

## **Spatial Distribution of *Munida intermedia* and *M. sarsi* (Crustacea: Anomura) on the Galician Continental Shelf (NW Spain): Application of Geostatistical Analysis**

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*Received 30 May 1991 and in revised form 1 June 1992*

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**Keywords:** geostatistical analysis; variograms; kriging; spatial distribution; *Munida intermedia*, *Munida sarsi*; Galician continental shelf; NW Spain

Geostatistical methodology was used to analyse spatial structure and distribution of the epibenthic crustaceans *Munida intermedia* and *M. sarsi* within sets of data which had been collected during three survey cruises carried out on the Galician continental shelf (1983 and 1984). This study investigates the feasibility of using geostatistics for data collected according to traditional methods and of enhancing such methodology. The experimental variograms were calculated (pooled variance minus spatial covariance between samples taken one pair at a time *vs.* distance) and fitted to a 'spherical' model. The spatial structure model was used to estimate the abundance and distribution of the populations studied using the technique of kriging.

The species display spatial structures, which are well marked during high density periods and in some areas (especially northern shelf). Geostatistical analysis allows identification of the density gradients in space as well as the patch grain along the continental shelf of 16–25 km diameter for *M. intermedia* and 12–20 km for *M. sarsi*. Patches of both species have a consistent location throughout the different cruises. As in other geographical areas, *M. intermedia* and *M. sarsi* usually appear at depths ranging from 200 to 500 m, with the highest densities in the continental shelf area located between Fisterra and Estaca de Bares.

Although sampling was not originally designed specifically for geostatistics, this assay provides a measurement of spatial covariance, and shows variograms with variable structure depending on population density and geographical area. These ideas are useful in improving the design of future sampling cruises.

### **Introduction**

The recent application of geostatistical analysis (Clark, 1979; Matheron, 1971) to biology (Burroughs, 1987; Legendre & Fortin, 1989), and particularly to the study of invertebrates subject to exploitation (Conan, 1985) has opened the way to new approaches in the assessment of populations, by introducing the analysis of spatial distribution in stock abundance estimates.

Up to the present, studies have focused on species under exploitation, and analyse the applicability of kriging to estimate stock abundance and biomass (Nicolajsen & Conan, 1987). These studies also show its value as a technique for spatial distribution analysis (Conan, 1987; Conan & Maynard, 1987; Conan *et al.*, 1989; Sullivan, 1991). Geostatistical analysis is an alternative approach to traditional methods (Hurlbert, 1990), which do not take into account the spatial autocorrelation (Cliff & Ord, 1973) between samples: kriging allows the analysis and modelling of the variability of a population in space in order to enhance both mean and variance estimates (Matheron, 1971).

*Munida intermedia* and *M. sarsi* (Crustacea, Anomura, Galatheididae) are abundant epibenthic species on the Galician continental shelf, which is an area of overlap in their geographic distribution (González-Gurriarán & Olaso, 1987). Data from several cruises designed to assess the stocks of harvested demersal species and the by-catch of invertebrate and fish species were analysed by geostatistical techniques. In this way the spatial structure and distribution of the *Munida* species was described and mapped, and the abundance of the populations was assessed.

Geostatistical analysis does not require a special sampling design although the quality of variograms, mapping and assessments is improved when samples are taken along a regular grid (Burroughs, 1987). The present study investigates: (1) the feasibility of using geostatistics for existing data collected by traditional sampling methods, and (2) the feasibility of enhancing such methodology.

## Materials and methods

### Sampling

The sampling is described in detail by González-Gurriarán and Olaso (1987). In this paper, we analyse the results of three cruises that took place in the Galician continental shelf: CARIOCA 83 (C83, September 1983), ICTIO-NW 84 (I84, May 1984) and CARIOCA 84 (C84, August–September 1984). During each cruise a randomly stratified sampling was carried out (up to 500 m deep), in which the shelf was divided into three geographical areas (Miño–Fisterra, Fisterra–Estaca de Bares and Estaca de Bares–Ortegal), considering two strata to be divided by the isobath of 200 m (Figure 1). A Baka type trawl was used, with each tow lasting between 30 and 60 min. For data analysis, the densities of the different species caught were standardised to 60 min tows.

### Data analysis

In geostatistical methodology (Clark, 1979; Conan, 1985; Matheron, 1971), the covariance of the parameter studied is analysed and modelled in terms of the distance between sampling units. Also the optimum weights are calculated for each sample in order to estimate the parameter, whether at a point (point kriging) or a block (block kriging).

The representation of the covariance in terms of distance is carried out using a variogram, where the semivariance ( $\tau(h)$ ) is represented. This is equal to the variance between independent samples minus the covariance between samples separated by a distance  $h$ .  $\tau(h)$  is estimated by:

$$\hat{\tau}^2(h) = 1/2n \sum_{i=1}^N [Z(x_i) - Z(x_i + h)]^2$$

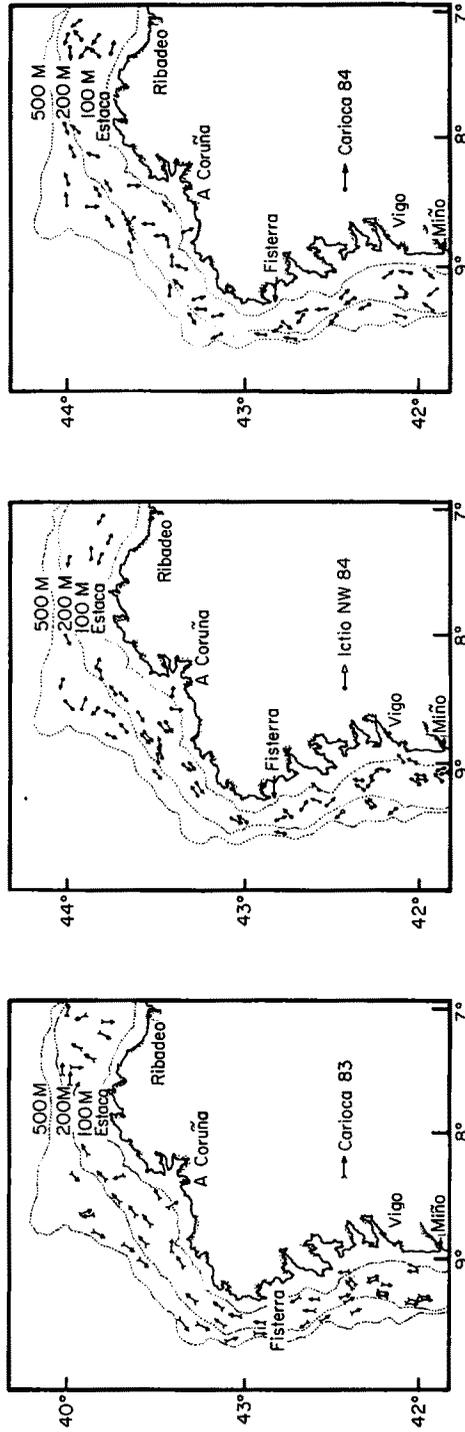


Figure 1. Galician continental shelf. Location of tows during cruises CARIOCA-83, ICTIO NW-84 and CARIOCA-84.

TABLE 1. Mean catches (number . one hour tow<sup>-1</sup>) of *Munida intermedia* and *Munida sarsi* during cruises C83, I84 and C84 on the Galician continental shelf and the north and south areas (standard deviation, SD, is shown). Parameters of the spherical models of variograms fitted for each species and cruise ( $C_0$  = nugget effect,  $C$  = sill-nugget,  $a$  = range). In cases with experimental variograms without spatial covariance a nugget model was fitted, and this parameter is shown

Species	Cruise	Area	Mean catch		Spherical model		
			$n \cdot h^{-1}$	SD	$C_0$	C	a
<i>Munida intermedia</i>							
	C83	Total	7.68	20.62	410.5		
		North	10.00	24.98	623.8		
		South	4.33	9.94	98.7		
	I84	Total	1.95	5.87	0	34	22
		North	2.11	7.26	0	70	16
		South	1.72	2.85	8.1		
	C84	Total	163.95	877.44	0	750 000	25
		North	190.60	1029.71	0	1 060 000	20
		South	100.37	377.61	—	—	—
<i>Munida sarsi</i>							
	C83	Total	6.64	25.55	0	650	15
		North	11.09	32.83	0	1070	12
		South	0.46	1.83	3.3		
	I84	Total	15.39	79.20	0	6300	15
		North	25.86	101.79	0	10 300	15
		South	0.32	1.05	1.1		
	C84	Total	83.57	289.02	0	83 500	20
		North	122.11	349.13	0	120 000	20
		South	8.53	17.50	—	—	—

where  $Z(x_i)$  and  $Z(x_i + h)$  are the density at point  $x_i$  and in the samples located at a distance  $h$  (lag) from  $x_i$ ,  $n$  is the number of pairs of stations sampled, and  $N$  the number of sampling points.

A theoretical model is then fitted to the experimental variogram. In the present study, we used the spherical model, which is the most common in the analysis of animal populations and in geostatistics in general. Others, such as the fractal model, are currently being researched, and they appear to give an accurate picture of the spatial distribution of certain organisms (Conan & Wade, 1989). The spherical model has the following form:

$$\tau(h) = C_0 + C(3/2 h/a - 1/2 h^3/a^3)$$

where  $C_0$  is the nugget effect, due to the variability between replicates, the microstructure which remains undetected because of the size of the sample, or errors in measurement or location.  $C$  represents the sill-nugget effect, where the sill is the asymptotic value of semivariance, reached with a value of  $h = a$ , called range, which represents the maximum distance at which spatial effects are detected.

The model of the variogram and the sampling data were used to calculate the optimum weights attributed to each sampling unit, which allowed us to estimate the density ( $Z^*$ ) at an unsampled point (point kriging) or area (block kriging), as well as the variance of the estimate,

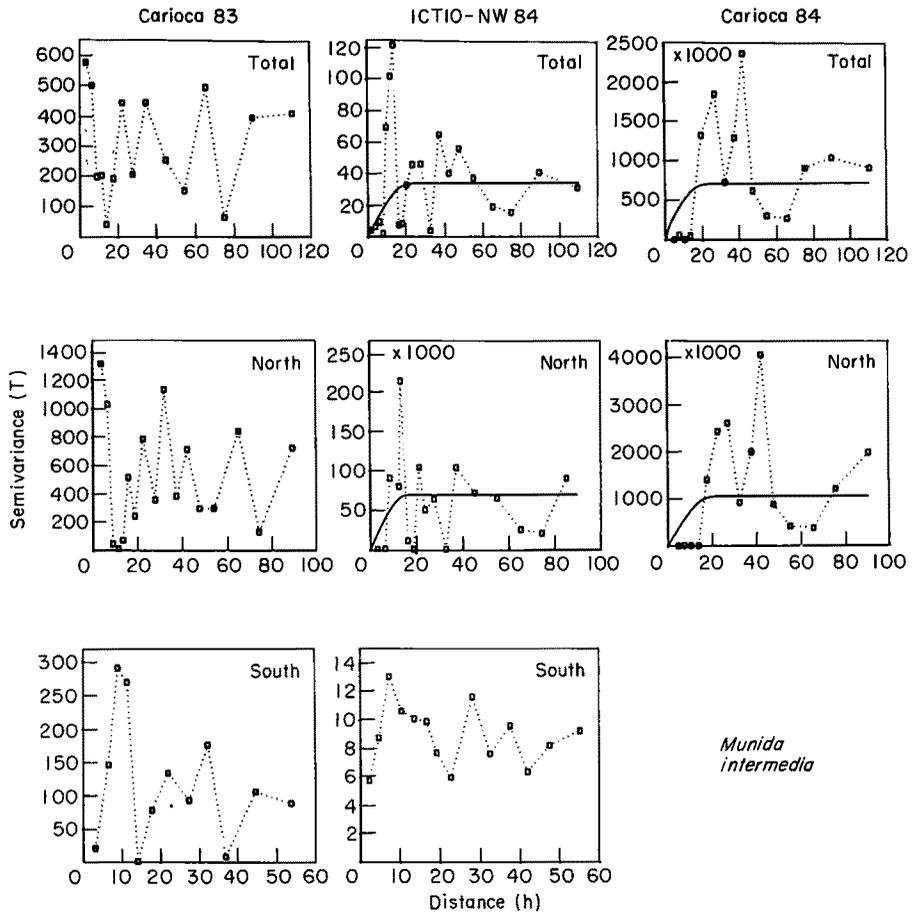


Figure 2. Experimental variograms (dashed line) and spherical models (solid line) for *Munida intermedia* during cruises C83, I84 and C84 in the Galician continental shelf. (In cases of spatial covariance undetected, only experimental variograms are shown.)

$$Z^* = \sum_{i=1}^N w_i Z(x_i)$$

where N is the number of samples,  $w_i$  is the weight attributed to sample  $x_i$  and  $\sum w_i = 1$  (in the traditional methods all samples show the same weight  $w = 1/N$ ).

Variograms were calculated for the overall sampling area and for two geographical zones of the shelf: North, from Fisterra to Ribadeo, with SW-NE shoreline orientation; and South, from Miño to Fisterra, with N-S orientation and a great influence from the Rías (in the C84 cruise experimental variograms for the southern area were not calculated because the number of sampling points was too small). Results presented correspond to isotropic variograms; anisotropy was not studied in detail, although anisotropic variograms calculated in the direction of the shoreline (not shown) have a similar structure to isotropic variograms for each area.

In the present case point kriging was used for estimating values at the nodes of a  $5 \times 5$  km grid covering survey area extending from the coast to the 500 m isobath. Variogram models fitted for the overall sampling area were used for kriging.

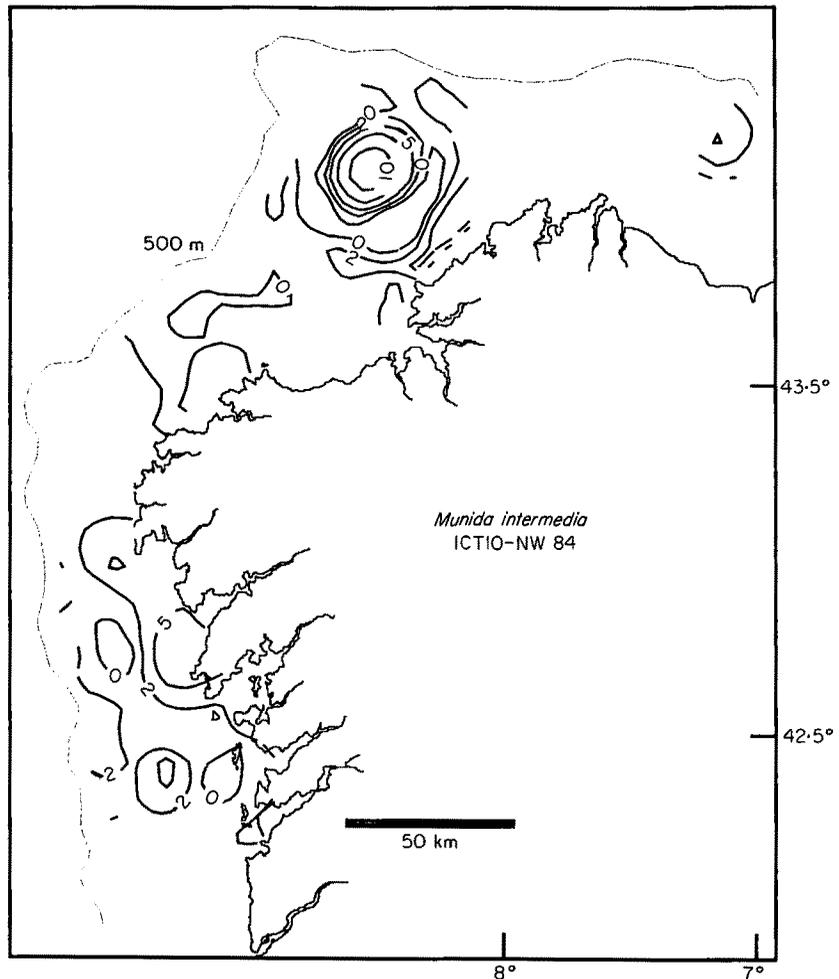


Figure 3(a).

The data analysis was carried out using GEOMIN software modified by G. Conan and E. Wade (Marine Biology Research Centre, Université de Moncton, Canada) and GEO-EAS software (Englund & Sparks, 1988).

## Results

### *Munida intermedia*

The variograms differ between cruises (Figure 2; Table 1). In C83, a period of low density ( $7.68 \text{ h}^{-1}$ ), spatial covariance is undetected (C83). In I84 (also with low densities,  $1.95 \text{ h}^{-1}$ ), the variogram has a spatial covariance showing two maxima of semivariance at 13 and 22 km, although the first lags are noise. This structure corresponds both to the variogram for all sampling points and for the north area, whereas in the south, where the densities are very low, spatial covariance is not detected. In cruise C84, which the highest densities were encountered ( $163.95 \text{ h}^{-1}$ ), spatial covariances range up to 25 km (20 km in the North). Variograms showing spatial covariance do not present nugget effects.

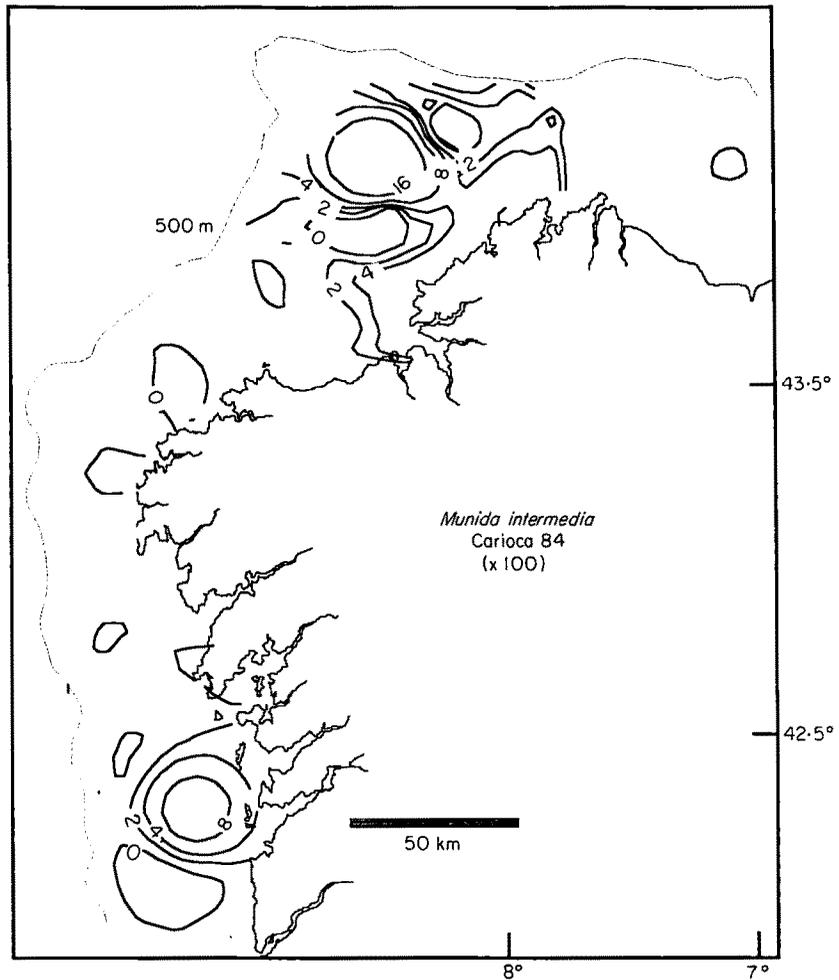


Figure 3(b).

Figure 3. Spatial distribution of *Munida intermedia* on the Galician continental shelf during cruises I84 and C84: Density isocontours obtained from point kriging. (Isocontour densities are 0, 2, 5 and 10 in I84 map and 0, 200, 400, 800 and 1600 in C84 map.)

The densities of *M. intermedia* are lower in cruises C83 and I84, with maximum catches located in the deepest zone of the Fisterra–Estaca de Bares area and out of the Rías, near the coast (Figure 3). During C84 *M. intermedia* occurred at very high densities with a spatial structure in patches along the continental shelf (Figure 3). Two large groupings can be distinguished, one coinciding with structures encountered in earlier cruises in the deep northern area (up to  $> 1600 \text{ h}^{-1}$ ), has a complex internal structure, and the other is situated opposite the most southern Rías Baixas in more shallow waters (up to  $> 800 \text{ h}^{-1}$ ).

#### *Munida sarsi*

*M. sarsi* displays well-defined spatial structure in the three cruises on the whole area and on the north shelf, which is satisfactorily modelled using a spherical variogram with a

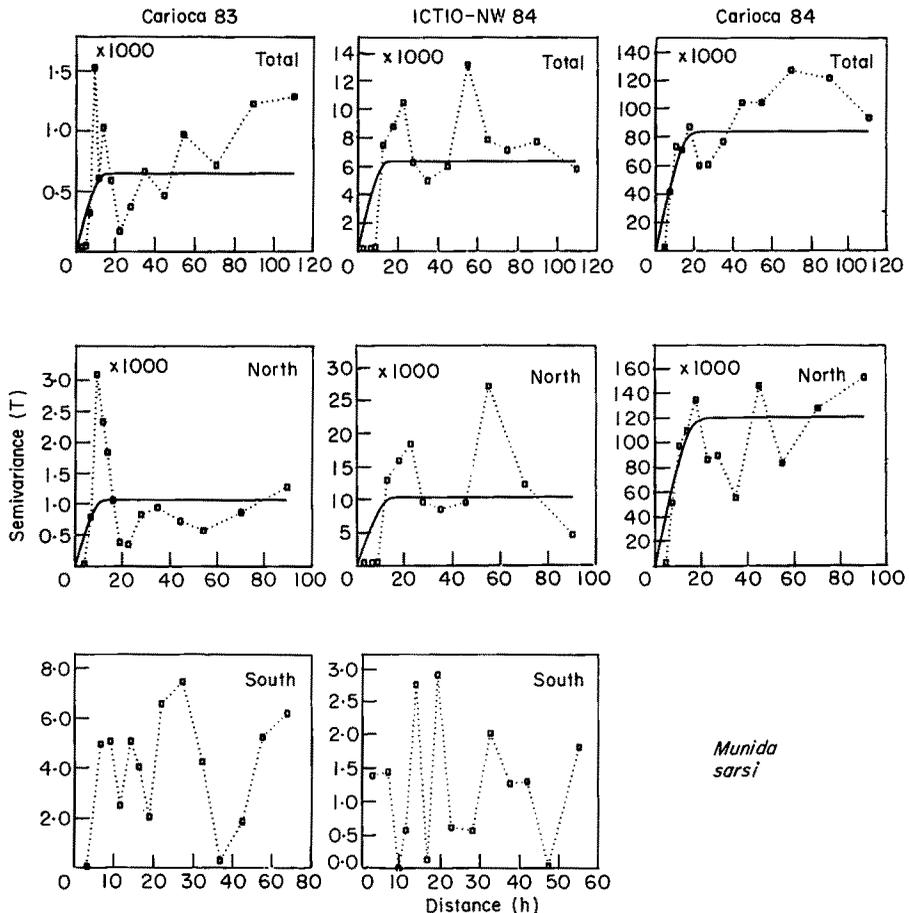


Figure 4. Experimental variograms (dashed line) and spherical models (solid line) for *Munida sarsi* during cruises C83, I84 and C84 in the Galician continental shelf. (In cases of spatial covariance undetected, only experimental variograms are shown.)

range of 12–15 km in C83 and I84 and 20 km in C84, and a nugget effect practically non-existent (Table 1; Figure 4). In the south the densities are lower than in the north and the variogram does not show a spatial covariance effect (Table 1; Figure 4).

This species is distributed along the Galician continental shelf reaching maximum densities in the Fisterra–Estaca de Bares area, especially in the deep water zones (over 200 m). The position of the groupings remained unchanged throughout the cruises (Figure 5), despite great fluctuations in density (from 6.64 and 15.39  $\text{h}^{-1}$  in C83 and I84 to 83.57  $\text{h}^{-1}$  in C84). However, the distribution within these areas becomes more complex in areas or periods of highest abundance.

### Discussion

Assessment methods which do not take into account spatial covariance may provide simplified analyses as they usually assume that the present density areas or strata are internally homogeneous unless the sampling design is perfectly random (Conan, 1987; Sullivan, 1991). Analysis of the spatial pattern of populations has not been carried out

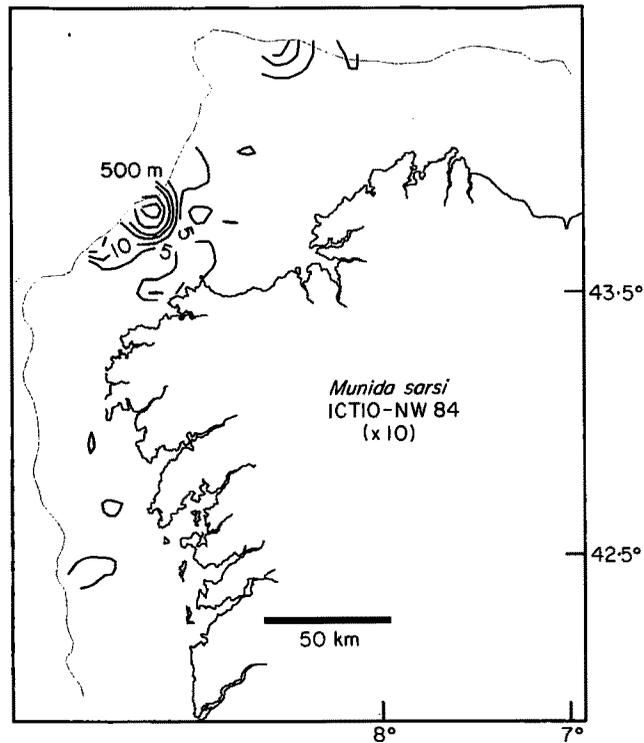
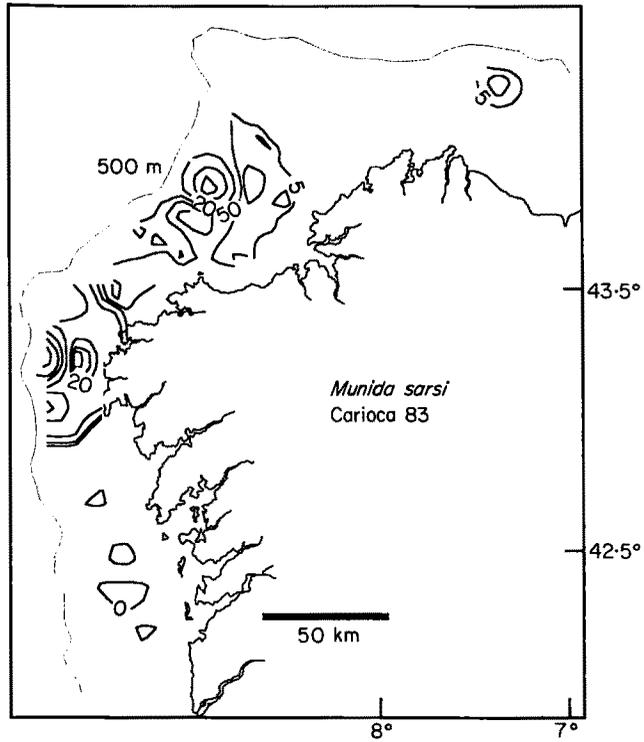


Figure 5(a) and (b).

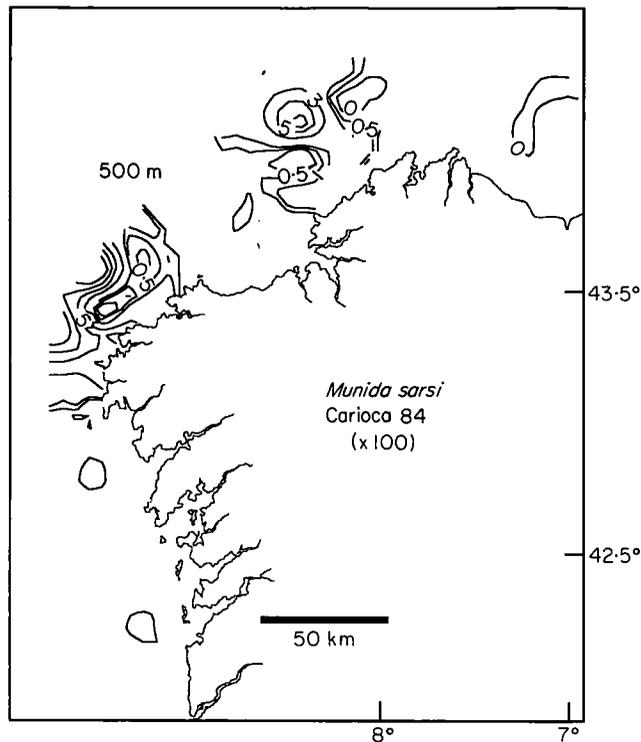


Figure 5(c).

Figure 5. Spatial distribution of *Munida sarsi* on the Galician continental shelf during cruises C83, I84 and C84: Density isocontours obtained from point kriging. (Isocontour densities are 0, 5, 10, 15, 20, 25 and 30 in C83 map, 0, 50, 100 and 200 in I84 map and 0, 50, 100, 300, 500, 700 and 900 in C84 map.)

accurately using traditional methods (Hurlbert, 1990), as they do not allow abundance gradients to be mapped and integrated in space, defining gradient density as well as the grain (size) of the patches. These factors are reflected in geostatistics giving a more realistic view of the distribution of a species.

*Munida intermedia* and *M. sarsi* are found in patches along the Galician continental shelf that were relatively stable during the different cruises. This suggests that there are stable physical factors that mainly determine how the two species are distributed. The Galician continental shelf is an area of overlap between distribution of *M. intermedia*, a species characteristic of warm temperate waters present in the Mediterranean, and *M. sarsi*, which is characteristic of cold temperate waters. It has been suggested that the difference in zoning of the two species in terms of depth is a result of their temperature preferences (González-Gurriarán & Olaso, 1987). However, correlation between environmental factors, such as depth and temperature, prevents us from determining the primary effects these factors have on the distribution of epibenthic organisms (Basford *et al.*, 1989).

Studies carried out in the Mediterranean continental shelf (Abelló *et al.*, 1988) as well as in the eastern Atlantic (Lagardere, 1973; Olaso, 1990) indicate that both species of *Munida* appear predominantly at depths of between 200 and 500 m and that they segregate to a certain extent. *M. intermedia* tends to be found in more shallow waters than *M. sarsi*. On

the Galician continental shelf the same pattern is encountered, although the main segregation factor is not evident. However during cruise C84, *M. intermedia*, as well as other species of epibenthic crustaceans, were located in areas near the coast off the Rías Baixas and at depths less than 200 m (González-Gurriarán & Olaso, 1987). This may be due to the fact that this area witnesses a high rate of biological productivity caused by the runoff of nutrient rich waters from the rías, as well as upwelling processes that occur periodically. This provides an increase in the availability of food to other levels of the food web (Tenore *et al.*, 1984).

The length of the tows and the distance between location of the stations do not allow spatial effects to be analysed and modelled over short ranges (< 3–5 km). However, the results, in particular the practically non-existent nugget effect in the variograms, indicate that the microstructures have minimal importance, in contrast to the situation for other species found in the same area (González-Gurriarán & Freire, unpubl. data). In the present analysis, it is not possible to produce high resolution maps, but this could be achieved with a modified sampling strategy. This application of geostatistical techniques suggests the following: (1) the existence of a spatial covariance with a range of 12–25 km, and (2) the variograms have a variable structure depending on the population density and/or geographical area. These ideas will be useful in the design of future sampling programmes, that must be carried out on a regular grid (Burroughs, 1987; Conan, 1987), with short tows and taking special care in the location of sampling points. The application of geostatistical techniques could be improved in areas such as the Galician continental shelf, where they could be extremely useful in mapping and estimating population size, particularly for fished species. The study of spatial distribution and structure of the different species or assemblages would be the first step towards an analysis of their relationships with the different environmental or biotic factors, and the spatial dynamics of the populations.

### Acknowledgements

We would like to thank Mr E. Wade and Dr G. Y. Conan (Marine Biology Research Centre, Moncton, Canada) for their assistance in the application of geostatistical methods and in data processing. We would like to give special thanks to Dr G. Y. Conan for his interest and critical reading of the manuscript. Ms C. P. Teed prepared the English version.

This paper was based on data obtained from the fishery survey cruises carried out by the Instituto Español de Oceanografía (ATN program—Fisheries in the ICES area).

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