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NURSERY AREAS OF MERLUCCIUS MERLUCCIUS IN THE ITALIAN SEAS AND IN THE EAST SIDE OF THE ADRIATIC SEA

AREE DI NURSERY DI *MERLUCCIUS MERLUCCIUS* NEI MARI ITALIANI E NEL MAR ADRIATICO ORIENTALE

Abstract

Bottom trawl-surveys were carried out within the EU MEDITS Program in the Italian, Slovenian, Croatian and Albanian Seas, adopting a stratified random sampling and a standard gear specifically designed. To identify nursery areas of the European hake Merluccius merluccius *(Merluccidae, Osteichthyes), abundance data were analysed using geostatistical techniques; thus the spatially correlated variable number of juveniles (ind.×km⁻²) was investigated. Consequently, the fractions of the length frequency distributions lower than 12 cm were determined, as, for the European hake, this size represents the upper limit of the first age group. Kriging techniques of the linear geostatistics were applied, extending the methodological approach to the spatio-temporal dimension. In this case, the co-regionalised models and the co-kriging techniques were adopted, after the identification of the auto and cross-variogram models. The spatial structure of the* M. merluccius *nursery areas was represented by aggregations of rather wide dimensions in some zones and by patches with shorter radius in others. However, the magnitude of the density estimates in the Northern Tyrrhenian Sea as well as in the Middle Tyrrhenian Sea dominated the scenario. Therefore, the disjunctive kriging technique of the non-linear geostatistics was introduced in the analysis to estimate the conditional probability of exceeding a given threshold value of the variable. This cut-off, which was stated at 3,500 ind.×km⁻², enabled the comparison of the different sub-areas in terms of probability of finding a European hake nursery.*

Key-words: Co-kriging, disjunctive kriging, nursery area, geostatistics, Merluccius merluccius.

Introduction

The juvenile phase of the European hake *Merluccius merluccius*, including recruitment time, juvenile growth, bathymetric and seasonal distribution of recruits, have been studied in several geographical regions (Jukic and Arneri, 1984; Karlovac, 1965; Orsi Relini *et al.*, 1988; Orsi Relini *et al.*, 1989a; Orsi Relini *et al.*, 1989b; Papaconstantinou and Stergiou, 1988; Pereiro and Fernandez, 1983; Zupanovic, 1968). Indeed, this knowledge represents a sound background for the identification of nursery areas, which can be considered as the grounds where juvenile European hakes move at the onset of the benthic stage of their life, becoming vulnerable to the trawl net. From the side of fishery management, the nursery areas could be considered as zones to be protected, in which the fishing pressure might be reduced throughout the year or in fixed periods. Such measures, coupled with a conventional approach (i.e. proper mesh size in the cod-end, closed season, etc...) could, thus, contribute to considerably decreasing the fishing mortality on the recruits, which represents a crucial issue for resources which are overexploited, like European hake (e.g. Ardizzone and Cau, 1990; Tursi *et al.*, 1996). Preliminary evaluation on the effects of fisheries restriction (closed areas) on yield increase of the European hake has been reported for the southernmost

Tyrrhenian basin (Giordano *et al.*, 1997). In this context, only a bathymetric criterion was adopted for introducing limitations to the fishery, which was not allowed in the shallow waters, within 100-m depth. However, this approach might not be definitely adequate to preserve juveniles of the European hake, which are mainly distributed in deeper waters (Orsi Relini *et al.*, 1988). Moreover, studies performed by GIS techniques have reported that higher density of recruits occurred in particular geographical areas (Ardizzone and Corsi, 1997; Corsi *et al.*, 1998). At present, little information is available on the localisation of nursery areas by methods explicitly accounting for spatial considerations, like those provided by geostatistics (Matheron, 1965). Indeed, such an approach has been widely applied in the analysis of marine and fishery data, as in Conan (1985), Fariña *et al.* (1994), Jurmas *et al.* (1977), Lembo *et al.* (1990), Maynou *et al.* (1996), Pelletier and Parma (1994), Petitgas (1993), Polacheck and Volstad (1993). Similarly, geostatistical methods can provide powerful tools to investigate the spatial correlation of juveniles' distribution and abundance, that is the first step in assessing and localising nursery areas (Lembo *et al.*, 1998a).

The main advantage of the geostatistics consists in the possibility of operating without restrictions on the probability distribution function of a variable. This is estimated in each unsampled point considering the intrinsic variability of the data, as well as the shape and the extent of the investigated area (Journel and Huijbregts, 1978; Matheron, 1971). In addition, when different variables are spatially inter-correlated the co-regionalised models can be adopted and the co-kriging techniques applied, after the identification of the auto and cross-variogram models (Bourgault and Marcotte, 1991; Rouhani and Wackernagel, 1990), reducing the variance of estimation (Isaaks and Srivastava, 1989). It is also possible to link the spatial and temporal dimension of a variable (Myers, 1982, 1988; Rouhani and Myers, 1990). Therefore, when the numerousness of the data is higher in the spatial than in the time dimension, the spatio-temporal series can be interpreted as a particular realisation of several correlated random functions. The advantages of this approach were first highlighted in a previous study on the spatio-temporal distribution of European hake abundance in the South Tyrrhenian Sea (Lembo *et al.*, 1998b), where a time series of trawl surveys data was analysed. The co-regionalised models and the co-kriging techniques can be thus an effective support both to geographically define nursery areas and to appraise the persistence of their localisation through the time, when at least two temporal data series are available.

Other desirable aims in establishing nursery areas could be represented by the definition of homogeneous criteria to state them, as well as by the need to compare adjacent regions. Furthermore, the knowledge of delineated zones, where the biomass exceeds given threshold values, would be advantageous in the assessment of fishery resources, whose exploitation profitability not only depends on the total stock, but also on its distribution. In this case, the non-linear geostatistics represents a suitable approach, as it allows estimation of the conditional probability of exceeding a given cut-off value of a variable applying disjunctive kriging technique (Rivoirard, 1994; Yates and Warwick, 1986). In this paper, trawl survey data were analysed by kriging and co-kriging techniques to perform a preliminary estimate of the spatio-temporal localisation of the European hake nursery areas. Different geographical regions were also compared in terms of probability of finding a nursery, in this case applying disjunctive kriging.

The data were collected by Italian, Slovenian, Croatian and Albanian teams within the surveys of the EU MEDITS program (Bertrand *et al.*, 1998).

Material and methods

a) *Survey data*

The data were collected during the surveys carried out in June-July of 1995 and 1996. All the research teams involved in the project adopted the same standardised protocol. Particularly, a stratified random sampling (bathymetric limits: 10, 50, 100, 200, 500 and 800 meters; each haul position randomly selected in small sub-areas) was applied, using the same sampling gear (GOC 73, by P.Y. Dremière, IFREMER-Sète) in the different geographical zones. The mesh size (20 mm stretched in the codend) enabled the focusing of the study on the recruitment phase of the European hake. The horizontal net opening ranged between 14 and 19.5 m, according to the warp length, which in turn depended on the depth. The hauls, carried out only during daylight, lasted 30 minutes in the strata 10-200 m and 60 minutes in the strata deeper than 200 m. Therefore, the abundance of *M. merluccius* juveniles was figured in the standardised form (individuals×km^{-2}), using the number of individuals, the distance and the wing spread of each tow ("swept area method"; Pauly, 1983). The number of *M. merluccius* juveniles at each location was determined calculating the fraction of the length frequency distribution lower than 12 cm. The length data were collected onboard, measuring the individuals at the lower half centimetre. The data elaboration was performed for the Italian Seas and extended to the East Side of the Adriatic Sea in 1996, when this area was sampled for the first time.

b) *Structural analysis*

The identification of the spatial structure of a variable represents the first step of the geostatistical analysis. The random variable $Z(x)$ under investigation was the "abundance index of recruits" of *M. merluccius*, measured as density (ind.×km^{-2}) at the geographical coordinates x in a two-dimensional space and observed at n sampling stations $\{z(x_i), i=1:n\}$. Following the trawl-survey theory and statistical design, the experimental catches were presumed to reflect the true distribution and abundance of the resource at sea (e.g. Saville, 1977). Moreover, we assumed a stable structure of the variable, i.e. the spatial organisation of the density was unchanging through the sampling period (about 1 month). Such an assumption could be considered rather strong for fish population (Pellettier and Parma, 1994). Nevertheless, the hypothesis that the displacement of the biomass was rather low, compared with the survey speed, seemed realistic in our case, according to the knowledge on migration of *M. merluccius* during the recruitment phase (Orsi Relini *et al.*, 1988; Orsi Relini *et al.*, 1989b). Furthermore, on the basis of the daylight sampling we presumed that catchability was not structured through the space, i.e. it was not affected by vertical migratory behaviour (day and night displacements). In addition, the following second-order stationarity conditions of the increments of $Z(x)$ (*intrinsic hypothesis*) were assumed (Journel and Huijbregts, 1978):

$$E[Z(x)] = m, \ \forall x;$$
$$\mathrm{Var}[Z(x+h) - Z(x)] = E\{[Z(x+h) - Z(x)]^2\} = 2\gamma(h), \ \forall x;$$

where E is the mathematical expectation, Var is the variance, h is the vector that separates the two points x and $x+h$, and the function $g(h)$ is the semi-variogram (or simply variogram). These two conditions mean that the mathematical expectation of $Z(x)$ exists and is the same over the whole area regardless of location, and the variance of the increments of $Z(x)$ does not depend on the locations x but only on the separation distance h. The variogram function $g(h)$, thus, characterises the spatial correlation structure of $Z(x)$. When more information are available, it can be generalised to spatial or spatio-temporal co-regionalisation of several variables. Indeed, the data set available from trawl-surveys may often contain information also on variables (secundary) other than that of interest (primary), moreover, the same variable can be known in two or more different sampling periods. Hence, if a secondary variable is spatially or spatio-temporally cross-correlated with the primary one, the former will give additional information on the latter (Isaaks and Srivastava, 1989).

Thus, in our study the cross-variogram function:

$$2\gamma_{12}(h) = E\{[Z_1(x+h) - Z_1(x)] \ [Z_2(x+h) - Z_2(x)]\}, \qquad \forall x,$$

was used to characterise the spatial correlation of the same variable "number of recruits", sampled in two different surveys. Therefore, whenever it was possible, the estimate of the variable was improved, for each survey, by using the cross-variogram information on temporal persistence of spatial continuity.

The variogram and cross-variogram functions were estimated empirically from the experimental data. The variogram estimator (auto or cross) was (Journel and Huijbregts, 1978):

$$\gamma_{12}^*(h) = \frac{1}{2n(h)} \sum_{k=1}^{n(h)} (z_1(x_k + h) - z_1(x_k))(z_2(x_k + h) - z_2(x_k))$$

where $z_1(x_k)$ and $z_1(x_{k+h})$ are the experimental values of the variable Z_1 "number of recruits" at time t_1 in the location x_k and (x_{k+h}), $z_2(x_k)$ and $z_2(x_{k+h})$ are the experimental values of the variable Z_2 "number of recruits" at time t_2 in the location x_k and (x_{k+h}), $n(h)$ is the number of distinct pairs of points separated by the vector h.

The structural analysis was first carried out on the whole area, finding very different density levels of the *M. merluccius* recruits. Subsequently, the structural analysis was performed partitioning the whole area in 6 more homogeneous sub-areas, in order to satisfy the stationarity assumption (Journel and Huijbregts, 1978). This procedure seems to be more effective than the whole region approach using traditional or relative variograms (Simard *et al.*, 1992).

A valid variogram model was fitted to each experimental variogram, adapting the most common type of theoretical models: Spherical, Exponential and Gaussian. The first two describe a good level of spatial continuity, with a quicker decay of spatial correlation in the Spherical one. The Gaussian is suitable in modelling highly continuous phenomena (Journel and Huijbregts, 1978; Matheron, 1971). However, the Spherical and Exponential models were expected to be more relevant for a spatial process like the distribution of abundance of a demersal resource and in particular of the recruit density.

The parameters of the variogram models were estimated. The Nugget, indicating a certain microscale variability or measurement error, the Range, i.e. the distance

beyond which there is no correlation between variable values at two points, the Sill, that is the value of variability at which the variogram reaches the plateau.

The variogram models were cross-validated by jackknife methods (Miller, 1974), adopting the two criteria that the mean error between the observed and estimated values of the variable should be close to 0 and the variance of the standardised error should be close to 1.

c) Spatial prediction

The prediction process was achieved through kriging techniques, considering the experimental data and the spatial structure described by the variogram model. In our analysis, ordinary kriging and co-kriging were used to estimate the density of recruits at each location of the investigated area, and disjunctive kriging to predict the conditioned probability of exceeding a given cut-off value of the recruit number.

On the investigated area a grid was designed, with a mesh size of 1 km, in order to perform estimates in each grid crossing point.

At each unsampled location x_0, the number of recruits of *M. merluccius* was estimated using the ordinary kriging estimator (Isaaks and Srivastava, 1989; Journel and Huijbregts, 1978):

$$\hat{z}(x_0) = \sum_{i=1}^{n} a_i z(x_i)$$

i.e., by a linear combination of the n observations of the variable, where the weights $a_1,...,a_n$ are determined by imposing on the estimator the constraints of non-bias and minimum estimation variance. In the same location, the minimum estimation variance, or kriging variance, was obtained from:

$$\sigma_K^2(x_0) = \mu + \sum_{i=1}^{n} a_i \gamma(x_i - x_0)$$

where μ is the Lagrange parameter (Isaaks and Srivastava, 1989; Journel and Huijbregts, 1978). The kriging variance can be explained in terms of the confidence level to be set on the estimates obtained in the prediction process, and depends only on the structural model and not on the experimental data.

The co-kriging method has been then applied considering the spatio-temporal inter-correlation of the number of recruits observed in the surveys carried out in two consecutive years. The cross-correlation can contribute to gain information on the investigated variable, reducing its variability. Consequently, this method should help in decreasing the kriging variance (Isaaks and Srivastava, 1989).

The two considered variables were Z_1 and Z_2 indicating the number of recruits in two different surveys. If the values of the variable to be estimated Z_1 are known in n locations $z_1(x_{11})$,...,$z_1(x_{1n})$ and those of the cross-correlated one Z_2 in m locations $z_2(x_{21})$,...,$z_2(x_{2m})$, the co-kriging estimator at each unsampled location x_0 is the linear combination:

$$\hat{z}_1(x_0) = \sum_{i=1}^{n} a_i z_1(x_{1i}) + \sum_{j=1}^{m} b_j z_2(x_{2j})$$

where $(a_1, a_2,...,a_n,\ b_1, b_2,...,b_m)$ are the weights determined imposing on the estimator the constraints of non-bias and minimum estimation variance (Isaaks

and Srivastava, 1989; Journel and Huijbregts, 1978). The co-kriging variance was obtained from:

$$\sigma_{CK}^2(x_0) = \mu_1 + \sum_{i=1}^{n} a_i \gamma_{11}(x_{1i} - x_0) + \sum_{j=1}^{m} b_j \gamma_{21}(x_{2j} - x_0)$$

where m_1 is the Lagrange parameter (Isaaks and Srivastava, 1989; Journel and Huijbregts, 1978).

The conditional probability that the estimated value of the variable $Z(x)$ "number of recruits" was greater than a given cut-off level z_c was then performed by non-linear geostatistics, applying disjunctive kriging technique. The first step was the definition of a transform variable, supposed to be bi-variate normally distributed. Therefore, this transform function was used to estimate the following conditional probability: $P = \text{Prob}\{Z(x) \geq z_c \,/\, z_1, z_2, ..., z_n\}$, where $\{z(x_\alpha) = z_\alpha, \alpha = 1$ to $n\}$ are the n available data.

The disjunctive kriging provided a non-linear estimator $P*_{DK}$ for this probability (Journel and Huijbregts, 1978).

The abundance threshold, in terms of number of recruits, was fixed at 3,500 ind.$\times$km^{-2}, according to Corsi and Ardizzone (1997). An advantage of the disjunctive kriging is represented by the possibility to localise the nursery areas in terms of probability. Moreover, this technique allows to adopt the same criteria of delimitation, that is particularly helpful in regions characterised by very different density of juveniles, making thus possible a rapid comparison among distinct zones.

Results

a) Structural analysis

The experimental variograms of the survey carried out in 1995 (Fig. 1) showed a dissimilar behaviour according to the different geographical sub-areas, except the Sardinian Seas and the Straits of Sicily, where a very analogous spatial pattern was found. These two variograms were well fitted by a spherical model with a range of 26.6 km, the distance beyond which the density of recruits was no longer spatially correlated. Furthermore, the maximum variability estimated by the variogram models, i.e. the sill, displayed comparable levels. On the contrary, the ranges of the models, referred to the survey of 1996, showed considerable differences in these two sub-areas (Fig. 2). In the Sardinian Seas the spatial continuity, still well described by a spherical model, was reduced (range of 13.2 km), while in the Straits of Sicily it increased (range of 37.8 km). Moreover, in both the sub-areas, the sill of 1996 was higher than in 1995.

In the South Adriatic Sea and Ionian Sea the spatial structure was characterised, both in the 1995 and 1996 surveys (Fig. 1 and 2) by a spherical model, with a short range, indicating the limit of the spatial auto-correlation of the recruits density at about 15 km. Analogous sill values were estimated in both the surveys.

In the Middle-South Tyrrhenian sub-area an exponential model was fitted both on the data of 1995 and 1996 (Fig. 1 and 2), and the similar range of about 11 km showed a short spatial continuity. A sill value as higher as 1.4 times that of 1995 was seen from the variogram of 1996.

Fig. 1 - Experimental and variogram models (g(h)) of the number of recruits (ind.×km^{-2}). MEDITS Survey of 1995. Distance h in km.

Variogrammi sperimentali e modelli di variogramma (g(h)) del numero di reclute (ind.×km^{-2}). Campagna MEDITS del 1995. Distanza h in km.

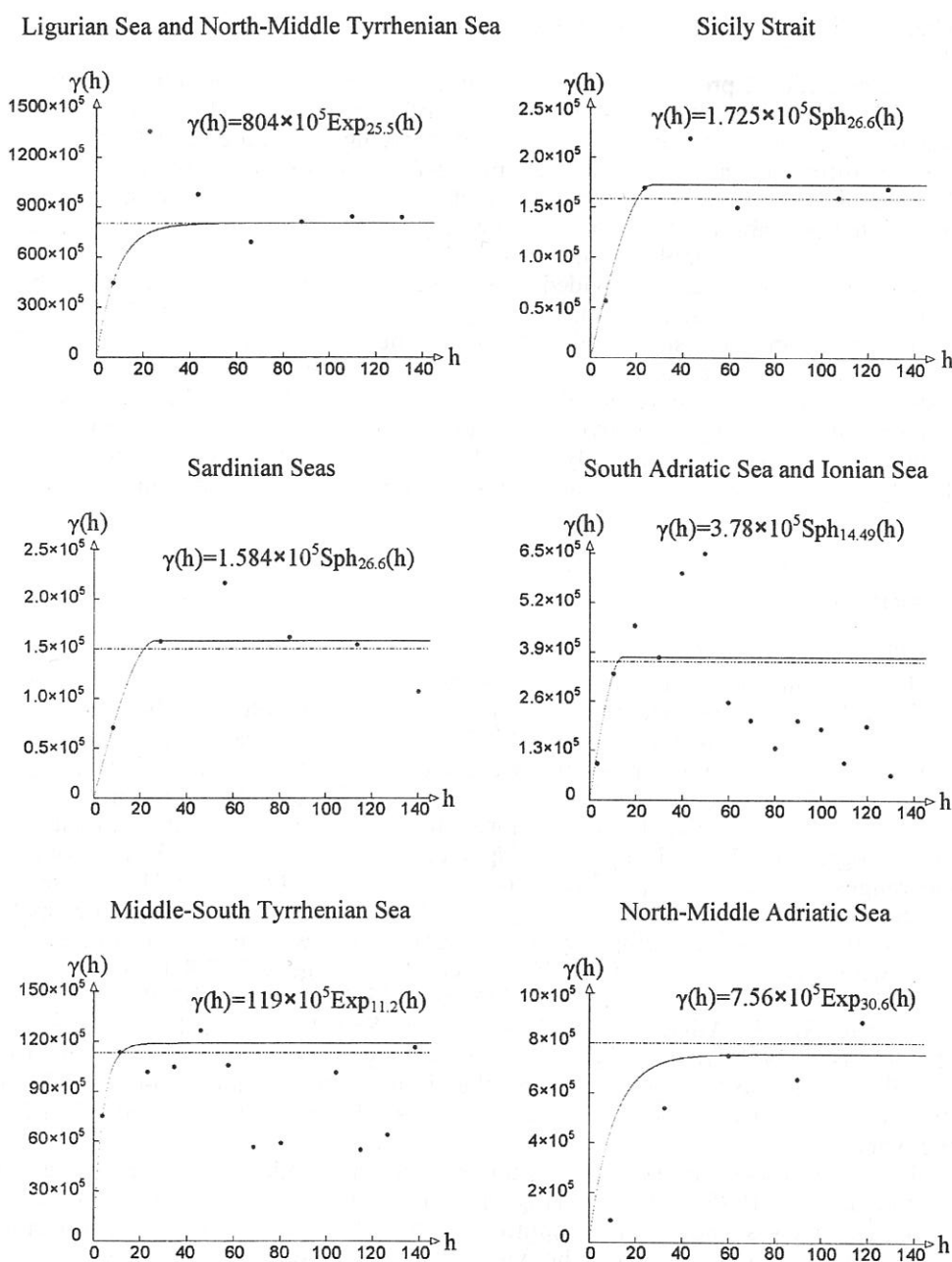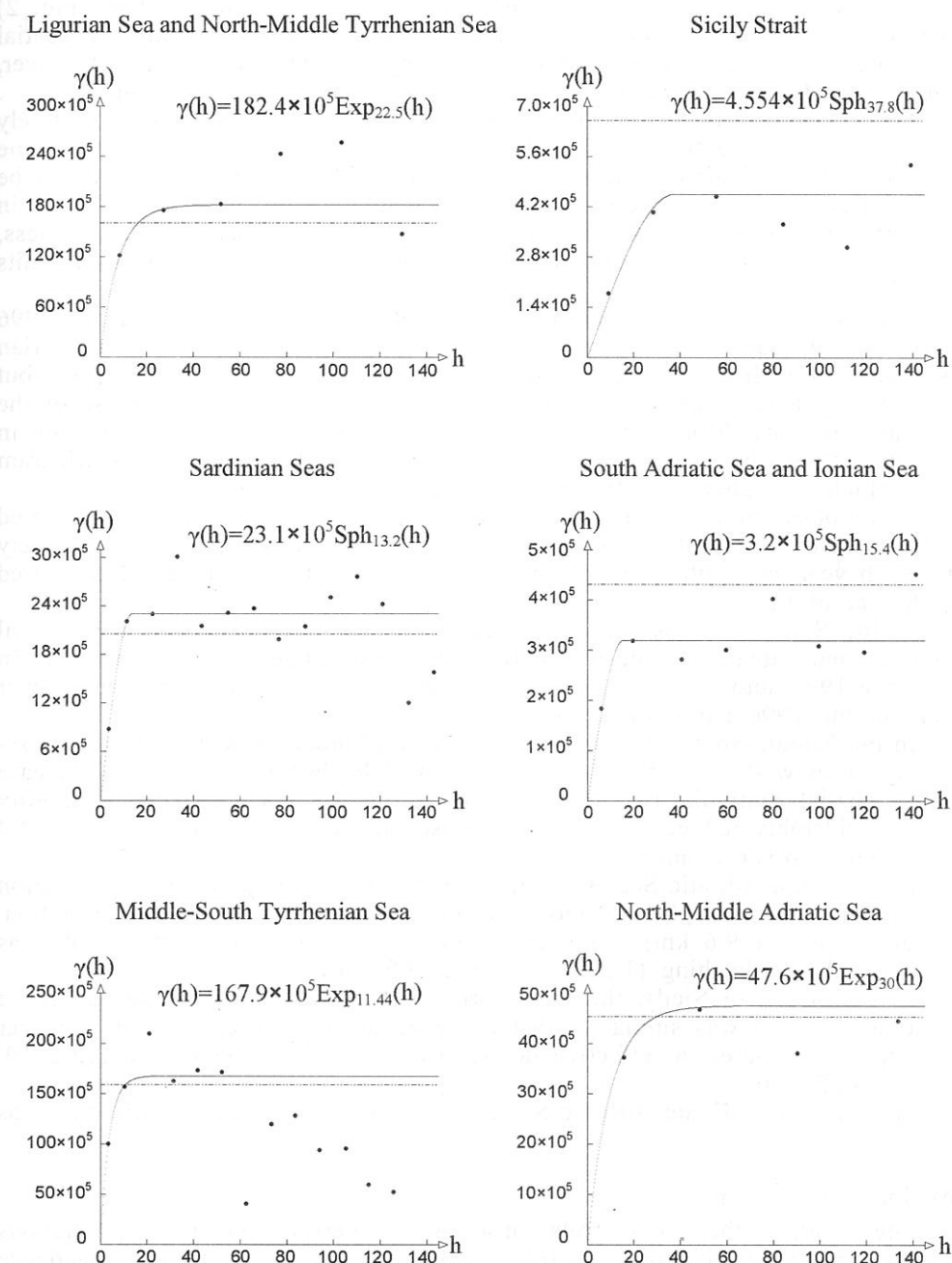### Ligurian Sea and North-Middle Tyrrhenian Sea

$$\gamma(h)=804\times10^5\mathrm{Exp}_{25.5}(h)$$

Sicily Strait

$$\gamma(h)=1.725\times10^5\mathrm{Sph}_{26.6}(h)$$

Sardinian Seas

$$\gamma(h)=1.584\times10^5\mathrm{Sph}_{26.6}(h)$$

South Adriatic Sea and Ionian Sea

$$\gamma(h)=3.78\times10^5\mathrm{Sph}_{14.49}(h)$$

Middle-South Tyrrhenian Sea

$$\gamma(h)=119\times10^5\mathrm{Exp}_{11.2}(h)$$

North-Middle Adriatic Sea

$$\gamma(h)=7.56\times10^5\mathrm{Exp}_{30.6}(h)$$

Fig. 2 - Experimental and variogram models (g(h)) of the number of recruits (ind.×km^{-2}). MEDITS Survey of 1996. Distance h in km.

Variogrammi sperimentali e modelli di variogramma (g(h)) del numero di reclute (ind.×km^{-2}). Campagna MEDITS del 1996. Distanza h in km.

Ligurian Sea and North-Middle Tyrrhenian Sea

$$\gamma(h)=182.4\times10^5\mathrm{Exp}_{22.5}(h)$$

Sicily Strait

$$\gamma(h)=4.554\times10^5\mathrm{Sph}_{37.8}(h)$$

Sardinian Seas

$$\gamma(h)=23.1\times10^5\mathrm{Sph}_{13.2}(h)$$

South Adriatic Sea and Ionian Sea

$$\gamma(h)=3.2\times10^5\mathrm{Sph}_{15.4}(h)$$

Middle-South Tyrrhenian Sea

$$\gamma(h)=167.9\times10^5\mathrm{Exp}_{11.44}(h)$$

North-Middle Adriatic Sea

$$\gamma(h)=47.6\times10^5\mathrm{Exp}_{30}(h)$$

In the Ligurian Sea and North-Middle Tyrrhenian Sea, the presence of an outlier value (1995 – Fig. 1) influenced the modelling phase, though the spatial structure of the recruit abundance enabled the interpolation of an exponential model, with a range of 25.5 km representing a rather high spatial continuity. An exponential model also fitted the experimental variogram of 1996 (Fig. 2) whose range was very similar (22.5 km) to that of 1995, confirming a spatial structure of the recruit density characterised by a rather long radius. Moreover, the sill of 1996 was remarkably reduced, in comparison to that of 1995.

For the North-Middle Adriatic Sea, the experimental variogram was tentatively fitted by an exponential model with a range of 30.6 km (Fig. 1). In the same sub-area, the variogram concerning the survey of 1996 (Fig. 2) seemed to be well interpolated by an exponential model with a range of 30 km, though in this case a considerable augmentation of the sill was observed. Nevertheless, a rather high spatial continuity in the abundance of the *M. merluccius* recruits could be seen.

The experimental cross-variograms obtained using the data of both the 1996 and the 1995 surveys are shown in figure 3. For the sub-area of the Ligurian Sea and North-Middle Tyrrhenian Sea an exponential model was fitted again, but with a very long range of about 60 km, indicating an effective increase of the spatial continuity. Moreover, the cross-correlation of the number of recruits in the two consecutive years contributed to remarkably reducing the cross-variogram sill, which was about 4.5 times lower than in 1996 auto-variogram.

In the other sub-areas the spatial structure of the recruit aggregations presented patterns that were similar to those detected in the analysis carried out separately for each year, but with a smaller extension of the spatial continuity if compared with that of the Ligurian Sea and North-Middle Tyrrhenian Sea.

In the Sardinian Seas the cross-variogram, still interpolated by a spherical model, contributed to extend the spatial continuity (range 21 km) in comparison with the 1996 auto-variogram (Fig. 2). Moreover, the sill value was much lower than in the 1996 auto-variogram.

In the Middle-South Tyrrhenian an exponential model was fitted to the cross-variogram as well as in the auto-variogram of 1996. In this case a slight increase of the spatial continuity (range 16 km) was estimated, but the spatial variability was considerably reduced and it was almost halved in comparison with that of the 1996 auto-variogram.

In the South Adriatic Sea and Ionian Sea the spatio-temporal cross-correlation was described by a spherical model as observed in the 1996 auto-correlation. A larger range (19.6 km) characterised the spatial continuity and the sill was substantially diminishing (1.312×10^5 versus 3.2×10^5).

In the Straits of Sicily, the cross-correlation did not enhance the pattern of continuity, which was similar to that observed in the auto-correlation, however also in this sub-area an effective decrease of the sill was estimated (1.02×10^5 versus 4.554×10^5).

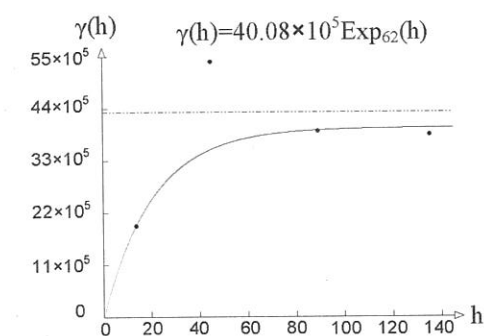For the North-Middle Adriatic Sea the interpolation of a cross-variogram was not possible.

b) Spatial prediction

The results of the cross-correlation allowed to perform the spatial predictions by the co-kriging technique. Therefore, the estimate of the juvenile abundance
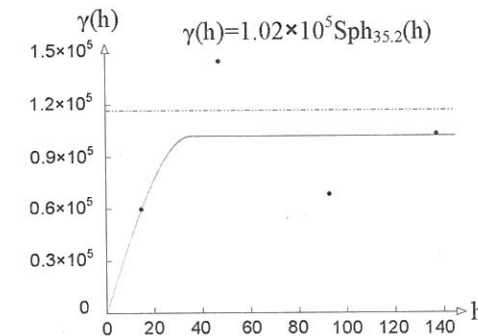
Fig. 3 - Experimental and cross-variogram models (g(h)) of the number of recruits (ind.×km^{-2}). MEDITS Survey of 1996-1995. Distance h in km.

Cross-variogrammi sperimentali e modelli di cross-variogramma (g(h)) del numero di reclute (ind.×km^{-2}). Campagna MEDITS del 1996-1995. Distanza h in km.
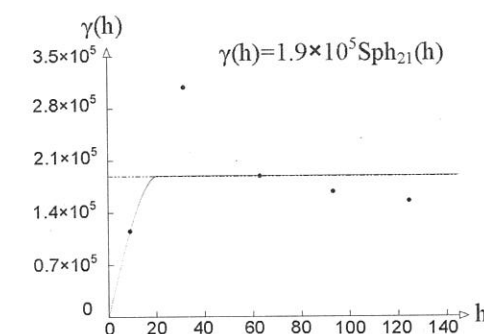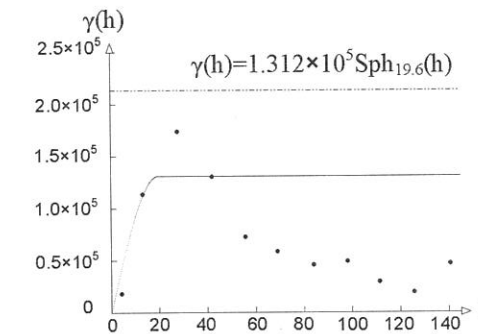
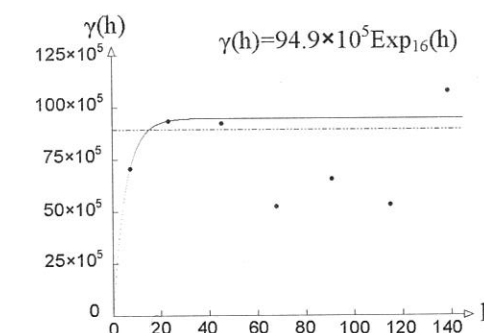Fig. 4 - Co-kriging estimation of juvenile abundance (ind.×km⁻²) of *Merluccius merluccius* (in the North-Middle Adriatic Sea the kriging estimate is reported). MEDITS survey of 1996. Six sub-areas are delimited by bold line. The geographical coordinates on the axis are expressed in the linear system (km).

Stima co-kriging dell'abbondanza dei giovanili (ind.×km⁻²) di Merluccius merluccius *(nel Mar Adriatico Centro-Settentrionale si riporta la stima kriging). Campagna MEDITS del 1996. Le sei sub-aree sono delimitate da linee spesse. Le coordinate geografiche sugli assi sono espresse nel sistema lineare (km).*
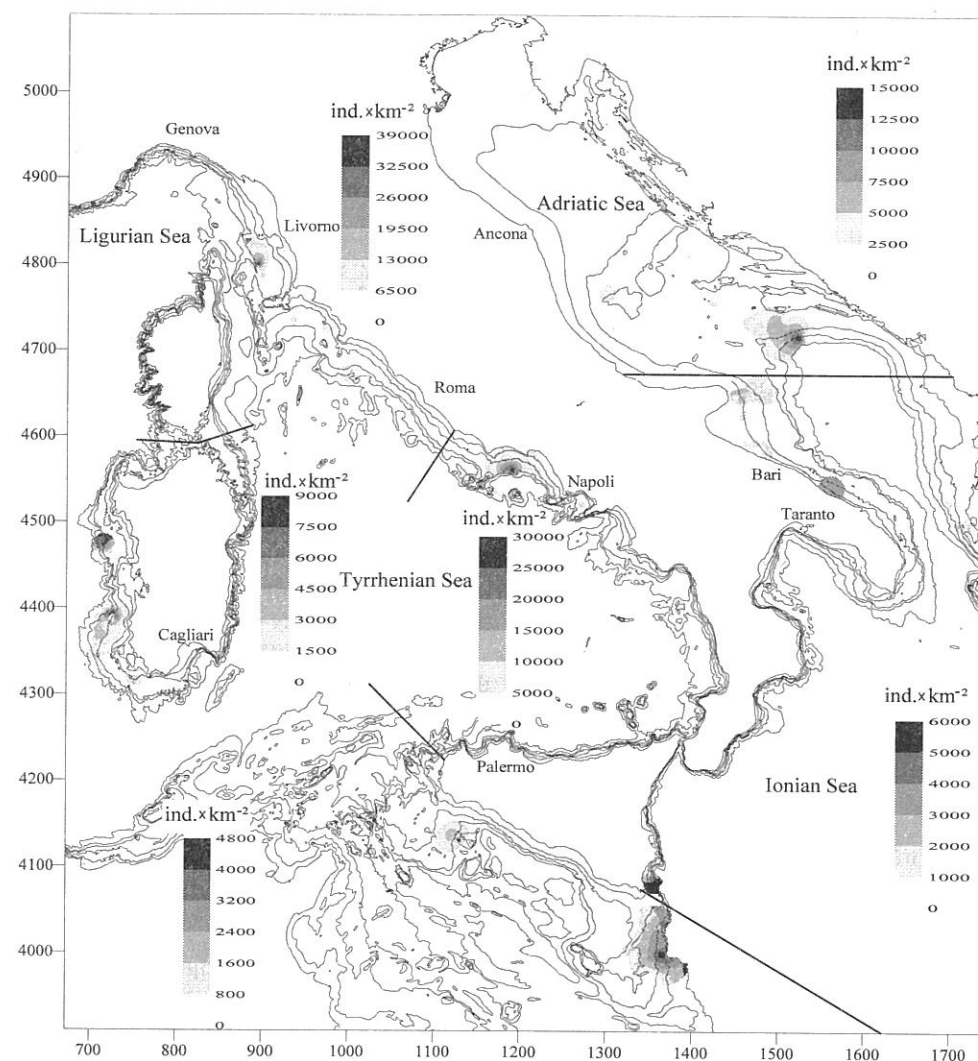
in 1996 was obtained using also the data of 1995, except in the North-Middle Adriatic Sea where, owing to the difficulties in the construction of the cross-variogram, the prediction was performed by kriging (Fig. 4).

Very different abundance levels of recruits were observed in the whole investigated area. The co-kriging estimates stressed the presence of very high recruit density in two sub-areas localised in the North and in the Middle Tyrrhenian Sea. In the former the maximum estimated value was about 38,000 (ind.×km⁻²) and in the latter about 30,000 (ind.×km⁻²). In these two sub-areas, the maximum of the recruit concentration was assessed in the stratum 100-200 m depth.

In the Ligurian Sea a rather high abundance of recruits was located in the Gulf of Genoa and in the Gulf of La Spezia (50-200 m depth in the latter). The maximum estimated values ranged between 2,000 and 8,000 (ind.×km⁻²).

In the Sardinian waters the areas with high density of *M. merluccius* juveniles were mainly located on the West and Southwest Side, but in contrast with what was observed in almost all the sub-areas, the maximum density (7,500-9,000 ind.×km⁻²) was estimated in the stratum 200-500 m depth. Similar bathymetric distribution was appraised in the Southeast Side of the Straits of Sicily and in the southernmost part of the Ionian Sea, where the maximum estimated abundance of recruits was lower (4,000-6,000 ind.×km⁻²) in comparison with those of the other sub-areas. Comparable levels of the maximum estimated values were appraised in the South Adriatic Sea and Ionian Sea, where the bathymetric distribution of recruits was mainly localised on the shelf, as in most of the sub-areas.

In the North-Middle Adriatic Sea the maximum estimated value of recruit abundance was about 15,000 ind.×km⁻². The area with the highest density was located off the Gargano Promontory and the maximum concentration of recruits was on the slope, beyond the depth of 200 m. This macrostructure dominated the whole sub-area. Indeed in other locations, as around the Pomo pit and Jabuka pit, known as the preferential grounds for the European hake juveniles, the maximum concentration of recruits was estimated at about 4,500 and 3,000 ind.×km⁻² respectively.

The map of the estimation variance, which should be interpreted in terms of estimate reliability, is shown in figure 5. The distribution of estimation variance indicates that, in wide areas of the North and Middle Tyrrhenian Sea as well as the North and Middle Adriatic Sea, a good level of reliability can be set on the estimates. Furthermore, it is useful to highlight that the localisation of such reliability level is often coincident with the areas exhibiting a high density of recruits.

Figure 6 was performed by disjunctive kriging and represents the probability distribution of finding a nursery of *M. merluccius*, defined as an area where more than 3,500 ind.×km⁻² (threshold value) can be localised. In the North Tyrrhenian Sea, on the North and South side of the Island of Elba, the highest probability of finding a nursery area was estimated, as well as in the Middle Tyrrhenian Sea (zone delimited by the Circeo Promontory and Island of Ischia). Another area with a similar level of probability was located in the Adriatic Sea, off the Gargano Promontory. Restricted zones with probability ranging between 0.25 and 0.5 were detected near the Pomo pit, as well as in the South Adriatic Sea, in the southernmost part of the Ionian Sea (Gulf of Noto) and in the Southeast side of the Straits of Sicily. Two nuclei with

Fig. 5 - Co-kriging estimation variance of juvenile abundance (ind.×km⁻²) of *Merluccius merluccius* (in the North-Middle Adriatic Sea the kriging estimation variance is reported). MEDITS survey of 1996. Six sub-areas are delimited by bold line. The geographical coordinates on the axis are expressed in the linear system (km).

Varianza di stima co-kriging dell'abbondanza dei giovanili (ind. ×km⁻²) di Merluccius merluccius *(nel Mar Adriatico Centro-Settentrionale si riporta la varianza di stima kriging). Campagna MEDITS del 1996. Le sei sub-aree sono delimitate da linee spesse. Le coordinate geografiche sugli assi sono espresse nel sistema lineare (km).*

Fig. 6 - Conditioned probability distribution of nursery areas of *Merluccius merluccius*, by disjunctive kriging estimation. MEDITS survey of 1996. The geographical coordinates on the axis are expressed in the linear system (km).

Distribuzione di probabilità condizionata delle aree di nursery di Merluccius merluccius, *mediante la stima del kriging disgiuntivo. Campagna MEDITS del 1996. Le coordinate geografiche sugli assi sono espresse nel sistema lineare (km).*
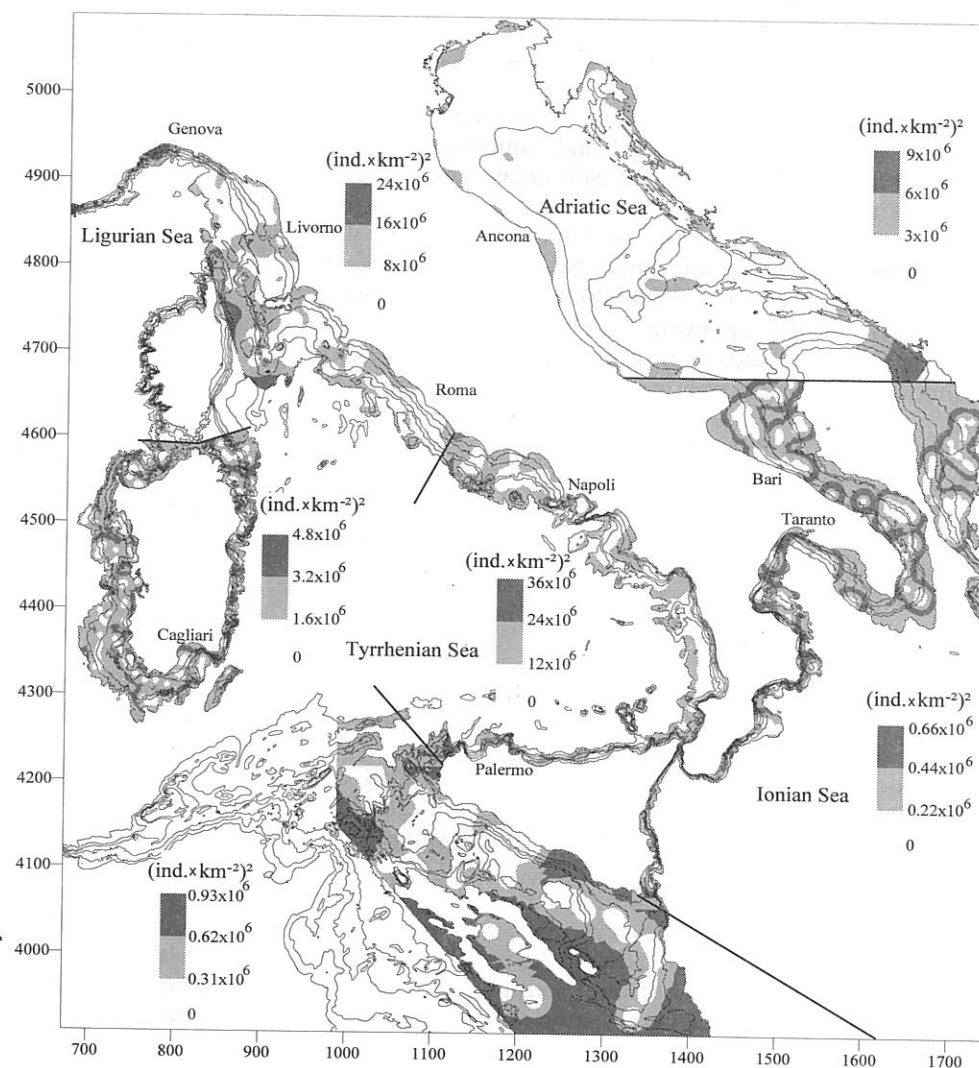
high probability (more than 0.5) were also localised on the West and Southwest Side of the Sardinian waters.
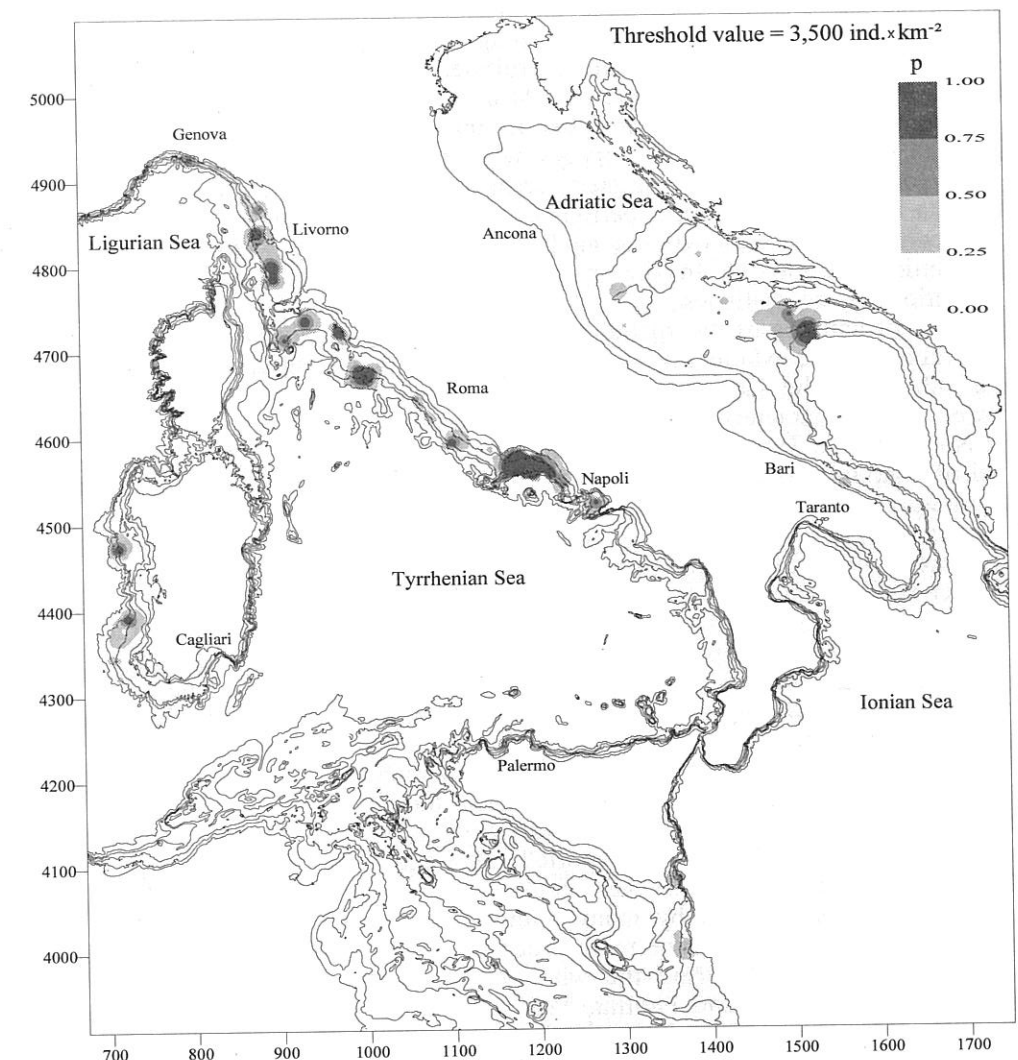
Discussion and conclusion

Though the size and the age at which a fish still belongs to the recruit phase could be a questionable assumption, many Authors have considered the *M. merluccius* recruits as the juveniles of the first age group (Alegria-Hernandez and

Jukic, 1988; Orsi Relini *et al.*, 1989a; Papaconstantinou and Stergiou, 1988) with an average length of 11.7 cm (Orsi Relini *et al.*, 1989a). The study of the nursery areas, defined as the grounds inhabited by the European hake recruits, should account for the specific recruitment pattern of the species, which in turn is closely related to its reproductive strategy. The European hake has been classified as a partial spawner (Biagi *et al.*, 1995; Sarano, 1986; Tsimenidis and Papaconstantinou, 1985) with three maturational peaks in correspondence with February-March, May and September (Biagi *et al.*, 1995). This long spawning season produces at least two main recruitment pulses, in spring (from March to June) and in late autumn (October-December), the former having generally a higher strength than the latter (Orsi Relini *et al.*, 1989a; Orsi Relini *et al.*, 1989b). Though the MEDITS surveys were carried out in a rather important season for the study of the nursery areas, a more accurate evaluation, using also data collected in different periods (i.e. from national surveys, Relini, 1998), could enhance the results of the analysis. Therefore, our evaluations represent a preliminary approach to the investigation of the European hake nursery distribution by geostatistics.

Different patterns of the spatial structure of the *M. merluccius* recruit density were found in the whole investigated area. After the geographical partitioning in 6 sub-areas, the variography (auto and cross) performed in each of them showed zones characterised by high spatial continuity (sub-areas: Ligurian Sea and North-Middle Tyrrhenian Sea, North-Middle Adriatic Sea), by an intermediate level of continuity (sub-areas: Straits of Sicily and Sardinian Seas) and by spatial continuity at a small scale level (sub-areas: Middle-South Tyrrhenian Sea, South Adriatic Sea and Ionian Sea). However, in most of the sub-areas, the cross-variograms allowed the highlighting of an increase of the spatial continuity, with a longer radius than estimated by the auto-variograms. Moreover, in all the sub-areas, the spatio-temporal cross-correlation contributed to remarkably reducing the spatial variability associated to the estimates of the recruit density.

Following the analysis on the spatio-temporal cross-correlation, the prediction process by the co-kriging techniques enabled us to detect a persistent localisation of recruit concentration in certain zones throughout the surveys. The magnitude of the density estimates in the Northern Tyrrhenian Sea (Tuscany) and in the Middle Tyrrhenian Sea dominated the scenario, though a considerable abundance of juveniles was assessed also in the Adriatic Sea, off the Gargano Promontory. Frattini and Paolini (1995) also reported the importance and the characteristic of this area, in which the *M. merluccius* recruits were distributed beyond the 200 m depth. As reported by many authors, Jabuka pit as well as Pomo pit were historically considered the main grounds in the Middle Adriatic Sea, where the recruits dominated during the whole year, occupying the sea depth from 150 to 250 m (Frattini and Paolini, 1995; Jukic and Arneri, 1984; Zupanovic, 1968). Alegria-Hernandez and Jukic (1988) also described a peak of recruitment in the month of May. Nevertheless, the abundance level of recruits estimated off the Gargano promontory makes this area at least as important as Pomo pit and Jabuka pit.

More homogeneous density levels of *M. merluccius* recruits were observed in all the other investigated sub-areas (South Tyrrhenian Sea, Straits of Sicily, Ionian Sea), where a lower abundance of recruits was estimated. Also in the southernmost Adriatic basin (Apulian and Albanian coasts) the areas of recruit

concentration presented lower densities if compared with those of the Gargano Promontory. Furthermore, the European hake juveniles were distributed according to the more common depth pattern (100-200 m), as also described in Ungaro et al. (1992).

Analysing some sub-areas, at mesoscale level, it is possible to stress, for example, that the predictions for the Ligurian Sea could be compared with those of Orsi Relini *et al.* (1992). These authors reported in the month of June a density (ind.×km^{-2}) of 1,400 and 10,590 in two different zones of the Gulf of Genoa. Likewise in the Middle Tyrrhenian Sea (South Latium and North Campania), where the presence of a site characterised by high recruit density was already focussed by Lembo *et al.* (1998a).

The disjunctive kriging technique, through the conditional probability distribution of the number of *M. merluccius* juveniles, effectively enabled us to identify and localise the European hake nursery areas all round the investigated region.

The spatial structure of the *M. merluccius* nursery areas were represented by aggregations of rather wide dimensions in some zones and by patches with a shorter radius in others. This spatial heterogeneity, and the pattern of spatial continuity, could be correlated to depth-related effect. Indeed, the aggregation of the European hake recruits could be not simply a response to the depth topography, but might be related to behavioural or ecological factors (e.g. response to patchy distribution of prey). The knowledge of these aspects needs further specific studies.

The use of a standardised criterion, like the threshold value of 3,500 ind.×km^{-2}, allowed comparison of the different sub-areas as regards the probability of finding a nursery. By this method, three main macro-structures were delineated, in the North Tyrrhenian Sea, on the North and South sides of the Island of Elba, in the Middle Tyrrhenian Sea (zone delimited by the Circeo Promontory and the Ischia Island) and in the Adriatic Sea, off the Gargano Promontory. Moreover, on the West and Southwest sides of the Sardinian waters two nurseries were also localised, though at a lower level of probability.

At this stage of our investigation, the disjunctive kriging technique represents a useful approach to the study of nursery areas, with advantageous potentiality in producing advice for fishery management. Moreover, the possibility of choosing among several threshold values makes the probability of finding a nursery area, more or less restrictive according to the different characteristics and distribution pattern of a resource, as well as to the specific purposes of the fishery policy.

Riassunto

Nell'ambito del Programma Europeo MEDITS sono stati effettuati trawl survey nei mari Italiani e nell'Adriatico orientale, adottando un campionamento random stratificato ed un attrezzo standard specificatamente progettato. Per individuare le aree di nursery del nasello *Merluccius merluccius*, i dati di abbondanza della variabile spaziale "numero di giovanili" (ind.xkm^{-2}) sono stati analizzati usando le tecniche della geostatistica. È stata quindi determinata la frazione delle distribuzioni di frequenza delle lunghezze minore di 12 cm. Infatti, questa taglia rappresenta il limite superiore del primo gruppo d'età per il nasello. Per stimare la distribuzione spaziale del numero di giovani sono state applicate le tecniche kriging della geostatistica lineare, estendendo l'approccio metodologico alla dimensione spazio-temporale. In questo caso, sono stati adottati i modelli co-regionalizzati e le tecniche di co-kriging, dopo aver individuato i modelli di auto e cross variogramma. I risultati dell'analisi hanno evidenziato che le aggregazioni dei giovanili di *M. merluccius* erano caratterizzate un'elevata continuità spaziale in Mar Ligure, nel Tirreno centro-settentrionale e

nell'Adriatico centro-settentrionale. La continuità spaziale presentava invece un più corto raggio nel Tirreno centro-meridionale, nell'Adriatico meridionale e nel Mar Ionio. I livelli di abbondanza di giovani stimati nel Mar Tirreno, sia nella parte settentrionale che centrale, dominavano lo scenario. Mediante la tecnica del kriging disgiuntivo (geostatistica non lineare) è stata quindi stimata la probabilità condizionale di superare un dato valore di soglia della variabile "numero di giovanili". Tale limite, fissato a 3,500 ind.xkm⁻², ha permesso di confrontare le diverse sub-aree in termini di probabilità di localizzare una nursery di nasello.

Acknowledgements

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THE CETACEAN SANCTUARY IN THE LIGURIAN SEA: A FURTHER REASON

IL SANTUARIO DEI CETACEI DEL MAR LIGURE: UN MOTIVO IN PIÙ

Abstract

Among Cetaceans stranded in the Central Mediterranean over the last 140 years, 53 cases of very young fin whales were found. These were classified as neonates (5 - 5.9 m), sucklings (6 - 11 m) and weaning individuals (11.1 – 13.9 m). A distribution map of these three categories has been drafted. The calving ground includes the Ligurian and North Tyrrhenian Seas. Suckling whales were found in a larger area that includes the Sardinia Sea and the South Tyrrhenian Sea. Weaning fin whales were observed across the entire latitudinal range of the Mediterranean, with numerous cases in the Ligurian Sea. To the well-known reasons for protecting the area designed to become the Pelagic Sanctuary of the Ligurian Sea can now be added the fact that it is the calving area of the Mediterranean fin whale.

Key-words: Balaenoptera physalus, *Mediterranean Sea, calving area, Cetacean Sanctuary.*

Introduction

When the idea of creating in the Ligurian Sea a Pelagic Sanctuary dedicated to Cetaceans was introduced to the international scientific community in Monaco in 1991, the biological reasons given were the richness and diversity of the pelagic fauna in that area (Notarbartolo *et al.*, 1992). Cetaceans were presented as the top predators of a very complex ecosystem, which is based on a 2500 m high water column. This role is shared with equally significant Teleosts and Selachians, some of which, such as tuna and swordfish, also represent considerable fishery resources for France and Italy. The key species, which ensured the co-existence of otherwise very diverse animals was found to be the Mediterranean krill, the Euphausiid shrimp *Meganyctiphanes norvegica*, whose consumption by the fin whale was ascertained for the first time in the summer of 1990 (Orsi Relini and Giordano, 1992).

The abundance of Cetaceans in the Ligurian Sea at the beginning of the 90s was documented by the study of stranding and by the first sighting cruises. The systematic study of strandings was organised in France and Spain from the 70s onwards (Duguy, 1972 and subsequent annual reports; Casinos and Filella, 1977) and in the 80s in Italy by the Italian Society of Natural Sciences with the creation of the Centro Studi Cetacei (1987-2000); however in Italy, about one century ago, Parona (1897; 1909) made pioneer studies in this field. A comparison of strandings along the coasts of Spain and France showed that they were more abundant in France and increased towards the Ligurian section (Duguy *et al.*, 1977). In Italy the comparative study of stranding on the coastlines along the six different seas (Ligurian, Tyrrhenian, Adriatic, Ionian, Strait of Sicily and Sea of Sardinia) showed the richness of finds in the Ligurian area (Podestà *et*