 344 | 0.053 | 0.047 |
| 2001 | $R$/Tot | Spherical | 10 | 12 000 | 25 495 | – | 0.134 |
| 2002 | Indicator $R$ (500) | Exponential | 8 | 11 500 | 32 884 | 0.168 | 0.064 |
| 2002 | $R$/Tot | Spherical | 8 | 14 000 | 38 940 | – | 0.125 |

The analysis carried out to test variables directionality did not show any anisotropy, with the exception of 1997 data, when a slightly higher spatial continuity was detected for the variable $R$ along the Adriatic coast direction (135°).

The prediction of the spatial aggregations of recruits by means of median indicator $R$ (indicator kriging carried out using the spherical model which interpolated the median indicator variogram of the variable $R$) and a cut-off of 500 N/km$^2$, indicating a patchy distribution of red mullet juveniles mostly concentrated along the coast of the South Adriatic Sea within 50 m of depth. The areas showing the highest probability and persistency were detected from 1997 to 2002 using cut-offs of 2000, 5000 and 10 000 N/km$^2$. In particular, increasing the indicator kriging threshold up to 5000 and 10 000 N/km$^2$, only the nursery areas distributed along the Gargano peninsula and along the coasts off Molfetta and Monopoli were observed with a probability up to 0.8, within 50 m of depth (Figs. 2 and 3).

Regarding the $R$/Tot variable, the kriging showed the main incidence of recruits along the South Adriatic coast. In particular, during 2001 and 2002 this phenomena was quite intense from the Gargano peninsula to Monopoli in the South Adriatic Sea and between Otranto and Santa Maria di Leuca in the North Ionian Sea.

### 3.2. Merluccius merluccius

Juveniles of hake were more abundant off the Gargano peninsula coasts in the South Adriatic Sea and between Otranto and Santa Maria di Leuca in the North Ionian Sea, whilst the $R$/Tot variable was, as expected, more homogeneously distributed. However, the correlation ($p \cong 0.5$, for the selected years) between the two variables showed that generally a higher number of recruits corresponded to increasing $R$/Tot ratios, and particularly over 1000 $R$ (N/km$^2$) this ratio was almost always between 0.7 and 1. The Quantile-Quantile Plot indicated that $R$ significantly shifted from a theoretical Gaussian distribution, whilst the variable $R$/Tot generally approximated a normal distribution ($p < 0.05$).

The experimental variograms of the indicator median $R$ showed a spatial continuity in the recruits of hake generally described by a spherical model (Table 2). The model parameters indicated a variability higher on short spatial scale (nugget effect), a correlation on short distance, with a range between 16 000 and 23 000 m, and a variability (sill) between 0.13 and 0.17, generally less than the sample variance.

The analysis carried out to test variables directionality did not show any anisotropy, with the exception of 2001 data, when a slightly higher spatial continuity was detected along the Adriatic coast direction (135°).

Even the spatial continuity of the variable $R$/Tot was generally described by a spherical model with a nugget effect, but with a longer range (between 28 841 and 70 635 m) than for the indicator median variable $R$ (sill between 0.04 and 0.06) (Table 2).

The prediction of the spatial aggregations of hake recruits carried out using an indicator kriging cut-off of 100 N/km$^2$, indicating a diffuse distribution along the coast of the South Adriatic Sea showing considerable extension down to 200 m ($p > 0.8$). When the thresholds were increased at 2000 N/km$^2$ the aggregations of *Merluccius merluccius* recruits were localised with persistency from 1997 and 2002 into two main zones. The former was in the area off the Gargano peninsula down to Molfetta, the latter in the area between Otranto and Santa Maria di Leuca, both between 100 and 200 m in depth and probability up to 0.8 (Fig. 4). Increasing the indicator kriging threshold to 6000 N/km$^2$, the nursery area in the northernmost side of the south Adriatic Sea was localised exclusively with a probability up to 0.5 in 2001 and 2002. On the

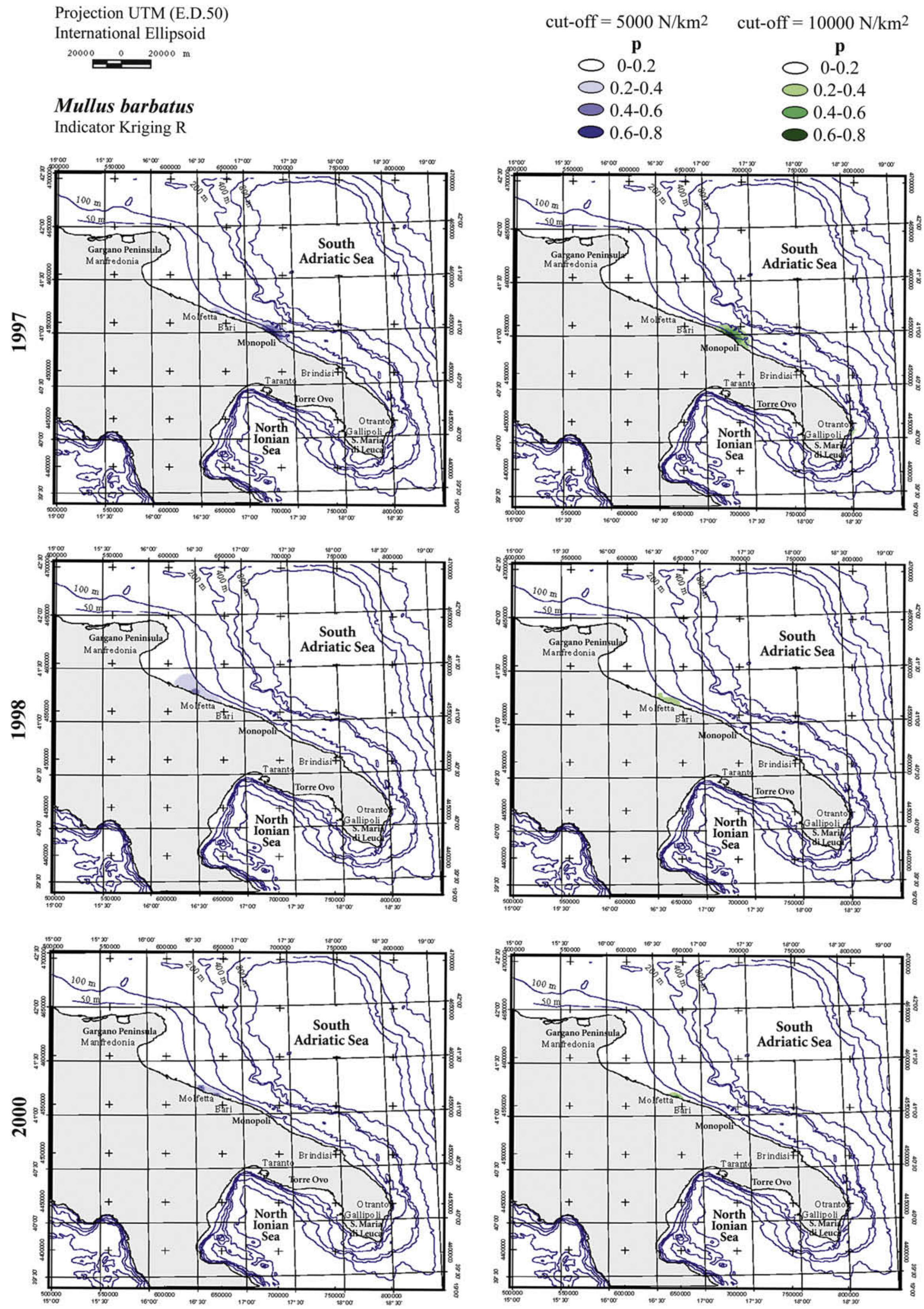


**Fig. 2.** Map of the nursery areas of *M. barbatus* defined at different levels of cut-off ($N$/km$^2$) and probability ($p$) in the South Adriatic and North Ionian Sea (1997, 1998, and 2000).

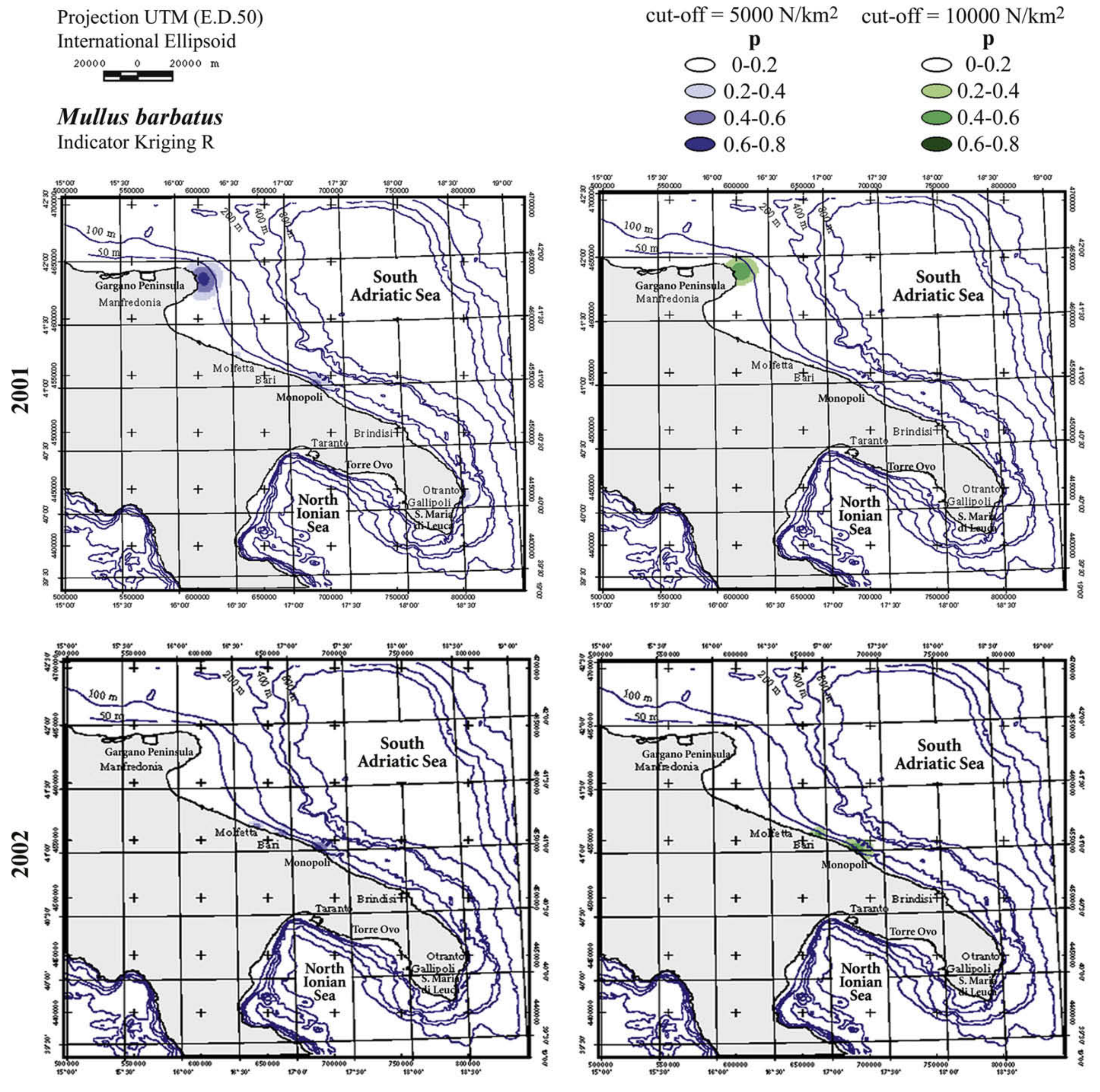


**Fig. 3.** Map of the nursery areas of *M. barbatus* defined at different levels of cut-off ($N$/km$^2$) and probability ($p$) in the South Adriatic and North Ionian Sea with 2001 and 2002.

**Table 2**
Variogram parameters (range, nugget and sill) calculated for *M. merluccius* with indication of the investigated variable, variogram model, number and value of the lag.

| Year | Variable | Model | N. lag | Lag (m) | Range (m) | Nugget | Sill |
|---|---|---|---|---|---|---|---|
| 1997 | Indicator *R* (100) | Spherical | 10 | 8000 | 19 500 | 0.098 | 0.166 |
| 1997 | *R*/Tot | Spherical | 13 | 10 000 | 28 841 | 0.048 | 0.050 |
| 1998 | Indicator *R* (100) | Spherical | 12 | 7000 | 16 200 | 0.081 | 0.151 |
| 1998 | *R*/Tot | Spherical | 11 | 15 000 | 50 000 | 0.047 | 0.046 |
| 2001 | Indicator *R* (100) | Spherical | 10 | 8500 | 16 000 | 0.110 | 0.140 |
| 2002 | Indicator *R* (100) | Spherical | 10 | 13 000 | 22 800 | 0.087 | 0.127 |
| 2002 | *R*/Tot | Spherical | 10 | 12 000 | 70 635 | 0.269 | 0.062 |

whole, the distribution pattern of the identified nursery areas was rather persistent throughout the period.

Regarding the variable *R*/Tot, the kriging showed the main incidence of recruits off the Gulf of Manfredonia and between Otranto and Santa Maria di Leuca between 100 and 200 m of depth with a spatial pattern comparable to that observed for the variable *R*.

### 3.3. Parapenaeus longirostris

The areas mainly interested by the recruitment phenomenon for this shrimp were off the Gulf of Manfredonia and Brindisi along the South Adriatic Sea, between Otranto and Santa Maria di Leuca and off Torre Ovo along the North Ionian Sea. Along the Adriatic coast,

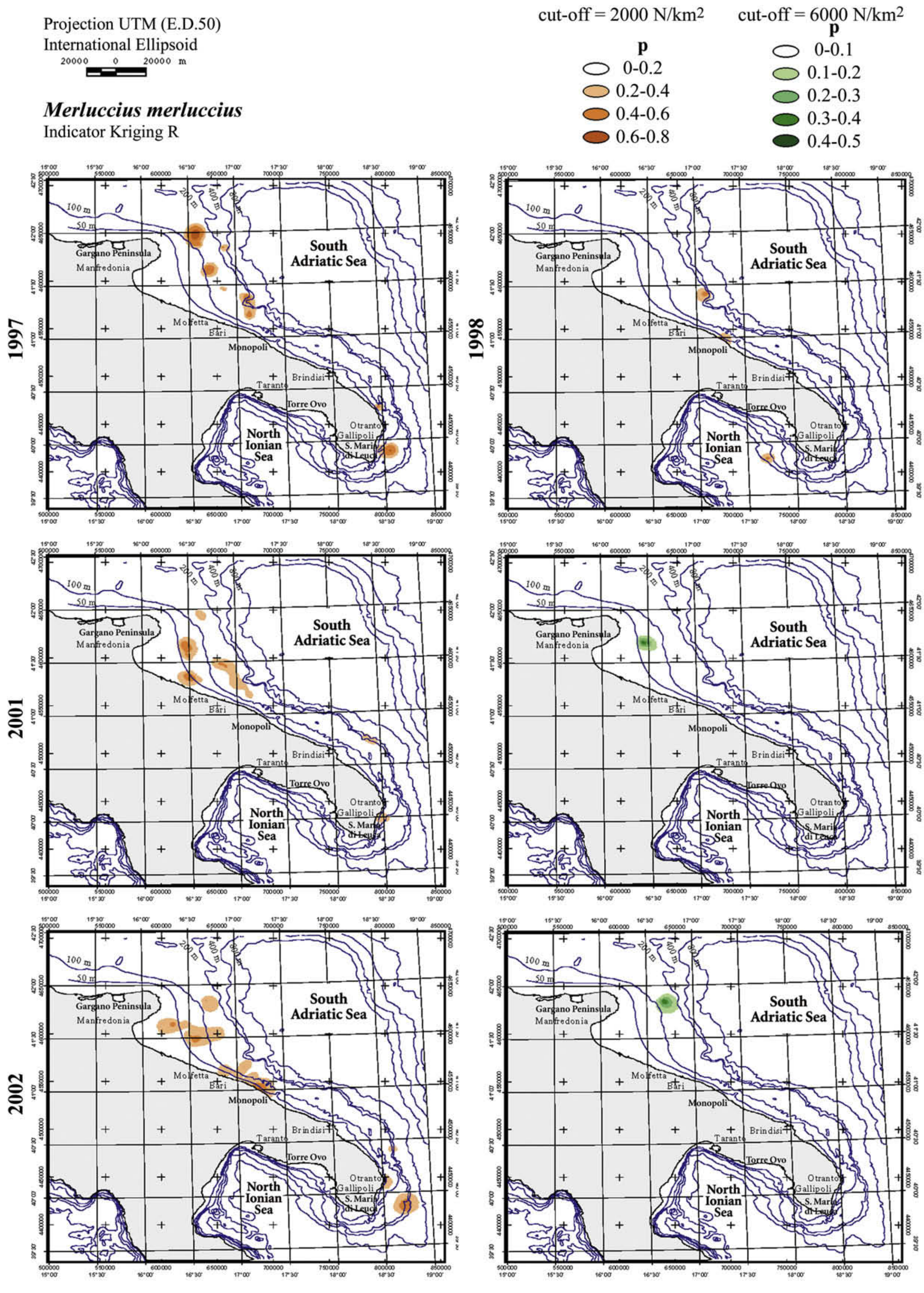


**Fig. 4.** Map of the nursery areas of *M. merluccius* defined at different levels of cut-off ($N$/km$^2$) and probability ($p$) in the South Adriatic and North Ionian Sea (1997, 1998, 2001, and 2002).

**Table 3**
Variogram parameters (range, nugget and sill) calculated for *P. longirostris* with indication of the investigated variable, variogram model, number and value of the lag.

| Year | Variable | Model | N. lag | Lag (m) | Range (m) | Nugget | Sill |
|---|---|---|---|---|---|---|---|
| 2001 | Indicator *R* (100) | Spherical | 9 | 14 000 | 19 882 | 0.114 | 0.142 |
| 2002 | Indicator *R* (100) | Spherical | 10 | 12 000 | 19 451 | 0.080 | 0.167 |
| 2003 | *R*/Tot | Spherical | 11 | 7500 | 26 928 | 0.020 | 0.038 |

the *R*/Tot index confirmed the remarkable fraction of recruits in the whole sampled population. In the North Ionian Sea, juveniles of deep-water rose shrimp showed comparable incidences mostly in the Otranto Channel. Very slight correlations were detected between the variable *R* and *R*/Tot ($p \cong 0.4$, for the selected years). Generally, the Q-Q Plot indicated that *R* shifted from a theoretical normal distribution. On the contrary, the variable *R*/Tot significantly approximated to a normal distribution ($p < 0.05$).

The spherical model adequately described the spatial continuity of the recruit abundance in 2001 and 2002 (Table 3). In both year, the model parameters indicated a high variability on the short spatial scale (nugget effect). A short distance spatial correlation was detected with range of 19 882 and 19 451 m in 2001 and 2002, respectively, with a corresponding sill of 0.14 and 0.17. The analysis carried out in order to test different possibly spatial behaviours of the variables did not show any anisotropy.

The spatial continuity of the *R*/Tot variable was only described by means of a spherical model in 2003. A nugget effect and a spatial continuity in the range of 26 928 m was detected, higher than that observed for the *R* variable. The sill was 0.04 and no different spatial behaviour was detected for the *R*/Tot variable.

Estimates and spatial interpolation, with the indicator kriging method and a cut-off of 100 N/km$^2$, showed juveniles of *Parapenaeus longirostris* distributed down to a depth of 200 m, mainly along the Adriatic coast and in the area between Otranto and Santa Maria di Leuca in the North Ionian Sea ($p > 0.6$). The indicator kriging with a cut-off of 1000 N/km$^2$ selected a lower number of areas with a probability between 0.4 and 0.8. In particular, aggregation areas were detected in 2001 and 2002 between Molfetta and Brindisi, between Otranto and Santa Maria di Leuca and off Torre Ovo. Using a threshold value of 2000 N/km$^2$, the aggregation of recruits was detected with a probability up to 0.4–0.6 in the Gulf of

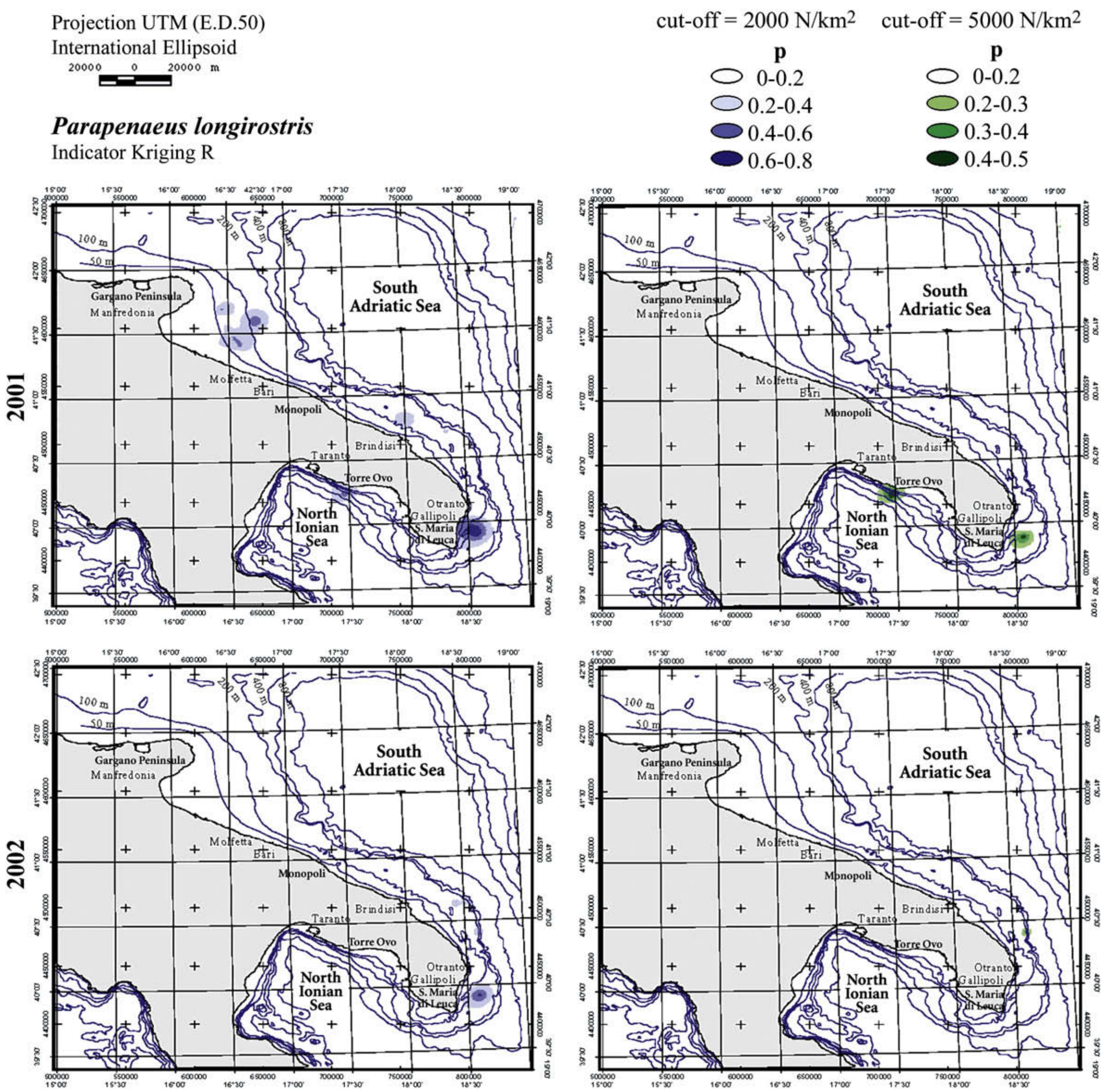


**Fig. 5.** Map of the nursery areas of *P. longirostris* defined at different levels of cut-off (*N*/km$^2$) and probability (*p*) in the South Adriatic and North Ionian Sea with 2001 and 2002.

Manfredonia in the South Adriatic Sea and off Torre Ovo in the North Ionian Sea, and up to 0.6–0.8 between Otranto and Santa Maria di Leuca in the North Ionian Sea (Fig. 5). Considering the highest cut-off (5000 N/km$^2$), the areas with a probability between 0.2 and 0.5 were again identified north-eastern Santa Maria di Leuca, between 100 and 200 m in depth and off Torre Ovo from 100 down to 400 m depth.

The kriging of the variable *R*/Tot showed a widespread presence of juveniles along the South Adriatic coast, generally down to 200 m in depth. In the North Ionian Sea, the remarkable fractions of recruits were observed down to 200 m between Otranto and Santa Maria di Leuca and down to 400 m in the area off Gallipoli and Torre Ovo.

## 4. Discussion and conclusions

The no-take zones, where harvesting might be permanently forbidden or temporarily regulated (e.g. during recruitment or spawning processes), allowing the renewal of the stocks, could play a fundamental role in the life cycle of important demersal species enabling their sustainable exploitation in neighbouring areas. They should correspond to "Essential Fish Habitats" (EFHs) where species concentrate for different reasons (spawning, nursery, feeding, etc.) and whose protection could enhance the management effect through closure to fisheries. The "no-take" marine reserves have been proposed worldwide with the aim of reducing the problems of overfishing and responding to uncertainty in fishery management (e.g. Hall, 1999; Agardy, 2000; Gislason et al., 2000; Gell and Roberts, 2003). Nursery areas closed to fishing can be considered as an additional form of fishery management (Lauck et al., 1998; Lundberg and Jonzén, 1999; Apostolaki et al., 2002; Gell and Roberts, 2003), which shows the advantages of being robust to the stochastic variability of the environment and comprehensive of multi-species and ecosystem objectives (Cochrane, 1999; Stokes et al., 1999; Gislason et al., 2000; Stergiou, 2002). According to Roberts (1998) and Crowder et al. (2000), protecting nurseries could be inadequate if these habitats depend on replenishment from adult populations elsewhere. Indeed, on the basis of "source–sink" population dynamics (Pulliam, 1988), a site with high recruitment could be a "sink" if this site has poor conditions for growth and reproduction by adults. On the other hand, if such conditions are good, the site might be a "source". The studies carried out in the Adriatic and Ionian Sea (e.g. D'Onghia et al., 1995, 1998; Ungaro and Marano, 1996; Marano et al., 1998) have proved that some nurseries are often in the same areas where growth and reproduction occur. They might be considered as a "source" and, thus, might be selected for the institution of no-take zones for fishery management objectives. These no-take zones would provide refuges for exploited species which could then recover and grow larger, enhancing the production of offspring and restocking fishing grounds. Thus, the fisheries could be supplemented through "spillover" of adults and juveniles into exploited areas. In practice, establishing no-take zones is not easy since preventing the use of productive areas meets with the opposition of fishermen who obtain the highest biomass of commercial species (e.g. those with nurseries). As a consequence, socio-economic pressures can lead to the location of no-take zones in unproductive areas (sink areas) that no fishermen or user groups are willing to protect (Crowder et al., 2000). This will increase overfishing since the fishing effort will be displaced to and increased in unprotected productive areas. Thus, siting no-take zones following social criteria alone may be risky or ineffective.

The geostatistical approach is a useful tool in order to identify the geographic location of the nursery areas of the red mullet, hake and deep-water rose shrimp (Petitgas and Poulard, 1989; Lembo et al., 1998a, 2000a,b), thus providing scientific criteria for the selection of no-take zones. In the present study, the spatial continuity of the recruits abundance (Variable *R*) is described by a spherical model typical of less continuous phenomena. On the contrary, a more spatial continuity was detected for the variable *R*/Tot, indicating that the incidence of the juveniles on the whole sampled population is a more widespread phenomenon than the spatial aggregation of the recruits. This confirms the geographical basis of the importance of the recruitment in the harvest of a stock biomass.

Considering the highest levels of density and probability, the nursery areas of the red mullet were identified off the Gargano peninsula and between Molfetta and Monopoli, within 50 m of depth, in the South Adriatic Sea. The nurseries for hake were identified off the Gargano peninsula in the South Adriatic Sea and, to a lesser extent, in the North Ionian Sea between Otranto and Santa Maria di Leuca. It is worth mentioning that the areas with the highest density of hake recruits were detected with temporal continuity and mainly down to 200 m in depth. The nursery areas of the deep-water rose shrimp were identified in the south of the Gulf of Manfredonia and between Monopoli and Brindisi in the South Adriatic Sea. Concerning the North Ionian Sea the nursery areas of *Parapenaeus longirostris* were detected between Otranto and Santa Maria di Leuca and off Torre Ovo. It is noteworthy that even for this species the areas with the highest density of recruits were mainly observed between 100 and 200 m in depth. Thus, a general bathymetric overlapping was detected, between 100 and 200 m, for the hake and the deep-water rose shrimp nurseries. Juveniles of *P. longirostris* showed a deeper distribution down to 400 m in depth in the area off Torre Ovo, reflecting a different morphology of the North Ionian side with respect to the South Adriatic (Senatore et al., 1980).

In our opinion, the water mass circulation plays an important role in the localization of the nursery areas identified in this study. In particular, the nurseries in the South Adriatic Sea could be linked to the main sea current flowing in the north–south direction along the western continental shelf (Artegiani et al., 1997). The presence of nurseries of hake and deep-water rose shrimp between Otranto and Santa Maria di Leuca is most probably linked to the energetic trophic system regarding this area due to the continuous flux of the Southern Adriatic water masses entering in the Northern Ionian Sea (De Lazzari et al., 1999; Manca et al., 2002).

Following a decree by the Ministry of Agriculture, Alimentary and Forestry Policy, two no-take zones have been established in the Southern Adriatic Sea. They overlap with the nursery areas of *Mullus barbatus*, *Merluccius merluccius* and *Parapenaeus longirostris* identified in this study. No closed areas have yet been proposed or established for fishery management in the Ionian Sea. Considering the present results, a no-take zone could be located between Otranto and Santa Maria di Leuca where the nursery areas of hake and deep-water rose shrimp overlap, constituting a sensitive habitat which deserves protection and management measures.

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