USE OF THE KRIGING METHOD FOR THE STOCK ASSESSMENT OF OYSTERS IN THE CHESAPEAKE BAY.

by

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INTRODUCTION

The kriging technique is now employed in more and more fields: mining (Journel, 1977), hydrology (Delhomme, 1978 ; Shamsi et al., 1988 ; Dingman et al., 1988), fishery (Conan, 1989) and ecology (Robertson, 1987 ; Schotzko and O'Keeffe, 1989, 1990). Recent developments of the mathematical theory tend to extend the number of applications where it may be used. Basically defined for the case of a stationary spatial process, it now encompasses more general processes assuming less and less strong hypotheses (intrinsic hypothesis, intrinsic generalised hypothesis, disjunctive kriging). In its most general formulation, it allows to study the spatial structure of a process including large scale or local trends. The basic idea remains to take into account the spatial structure in order to estimate the mean and the variance of the sampled variable either over a given area, either at a point. In the one dimensional case, it may be applied to time series (Ibanez, 1985 ; Robertson, 1987). Details and mathematical formulations may be found in the references cited above and will not be recalled in this report. It is just necessary to know that the linear kriging estimator of a process is the best linear unbiased estimator and that the estimation consists in computing the weights of the estimator from the spatial structure, so that observed points closed to the point to estimate have a greater influence than observed points which are far from it.

Systematic sampling was applied to the study of the oyster populations in some oyster bars of the Chesapeake Bay. Some of the results were chosen in order to evaluate the advantages and drawbacks of the kriging method compared to more classical ones (random sampling). We are faced with the following problems :

- does the use of a regular grid yield to an interesting result (feasability, good precision)? In that case, the sampling points are not randomly drawn, so that the estimators used for random sampling do not work. That means that we must use more efficient techniques for the stock assessment. Consequently, the kriging method was chosen.

– is it possible to make some proposals for a global survey of the bay? In other words, is the previous method efficient enough to be incorporated into a global strategy. It appears that this question is linked to at least two more points:

-- the choice of units and subunits of the sampling schemes and of the method to draw these units.

-- the comparison of the cost (number of points) and the precision (variance) obtained for the few examples that were analysed.

MATERIAL AND METHOD

1) stock assessment

The list of the oyster bars which were analysed is given table 1. They were chosen because of the number of samples and non zero values for the variables representing the live oysters. In each case two variables were studied:

- the weight of blank oysters. This variable defined the boundaries of the bar. The weight itself had no interest but to compare the spatial structure of the living oysters with the one of its substrate.

– the weight of live oysters. It was preferred to the abundance which is known to have a skewed distribution and may suffer from linear interpolation.

Kriging was applied on the raw data without any transformation of variable which would have yielded some bias (see number of zero values). In some cases, some zero values were removed, at least on the first variable, when the points were obviously out of the boundaries of the bar. The GEOEAS software package was preferred to MAGIK because of its facilities (parameter files). The main advantage of the second one consists on the ability to provide structural analysis and to compute general covariance function. It is a more general method than the one based on the estimation of the variogram (stationary or intrinsic cases) because of its ability to remove local polynomial trends, but it is of little help when assessing the global mean over the bar with that version of MAGIK software. More details about the latter method may be found in the litterature (e.g. Shamsi et al., 1988) and will not be recalled here.

The steps followed in this study are listed below :

- computation of the isotropic experimental variogram. When there were enough points (more than 60), and if it was necessary, anisotropic variograms were computed along (at least) the two main directions.

- once the variogram was modeled (spherical model), the cross-validation was the crucial step. It allowed to compute the kriged value and the kriging variance and each point that was sampled. The comparison between the observed and predicted values yielded to accept or to reject the model. In the latter case, that means that a new model of the variogram had to be fitted to the data. The previous trial and error process was pursued until the predictions seemed acceptable. Two criteria are commonly used to validate the model. The first one is the ratio between the mean kriging standard deviation and the standard deviation of the residuals which must be close to 1. The second one is a measure of the bias, i.e. the mean difference between the kriged values and the observed values, which must be close to 0.

- mapping the variable was obtained through the computation of the kriged values at each node of a grid generally finer than the one used for the sampling. The software enabled to draw constant level lines on a bidimensional graph. This map gives an idea of the locations where the greatest and lowest abundances were found. Since the sampled points were regularly spread over the area, the map of the local variances corresponding to the local means will not provide much information. The kriging variance depends only on the location of the samples and a high variance comes from the lack of data in the neighborhood of the kriged point.

- the variance of the global mean was derived from the tables given by Journel (1977). It is a function of the range of the variogram (distance from which the variogram is flat) and the polygon of influence (the rectangular area around each sampling unit). The nugget effect, which represents the variability not explained by the model, was added to the previous estimation of the variance. Since the kriging estimator is a true interpolator, the mean was given by the mean computed at all the nodes of the grid used for the map. Some sampling units were removed from the set of data since the corresponding 'blank weight' was null and the point was located on the periphery of the bar. The surface of the area was derived from the intersection between a polygon around the remaining points and the grid of points used for the local kriging. It is the most straightforward way to define the area. In an example, Armstrong et al. (1989) showed that including or not zero values that lie at the boundaries of the area did not change much the global estimation. In fact it acted on the distribution of the local values and on the mapping.

The stock was the product of that mean by the size of the mesh and the number of meshes defining the studied area.

The maps and variograms are given in the annex. An analysis of all the results would yield very redundant remarks. In all cases an isotropic model of variogram could be fitted to the experimental variogram and allowed to compute the global mean and variance of the weight with enough reliability. The summary of the results are presented and discussed.

2) optimization

Once the spatial structure assessed for the oyster bars which were examined, we focused on the computation of the number of sampling units that should be drawn on each bar in order to obtain the lowest variance with a given total number of points. This is a way to define a global strategy, though in our case only seven bars were concerned.

From Journel's table, it may be seen that, in the case of a variogram with no nugget and a sill equal to 1, the kriging global variance V1 of the mean is related to the ratio between the mesh size (l) and the range of the spherical variogram (a) according to a log-linear relationship (when l/a is not too great) :

$$\ln(V1) = p \,.\, \ln(l/a) + q$$

The l/a ratio is inversely proportional to the square root of the number of sampling units (n). Then the previous relation becomes:

$$\ln(V1) = p \,.\, \ln(r/\sqrt{n}) + q,$$

where r depends on the area of the bar and the range of the variogram.

When the variogram includes a nugget (u) and a sill (s), the variance of the mean may be written:

$$V2 = (s \,.\, V1 + u) \,/\, n,$$

and the variance of the stock V3 is equal to:

$$V3 = V2 \, . \, S^2,$$

where S is the area of the bar. The relation between V1 and n yields:

$$V3 = A \, . \, n^{(-1-p/2)} + B \, . \, n^{-1},$$

where A and B depend on the characteristics of the variogram.

The optimization problem may be defined as to minimize the function :

$$V = \Sigma A_i \, . \, n_i^{(-1-p/2)} + \Sigma B_i \, . \, n_i^{-1},$$

under the constraint :

$$\Sigma n_i = N,$$

where i is related to the bar number i (i=1 to Nb).

The use of the Lagrangian multiplier λ yields to solve the equations:

$$C_i \, . \, n_i^{\beta} + D_i \, . \, n_i^{-2} + \lambda = 0 \, , \, i=1 \text{ to Nb}, \qquad (1)$$

where C_i and D_i are derived from A_i, B_i, β, p and with the same constraint:

$$\Sigma n_i = N \qquad (2)$$

There is no analytical solution of the equation (1) giving n_i as a function of λ, but numerical computations may be used to find n_i and λ.

Knowing ni yields to calculate the corresponding variance. Consequently, the gain of precision due to the optimization can be estimated, under the assumption that the models of the variograms are still valid.

GENERAL RESULTS

The results were summarized in tables 1 to 3 for the seven oyster bars which were analysed. The coefficient of variation lay from 4 % to 15 % according to the bar or the variable. The whole stock of live oysters derived from the computations reached 5298 metric tons with a coefficient of variation equal to 4.8%. The gain of precision yielded by the application of the kriging method was not constant and might be not very interesting in every case. It was defined by the ratio between the estimated standard deviation and the standard deviation of the population divided by the square root of the number of units (table 3). The latter standard deviation is not the true one yielded by a random sampling survey

Table 1 : Isotropic variograms for the "live weight" (1) and "blank weight" (2) variables.

oyster bar name		range	sill	nugget	sample number	percentage of zeros
Black Buoy	1) 2)	5.5 12	2.7 9	2 3	68 68	26 4
Sandy Hill	1) 2)	25 30	0.75 45	0.75 40	187 187	55 27
Mill Dam and Dixon	1) 2)	18 18	2 13	1.8 20	137 137	58 45
British Harbour and Oyster Shell	1) 2)	15 18	3.5 39	6 25	88 88	45 35
France	1) 2)	1 1	1 14	0 0	80 80	43 20
Cabin Creek	1) 2)	15 10	1 50	1.8 28	98 98	64 48
Bachelor Point	1) 2)	18 18	1.8 46	1.5 25	151 151	57 56

Table 2 : Experimental kriging in order to cross validate the model of variograms for the "live weight" (1) and "blank weight" (2) variables.

oyster bar name		mean kriging standard deviation	ratio between residual and kriging standard deviation	mean residual
Black Buoy	1) 2)	1.81 2.21	1.00 0.92	0.02 0.00
Sandy Hill	1) 2)	1.03 7.49	1.00 1.03	0.03 -0.24
Mill Dam and Dixon	1) 2)	1.74 5.38	0.97 0.99	-0.03 -0.07
British Harbour and Oyster Shell	1) 2)	2.93 6.71	1.02 0.94	0.18 0.23
France	1) 2)	1.02 3.83	0.97 0.95	0.02 0.14
Cabin Creek	1) 2)	1.53 7.54	0.95 1.02	0.05 0.34
Bachelor Point	1) 2)	1.65 7.32	0.99 1.00	0.12 0.52

Table 3 : Global estimation and gain of precision (ratio between the coefficients of variation obtained with the kriging and the random sampling estimators) for the both variables "living weight" (1) and "blank weight" (2).
1 metric ton = 25 bushels.

Oyster bar name		mean (kg/ sampling unit)	σ	Surface (10^3 m^2)	Stock (metric tons)	σ	gain
Black Buoy (Upper Choptank)	1) 2)	2.45 6.04	0.18 0.25	37	63 157	5 6	0.72 0.69
Sandy Hill (Middle Choptank	1) 2)	0.79 5.20	0.07 0.48	1427	795 5259	66 484	0.75 0.78
Mill Dam and Dixon (Upper Choptank)	1) 2)	1.22 4.15	0.12 0.40	1322	1147 3886	114 370	0.69 0.81
British Harbour and Oyster Shell (Upper Choptank	1) 2)	2.42 8.07	0.27 0.58	635	1089 3633	122 259	0.85 0.70
France (Lower Choptank)	1) 2)	0.46 3.44	0.07 0.27	2045	670 4989	104 389	0.63 0.61
Cabin Creek (Upper Choptank)	1) 2)	0.93 5.86	0.14 0.59	340	225 1414	33 143	0.82 0.69
Bachelor Point (Tred Avon River)	1) 2)	1.00 5.23	0.11 0.46	1853	1308 6870	142 604	0.80 0.72

because the units were not drawn randomly but we may expect that it is not too far from it. A low value means that taking into account the spatial structure brings much information. For instance, the lowest values (for the 'live weight' variable) lay around 0.63 (e.g. France oyster bar) which means that the precision was improved of about 37%. The greatest values (i.e. the lowest gain of precision, see Cabin Creek, Bachelor Point, British Harbour and Oyster Shell oyster bars for which the gain was less than 20 %) seemed not to depend on the mean weight, the number of sampling units nor the number of zero values, which could have influenced the results of the analysis. These values came from variogram models containing high nugget effects (compared to the sill, table 1). That means that the spatial structure was not easy to describe with the sampling design used in this study. In other words, the size of the mesh of the grid defined for the survey was not appropriate. The spatial scale was smaller than the minimum distance between two nodes of the grid. In France oyster bar, the nugget was null, but the lack of observations at small distances makes this estimation doubtful. In such a case, we were really closed to a pure nugget effect and only a trial and error process of cross validation of the model allowed to choose the best model (table 2). Since the experimental variogram was irregular and that its range was obviously less or equal to the shortest distance between the sampling units, there was no other way to get acceptable parameters. However, this does not mean that no spatial structure existed. It would only demand a finer grid, i.e. more points.

The range of the global means of the oyster bars was really wide. Though no statistical test was performed, an obvious classification of the mean densities could be derived from the mean values. The mean value of Black Buoy was equal to 2.45. British Harbour had a similar mean (2.42). Following a decreasing order, we found Dixon and Mill Dam, Bachelor Point and Cabin Creek bars (around 1), Sandy Hill (0.79) and France (0.46).

The variable 'blank weight' was also studied. The gain of precision lay between 0.61 and 0.81, which was quite similar to the previous variable. In fact, a more regular distribution was noticed. The percentage of the variance explained by the nugget was generally lower for this variable than for the 'live weight' variable (fig. 1). There was not such an obvious difference between the ranges of the two variables (fig. 2), even though the range of 'blank

Figure 1. Comparisons of the nuggets (expressed as a percentage of the variance) of the two variables 'live weight' (x axis) and 'blank weight' (y axis) for the seven banks, showing a generally greater nugget for the 'live weight', i.e. a less strong structure.

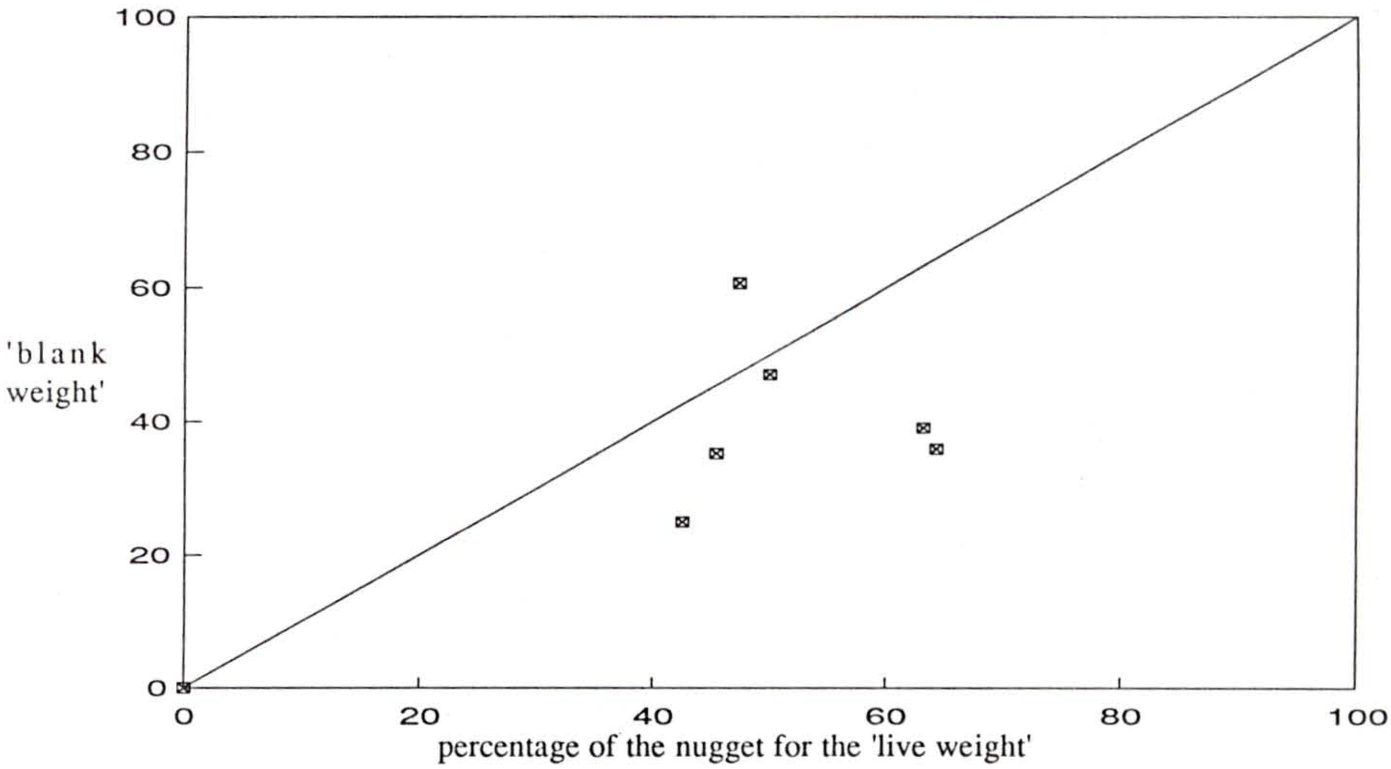
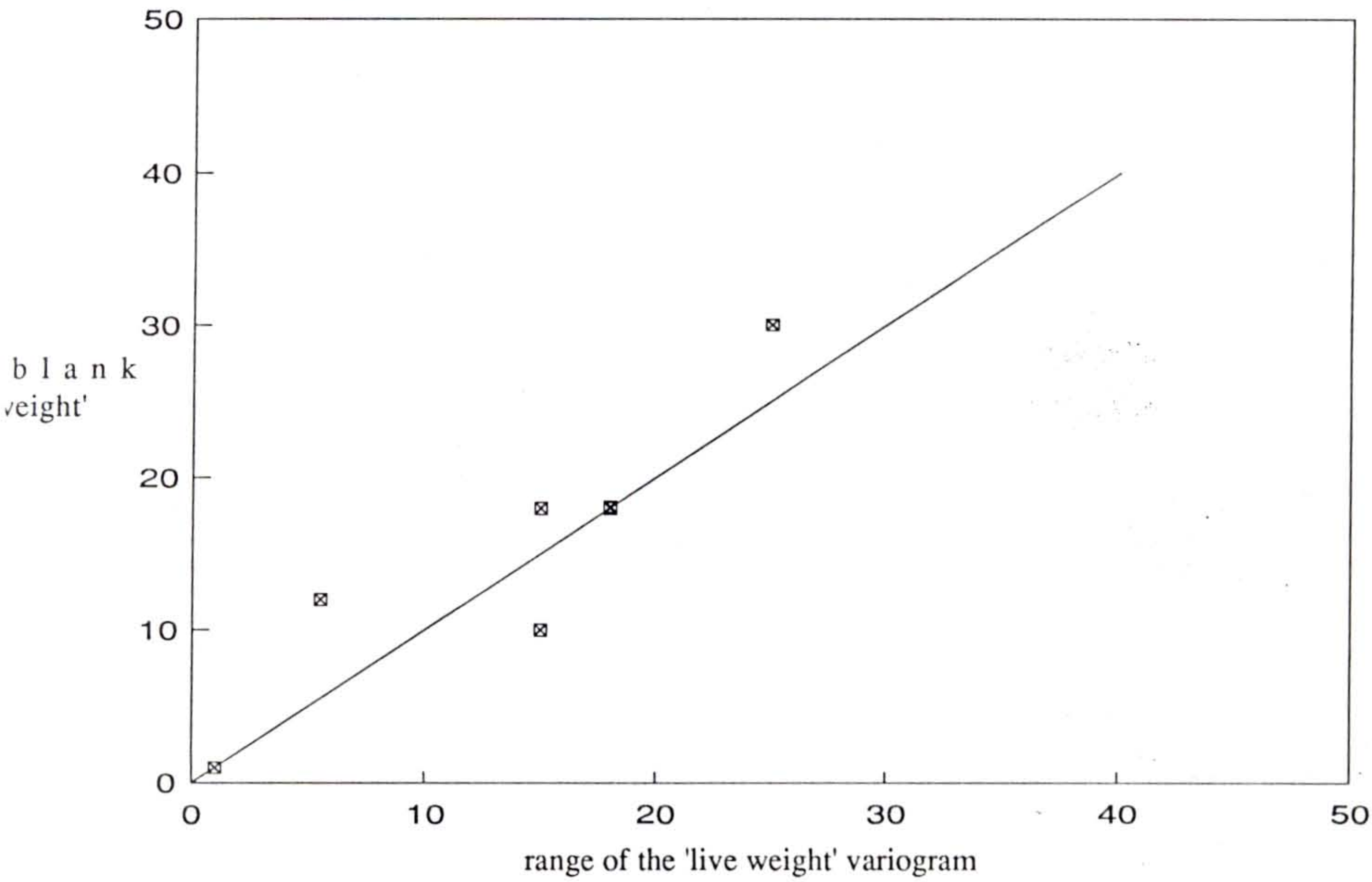


Figure 2. Values of the range of the 7 experimental variograms for the two variables 'live weight' (x axis) and 'blank weight' (y axis), which shows that the spatial scale of the patchiness are comparable for the two variables.



weight' was generally greater than the range of 'live weight' or equal to it. These structural remarks aside, the main interest of this variable is that it allows to give sensible boundaries to the bar. The number of sampling units was lowered by removing some zero points lying in the external part of the area. The surface of the bar was derived from the remaining points. In some examples however (e.g. Cabin Creek, Bachelor Point), many zero values were still kept inside the bar. Some question may arise since blank shells are the substrate of the living oysters. The habitat seemed then not at all uniform and this feature could have an effect on the distribution of the living oysters. However, the means of blank oysters were more homogeneous than the means of living oysters when all the oyster bars were compared and varied from 3.4 (France) to 8.1 (British Harbour and Oyster Shell). By the same way, the precision was slighthly better for the 'blank weight' than the 'live weight'.

As far as it could be studied, no anisotropy was noticed or could explain some irregularity of the variogram. The study of the anisotropy requires much more sampling units than the isotropic variogram because of the calculation of the spatial correlations along several distinct directions. The variograms were visualised for the Sandy Hill oyster bar along four directions (O°, 45°, 90°, 135°) for both variables (fig. 3). The comparison between isotropic model and the experimental variograms showed no major differences in the parameters (sill, range and nugget), at least along the two main directions (45°, 90°) for which the number of available pairs of points were the more numerous.

Giving a glance at the maps showed that the spatial distribution for both variables, and especially the 'live weight', varied from one case to another. For Bachelor Point and France oyster bars, the spatial variability was highly pronounced when compared to the scale of the bar. The distributions were less variable for Cabin Creek. The Black Buoy was almost constant. In the latter however, and in Mill Dam and Cabin Creek too, the boundaries of the bar were not well defined. Some peaks were obviously incomplete and cut off by the boundary of the sampled area. When comparing the peaks of 'live weight' and 'blank weight', no general rule was found to correlate the abundance of the two variables. There was no evidence of a link between them in the Black Buoy oyster bar for instance. On the contrary, similar patterns could be noticed in Cabin Creek or Bachelor Point.

Figure 3a. Experimental variogram for the 'live weight' variable along the four directions 0°, 45°, 90°, 135° with a tolerance of +/- 30°. The experimental variogram is compared to the isotropic model (continuous line). Some slight differences appear (e.g. 45°) and may be explained by a second structure at distances greater than 30 (units are arbitrary).

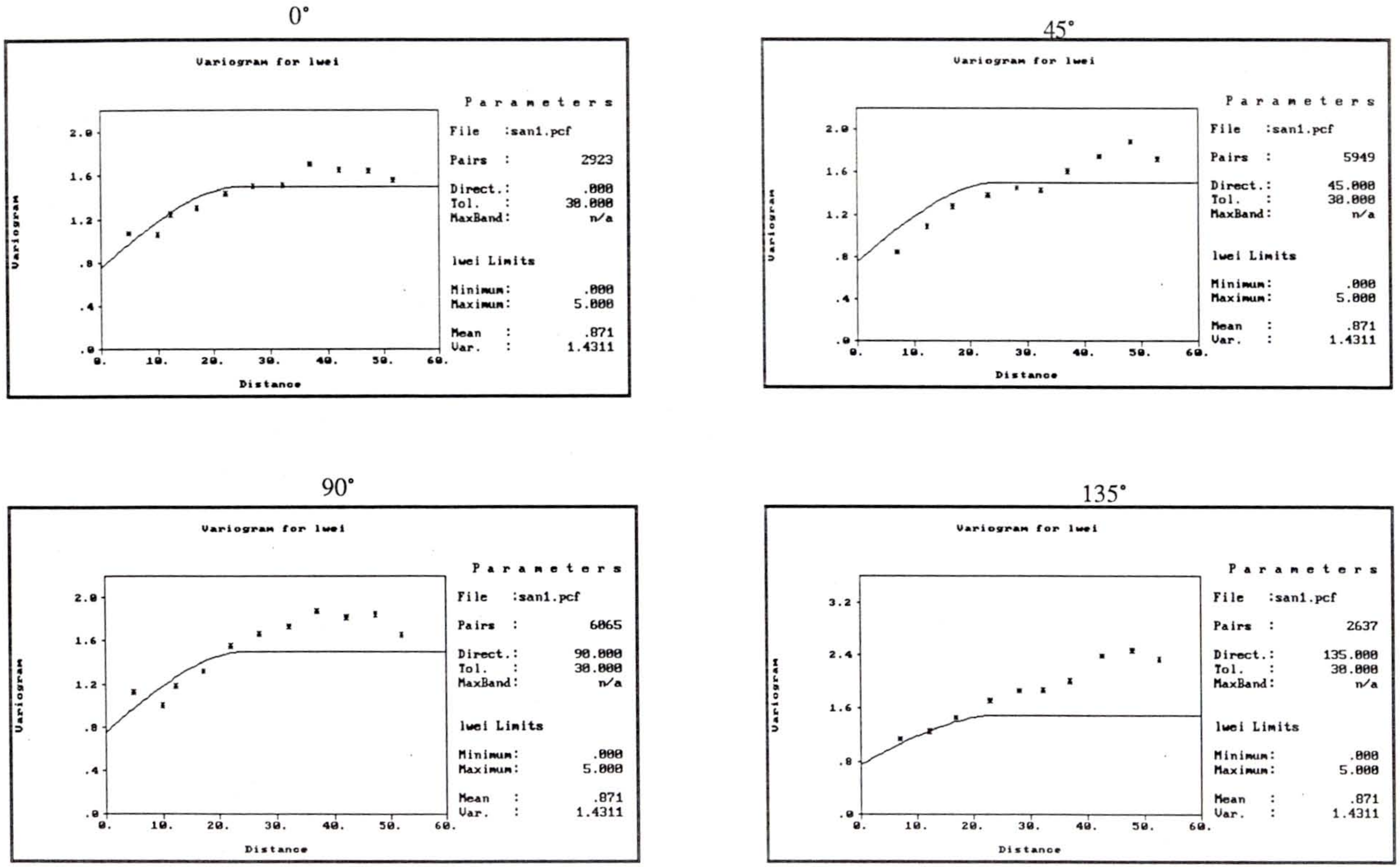
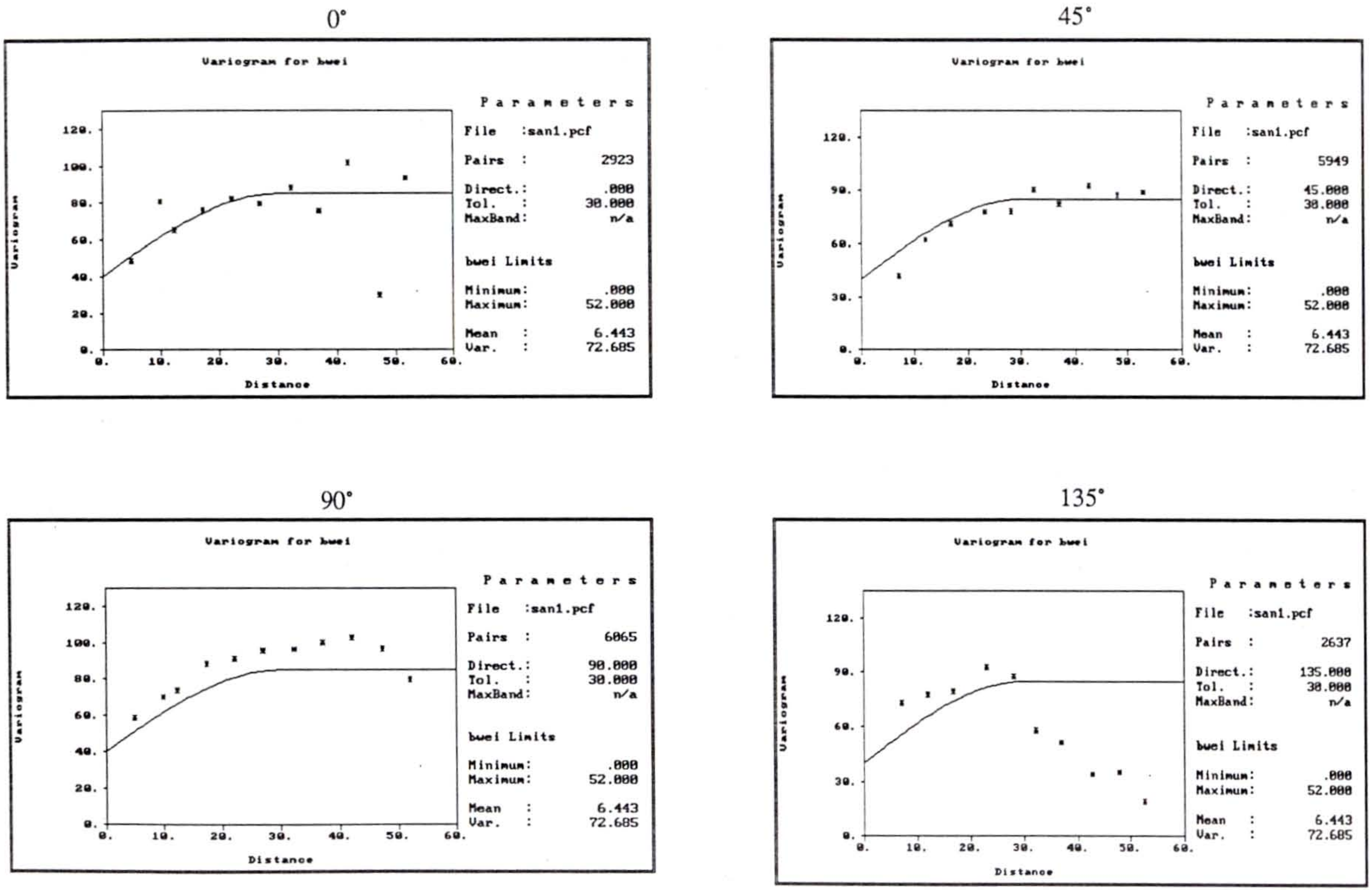


Figure 3b. Experimental variogram for the 'blank weight' variable along the four directions 0°, 45°, 90°, 135° with a tolerance of +/- 30°. The experimental variogram is compared to the isotropic model (continuous line). No sensitive difference appears so that we are sure that there is no anisotropy.



The relation between the number of sampling units and the coefficient of variation of the live weight on each oyster bar was derived from the equations described previously and plotted on figure 4. As expected, there was a strong decreasing effect of the number of units. This effect is particularly strong for the France oyster bar. Since the nugget was put to 0, lowering the size of the grid used in the survey would result in taking into account the spatial structure more effectively. On the other hand, the gain of precision (from a random to a systematic survey) would remain the same for all the bars but France (fig. 5). The number of units and the related variance yielded by the optimization were summarized in the table 4. It allowed to lower the variance of the whole stock from 64300 to 49500. The number of units was increased on Mill Dam/Dixon, British Harbour/Oyster Shell, France and Bachelor Point. Two reasons may be put forward to explain the new allocation of the units. First, small bars (Cabin Creek, Black Buoy) may be neglected without great loss. Then for great bars, a greater precision would be obtained when the nugget is low so that decreasing the size of the mesh would lower the kriging variance (e.g. Bachelor Point, France bars).

CONCLUSION

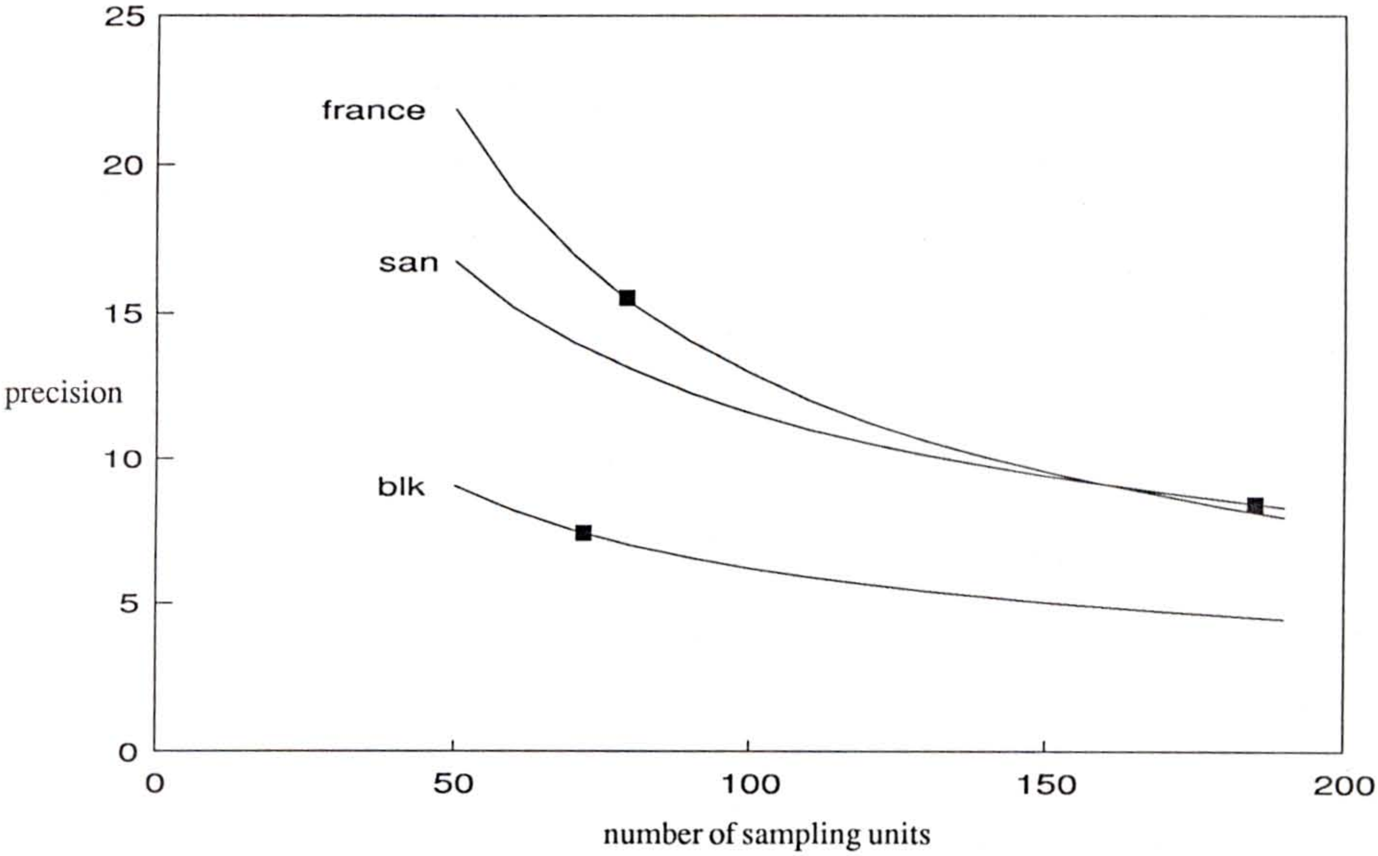
A general remark brought by the previous considerations is that there is a wide number of spatial structures. There may be historical or biological reasons for the heterogeneity of the distributions since changes due to biological events or fishing effort and management can occur. The bathymetry of the oyster bars was generally highly variable. France and Black Buoy apart, a trend was noticed (Cabin Creek, Sandy Hill) or the bar was separated by a ridge (British Harbour/Oyster Shell Point, Dixon/Mill Dam, Bachelor Point). There was no direct link between this variability and the spatial structure of both 'live weight' and 'blank weight' variables. This factor could however be combined to biological ones to explain the different kinds of spatial structures. The fact that the repletion program was applied to some bars (Cabin Creek, Dixon, Black Buoy, Sandy Hill, Oyster Shell Point) in 1988, 1989, does not give clues to interprete the spatial structure or the mean density.

The boundaries of the oyster bars seemed to be very uncertain. Zero values for the variable 'blank weight' and peak of abundance near the theoretical boundaries defined by

Table 4 : Optimization of the number of sampling units per oyster bar. Actual and simulated values of the number of units and the variance of the stocks are compared. The optimization could allow to lower the whole variance by 24 %.

Bar	n	nsim	V	Vsim
Black Buoy (Upper Choptank)	68	8	22	264
Sandy Hill (Middle Choptank)	187	115	4415	7339
Mill Dam and Dixon (Upper Choptank)	137	167	12889	10496
British Harbour and Oyster Shell (Upper Choptank)	88	136	14832	9489
France (Lower Choptank)	80	124	10781	5424
Cabin Creek (Upper Choptank)	98	40	1120	2831
Bachelor Point (Tred Avon River)	151	219	20243	13653
TOTAL	809	809	64304	49497

Figure 4. Simulation of the relation between the number of sampling units and the precision (%) obtained by the kriging method. The squares show the actual precision for the actual survey.



san : Sandy Hill - cbc : Cabin Creek - france : France - btos : British Harbour/Oyster Shell
bach : Bachelor Point - blk : Black Buoy - mddx : Mill Dam/Dixon

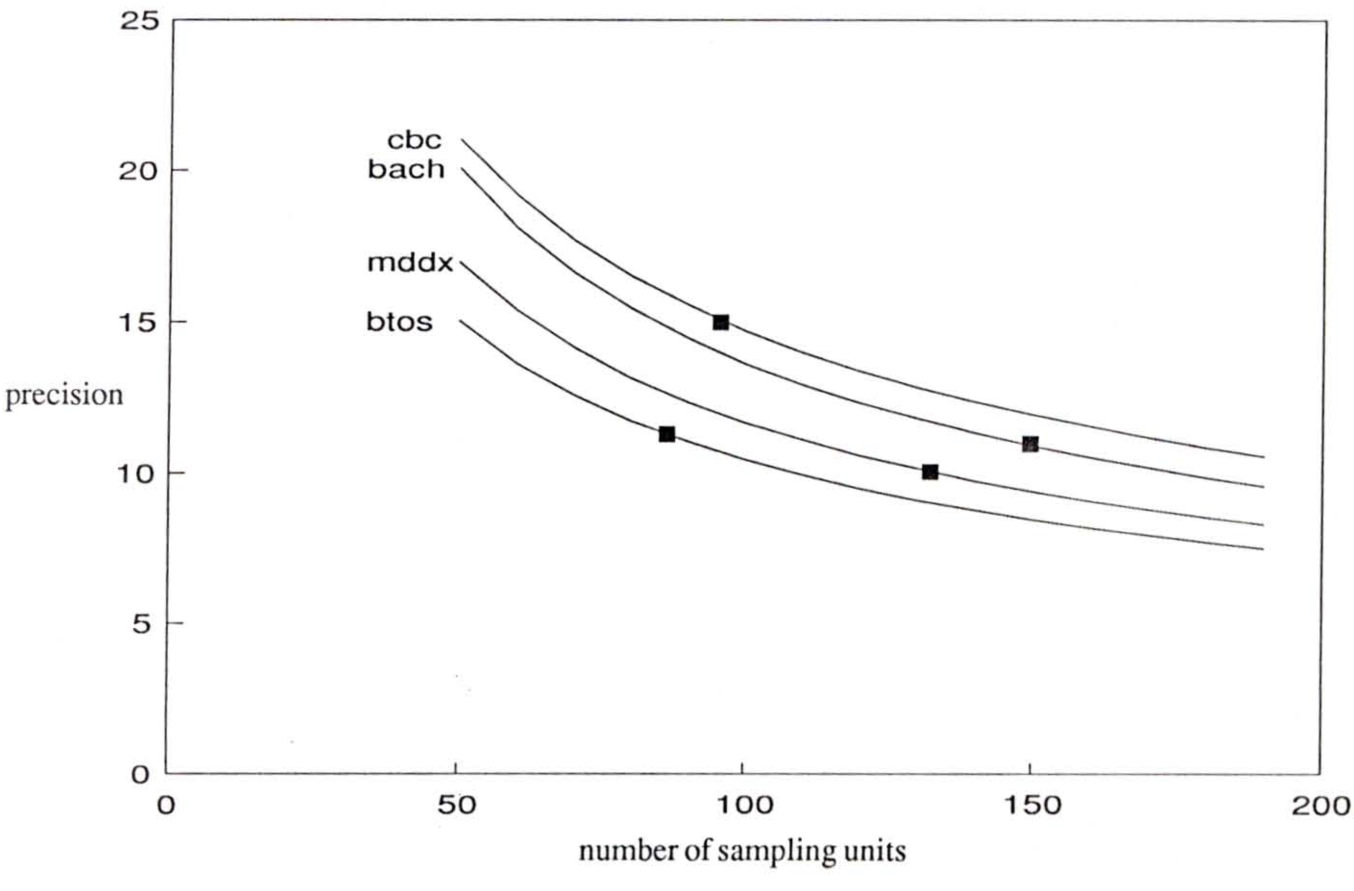
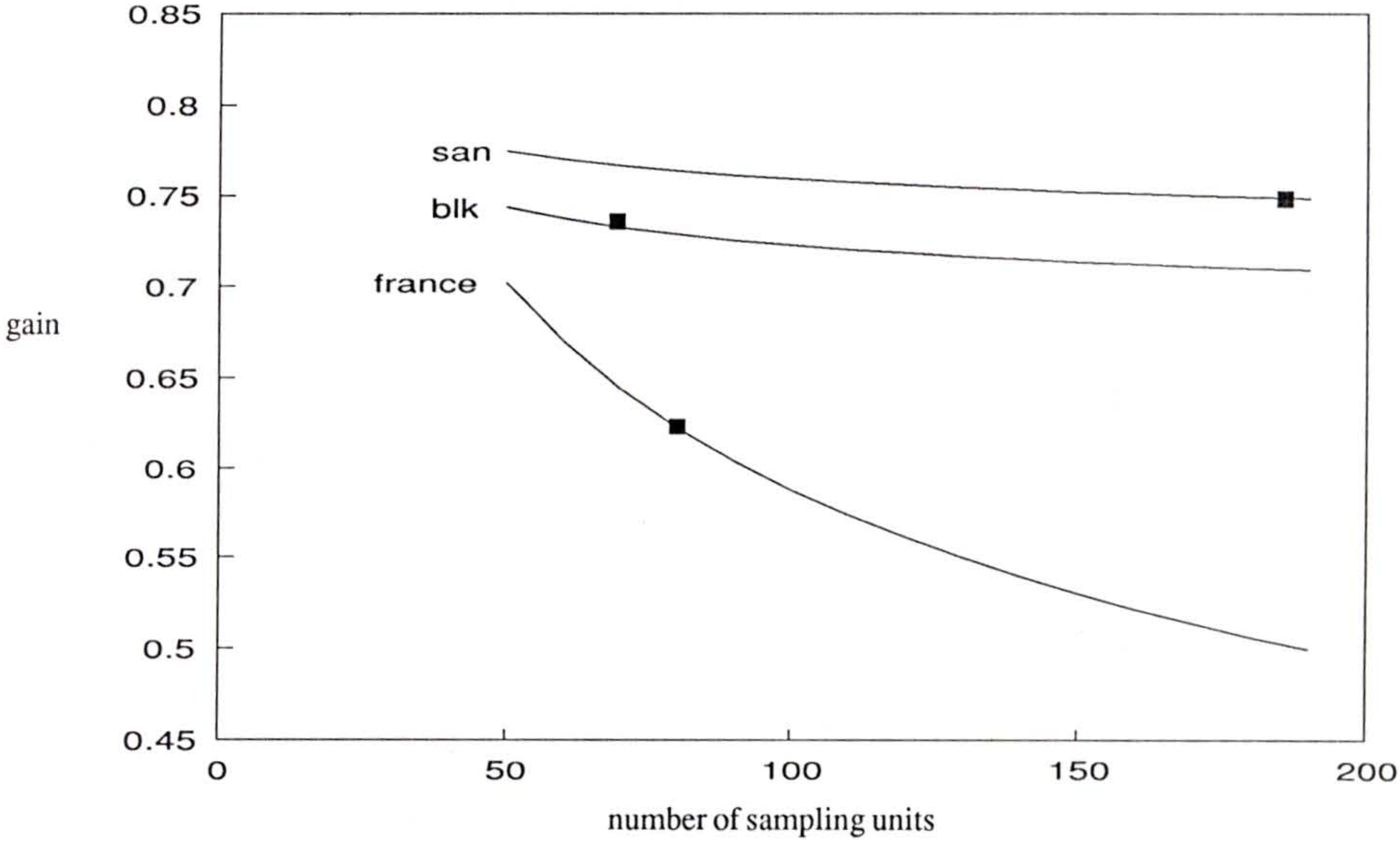
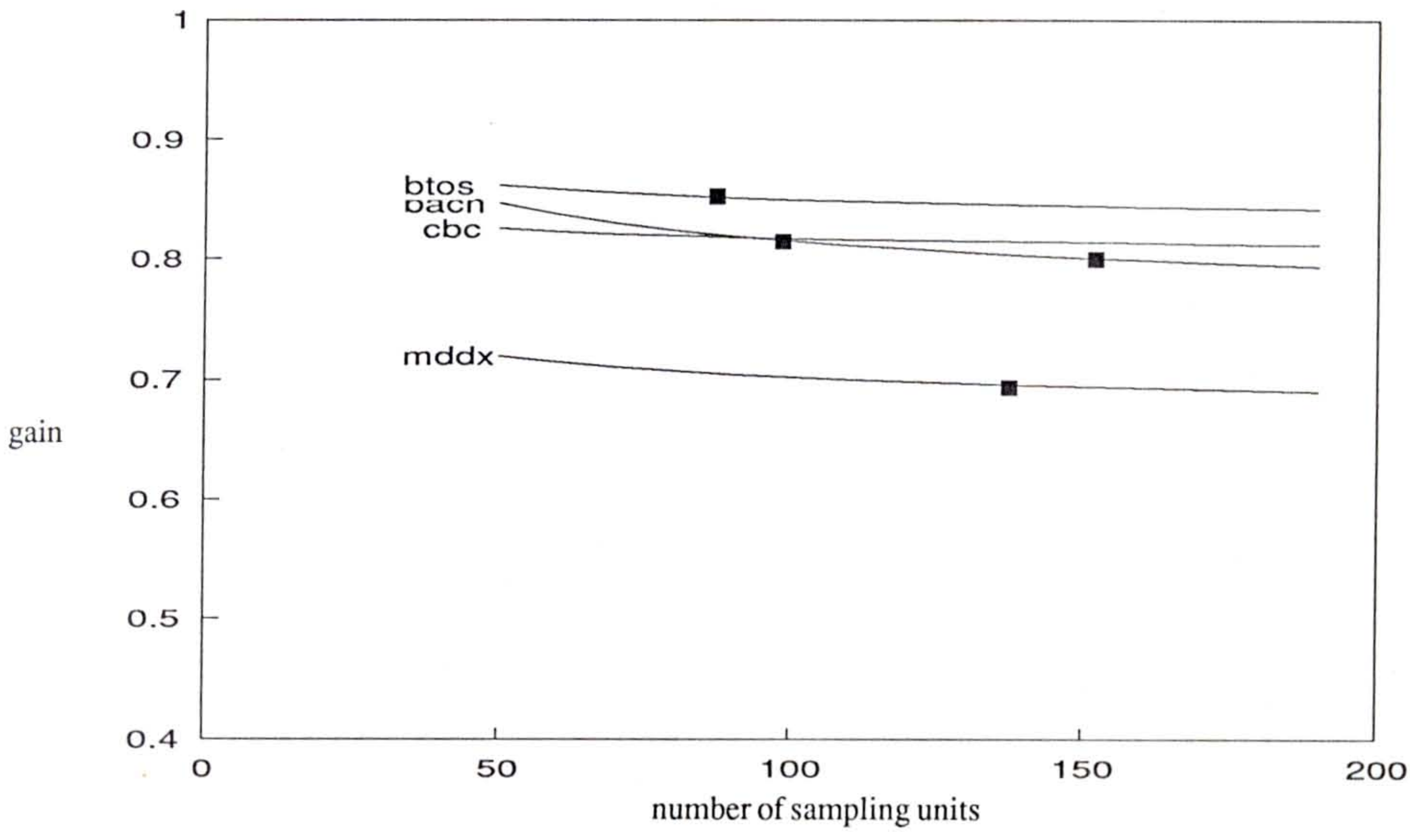


Figure 5. Simulation of the relation between the number of sampling units and the gain of precision obtained by the kriging method when compared to random sampling . The squares show the actual gain obtained for the actual survey. The gain is more or less constant for all the bars but France which may be related to the 0-nugget put in the model of the variogram.



san : Sandy Hill - cbc : Cabin Creek - france : France - btos : British Harbour/Oyster Shell
bach : Bachelor Point - blk : Black Buoy - mddx : Mill Dam/Dixon



the sampling grid showed that the bar may have shifted or shrunk. From a practical point of view, attention must be paid to the location and the size of the grid used for the survey. Systematic sampling is required because of the lack of information on the boundaries of the oyster bars. It represents an important effort which has to be handled with care. Because of the importance of the nugget in the computation of the variance, one has to focus on the reduction of the size of the mesh. Schotzko and O'Keeffe (1990) suggest that an hexagonal design instead of a rectangular, should give better results since shorter spatial scale would be considered for the same number of sampling units. On the other hand, the replication of some sampling units did not bring much information because of the low number of couples of points concerned – the variogram is very sensitive to the number of couples. If another survey had to be conducted on the same areas, the previous considerations joined to the fact that the boundaries of the oyster bars are more precisely defined from this study would result in better estimations of the spatial structures and the global means.

A survey of the whole bay or even of the whole Choptank river by such a sampling scheme would require an important sampling effort. A less ambitious purpose could be to choose some key oyster bars that would be sampled from time to time (each year for instance) in order to follow the impact of the fishing effort or the repletion program on the structure and the evolution of the population. In any case however, it is impossible to define an automatic way of analysing the data. Under the assumption that the spatial structure (e.g. the experimental variogram) does not change in time (even if the mean or the locations of the peaks of abundance can change), optimization may be used to improve the estimation of the whole stock. More mathematical constraints should be added to the set of equations (see Material and Methods) since the number of sampling units should be consistent with the number of points required for kriging. It would be then interesting to compare the strategy provided by the optimization to other strategies studied in the Bay.

An interesting point that was not put forward till now is that the kriging method allows to compute the recoverable stock, i.e. the area and the stock corresponding to a density greater than a given level. Armstrong et al. (1989) used disjunctive kriging and conditional simulations to estimate the recoverable stock of a population of bivalves. Disjunctive kriging is also used by Wood et al. (1990) to estimate the probability for soil salinity to exceed a threshold. If necessary, these techniques could be applied in our case study. However, it would make necessary to use another software package (such as BLUEPACK) able to perform these computations. By the same way, some shortcomings of the GEOEAS software (e.g. no faults taken into consideration, lack of structural analysis) could be overcome.

Another point deals with the definition of the sampling unit. Two kinds of patchiness were observed. The first one was more or less detected by the sampling scheme and was defined from the range of the variogram. The high punctual variability generally observed (see replicates) and the great number of zero values for both variables suggest that there are aggregations of shells and living oysters at a very low spatial scale (a few meters). Some available data could not be analysed because of the too great number of zeroes. Another sampling unit should then be defined in order to smooth that variability by sampling an area of several meters squared (instead of the actual 1.41 m^2 of the patent tong). An alternative could be to sample replicates at each location and to consider that the sampling unit is the summation of the surfaces of each subunit.

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ANNEX

The following graphs show the isotropic variogram and the mapping yielded by the kriging method on seven oyster bars named at the top of each page, for two variables : 'live weight' of oysters (lwei) and 'blank weight' (i.e. weight of blank shells') (bwei).

a) isotropic variogram as a function of the distance between the sampling units:

* represents the experimental variogram

--- represents the spherical model of the previous variogram

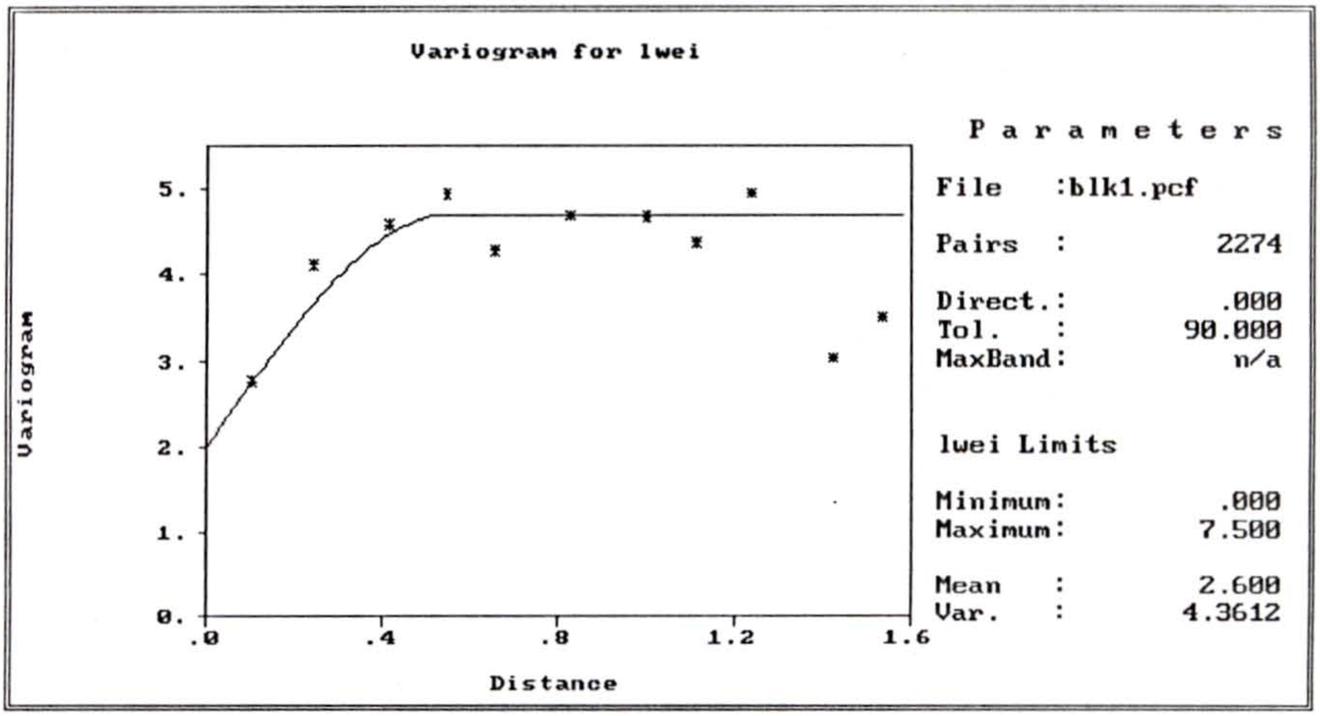
The direction is defined as 0° with a tolerance of +/- 90°, which means that there is in fact no particular direction. The model is fitted by eye since some computed values may appear as numerical artefact due to the lack of pairs of points used for the computation. By the same way, some values at a distance far beyond the range (i.e. the threshold distance from which the variogram is more or less flat) may be neglected.

b) map derived from the punctual kriging at each node of regualr grid. The kriging equations are solved using the model of variogram to compute the weights of each observed value in the linear interpolation. The parameters of the model are :

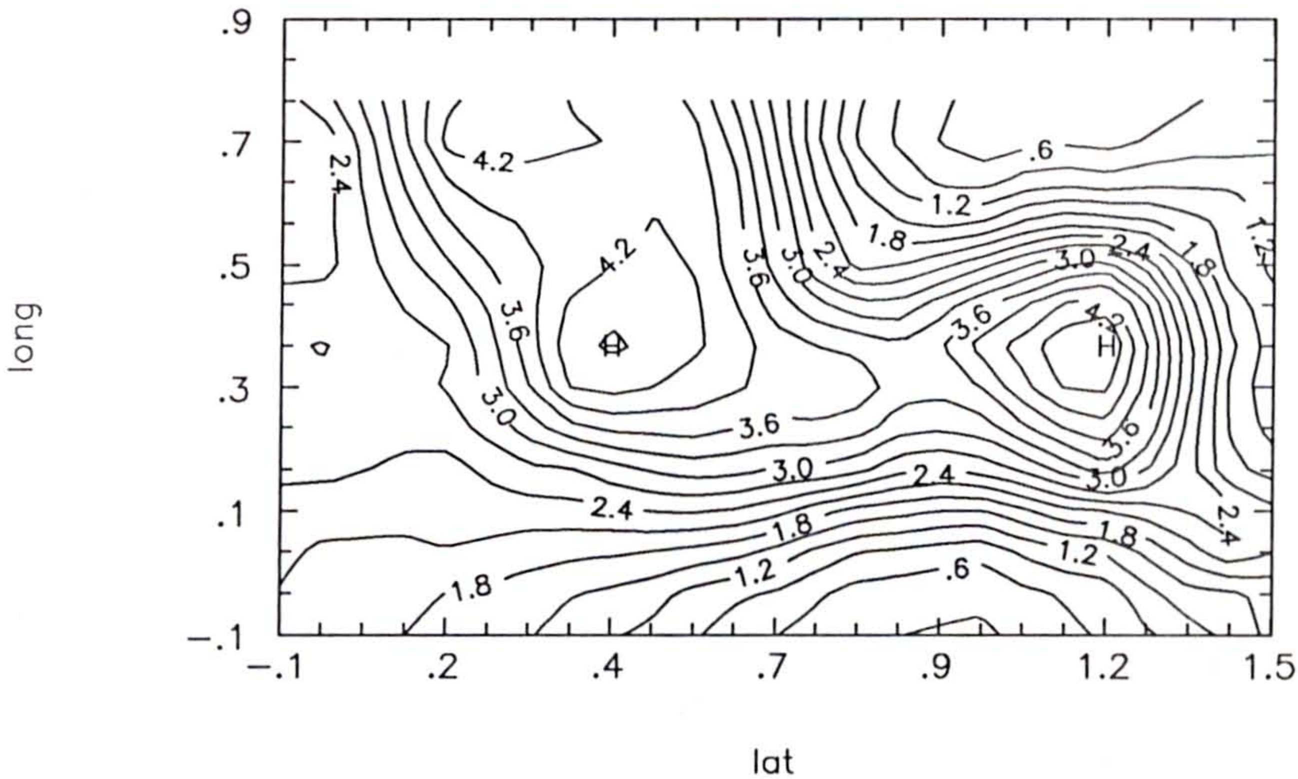
- the nugget, defined as the value of the variogram at the origin.
- the sill, which is the difference between the constant value of the variogram beyond the range and the nugget.
- the range, equal to the distance from which the variogram is flat (i.e. there is no more spatial correlation) .

The figure on the lines of constant level are related to the mean per sampling unit. The x, y, and distance values are expressed in arbitrary units.

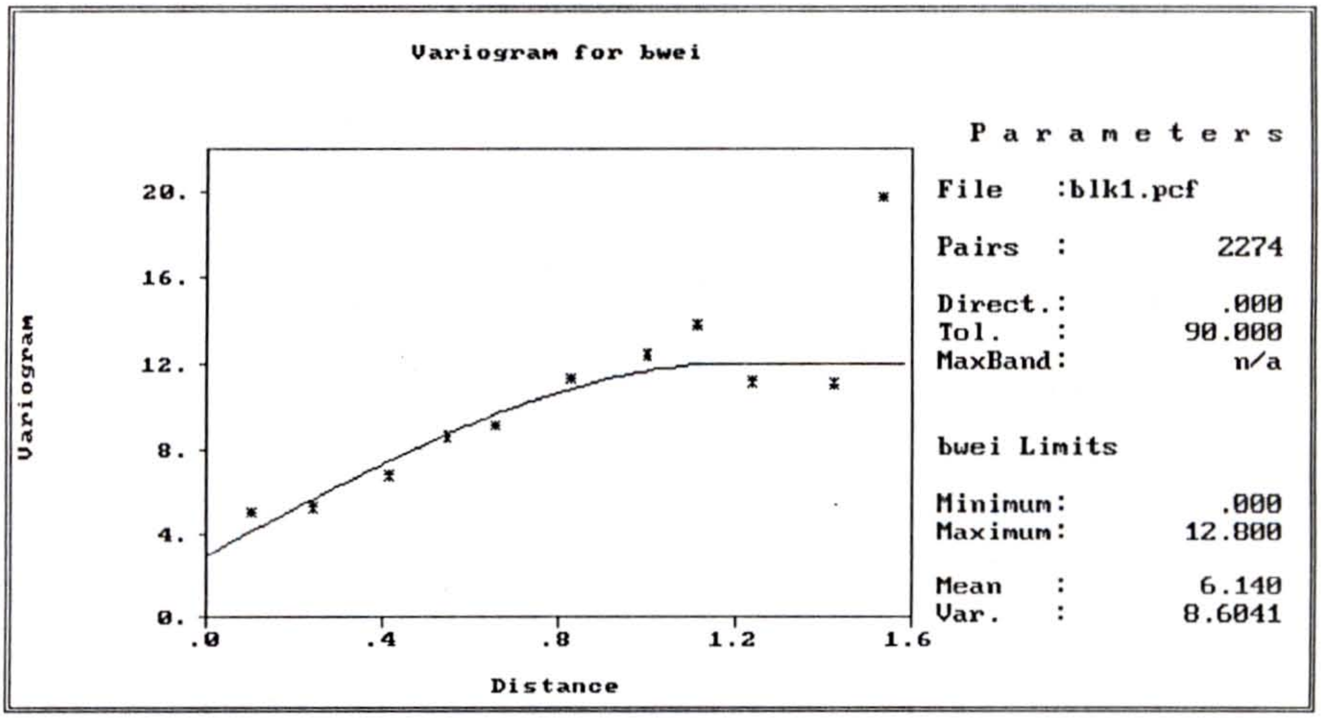
BLACK BUOY/'LIVE WEIGHT'



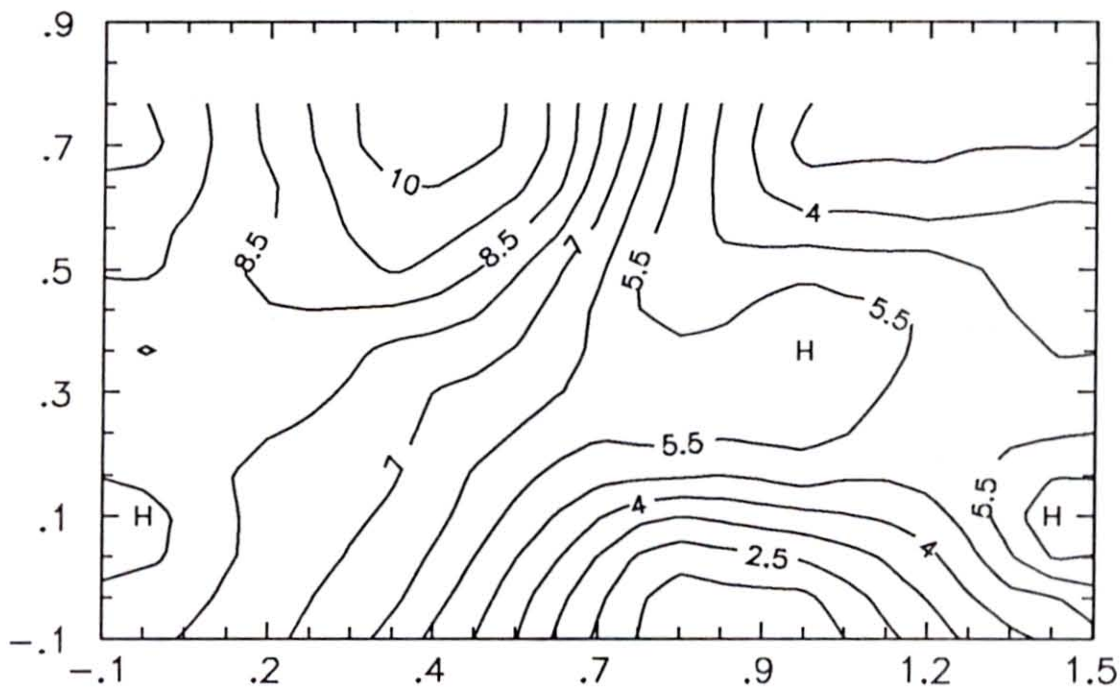
Kriging of lwei
spherical model : 2, 2.7, .55



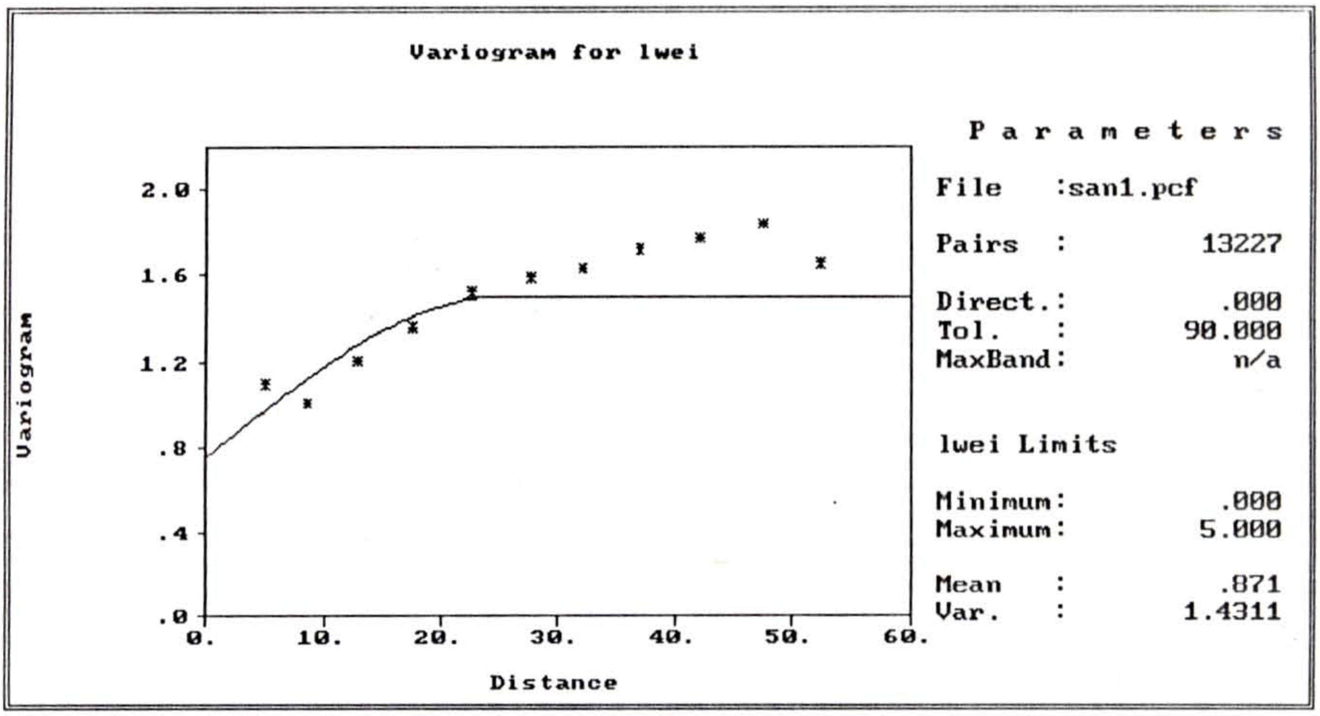
BLACK BUOY/ 'BLANK WEIGHT'



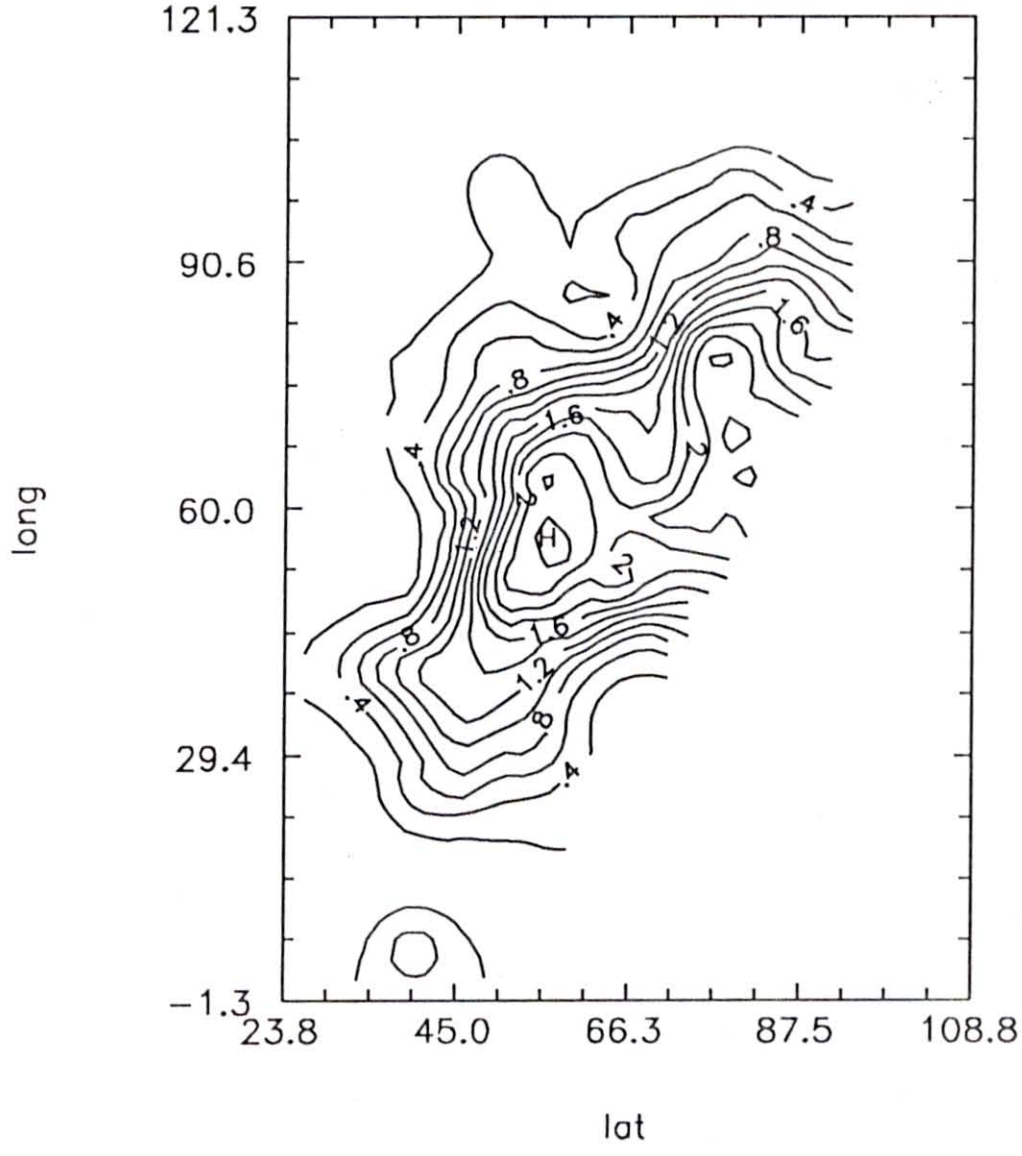
kriging of bwei
spherical model : 3, 9, 1.2



SANDY HILL / 'LIVE WEIGHT'



kriging of lwei
spherical model : .75, .75, 25



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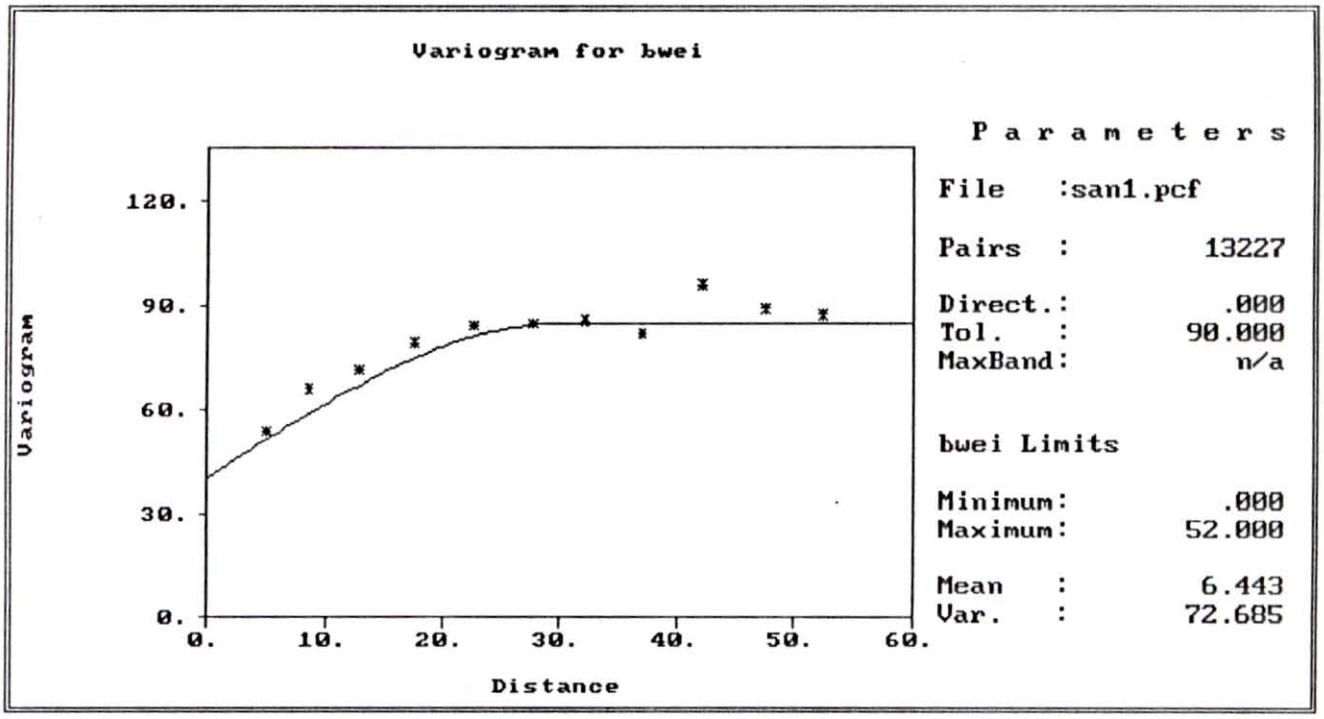
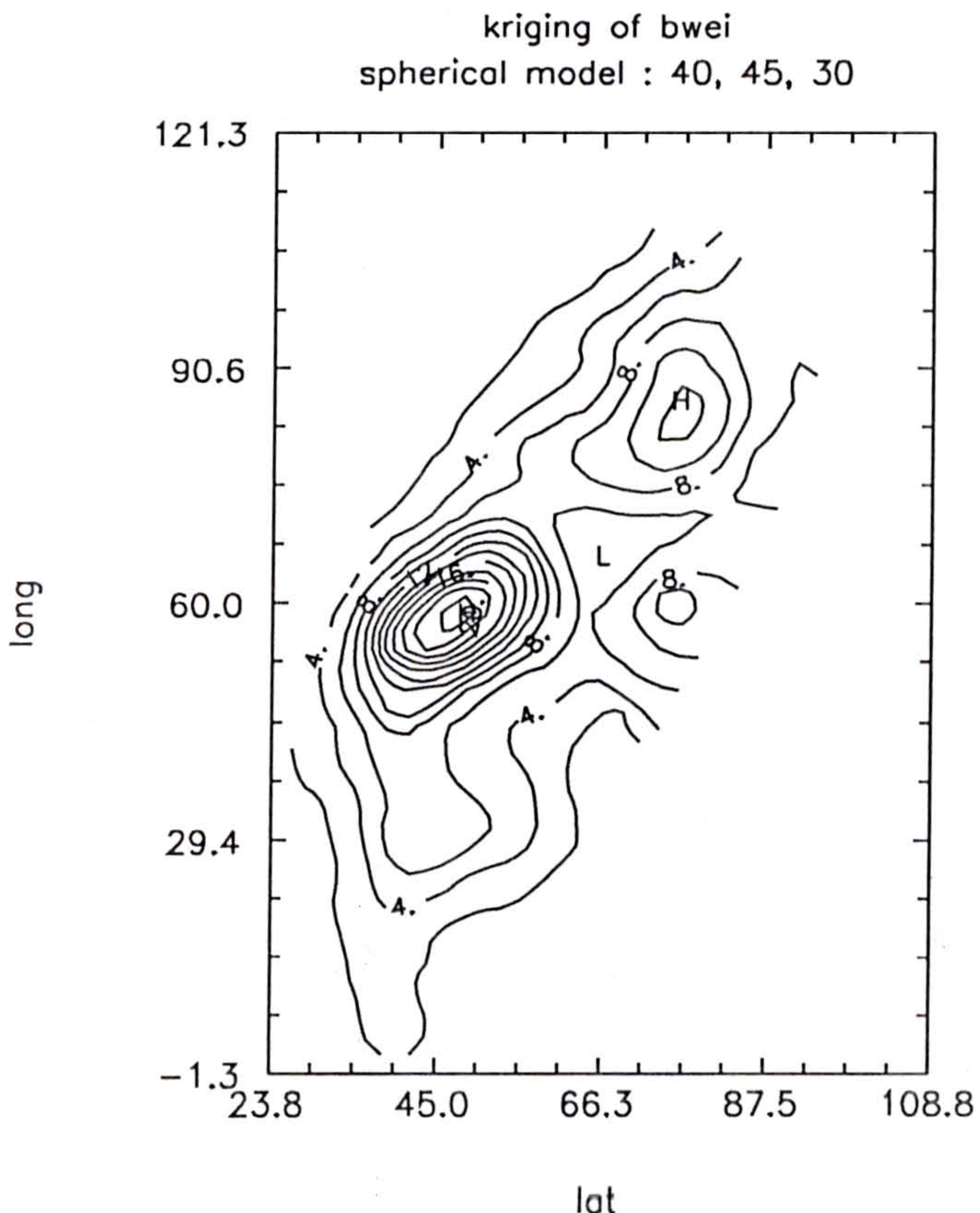
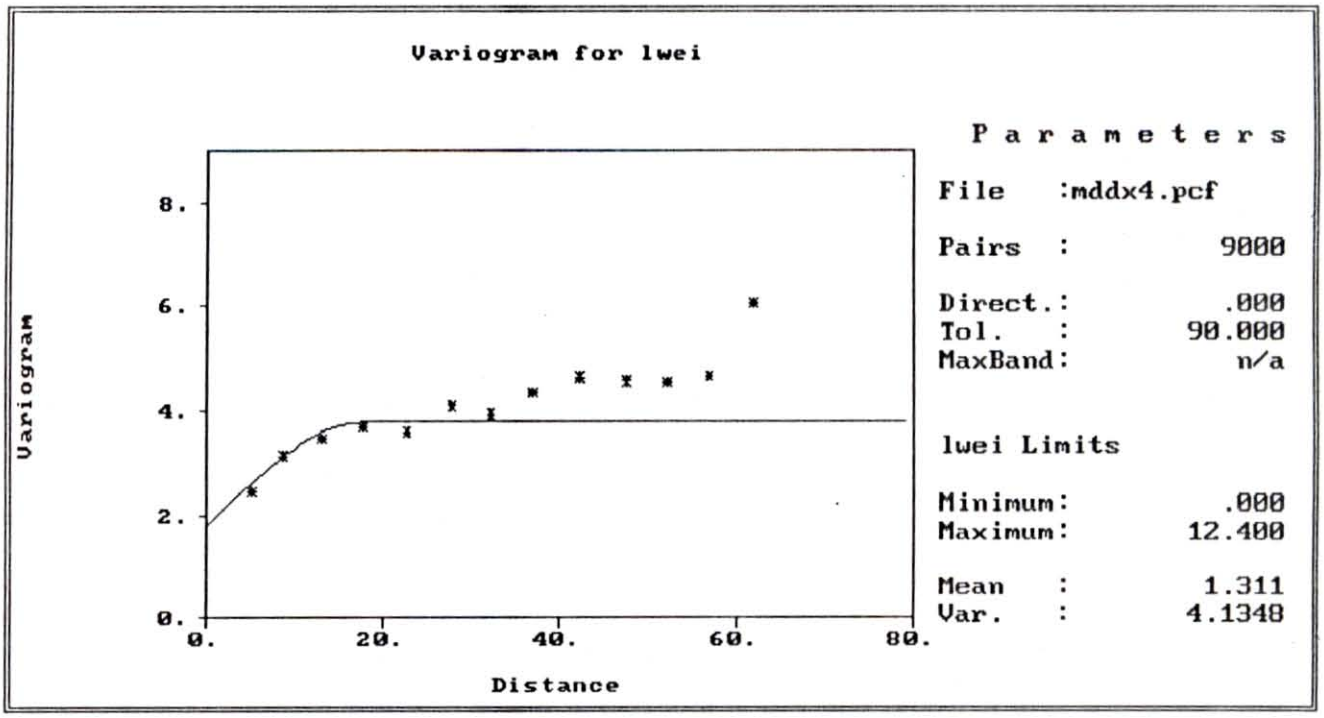
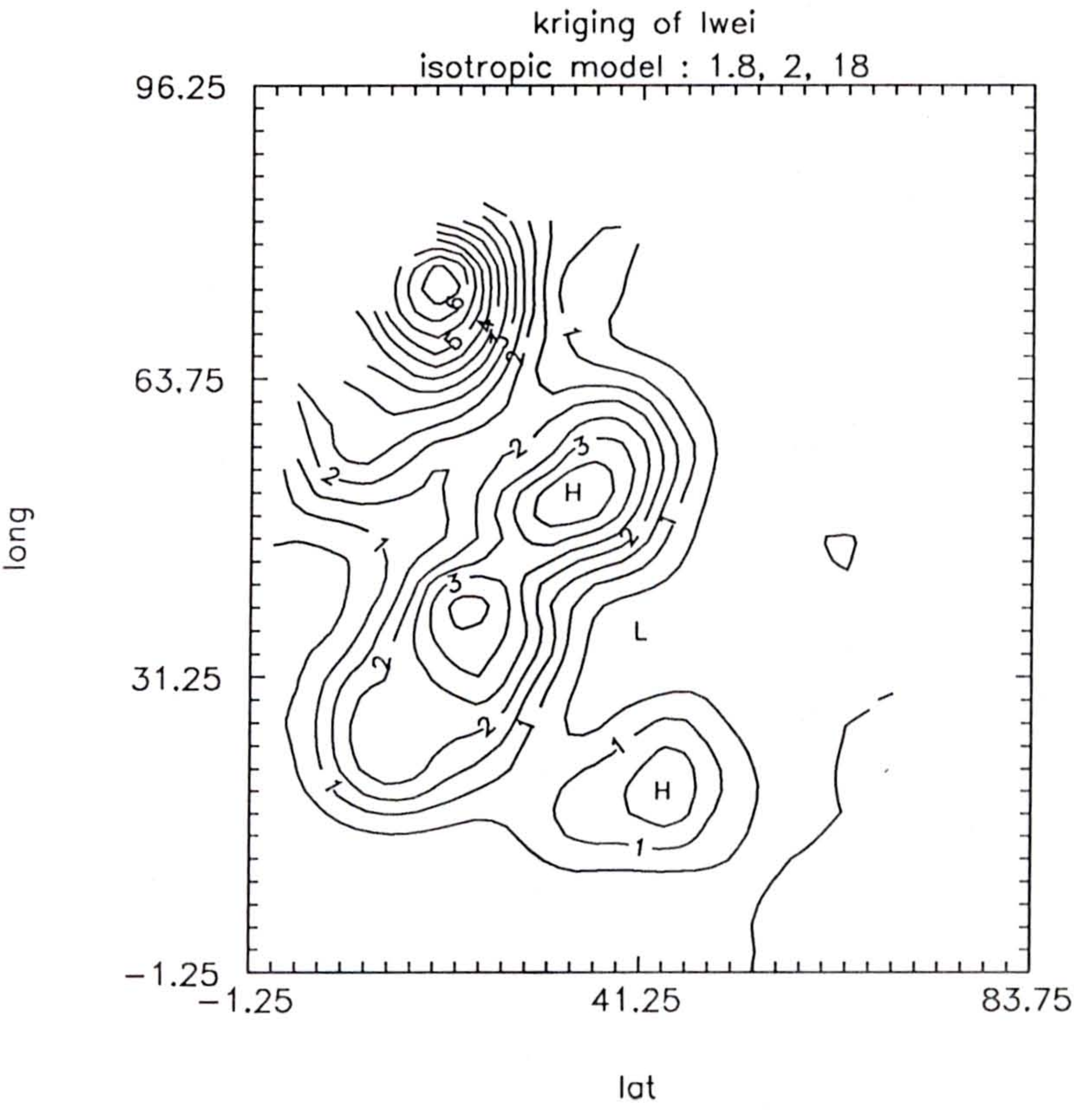




MILL DAM-DIXON/ 'LIVE WEIGHT'





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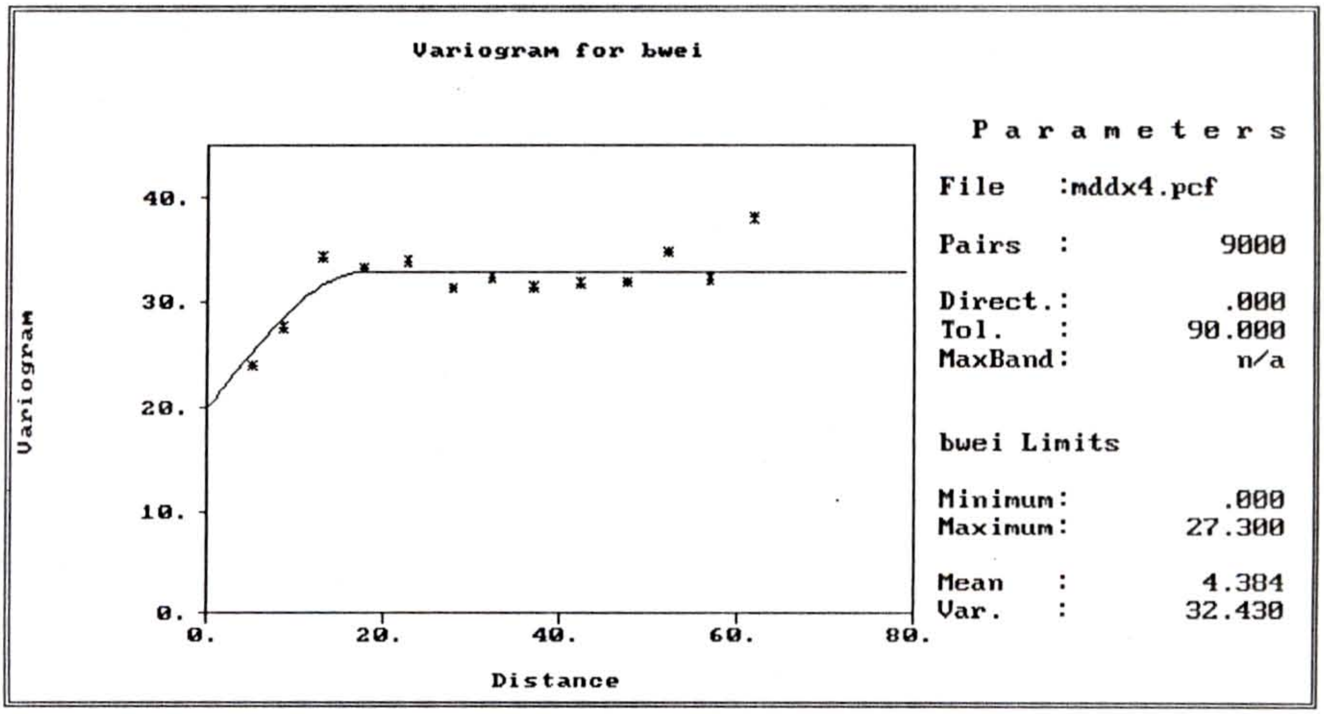
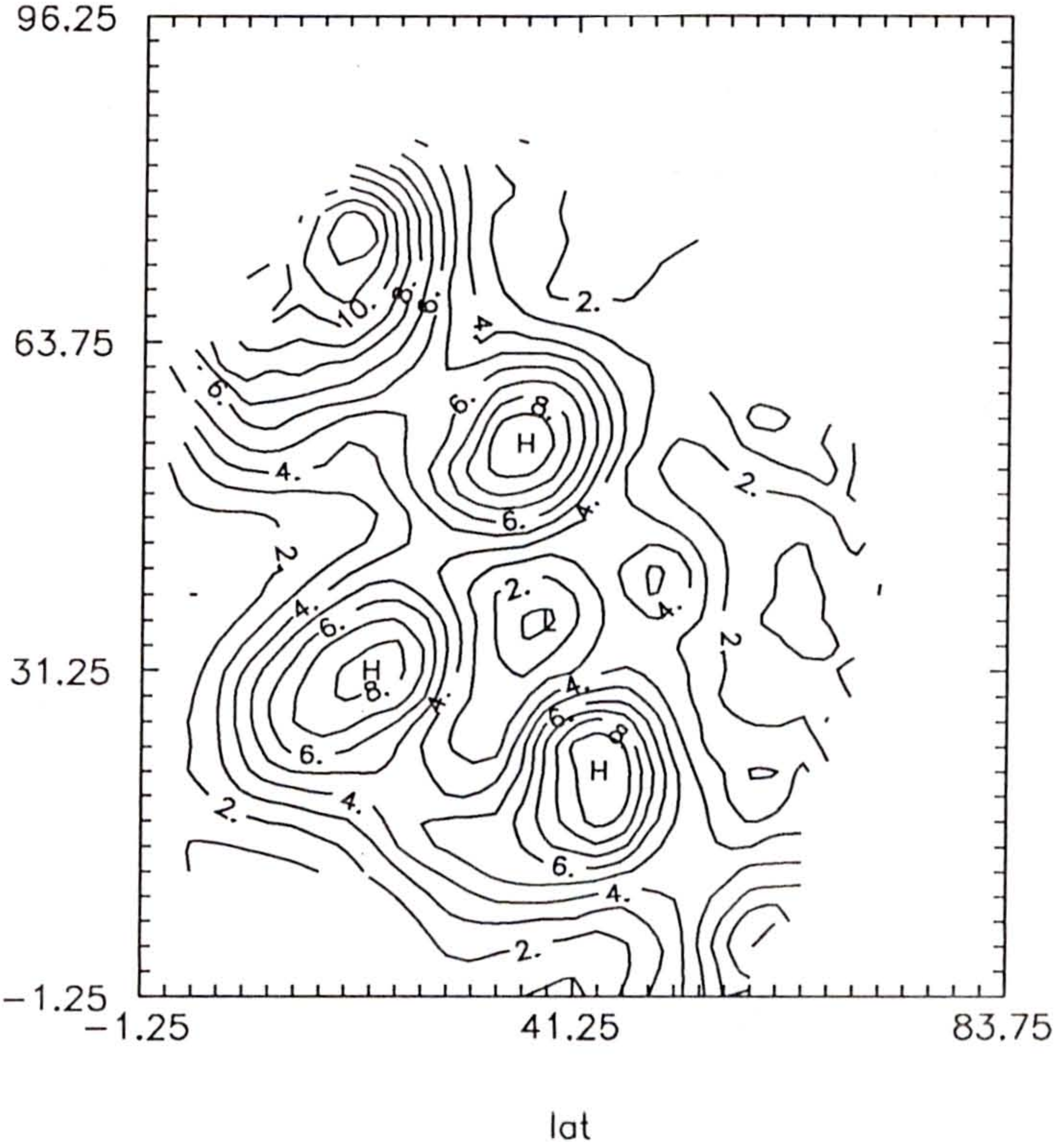
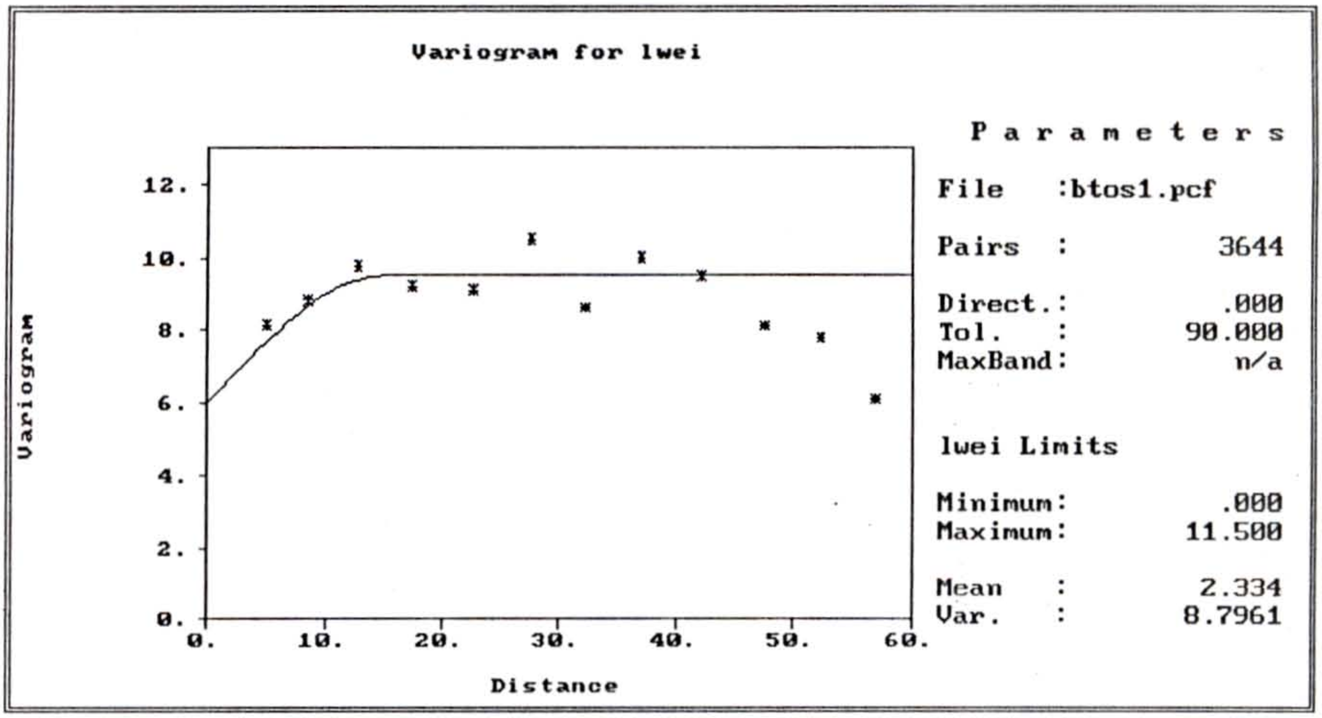
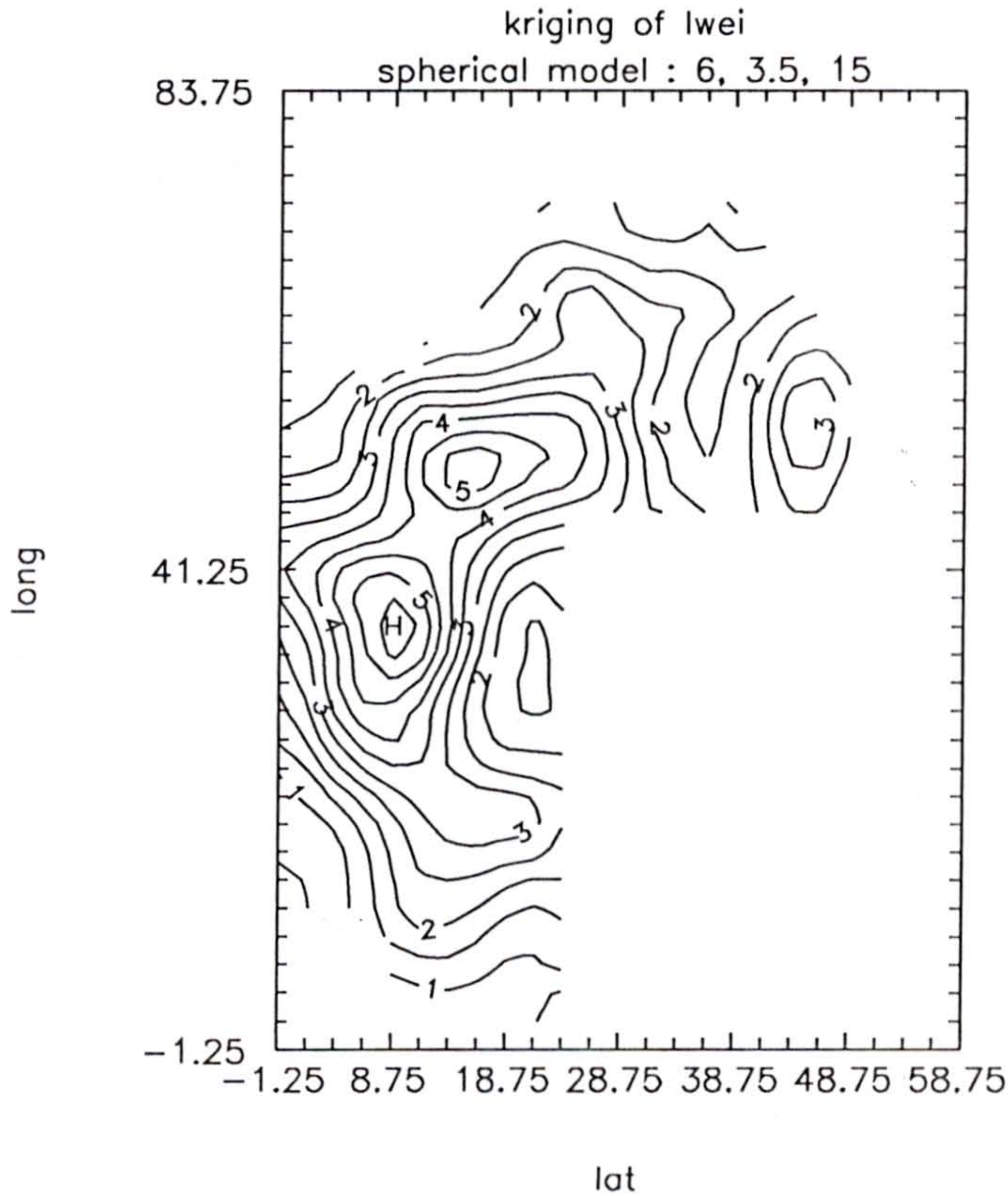


kriging of bwei
isotropic model : 20, 13, 18

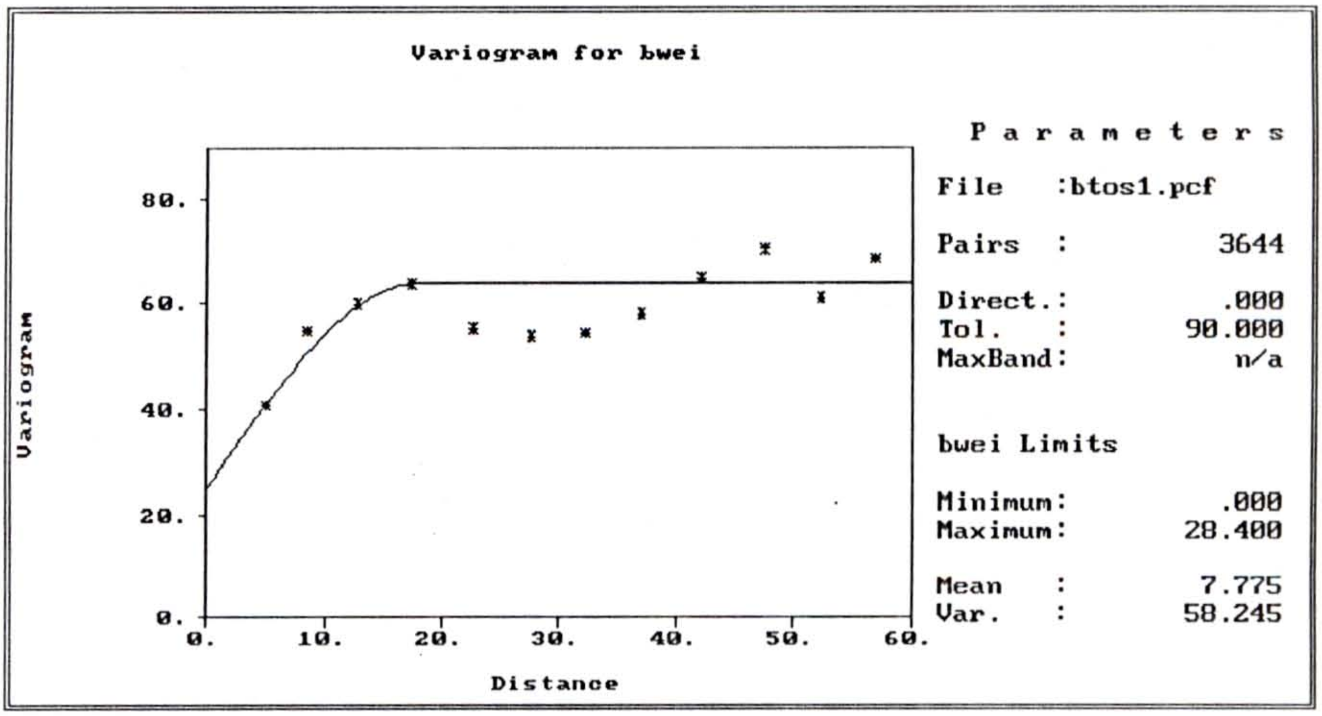


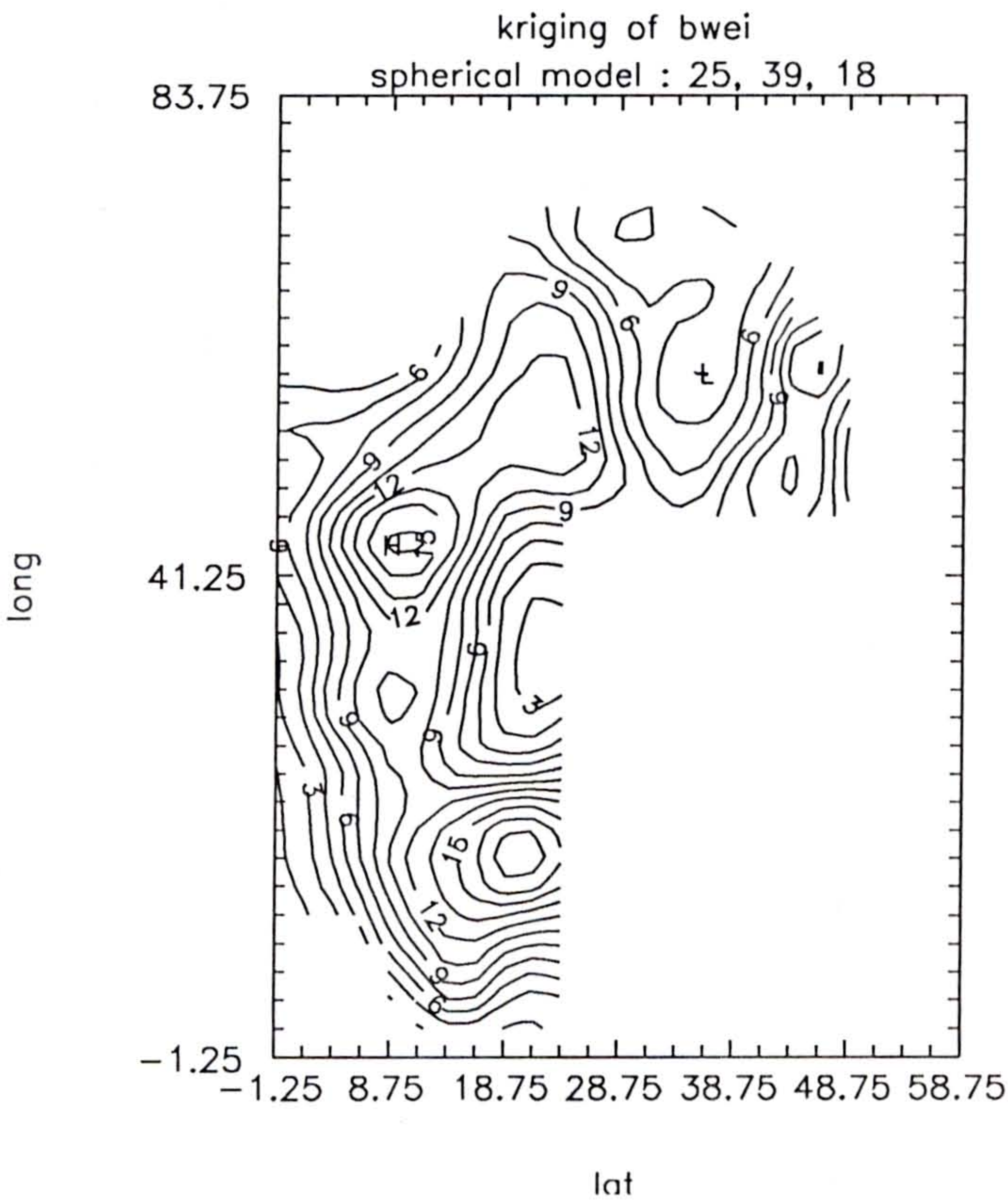
BRITISH HARBOUR-OYSTER SHELL/ 'LIVE WEIGHT'



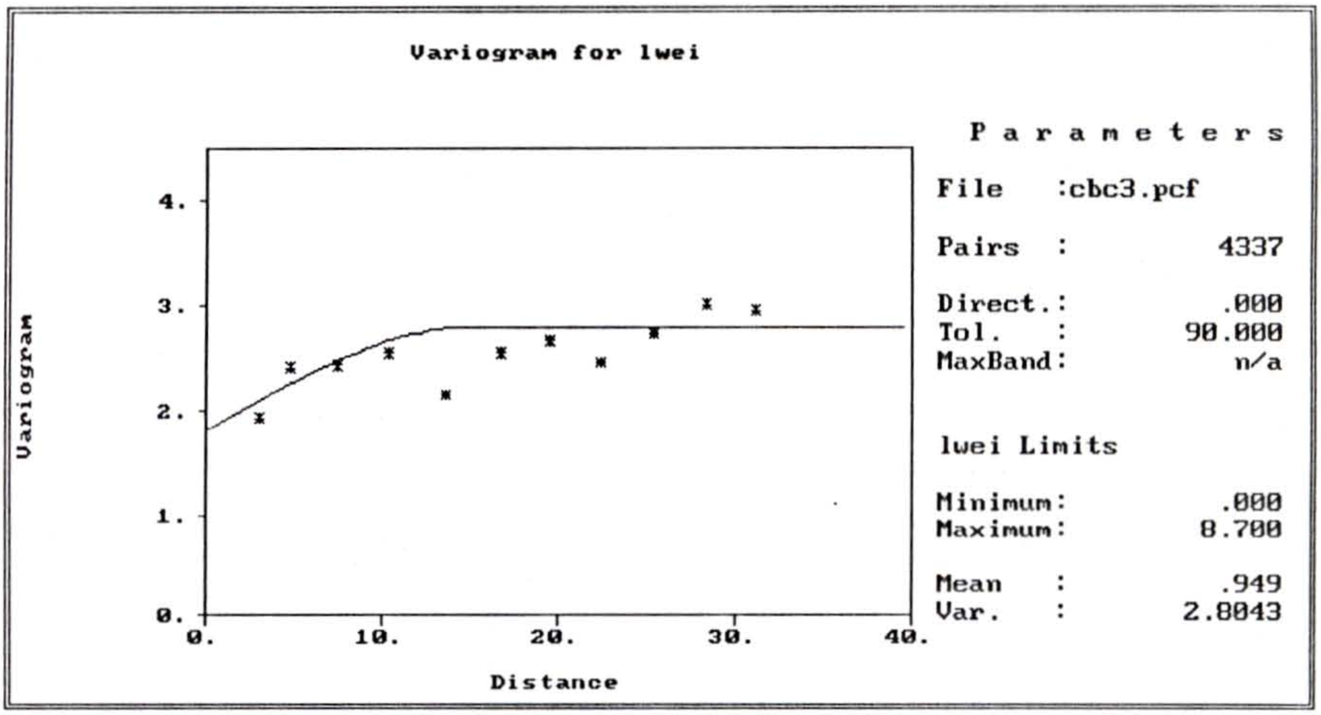


BRITISH HARBOUR-OYSTER SHELL/ 'BLANK WEIGHT'



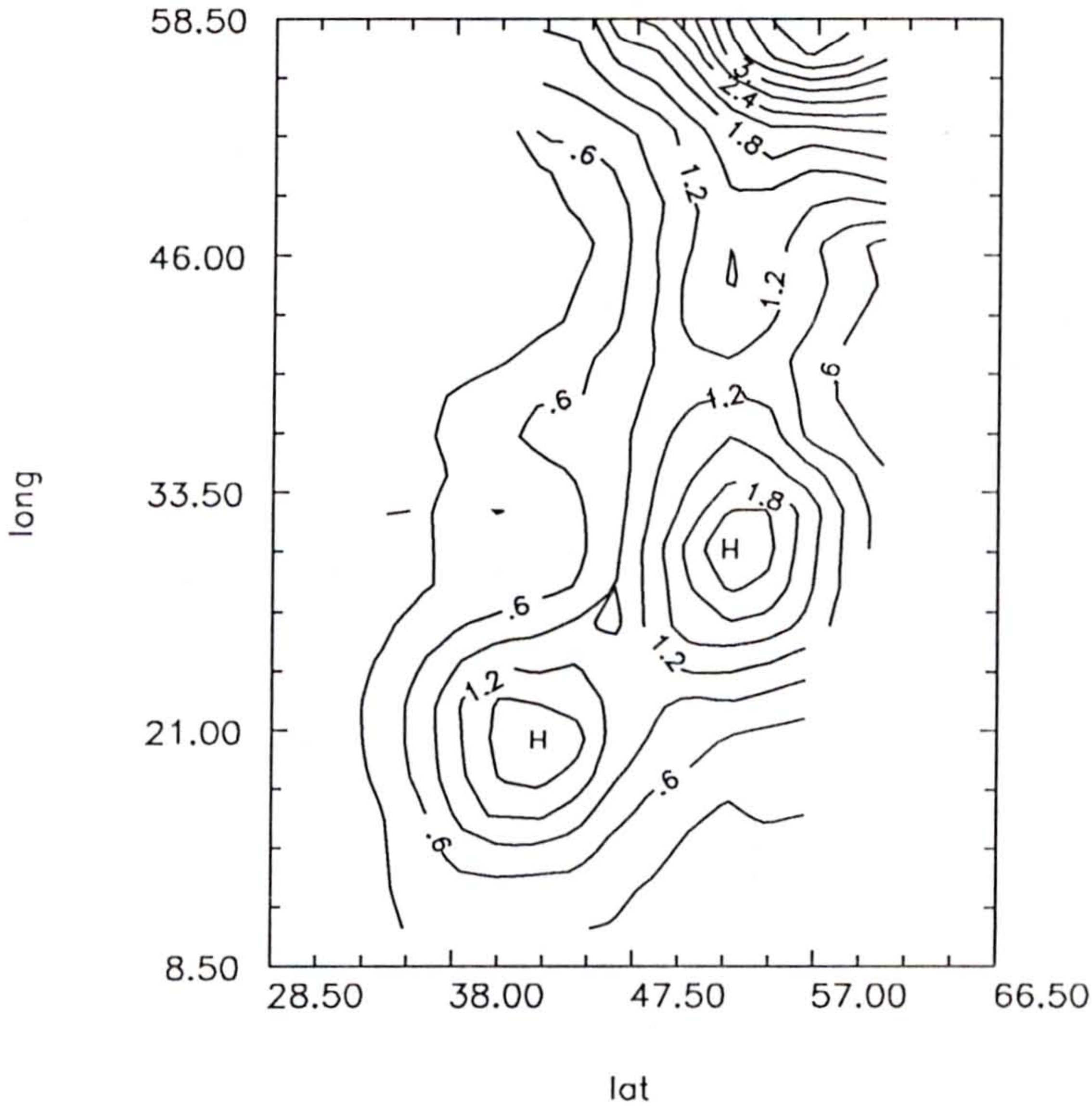


CABIN CREEK/ 'LIVE WEIGHT'

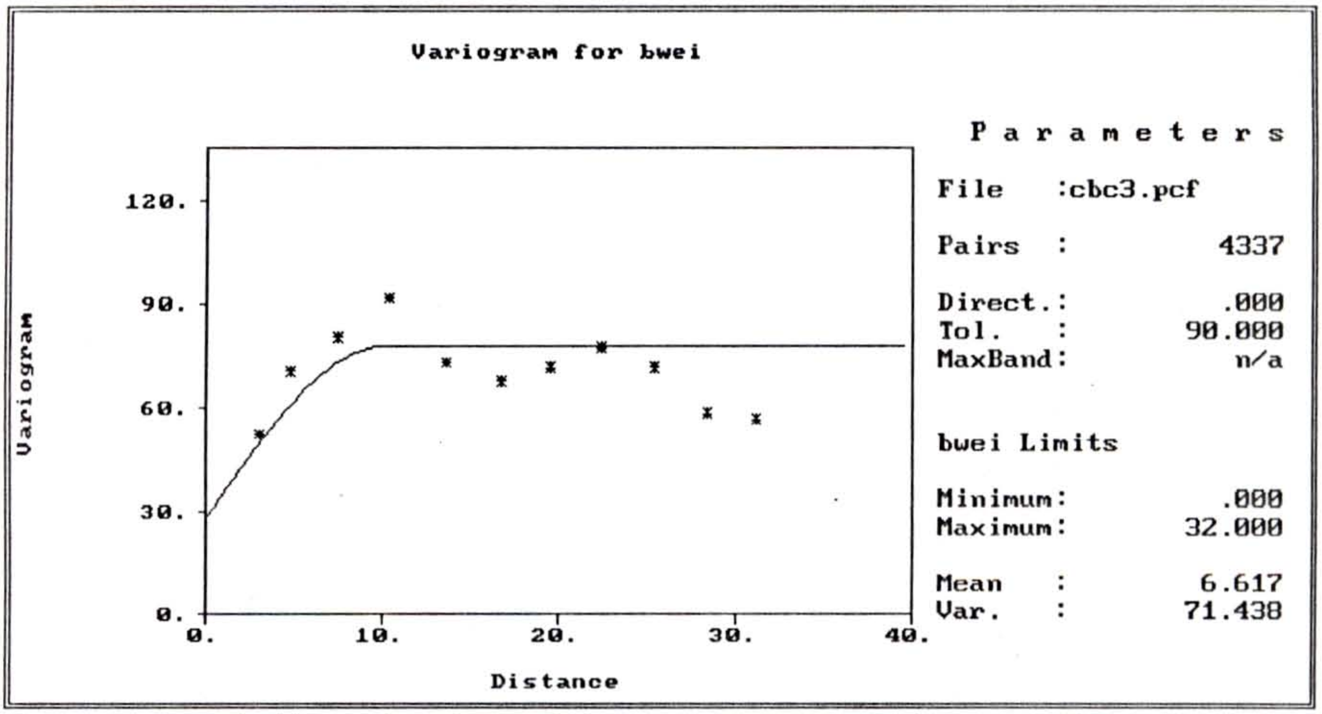


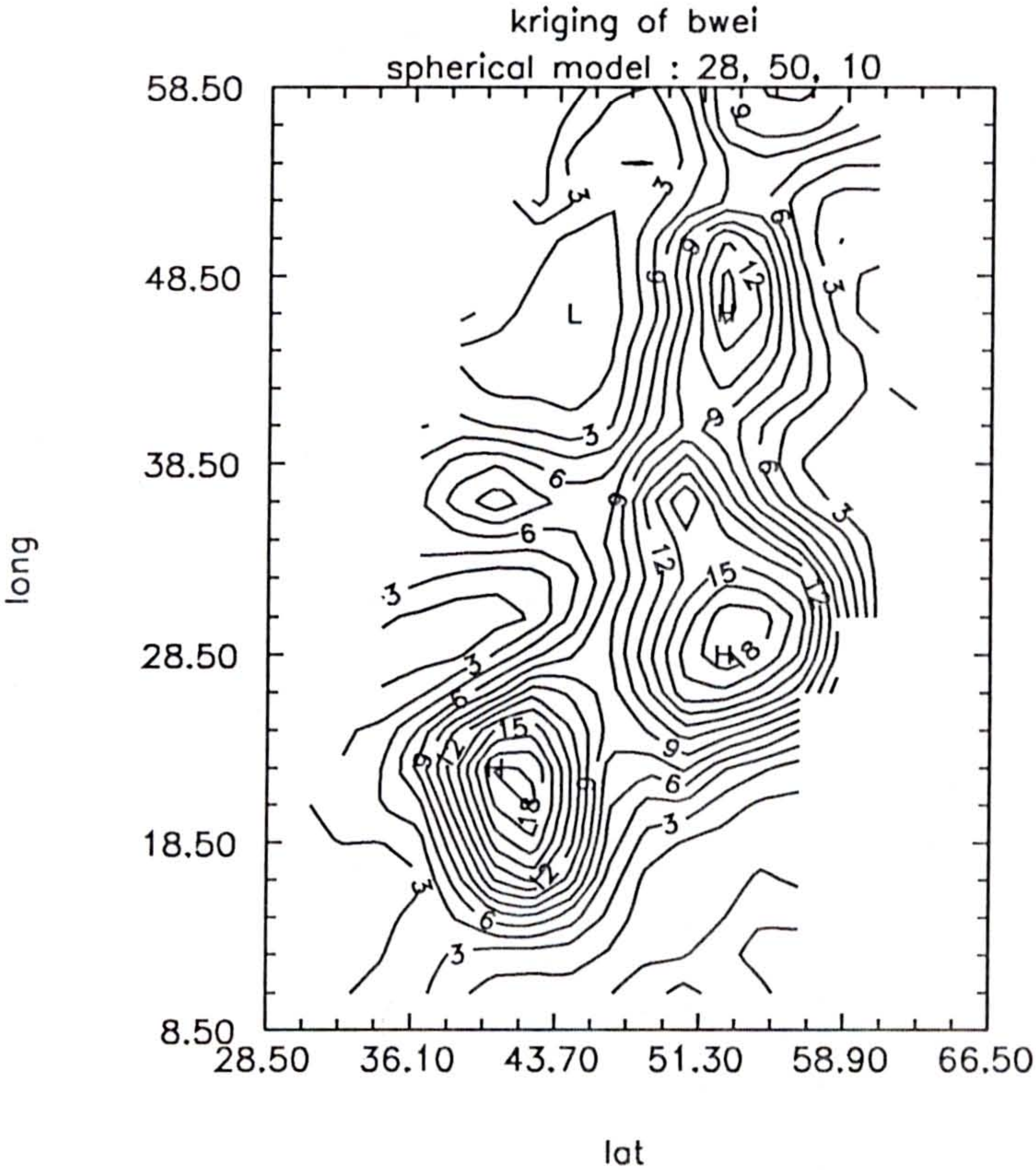
kriging of lwei

isotropic model : 1.8, 1, 15

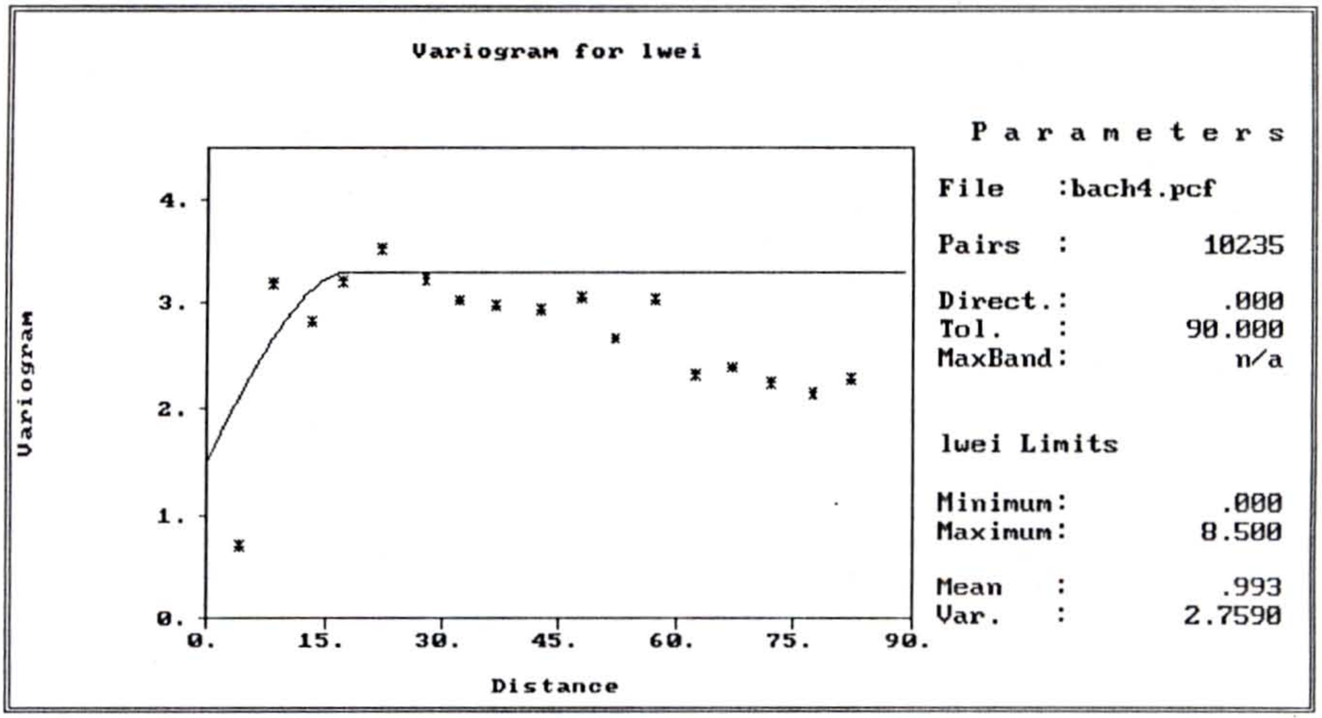


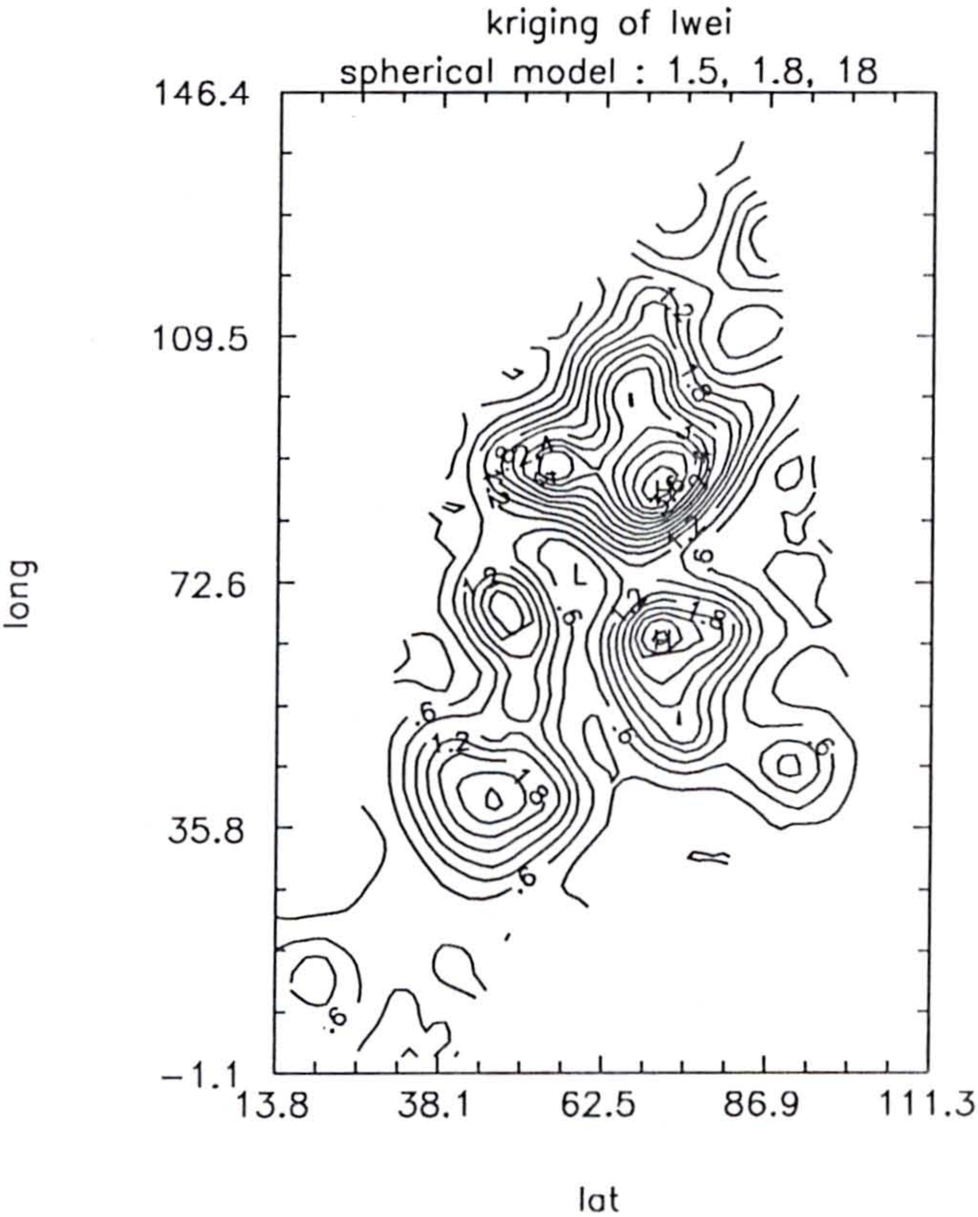
CABIN CREEK/ 'BLANK WEIGHT'





BACHELOR POINT/ 'LIVE WEIGHT'





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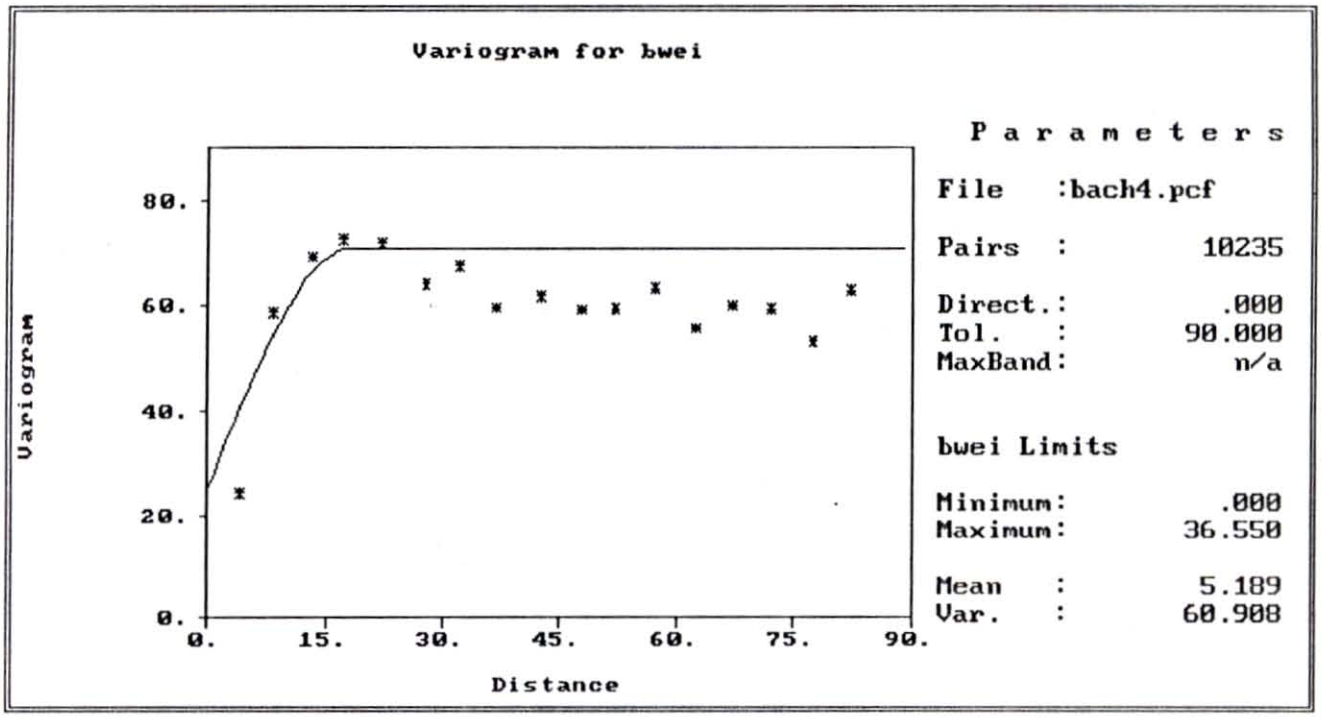
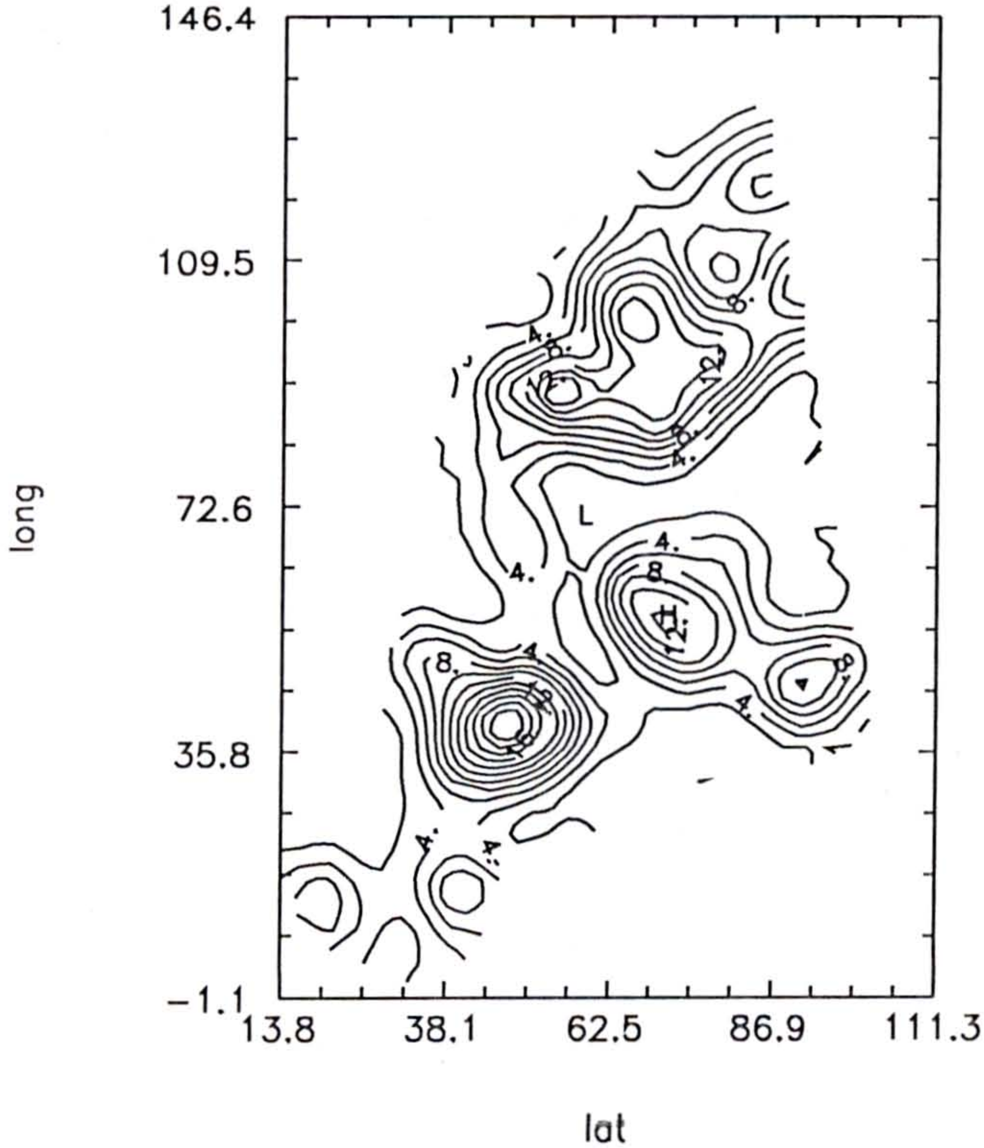
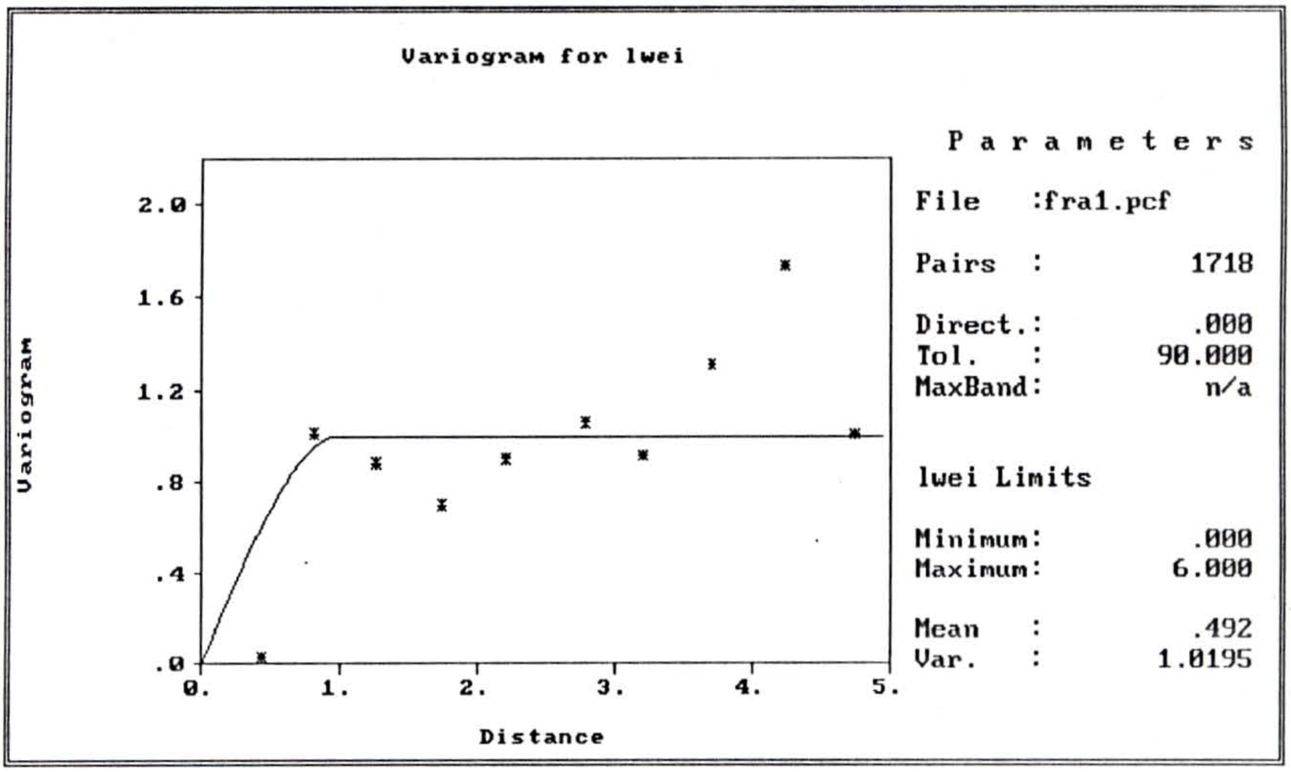
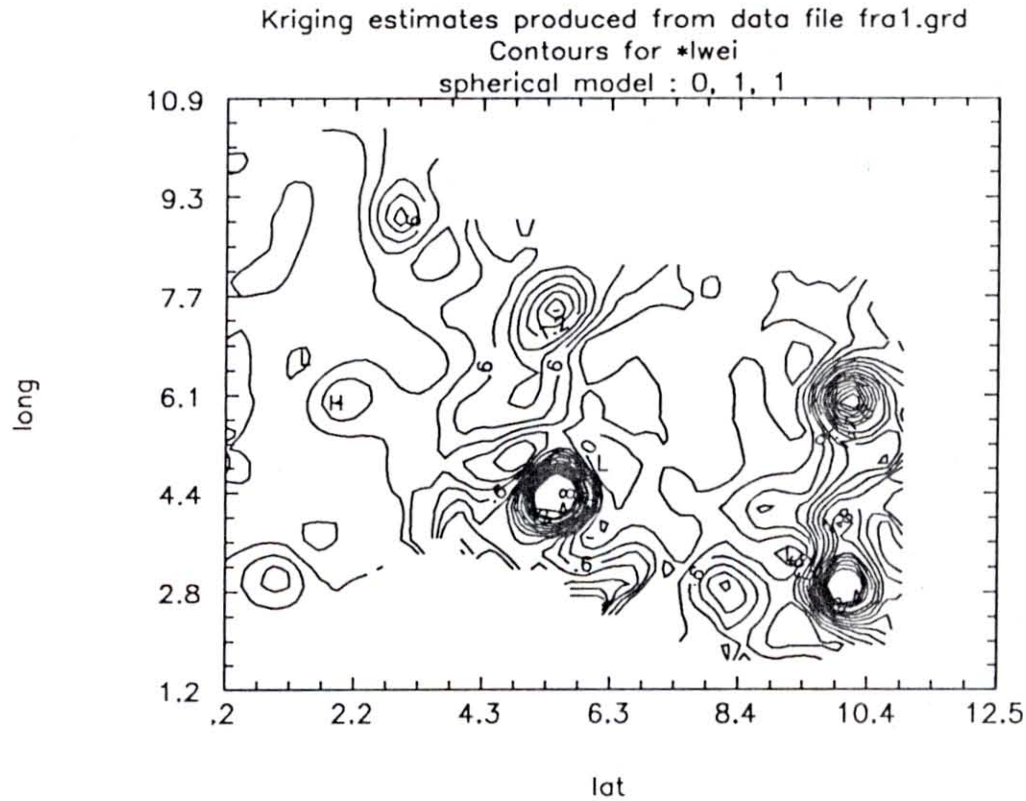


kriging of bwei
spherical model : 25, 46, 18



FRANCE/ 'LIVE WEIGHT'





FRANCE/ 'BLANK WEIGHT'