

Species density estimated by kriging and stratified random sampling estimators

by

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ABSTRACT

Aiming the study of deep-water resources off the Portuguese continental coast IPIMAR conducted three research surveys since 1994.

The sampling program adopted was a stratified one and I use the stratified sampling estimator to obtain indexes of biomass estimates.

I also undertake a geostatistical approach for Bluemouth (*Helicolenus dactylopterus dactylopterus*) and Greater forkbeard (*Phycis blennoides*) with 1997 data and for the Algarve region only.

The estimates obtained with both approaches are of the same order of greatness.

Nevertheless the geostatistical approach is preferable, since neither an assumption of independence of the samples is necessary nor the calculation of the area of the *strata*. On the other hand, it is possible to obtain better results (smaller variances) with a regular grid, which is a better option in the design of a survey.

The main drawback of the geostatistical approach is the more laborious underlying theory.

Introduction

Since 1994, IPIMAR conducted three summer research surveys on deep-water species. These surveys aim to the study of the distribution and biology of deep-water species as well as the estimation of their abundance.

Besides the summer surveys two winter surveys were conducted to get information on biological data.

The Sampling design of these surveys obeys to a Random Stratified Sampling scheme. This method assumes independence between samples. As this assumption could be highly violated, specially for sedentary species, another approach could be interesting. Geostatistical methods, build for correlated data could be a useful tool.

Geostatistics were mainly developed with data from mining industry, but could apply to other earth sciences with success.

In fisheries they were chiefly applied by Conan (1985, 1987, 1988, 1989) to crustacean species.

Material and methods

This paper presents the indexes of abundance estimates for Bluemouth (*Helicolenus dactylopterus*) and Greater fork-beard (*Phycis blennoides*) based on data obtained in the summer 1997, along the southern Portuguese coast (Fig. 1). The surveyed area extends from 400 m deep to 900 m.

Each tow has a duration of one hour (time of effective trawling) with an average towing speed of 3 knots and the position of each tow was measured by GPS. The bottom trawl net used was expressly designed to catch crustaceans and the codend mesh size is 20 mm to retain small individuals, not normally available to the commercial fishing gear.

Among geostatistical methods, **kriging** is the Best Linear Unbiased Estimator - **BLUE** (Journel and Huijbregts, 1993).

Kriging procedure includes two steps:

- in the first a model for the spatial structure is fitted to the experimental variogram;
- in the second one optimal weight are assigned to each sampling unit to get a BLUE estimate of the random function.

Usually in fisheries data locations that average high densities show also higher variability than low-density locations. This is the so called proportional effect (Isaaks and Srivastava, 1989). To detect such effect I apply the moving window method, with a $20 \times 20 \text{ nm}^2$ window.

When a proportional effect is present the spatial structure is better modelled by a relative variogram, which re-scales the local variance by the local mean.

I apply ordinary kriging for mapping the resources within the boundaries defined by the presence of samples and block kriging to produce global estimates of mean density over the surveyed area.

This study uses the GEO-EAS 1.2.1 software designed for environmental data.

Results

Bluemouth (*Helicolenus dactylopterus*)

I detected the proportional effect in the data and I established the following relationship between the mean and the standard deviation:

$$\text{std dev} = 1.5527 \times \text{mean}^{0.980}; \quad \text{correl. coeff.} = 0.950$$

As I detected the proportional effect and the data cannot show anisotropy, I compute the omnidirectional relative variogram.

I fit an exponential model (Fig. 2)

$$\gamma(h) = C (1 - \exp(-3h/a))$$

with a sill $C = 6 (kg/nm^2)^2$ and a range $a = 40 \text{ nm}$ and compute ordinary block kriging estimates with this model.

I calculate for each cell on a $5 \times 5 \text{ nm}^2$ regular grid the index of biomass (density in kg/nm^2). Figure 3 shows the results.

As there are more than 50 cells, I calculate the mean density for all the cells to get a global estimation. Table 1 presents this estimation, the standard deviation and the 95% confidence interval as well as the ones obtained with the sampling estimators.

Table 1

Method	Mean	Stand.deviation	95% conf. Interval
Simple random sampling	182.0	54.97	(72; 292)
Stratified random sampl.	102.9	7.15	(83; 123)
Kriging	116.0	18.07	(80; 152)

Greater fork-beard (*Phycis blennoides*)

I detected the proportional effect in the data and I established the following relationship between the mean and the standard deviation:

$$\text{std dev} = 0.413 \times \text{mean} + 29.174; \quad \text{correl. coeff.} = 0.671$$

As I detected the proportional effect and the data cannot show anisotropy, I compute the omnidirectional relative variogram.

I fit a gaussian model (Fig. 4)

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

with a nugget $C_0 = 0.4 (kg/nm^2)$, a sill $C = 0.5 (kg/nm^2)^2$ and a range $a = 30 nm$ and compute ordinary block kriging estimates with this model.

I compute for each cell on a $5 \times 5 nm^2$ regular grid the index of biomass (density in kg/nm^2). Figure 5 shows the results.

Table 2 presents the global mean estimate, the standard deviation and the 95% confidence interval as well as the ones obtained with the sampling estimators.

Table 2

Method	Mean	Stand.deviation	95% conf. Interval
Simple random sampling	113.7	13.4	(87; 141)
Stratified random sampl.	114.6	12.6	(82; 147)
Kriging	110.7	1.6	(108;114)

Discussion

Geostatistical models are advantageous tools for the study of spatial distribution patterns in relation to abundance. Density maps are also helpful for assessing the economical potential of the catch.

In this study the global estimation of the mean densities obtained with kriging were similar to those obtained with random stratified estimator.

As usual better data lead to better estimates. Kriging assumes a certain degree of homogeneity. This assumption is not very well accomplished in the case of Bluemouth, which presents a patchy distribution. Therefore the less standard deviation is obtained with stratified random sampling. However this method assumes independence between samples, which is not true, so the results must be considered with care.

As the distribution of greater fork-beard is very homogenous the range of confidence intervals obtained with kriging diminishes dramatically in relation to the ones obtained with sampling estimators. For the same reason we cannot achieve better estimates (low variance) with strata than with simple random sampling.

References

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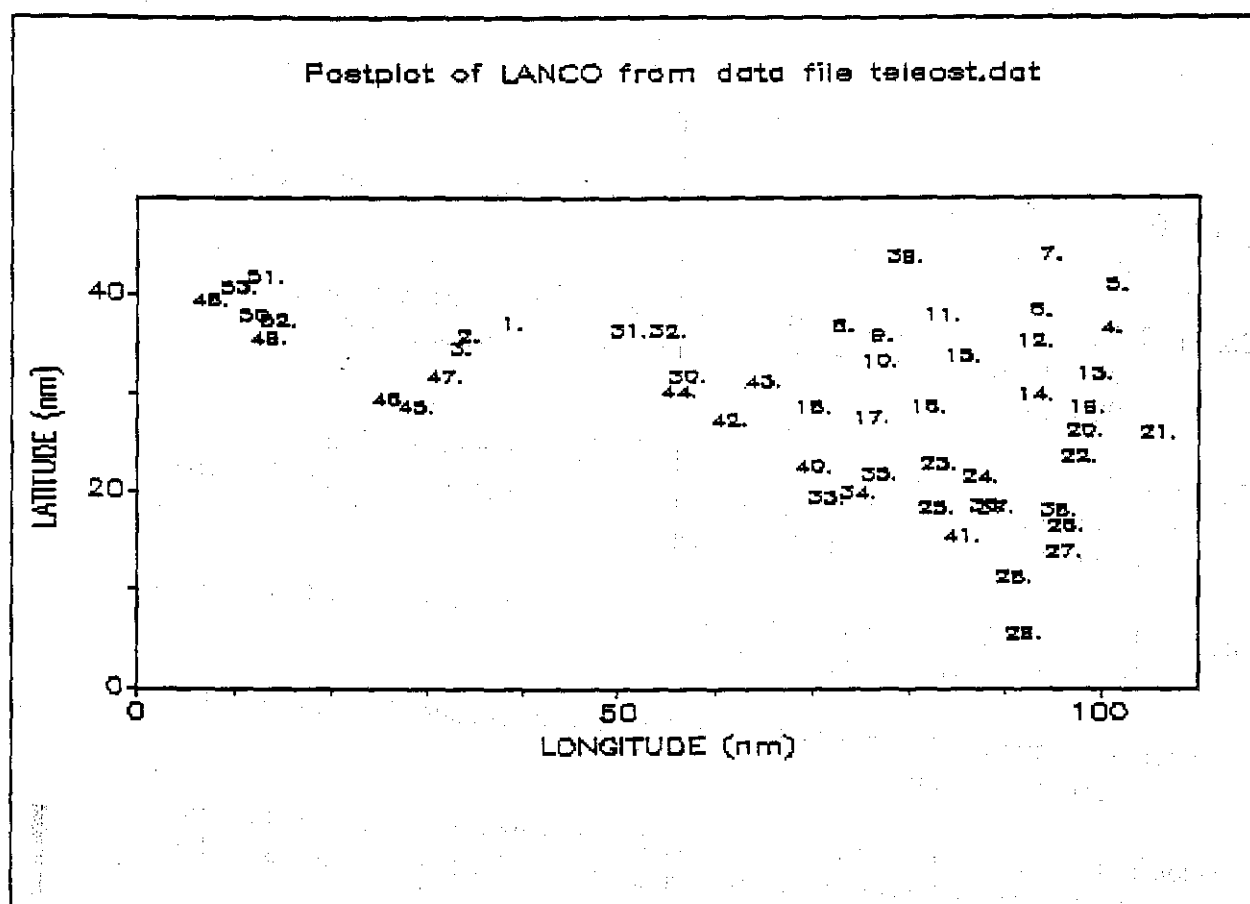


Fig. 1 - Post plot of fishing hauls in the summer 1997 along the southern Portuguese coast (Origin: 9° 30' W; 36° 10' N)

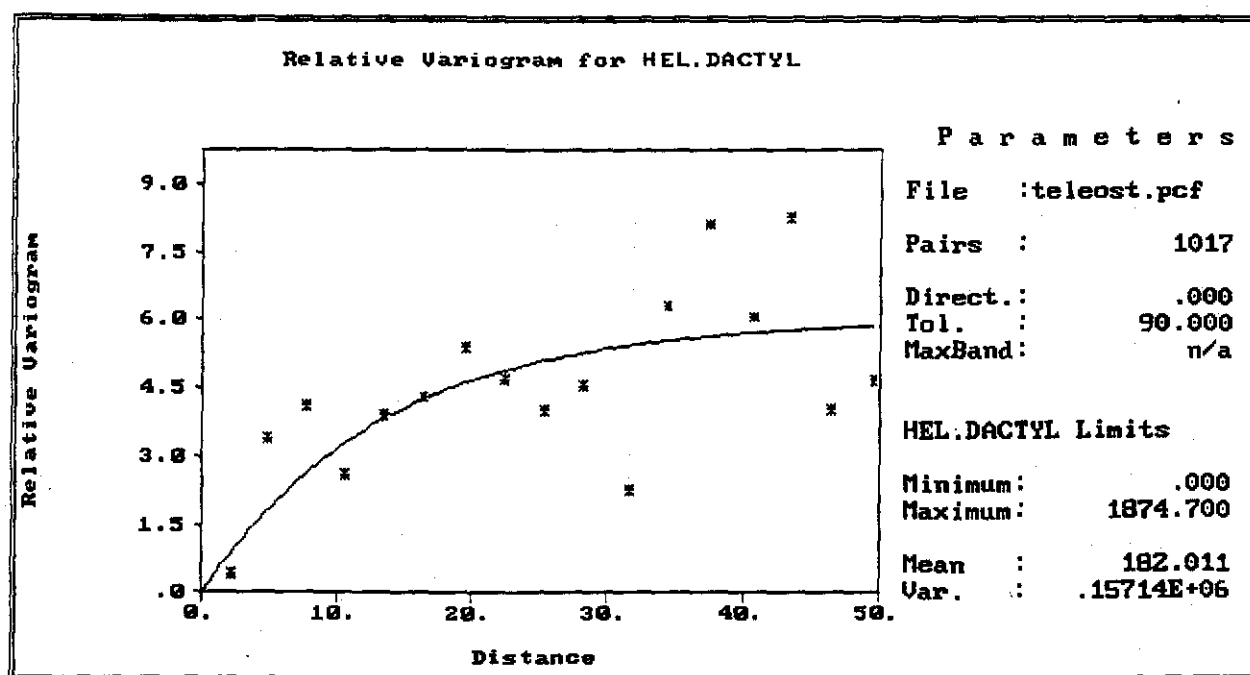


Fig. 2 - Exponential model fitted to the relative omnidirectional variogram obtained with Bluemouth data

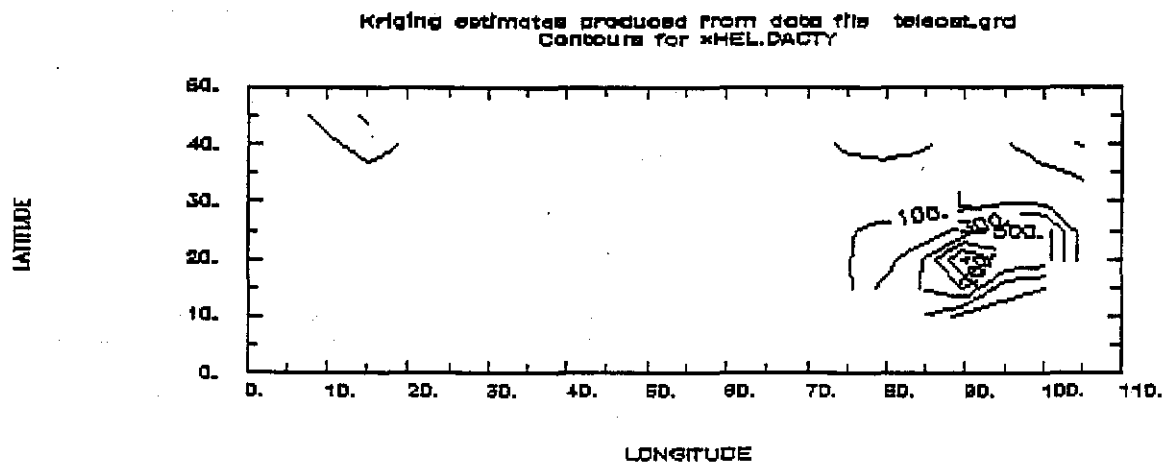
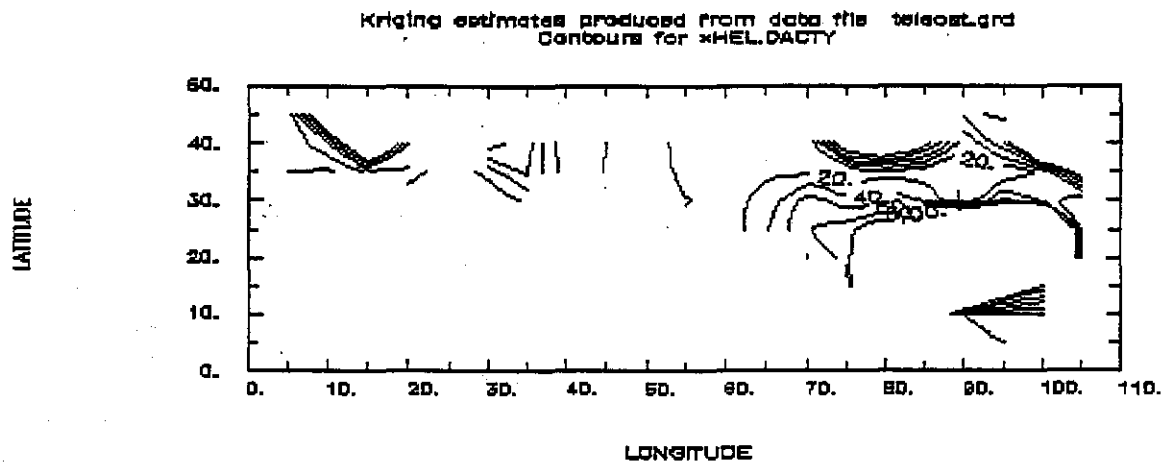


Fig. 3 - Density contour map for Bluemouth in the summer 1997 along the southern Portuguese coast

a - 0 to 100 kg/nm² with a interval of 20 kg/nm²

b - 100 to 1100 kg/nm² with a interval of 200 kg/nm²

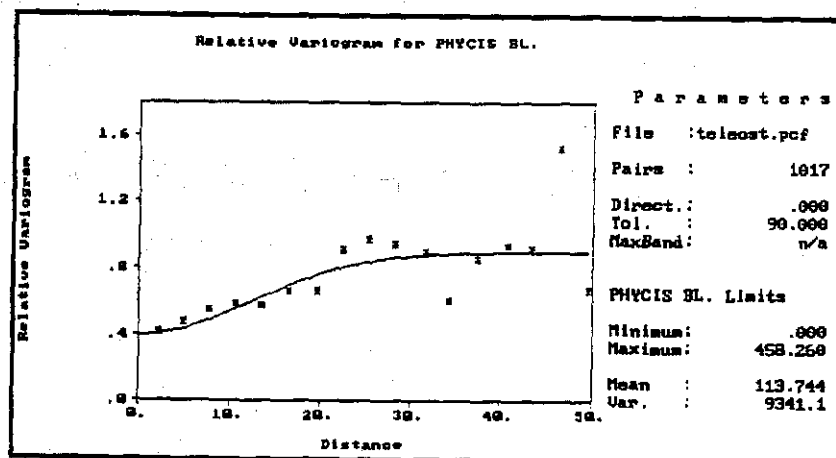


Fig. 4 - Gaussian model fitted to the relative omnidirectional variogram obtained with Greater forbeard data.

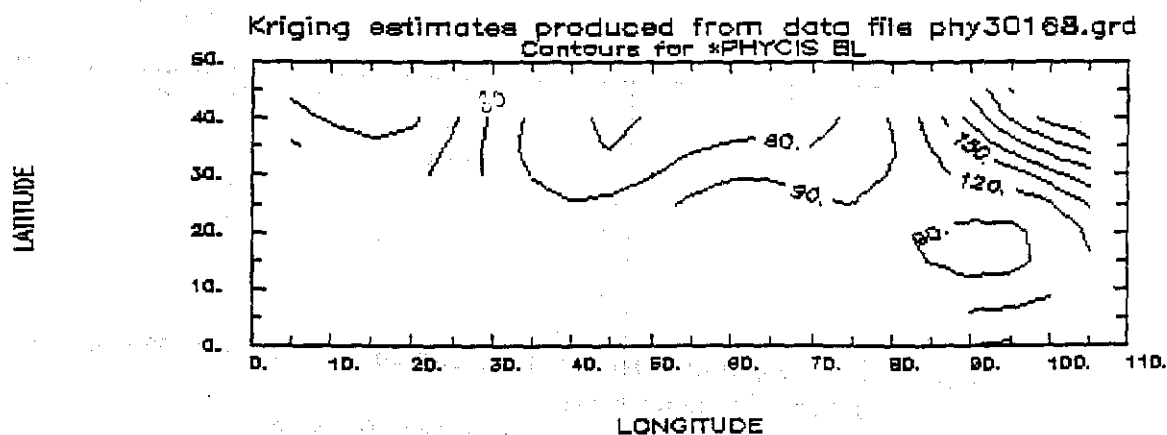


Fig. 5 - Density contour map for Greater forkbeard in the summer 1997 along the southern Portuguese coast
0 to 270 kg/nm² with a interval of 30 kg/nm²