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Spatial distribution of decapod crustaceans in the Galician continental shelf (NW Spain) using geostatistical analysis

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ABSTRACT

Geostatistical methodology was applied to analyze spatial structure and distribution of the epibenthic crustaceans *Liocarcinus depurator*, *Macropipus tuberculatus*, *Polybius henslowii*, *Munida intermedia*, *Munida sarsi*, *Plesionika heterocarpus* and *Solenocera membranacea* in the Galician continental shelf during three survey cruises carried out in 1983 and 1984. The experimental variograms were calculated and fitted to spherical models. The spatial structure model was used to estimate abundance and map the populations using kriging.

The variograms have a variable structure depending on species, population density and/or geographical area. Spatial structure becomes well-defined as density increases for *L. depurator*, *M. tuberculatus*, *M. intermedia* and *M. sarsi*, whereas *P. henslowii*, *P. heterocarpus* and *S. membranacea* do not present a simple relationship. Range of spherical models, patch size, fluctuates between 7 and 32 Km, and is linked both to interspecific differences in spatial pattern, and, in some cases, to density.

L. depurator and *M. tuberculatus* are distributed over wide areas of relatively low average density, and with variable location of the groupings. Patches of *P. henslowii* stay in a fairly constant location from one cruise to another, in spite of the great fluctuations in density. Anomuran (*M. intermedia* and *M. sarsi*) and shrimp (*P. heterocarpus* and *S. membranacea*) species present relatively stable high density areas during the different cruises on a medium scale, although the location of the patches changes on a small scale. This suggests that there are stable physical factors that contribute to determine how the species are distributed. Depth is a limiting factor on a large scale, whereas oceanographic conditions, in particular upwelling processes and nutrient-rich water from the rías, make up the spatial structure on a smaller scale in some species.

INTRODUCTION

The use of geostatistics (CLARK, 1979; MATHERON, 1971) in marine biology was introduced during the second half of the 1980's (CONAN, 1985). It is currently used in the assessment of harvested populations, mainly invertebrates (CONAN & WADE, 1989; CONAN ET AL., 1988; NICOLAJSEN & CONAN, 1987; PETITGAS & POULARD, 1989). The introduction of this type of analysis to fisheries was motivated by the criticism of the traditional methods of stock assessment (arithmetic mean or swept-area based in random or stratified random sampling), and in particular their application to invertebrates (CONAN, 1984). These assessments are subject to estimation errors, as the spatial distribution of the organisms is not taken into account, nor, in the case of many invertebrate species, is their limited or non-existent mobility. Also, regionalized estimates are obtained with geostatistical methodology, and they are important for the analysis of spatial fishery dynamics (CONAN, 1985).

However, spatial analysis in ecology has evolved from the study of probability distributions of samples considered to be independent (see HURLBERT, 1990 for a recent critique), to autocorrelation and spatial structure analysis (CLIFF & ORD, 1981; JUMARS ET AL., 1977). In this sense geostatistical analysis allows us to analyze and model spatial variability which has traditionally been avoided, and uses the spatial structure of the population to enhance both mean and variance estimates (MATHERON, 1971).

Geostatistical analysis does not require a special sampling design albeit best results of variograms, mapping and assessments are obtained for samples taken along a regular grid (BURROUGHS, 1987). The present study analyzes data from three survey cruises carried out in the Galician continental shelf (NW Spain) using geostatistical techniques to describe and map the abundance and spatial structure of seven species of epibenthic decapod crustaceans (*Liocarcinus depurator, Macropipus tuberculatus, Polybius henslowii, Munida intermedia, Munida sarsi, Plesionika heterocarpus* and *Solenocera membranacea*). The results will allow us to analyze 1) the feasibility of using geostatistics for existing data collected according to traditional methods, and 2) the feasibility of enhancing such methodology.

MATERIAL AND METHODS

Sampling

The sampling is described in detail by GONZÁLEZ-GURRIARÁN & OLASO, 1987. We analyze data 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 (Fig. 1). Baka type trawl was used, with each tow lasting between 30 and 60 minutes. For data analysis, the densities of the different species were standardized to 60 minute trawls.

Data analysis

In geostatistical methodology (CLARK, 1979; CONAN, 1985; MATHERON, 1971), the covariance of the parameter studied is analyzed and modelled in terms of the distance between sampling units (**variogram**), and the optimum weights are calculated for each sample in order to estimate the population density as well as the variance of the estimate, whether at a point (**point kriging**) or a block (**block kriging**).

The variogram represents the semivariance $\gamma(h)$ (variance between independent samples minus the covariance between samples separated by a distance h):

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

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 fitted to the experimental variogram. We used the spherical model (the most common in the analysis of marine populations and in geostatistics in general):

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

where C_0 is the nugget effect, due to the variability between replicates, the microstructure which remains undetected because of the sample size, or errors in measurement or location; C represents the sill minus the 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.

Variograms were calculated for the overall sampling area and for two geographical zones of the shelf (Fig. 1): North, from Fisterra to Ribadeo, with a 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. Point kriging was used for estimating values at the nodes of a 5 x 5 Km grid covering a survey area extending from the coast to the 500 m isobath. Variogram models fitted for the overall sampling area were used for kriging.

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

Table 1 shows data on catches for each species and cruise as well as parameters of variogram models. Figs. 2-7 present experimental and model variograms and point kriging based isocontour density maps.

Liocarcinus depurator. In C83 in the southern area a spatial covariance with a range of 14 Km is detected; and in C84, when this species reaches greater densities, the variogram points to a spatial structure having a practically non-existent nugget effect and a range of around 20 Km. In this cruise, *L. depurator* occupies an extensive area of relatively high density to the north of Fisterra, and maximum values found in shallow waters (approximately 100 m).

Macropipus tuberculatus. A spatial covariance in the distribution of this species is detected in all three data sets analyzed. The range of the variograms fluctuates between 10 and 28 Km. The nugget effect is important only in C84, suggesting the existence of groupings with less than 28 Km in size. *M. tuberculatus* appears mainly in the northern area, although the centres of greatest density are relatively variable in the different cruises, and very widespread, generally located at depths of over 200 m.

Polybius henslowii. Variograms show ranges between 12-20 Km in cruise C83 and 28 Km in C84. C83 variograms have an important nugget effect, suggesting undetected microstructures. In cruise I84, with very low densities, spatial covariance is present only in a short range (7.5 Km) and no pattern is apparent analyzing northern and southern areas separately. In the three cruises, maximum densities are located in zones opposite the Rías Baixas and in the Fisterra-Estaca zone, with maximum density values ($>2000 \cdot hour^{-1}$)

found in coastal areas. The patch structure in C84 is less complex than in other cruises.

Munida intermedia. In C83 spatial covariance is undetected. In I84 the variograms are noisy although they show two maximums of semivariance at 13 and 22 Km. In cruise C84, which the highest densities, spatial covariances range up to 25 Km (20 Km in the North). Variograms showing spatial covariance do not present nugget effects. Maximum catches of *M. intermedia* are located in the deepest zone of the Fisterra-Estaca area and out of the Rías Baixas, near the coast.

Munida sarsi. This species displays a well defined spatial structure in the three cruises (similar in total and northern shelf), with a range of 12-20 Km, and a practically non-existent nugget effect. In the south, variograms do not show a spatial covariance effect. This species presents maximum densities in the Fisterra-Estaca area, especially in the deep water zones (over 200 m). The position of the groupings remained unchanged throughout the cruises, despite great fluctuations in density. However, the distribution within these areas becomes more complex in areas or periods of highest abundance.

Plesionika heterocarpus. Range of spatial covariance is variable, fluctuating between 30 Km (in total and northern area in C83) and 7-8 Km (in the south C83, and in I84), and the nugget effect is non-existent. In C84 cruise range is 18 Km, but in the northern area, with very low densities, spatial structure is undetected. *P. heterocarpus* displays two groupings in C83 (in Fisterra-Estaca sector and in the shelf opposite Rías Baixas). In I84 an C84 this species is widely distributed from Fisterra to Miño, with a more complex spatial structure during I84 cruise. Maximum density zones are found in different locations in each cruise.

Solenocera membranacea. Cruises C83 and I84 display autocovariance ranging from 15 to 25 Km, although variogram structure is variable for different cruises and areas. *S. membranacea* is widely distributed in the Galician shelf with highest densities in the Fisterra-Estaca area and deep zones (> 200m). Patches show a complex structure in C83. C84 does not show a well-defined spatial structure.

DISCUSSION

The analysis of the spatial pattern of populations has not been carried out accurately using the traditional methods, which do no take spatial autocorrelation into account (CLIFF & ORD, 1981), as they do not allow for the definition of the grain (patch size) and intensity (density gradients in the space) (HURLBERT, 1990). Both of these factors are reflected in geostatistical techniques, giving a much more realistic view of the description of the distribution of a species than in patches, with high and low density zones or strata which are internally homogeneous (CONAN, 1987). Crustacean populations in the Galician continental shelf show a spatial structure in the sense of a spatial covariance effect. The use of variograms and kriging allows us to model and map spatial distribution patterns of the species under study, both on a medium and large scale, depending on the sampling characteristics.

The comparative analysis of the three cruises and north and south areas defines patterns in spatial structure of populations. The range of the spherical models shows a variability linked both to interspecific differences in spatial pattern, and, in some cases, to the density of each species, although there is no simple relationship between density and grouping size. In general, the different species show major temporal variations in density, as well as between the northern and southern areas of the shelf. Spatial structure of the portunid crabs and *Munida* populations appears to become greater as density increases, except in *P. henslowii*, which forms patches with a very high density over a small expanse (especially in C83 cruise), and range and density don not appears to be correlated.

Similarly, temporal and spatial variations in density for *P. heterocarpus* and *S. membranacea* do not appear to be related in a simple way to the distinct spatial structure reflected in the variograms obtained.

L. depurator and *M. tuberculatus* are distributed over wide areas of relatively low average density, and with variable location of the groupings. Patches of *P. henslowii* stay in a fairly constant location from one cruise to another, in spite of the great fluctuations in density. Anomuran and shrimp species present relatively stable high density areas during the different cruises on a medium scale although the position of the patches changes on a small scale. This suggests that there are stable physical factors that contribute to determine how the two species are distributed. Depth is a major physical factor on a large scale (ABELLÓ ET AL., 1988; BASFORD ET AL., 1989, 1990). In the Galician continental shelf decapod crustacean bathymetric distribution ranges are similar to those in other Atlantic (BASFORD ET AL., 1989; LAGARDERE, 1973; OLASO, 1990) and Mediterranean zones (ABELLÓ ET AL., 1988). The Galician continental shelf is an area of contact for the 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). Other studies (ABELLÓ ET AL., 1988; 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 segregation is not evident. Another important factor in the distribution of epibenthos appears to be sediment, especially in species such as *S. membranacea*, which lives closely linked to the substrate (LAGARDERE, 1973).

On a smaller scale, the oceanographic conditions may have a direct influence on the distribution of crustaceans in he Galician continental shelf. Areas of upwelling or where the contribution of nutrients from the rías to the continental shelf occurs, are zones of great biological productivity. This increase in productivity means that food is more readily available at higher levels of the food web, which produces an increase in the biomass of the species that make up these levels (TENORE ET AL., 1984). The distribution of the different species changes opposite the Rías Baixas, being found in areas near the coast off the Rías Baixas and at depths less than 200 m (GONZÁLEZ-GURRIARÁN & OLASO, 1987).

The sampling was not designed for geostatistical analysis and although sampling does not prevent the application of kriging, regular sampling (BURROUGHS, 1987) with short tows and special care in the location of sampling points is considered to be more appropriate for this type of statistical methodology, contrary to what is proposed in the usual stock assessment techniques (CONAN, 1987). The length of the tows and the distance between location of the stations do not allow to analyze or model spatial effects over short ranges (<3-5 Km). However, the results, in particular the practically non-existent nugget effect in the variograms for some species (especially both *Munida* species), indicate that the microstructures have minimal importance. In the present analysis, it is not possible to get high resolution maps, but they can be improved with a modified sampling strategy. The results of this assay of application of geostatistical techniques suggest the following: (1) the existence of a spatial covariance with a range of 7-32 km, and (2) the variograms have a variable structure depending on species, population density and/or geographical area. These ideas will be useful in the design of future samplings designed for mapping and estimating population size, particularly in the case of species harvested. The study of spatial distribution and structure of the different species or assemblages would be the first step towards an analysis of their relation to the different environmental or biotic factors, and the spatial dynamics of the populations.

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Table 1. Mean catches (number· one hour tow^{-1}) of crustacean populations 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.

			MEAN CATCH		SPHERICAL MODEL		
SPECIES	CRUISE	AREA	n·hour^{-1}	SD	C_0	C	a
Liocarcinus depurator	C83	TOTAL	2.58	6.01	36.1		
		NORTH	3.58	7.49	56.1		
		SOUTH	1.21	2.33	0.5	5.0	14
	I84	TOTAL	2.79	9.50	90.3		
		NORTH	0.39	1.14	1.3		
		SOUTH	6.24	14.08	198.3		
	C84	TOTAL	33.36	170.82	0	29100	22
		NORTH	46.27	208.75	0	43500	20
		SOUTH	8.21	13.76	---	---	---
Macropipus tuberculatus	C83	TOTAL	1.77	4.11	0	11	18
		NORTH	2.73	5.14	0	22	18
		SOUTH	0.46	0.87	0	0.75	10
	I84	TOTAL	1.21	2.97	0	8.8	10.5
		NORTH	1.64	3.26	0	10.6	12
		SOUTH	0.60	2.34	5.6		
	C84	TOTAL	3.39	6.86	5.0	41.0	28
		NORTH	4.87	7.89	10.0	53.0	28
		SOUTH	0.53	1.53	---	---	---
Polybius henslowii	C83	TOTAL	1011.47	1601.25	800000	1750000	12
		NORTH	619.12	1240.97	100000	1500000	20
		SOUTH	1550.96	1862.61	800000	2650000	14
	I84	TOTAL	7.05	17.92	50	270	7.5
		NORTH	4.97	11.13	123.9		
		SOUTH	10.04	24.30	590.4		
	C84	TOTAL	54.21	148.61	0	25000	28
		NORTH	59.95	180.29	0	32000	28
		SOUTH	43.05	40.09	---	---	---

Table 1. Continuation

			MEAN CATCH			SPHERICAL MODEL	
SPECIES	CRUISE	AREA	n·hour^{-1}	SD	C_0	C	a
Munida intermedia	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	750000	25
		NORTH	190.60	1029.71	0	1060000	20
		SOUTH	100.37	377.61	---	---	---
Munida sarsi	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	10300	15
		SOUTH	0.32	1.05	1.1		
	C84	TOTAL	83.57	289.02	0	83500	20
		NORTH	122.11	349.13	0	120000	20
		SOUTH	8.53	17.50	---	---	---
Plesionika heterocarpus	C83	TOTAL	3.47	12.08	0	150	30
		NORTH	3.09	14.37	0	300	30
		SOUTH	4.00	8.67	5	70	7
	I84	TOTAL	44.08	151.17	0	22500	7
		NORTH	11.14	22.33	100	400	8
		SOUTH	91.52	226.33	0	51000	7
	C84	TOTAL	116.71	463.21	0	215000	18
		NORTH	9.32	25.74	662.5		
		SOUTH	325.84	751.60	---	---	---
Solenocera membranacea	C83	TOTAL	37.90	91.65	500	7900	15
		NORTH	32.00	95.88	9192.9		
		SOUTH	44.96	85.00	1000	6200	37
	I84	TOTAL	89.20	190.44	20000	16000	25
		NORTH	73.61	154.39	0	24000	32
		SOUTH	111.64	230.91	53318		
	C84	TOTAL	63.52	155.90	24306		
		NORTH	77.46	183.93	33829		
		SOUTH	36.37	68.16	---	---	---

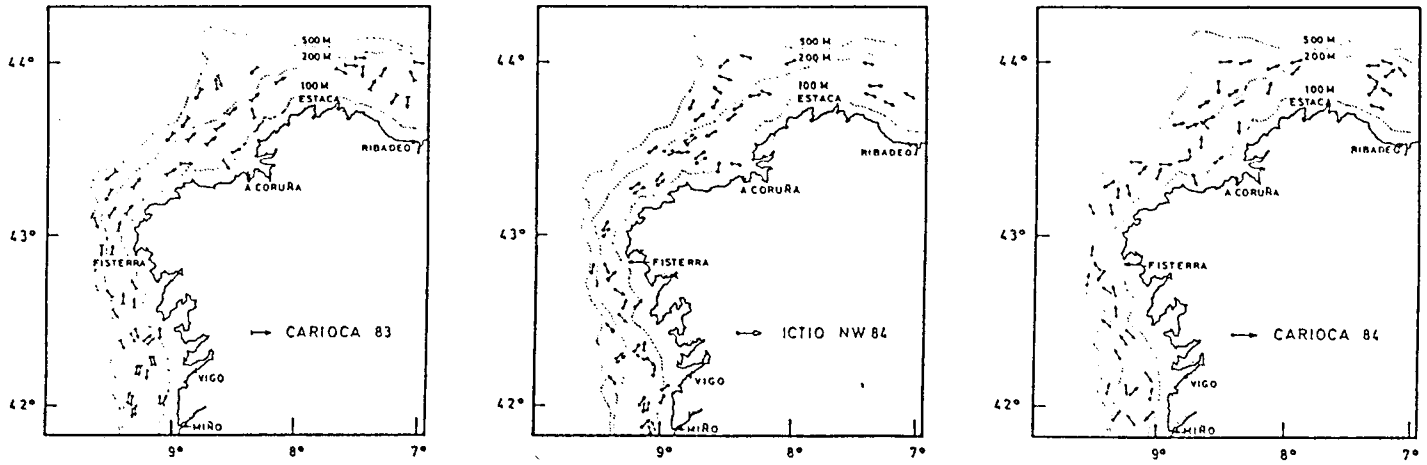

Figure 1. Galician continental shelf. Location of tows during cruises CARIOCA-83, ICTIO NW-84 and CARIOCA-84.

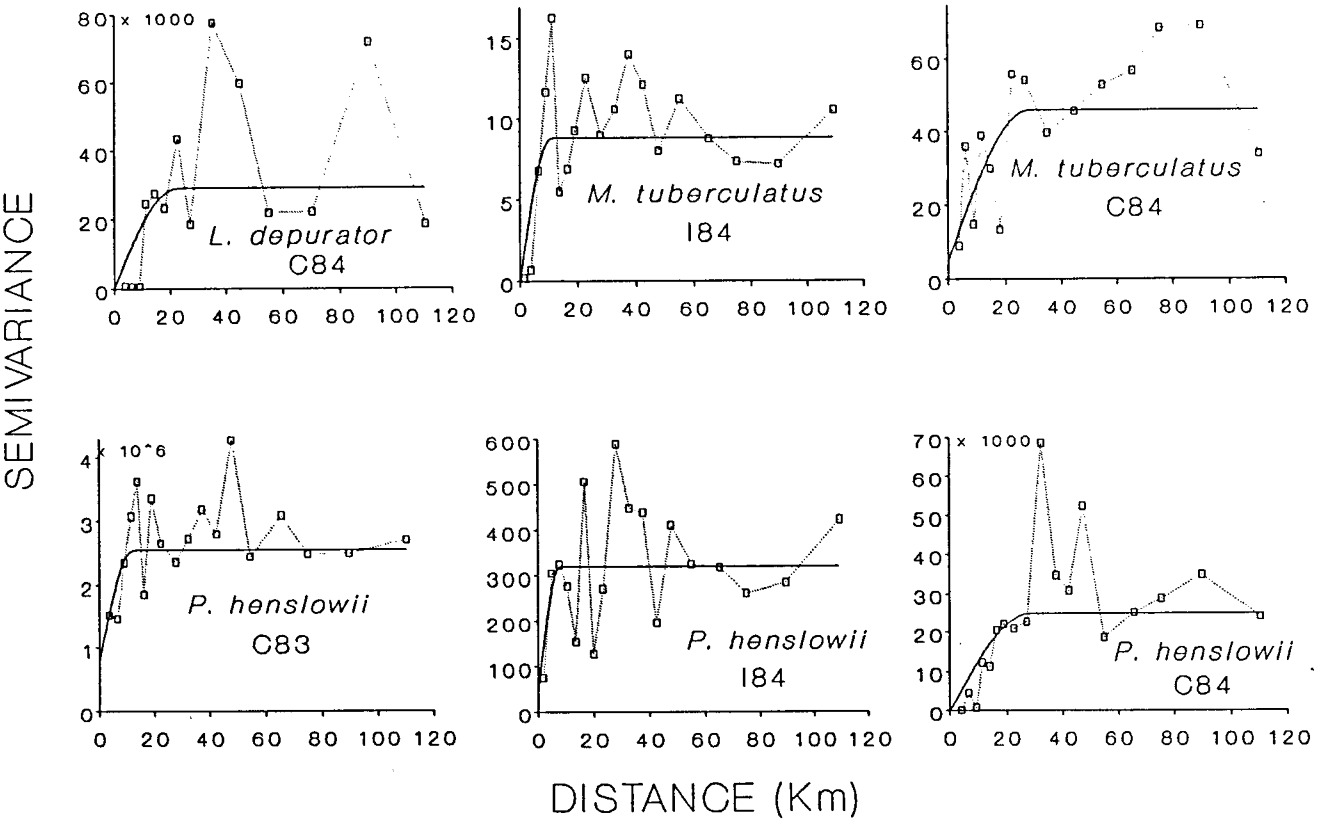

Figure 2. Experimental variograms (dashed line) and spherical models (solid line) for *Liocarcinus depurator, Macropipus tuberculatus* and *Polybius henslowii* in the Galician continental shelf.

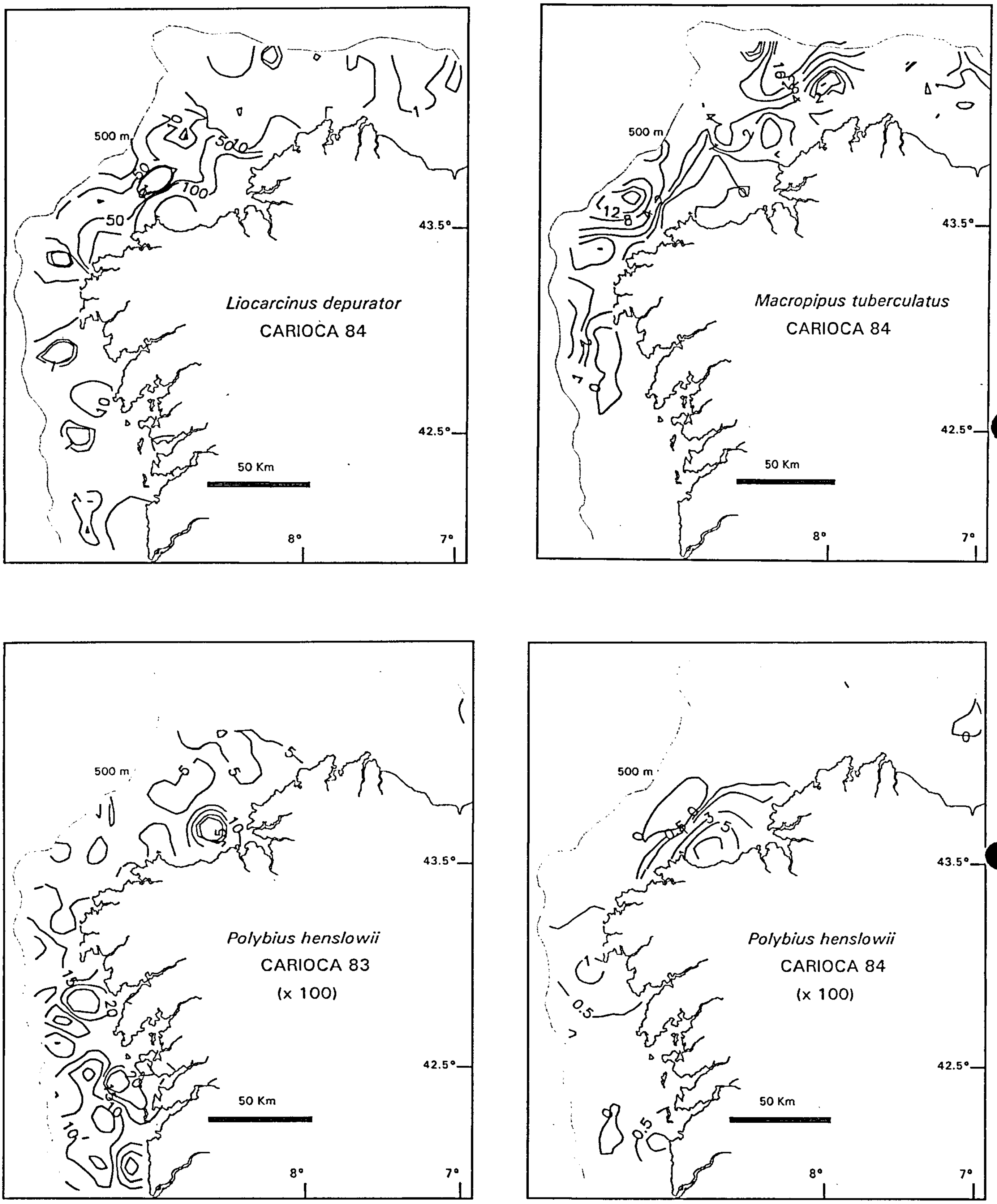

Figure 3. Spatial distribution of *Liocarcinus depurator, Macropipus tuberculatus* and *Polybius henslowii* on the Galician continental shelf: Density isocontours obtained from point kriging.

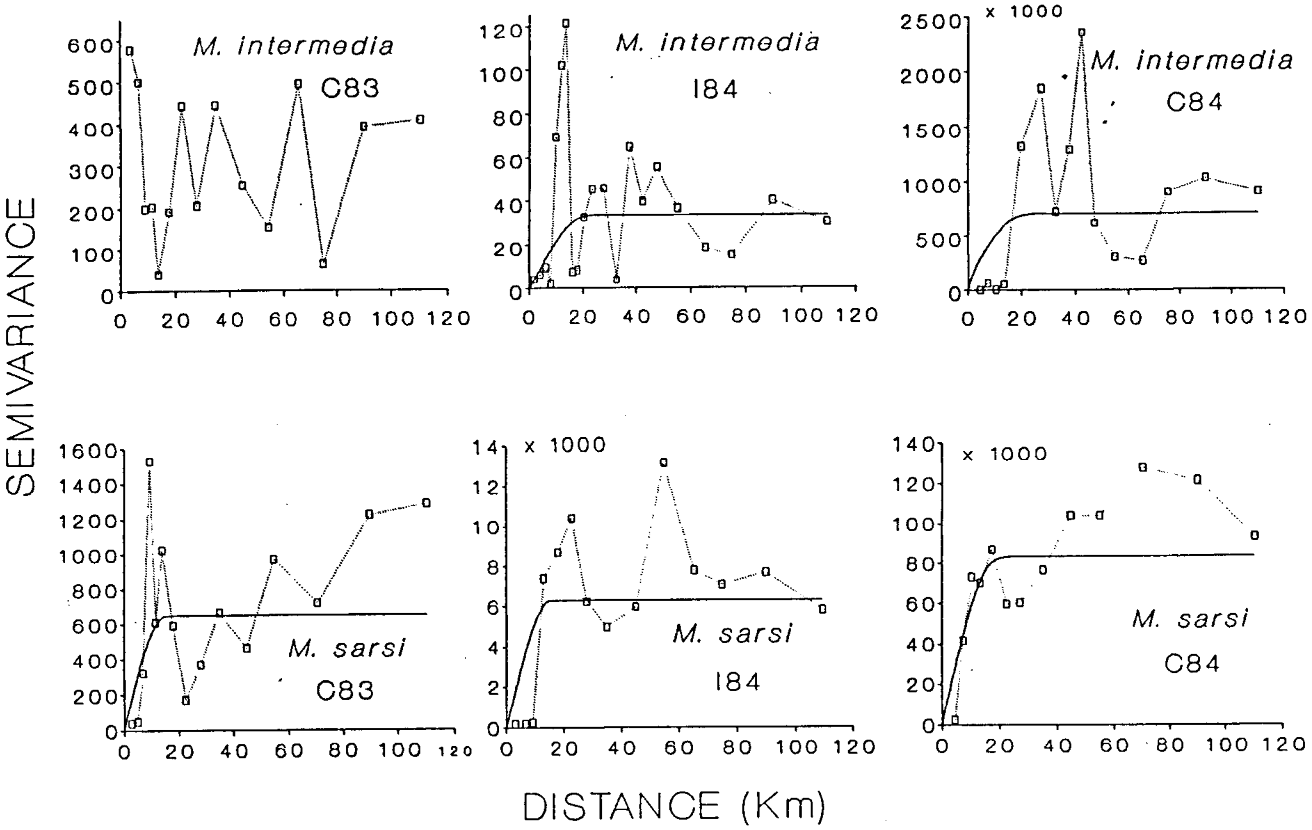

Figure 4. Experimental variograms (dashed line) and spherical models (solid line) for *Munida intermedia* and *Munida sarsi* in the Galician continental shelf.

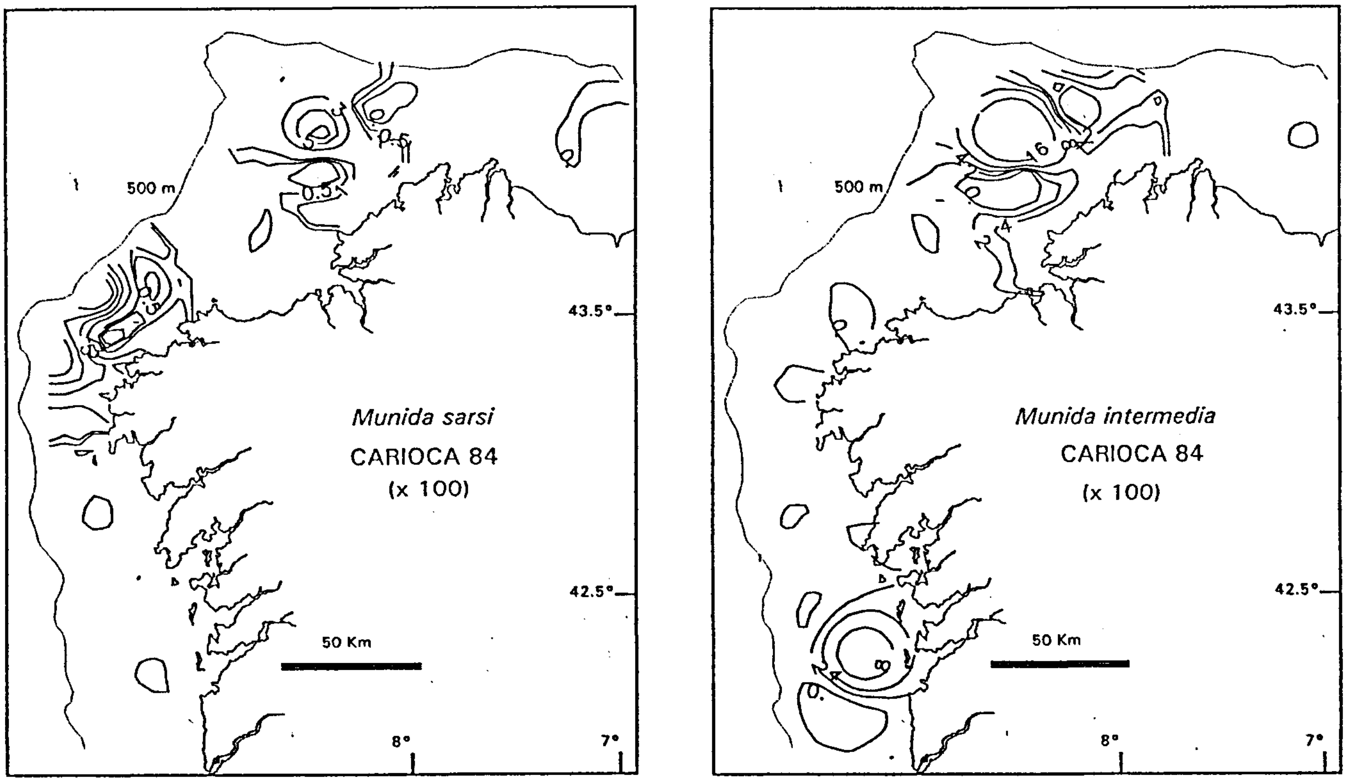

Figure 5. Spatial distribution of *Munida intermedia* and *Munida sarsi* on the Galician continental shelf: Density isocontours obtained from point kriging.

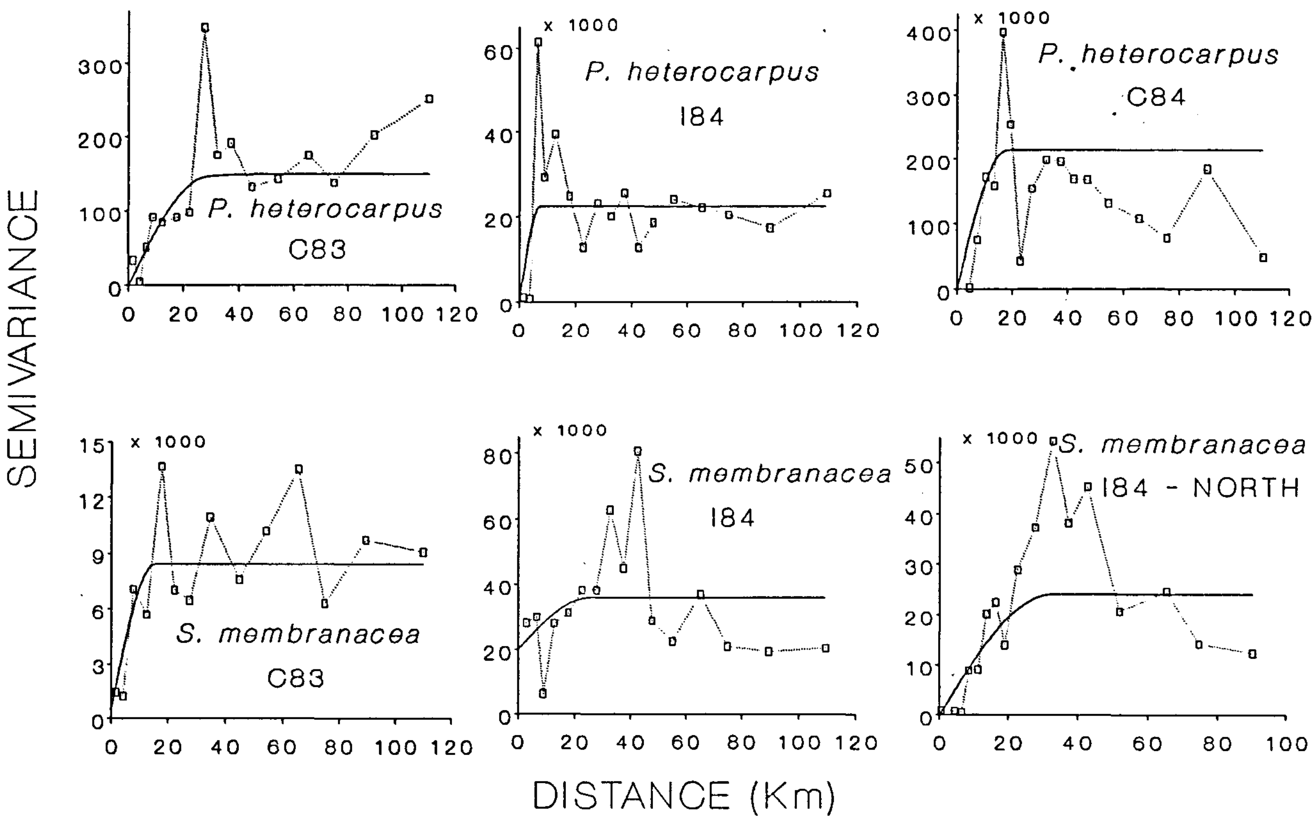

Figure 6. Experimental variograms (dashed line) and spherical models (solid line) for *Plesionika heterocarpus* and *Solenocera membrancea* in the Galician continental shelf.

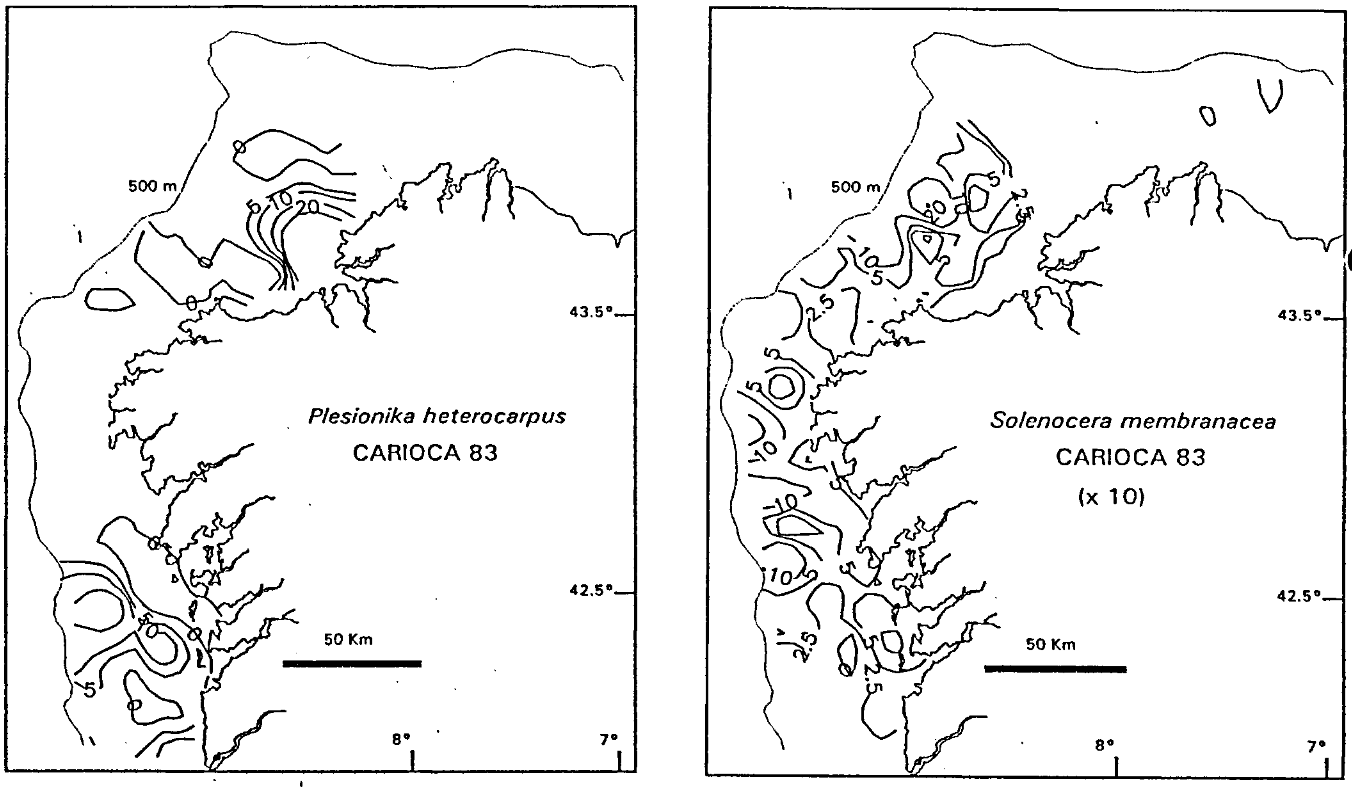

Figure 7. Spatial distribution of *Plesionika heterocarpus* and *Solenocera membrancea* on the Galician continental shelf: Density isocontours obtained from point kriging.