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Distribution of nursery areas of *Merluccius merluccius* obtained by geostatistical techniques

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SUMMARY - In this paper the spatial distribution of *Merluccius merluccius* recruits, by geostatistical analysis techniques, is investigated. The aims are to assess the abundance of recruits and localize the nursery areas in order to provide useful information for fisheries management. The data were collected in the central-southern Tyrrhenian Sea during the bottom trawl survey carried out in the summer 1996, as part of Medits-it programme. The fraction of length frequency distribution lower than 12 cm was used. The variables under investigation were the number of juveniles and depth, they were used to construct the experimental auto and cross-variograms. The models which best describe the spatial continuity were detected by structural analysis. In the modelling phase the anisotropic behaviour was considered stressed by the variable number of juveniles. After the structural analysis the estimated value of the given variable was obtained by applying the co-kriging techniques. The conditioned probability of exceeding a given threshold value of the variable number of juveniles was estimated by disjunctive kriging techniques. Different types of maps were generated, which represented the localization of nursery areas, the estimation variance of the investigated variable and the conditioned probability of finding an abundance index higher than 300 individuals/hour.

Key words: Nursery areas, *Merluccius merluccius*, recruitment, trawl survey, co-kriging, disjunctive kriging.

RESUME - *"Distribution des aires de nursery de* Merluccius merluccius *obtenue par des techniques géostatistiques". Dans ce travail on étude la distribution spatiale des recrues de* Merluccius merluccius *au moyen des techniques d'analyse géostatistique. Le but est d'estimer l'abondance des recrues et de localiser les aires de nursery afin de fournir des informations utiles à la gestion de la pêche. Les données ont été collectées dans la Mer Tyrrhénienne centrale-méridionale pendant la campagne de chalutage démersal du programme Medits-it conduite en été 1996. La fraction de la distribution des fréquences de taille moins de 12 cm a été employée. Les variables examinées étaient le nombre des recrues et la profondeur, utilisées pour construire les auto- et cross-variogrammes expérimentaux. Les modèles, qui décrivent le mieux la continuité spatiale, ont été détectés par analyse structurelle. Dans la phase de modélisation on a tenu compte du comportement anisotrope manifesté par la variable nombre de recrues. Après l'analyse structurelle, la valeur estimée de la variable examinée a été obtenue en appliquant les techniques du co-krigeage. La probabilité conditionnée de dépasser une valeur seuil spécifiée de la variable nombre de recrues a été estimée au moyen des techniques du krigeage disjonctif. Plusieurs sortes de cartes ont été produites, qui représentaient la localisation des aires de nursery, la variance d'estimation de la variable étudiée et la probabilité conditionnée de trouver un indice d'abondance plus grand que 300 individus/heure.*

Mots-clés : *Aire de nursery,* Merluccius merluccius, *recrutement, campagnes de chalutage, co-krigeage, krigeage disjonctif.*

Introduction

The demersal trawl fishery around the central and southern Tyrrhenian coasts targets a large group of species, one of the most important of which is the European hake, *Merluccius merluccius* (Spedicato and Lembo, 1993). Moreover this species is widely represented in the catches of trawl surveys with a fairly high number of recruits (Spedicato and Lembo, 1993), where the fish of the age group 0 are considered as belonging to the recruitment phase (Orsi Relini *et al.*, 1989).

The study of the spatial correlations of the juveniles distribution, and their relative abundance, is the first step in assessing and localizing the nursery areas of demersal resources.

These data can provide useful information, both for a deep understanding of the biology (i.e., migration) of the species under investigation and advice for fisheries management. For example, the fishing pressure could be reduced in the nursery areas throughout the year or in fixed periods.

In this paper the spatial distribution and abundance of *Merluccius merluccius* recruits were estimated using geostatistical analysis techniques. The data were collected during the bottom trawl survey carried out in the summer of 1996 as part of the International MEDITS-IT Programme (supported by UE DG XIV and the Italian Ministry of Agriculture, General Directorate for Fisheries and Aquaculture).

The geostatistical approach has already been adopted in the North Sea (AA.VV., 1990), in the Atlantic Ocean around the Galician coasts (Fariña *et al.,* 1994) and in the Mediterranean (Lembo *et al.,* 1990; 1996) to estimate the spatial distribution and abundance of fishery resources from bottom trawl survey data. Generally the results are also represented by maps when GIS (Geographic Information System) technologies are applied.

The linear geostatistical approach allows, by different kriging techniques, the value of the given variable in each unsampled point to be estimated, accounting for spatial correlations (Matheron, 1965). These methods can also be extended to the space-temporal dimension, as reported by Rouhani and Myers (1990). In this case co-regionalized models are adopted and the co-kriging techniques applied, after identification of the auto and cross-variogram models (Myers, 1982; 1988). Many authors followed this approach also when different variables are spatially correlated (Rouhani and Wackernagel, 1990; Bourgault and Marcotte, 1991). Moreover the unlinear geostatistics allows the conditioned probability of exceeding a given threshold value of the variable to be estimated by disjunctive kriging techniques (Yates and Warwick, 1986; Rivoirard, 1994).

Materials and methods

The investigated area is in the central-southern Tyrrhenian Sea, from the Garigliano River to Cape Suvero and at a depth of 10 to 800 m (total surface: 12.999 km^2). The survey design was stratified random sampling with 57 hauls proportionally allocated to the area of the strata. Tows were carried out aboard the commercial trawler M/P S. Anna (32.2 m in length, 97.06 GRT and 1,357.11 KW) in daylight at a speed of 3 knots. The tows at a depth of 10 to 200 m lasted 30 min and those at 201 to 800 m 1 hour. The yield in number of *Merluccius merluccius,* in each haul, was then referred on the basis of 1 hour towed. The gear employed was the standard type adopted in the MEDITS program (reference: Ifremer GOC 73) with a 20 mm stretched mesh size in the coded (Bertrand, 1996). The data given here were collected in the survey carried out from June 25 to July 5, 1996.

The fraction of length frequency distribution lower than 12 cm was employed. This threshold size was first chosen by the Grund Group (Italian Research Group on Demersal Resources) and used in the Mapping Project (Relini, 1995); as for the European hake the 12 cm size represents the upper limit of the first age group (Orsi Relini *et al.*, 1992).

The spatially correlated variables under investigation were the abundance of juveniles (in number) and depth.

The model describing the spatial continuity was constructed using structural analysis. The information on the spatial correlation of each variable is represented by the auto-variogram function, while the cross-variogram function describes the correlation between the two variables. The variogram estimator (auto, on the samples z_i of the variable Z_i in the locations x_{ik}; cross on the samples z_i and z_j of the variables Z_i and Z_j in the locations x_{ik} and x_{jk}) is that reported by Journel and Hujgregts (1978):

$$\gamma^{*}_{ij}(h) = \frac{1}{2n(h)} \sum_{k=1}^{n(h)} (z_i(x_{ik}+h) - z_i(x_{ik}))(z_j(x_{jk}+h) - z_j(x_{jk}))$$

where *n(h)* is the number of crossed increments at a distance *h*. In the case of the cross-variogram estimation, in the same location both the z_i and z_j values of the variables Z_i and Z_j should be available. When the cross-variogram is adopted the increments are not squared and can be negative.

Then the number of juveniles and depth value were used to construct the experimental variograms, namely the auto-variograms for each variable, number of juveniles and depth, and the cross-variogram for the combination of the two variables. The model which best describes spatial continuity (exponential, gaussian, spherical) was detected for each experimental variogram and the values of Range, Sill and Nugget were obtained. The models were cross-validated by "jackknife" methods (Miller, 1974).

The estimated value of the given variables in each unsampled point was obtained by *linear geostatistics*, applying the co-kriging techniques (Journel and Hujgregts, 1978).

The estimate of the conditioned probability of exceeding a given threshold value of the variable number of juveniles, fixed at more than 300 juveniles, was performed by unlinear geostatistics, applying disjunctive kriging techniques (Journel and Hujgregts, 1978).

Results and discussion

The auto-variogram function of the variable juveniles number is shown in Fig. 1. The average squared differences of the variable are plotted on the y axis, while on the x axis the distance in km between the sampled points. The model which best describes the spatial continuity is the exponential one. The Range, about 38 km, is the maximum distance at which the data are related. At this point, it is possible to read, on the y axis, the value of the Sill, which is the variability at which the variogram appears to flatten out or plateau; conversely the straight line parallel to the x axis represents the sample variance.

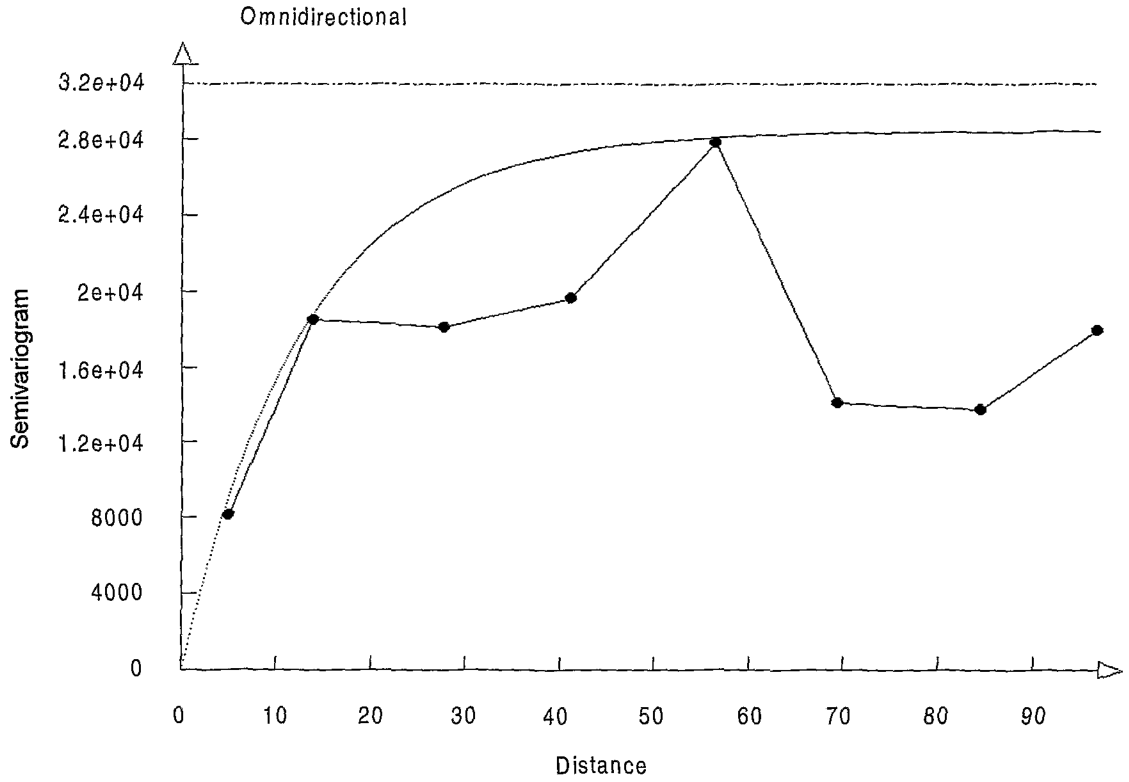

Fig. 1. Variogram model of juveniles number variable.
$\gamma(h)$ = 28520*Exp 38.4 (h). Distance h in km

The study of the spatial continuity of the variable number of juveniles stressed an anisotropic behaviour, which was considered in the modelling phase. A higher spatial continuity of the juveniles abundance was observed in the geographic direction oriented on the north-west south-east axis, with an anisotropy ratio of 0.4. In the investigated area the coastal line is relatively parallel to this axis, along which a higher continuity of batimetry was also observed.

Figure 2 shows the auto-variogram function of the variable depth. In this case the model is the spherical type, with a good degree of spatial continuity. The maximum distance at which the data are still well correlated (Range) is about 32 km

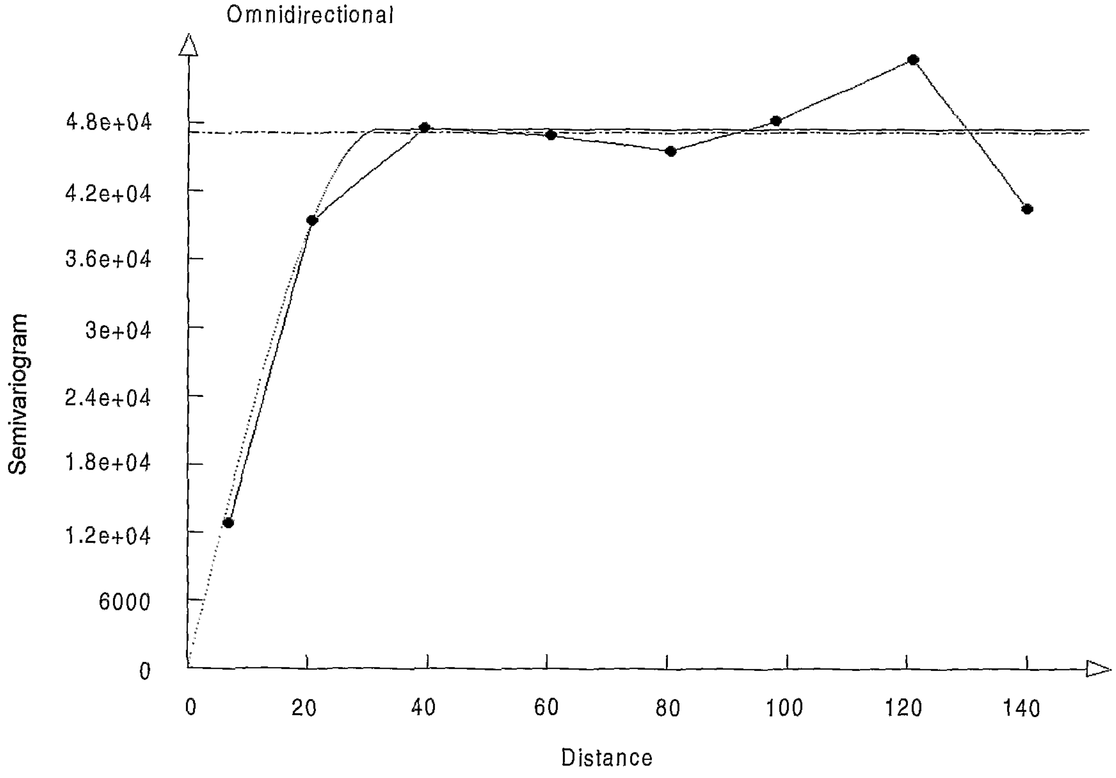

Fig. 2. Variogram model of depth variable.
$\gamma(h) = 47600 * Sph\ 32.2\ (h)$. Distance h in km

The cross-variogram function for the combination of the two variables, number of juveniles and depth, is shown in Fig. 3. The y axis gives the average product increments of the two variables, therefore the exponential model, which best describes the spatial continuity in this case too, is negative. This means, for example, that by increasing the depth, the number of recruits decreases.

After the structural analysis and the estimation procedure, different types of maps were generated. Fig. 4 represents the localization of nursery areas obtained by co-kriging in the summer of 1996. During this sampling season the highest number of recruits is concentrated on the north side of the investigated area, with an index of relative abundance estimated at about 700 individuals/hour in the Gulf of Naples and 900 ind./hour in the Gulf of Gaeta. Otherwise the estimated abundance is less than 100 ind./hour on the south side.

The stretched shape of the contour lines, stressed by the figure, is due to the anisotropic behaviour of the variable detected in the structural analysis.

The map shown in Fig. 5 represents the estimation variance of the variable juveniles abundance. This map can be explained in terms of the confidence level to be set for the estimates. In most of the area a good confidence level, represented by the more light shadowed zones, can be set.

The map in Fig. 6 shows the distribution of the conditioned probability of finding an abundance index higher than 300 ind./hour. Naturally, different threshold values can be selected on the basis of specific knowledge. In the sampled season the probability of finding a localization of nursery areas south of the Gulf of Salerno is lower than 12%. Conversely in the Gulf of Naples the probability increases to 70% and in the Gulf of Gaeta it reaches the maximum of 90%.

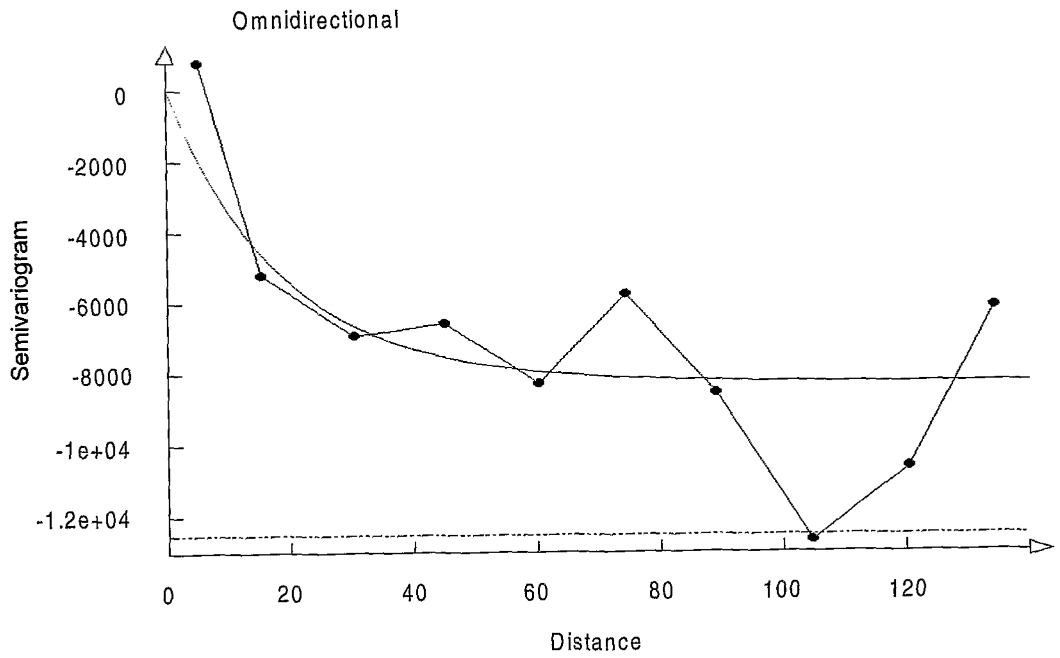

Fig. 3. Cross-variogram model of juveniles number and depth variables.
$\gamma(h)$ = -8280*Exp 55.9 (h). Distance h in km

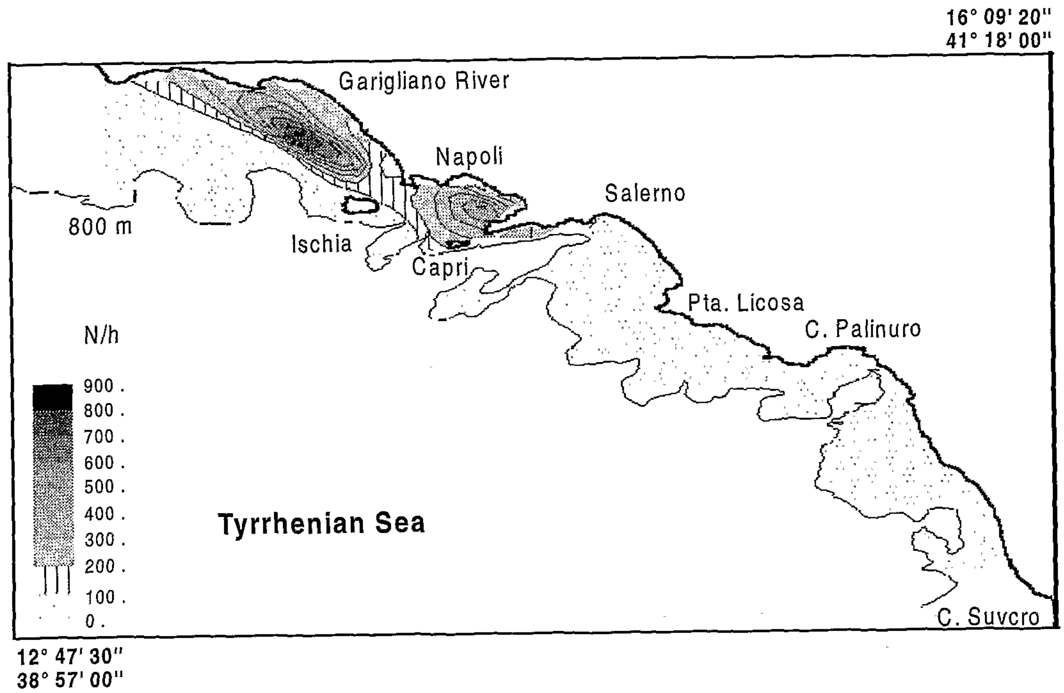

Fig. 4. Nursery area of *Merluccius merluccius* by Co-kriging. Survey of 1996.

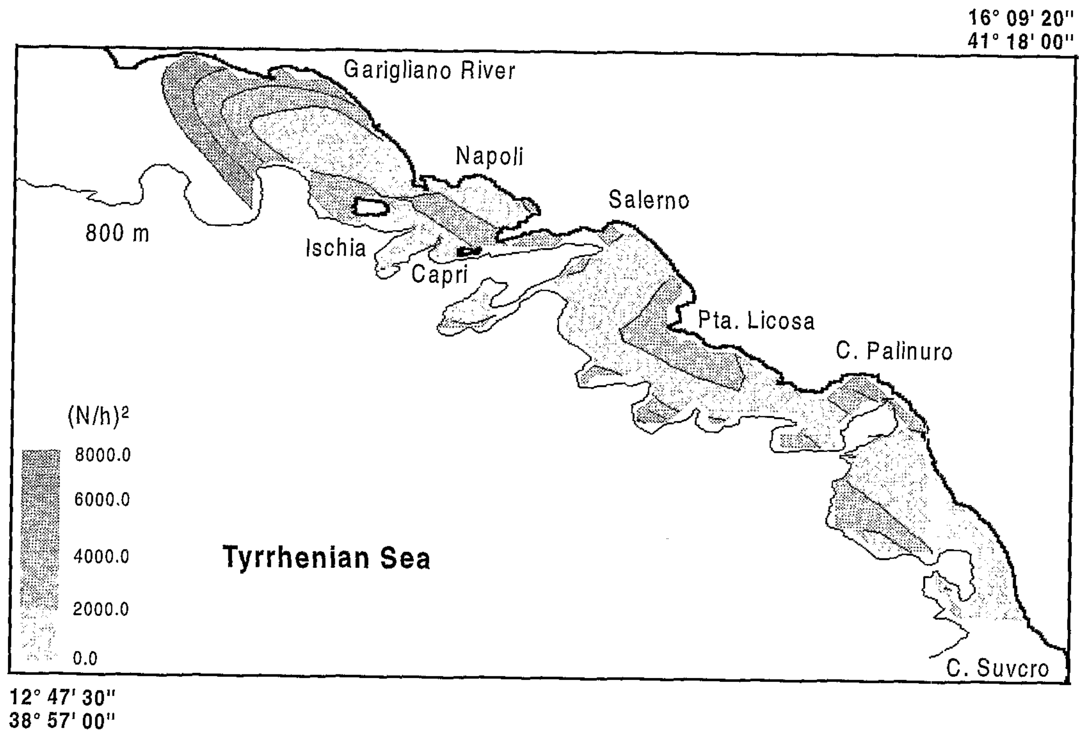

Fig. 5. Estimation variance of nursery area of *Merluccius merluccius* by Co-kriging. Survey of 1996.

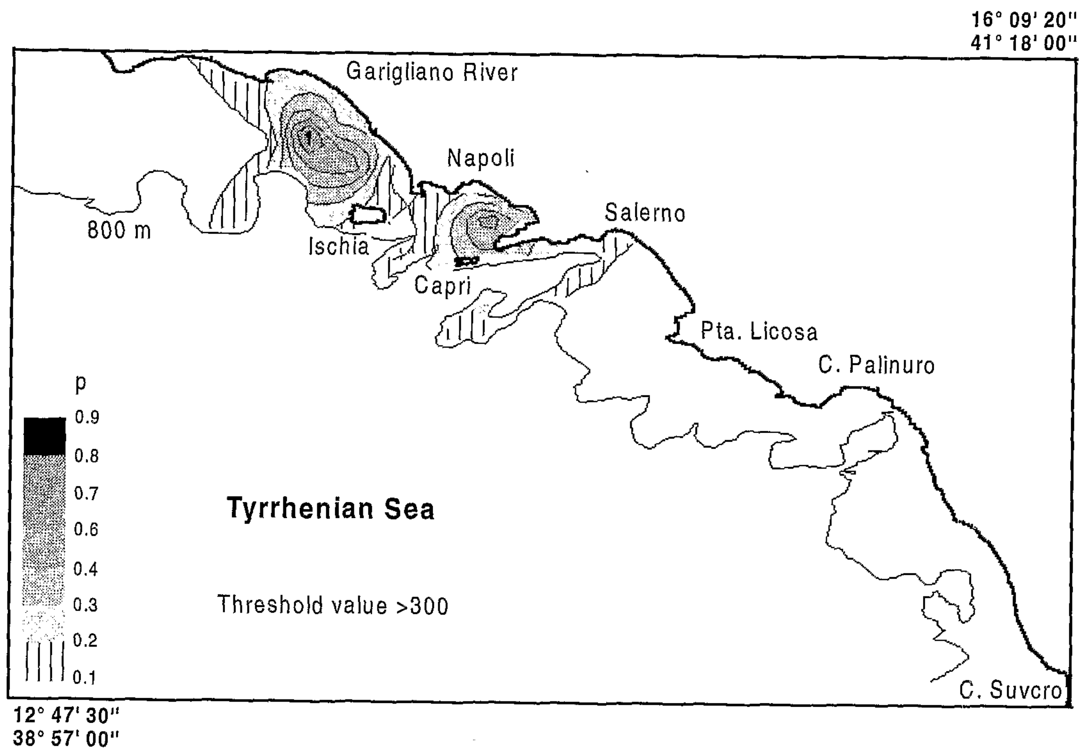

Fig. 6. Probability distribution of nursery area of *Merluccius merluccius* by Disjunctive Kriging. Survey of 1996.

Conclusions

The geostatistical techniques provide useful tools for assessing variables without restrictive assumptions on their probability distribution (Matheron, 1965). Therefore these methods can be applied for elaborating trawl survey data and assessing variables not normally distributed, as the abundance index (Smith, 1988).

The co-kriging technique applied accounting for the two variables depth and number of juveniles allowed us to minimize the variance of the estimation errors, as the secondary variable depth was more widely represented than the primary one number of juveniles. In fact when a primary variable is spatially cross-correlated with a secondary one, the latter contributes to reduce the variance of estimation, and the usefulness of this contribution is enhanced by the fact that the primary variable is often undersampled (Isaaks and Srivastava, 1989).

The structural analysis plays a relevant role in the understanding of the spatial behaviour of the variable. Therefore the information on anisotropy phenomenon in the variable number of juveniles was considered in the modelling phase, in order to improve the precision of the estimate.

Moreover the technique of disjunctive kriging allowed us the setting up of a comparative method for explaining the localization of nursery areas in terms of probability, after threshold values were fixed.

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