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GEOSTATISTICAL ESTIMATIONS AND MAPS OF THE NORTHERN SHRIMP BIOMASS IN THE GULF OF ST.LAWRENCE FROM 1990 TO 1992, BY SIZE GROUP AND FOR ALL SIZES TOGETHER

by

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RESUME

Des méthodes de la géostatistique stationnaire sont employées pour estimer et cartographier la biomasse d'automne de crevette nordique (Pandalus borealis) dans le golfe du Saint-Laurent en 1990, 1991 et 1992. Les estimés et les cartes sont calculés séparément par groupe de taille et globalement pour toutes les tailles réunies. Les échantillons ont été récoltés pendant le jour par le chalutier FRV/Alfred-Needler équipé d'un chalut à crevette. Des modèles isotropiques de la variabilité spatiale sont estimés à partir des données, séparément pour chaque année ainsi que globalement pour toutes les années ensemble. Ces derniers modèles étaient moins erratiques que les modèles annuels et ils furent utilisés pour calculer les estimés de biomasse et leur intervalle de confiance. Les estimés globaux sont calculés pour les fonds de pêche plus profonds que 150 m, séparément pour les 4 zones correspondant aux unités de gestion de la pêcherie.

Les estimés globaux montrent que la biomasse du Golfe dans les fonds supérieurs à 150 m étaient de 63.7, 69.9 and 47.5 kt. pour les années 1990, 1991 et 1992 respectivement. Des variations régionales furent notées, la biomasse de crevettes augmentant dans certaines zones alors qu'elle diminuait dans d'autres. Similairement, la biomasse globale par groupe de taille a montré une grande variabilité dans ses patrons de répartition et d'abondance. La diminution notable en 1992 est due à un fléchissement des cohortes les plus agées (femelles) seulement, dans deux zones: le chenal d'Esquiman et la région de Sept-Iles.

ABSTRACT

Stationary geostatistical methods are used to compute estimates and map the fall biomass of northern shrimp (Pandalus borealis) in the Gulf of St.Lawrence in 1990, 1991 and 1992. Estimates and maps are computed separately by size groups and globally for all sizes. The samples used were collected during daylight from the FRV/Alfred-Needler with a shrimp bottom trawl. Isotropic models of the spatial variability are estimated from the data, for each year separately and for all years together. The all-years models were less erratic than the annual models and were used for estimating the biomass and its confidence interval. The global estimates are computed for the fishing grounds deeper than 150 m, separately for four zones corresponding to the management units of the fishery.

Global estimates showed that the Gulf biomass below the 150 m depth contour were 63.7, 69.9 and 47.5 kt for 1990, 1991 and 1992 respectively. Local variations ocurred, some zones increased their shrimp biomass while it decreased in others. Similarly, the global biomass by size groups exhibited a large variability in its distribution and abundance pattern in time and space. The notable decrease of global biomass in 1992 was the fact of a weakening of the oldest cohorts (female) only, in the two zones of Esquiman channel and Sept-Iles region.

INTRODUCTION

Following our works of 1991 (Simard 1991) we use here geostatistical methods to estimate and map a regionalized variable: the northern shrimp biomass on the fishing grounds in the Gulf of St.Lawrence. The advantages of geostatistics for this task has been demonstrated in many fields of research, for references to the marine resources assessments see Simard et al. 1992 and for a general discussion see Cressie 1991. The objectives of this work were to produce, for each year surveyed and separately for 4 size groups as well as for all sizes together: 1) optimal local estimates and map the biomass for the whole Gulf of St.Lawrence, 2) estimate the global biomass with its confidence limits for the whole Gulf and regionally for the four management units.

METHODS

Sampling

In 1990, 1991 and 1992, from August to October, northern shrimp biomass was sampled during daytime at 130-163 stations in the Gulf of St.Lawrence (Fig. 1, Table 1). At each station, bottom shrimp trawls were towed for 20 minutes at 2.5 - 3.0 knots by the research trawler FRV Alfred-Needler (Table 1). Trawl vertical and horizontal openings were monitored with a Scanmar trawl monitoring system and the position at the begining and end of sampling on the bottom was obtained from a GPS and Loran positioning system. A S-12 Applied Microsystem CTD was mounted on the trawl to profile the temperature and salinity of the water column and to monitor these variables on the bottom during trawling. The stretched mesh aperture of the trawl was 38 mm and the codend was lined with a 19 mm mesh net. Even though sampling was carried out day and night, only daytime samples are considered here because of possible vertical migrations of the shrimp off the bottom at night (Barr 1970, Apollonio et al. 1986, Simard et al. 1990), that could change their capturability. No attempt was made to weigh all the catches by capturability and retention coefficients, to take into account the sampling efficiency of the trawl and the shrimp retention and availability to the fishing gear. The catches were converted to biomass of northern shrimp per bottom surface unit (kg/km^2), using the area swept by the trawl from the recorded positions and trawl openings. Although the samples were not punctual but covered an average area of about 0.022 km^2, they were considered as point samples centered at the starting tow coordinates for further analysis. Each sample was subsampled for measuring the carapace length (CL) of 200-250 shrimps to the nearest 0.1 mm with electronic calipers linked to a computer, to determine the length frequency distribution. The shrimps were then grouped by four size groups: 10-14 mm, 14-18 mm, 18-23 mm, 23-30 CL.

Geostatistical estimation

For the estimations, we first started by computing the variograms from the samples for each year, excluding the zeros and the outliers because of their strong disruptive effects on the variogram structure. The number of zeros and outliers varied with cohort (Figs. 1-5). This was done for all shrimps and for each size group separately, except the smallest one, where random distribution (nugget=variance) was assumed because of the low number of samples where these shrimps were present (Fig. 2). Biomass intervals included in the variograms were 5-2500 kg/km^2 for shrimps larger than 18 mm CL and 5-500 kg/km^2 for CL of 14-18 mm. These annual variograms were sometime erratic and difficult to model. Therefore, in order to stabilize the variograms, the data of all three years were pooled together to compute multi-years variograms. This was possible because the whole biomass did not vary by large factors from year to year (e.g. >10). Such pooling of the data from many years have been found more performant than the annual models in a recent study of the shrimp variability in the Gulf (Simard and Marcotte, 1992). The smallest percentage of zeros (i.e. biomass < 5 kg/km^2) was 37.1% and the largest percentage of outliers (i.e. biomass > 2500 kg/km^2) was 4.6 %. These multi-years variograms together with the number of pairs used to compute them and models fitted are presented in Annexe 1.

The local estimates on a regular grid of blocks of 10 min latitude and 10 min longitude, bounded by the 150 m depth contour, were obtained from ordinary block kriging (Journel and Huijbregts 1978, Clark 1979, Isaaks and Srivastava 1989, Cressie 1991). Twelve discretization points (4 lat. X 3 long.) per block were used. The search neighborhood was 30 km in radius and a maximum of 10 nearest samples were considered in the interpolation. These block estimates of biomass were averaged for each of the 4 management units (Fig. 11), and the means were weighted by the surface of the units to obtain the regional estimates. Finally, the variances of these regional estimates were computed using the estimated variograms, according to the combination of the average elementary sampling error (Journel and Huijbregts 1978; see Simard et al. 1992). The formula used was:

$$\sigma_D^{2*} = \bar{\gamma}(s,s) \cdot s^2 \cdot N \qquad (1)$$

where $\bar{\gamma}(s,s)$ is the average semi-variance within the average elementary sampling unit **s** of surface **s**^{2}, **N** is the number of samples in the envelope to be estimated. The dimensions of **s** must respect the length/width ratio of the envelope **D**. This is an easy approximation of σ_D^{2*}, when the sampling density is uniform, which is almost the case here. Its solution can be obtained rapidly from geostatistical charts or from a computer program.

RESULTS AND DISCUSSION

The data.

The catch of northern shrimp biomass during the surveys is presented for all shrimp and separately by size group in Figs. 1-5 (note the different symbol scales for the small sizes, which were not fully retained by the trawl mesh). These figures show that the samples were well distributed in the main three channels of the Gulf every year and no area had large variations of sample density among years. As expected, they also show that the small shrimps are located in shallower depths than the large ones. Day and night differences in catches occured, likely because of vertical migrations, night catch tending to be lower than day catch in the same neighborhood, but a notable variability to this was however manifest.

The estimates.

Local estimates on the grid of blocks are presented in Figs. 6-10. The maps of all sizes grouped (Fig 6.) indicate that the center of mass of shrimp in the western Gulf (zones 1 and 4) moved south and south-westward from 1990-1992. Substantial concentrations were thus found at the mouth of the Estuary in 1992 contrary to 1991 and 1990, and the north eastern end was simultaneously depleted. In the eastern Gulf (zones 2 and 3), a small eastward move and compression of the shrimp mass occurred in zone 2 from 1990 to 1992, while zone 3 experienced a substantial depletion in 1992. Many factors may be involved to explain these mesoscale changes in shrimp distribution in the Gulf. Among them are (1) biologically-driven causes like recruitment, growth, natural mortality, etc. (e.g. Simard and Savard 1990), (2) environmental changes, such as bottom temperature and other water mass properties, (3) transport under the combined effect of the deep circulation and the behavior of shrimp or their food and (4) the effect of the fishing mortality, which can contribute to temporary reduce the mass of shrimp in a given area. The decrease of shrimp in the Grande Coulée, west of Anticosti Island, and in the head of the Esquiman Channel in 1992 was paralleled with a lowering of bottom temperature (from the temperature data taken during trawling and the maps drawn by D. D'Amours and J. Landry, MLI). Not a single one but many of these factors are probably involved in the change of spatial pattern. The apparent movement from one zone to another supports the idea that the Gulf shrimp is a whole system, where all zones are interdependent.

The maps of the different size groups show a different pattern of spatial changes. The map of cohort II (Fig. 7) is anecdotic considering that this small size is very poorly retained by the trawl. It indicates potential locations of recruitment sources. Cohort III (Fig. 8) is spreading its mass from 1990-1992 in the whole western Gulf, while, in the eastern Gulf it retreated towards the head of the channels in 1991 to spread again in the whole channels in 1992. Cohorts IV and V-VI+ (Figs. 9-10) were responsible for the general trends observed above for the total shrimps but differences were apparent between these two groups, largest shrimps tending to be more localized than the intermediate size of cohort IV.

The kriging estimates of the global biomass of northern shrimp in the whole Gulf was similar in 1990 and 1991 but decreased by about 30% in 1992 (Table 2A). The regional estimates by management unit, indicate that this substantial decrease was attributable to only the two zones 1 and 3, whose biomass decreased respectively from 37 kt to 20 kt and 19 kt to 8 kt (Table 2A). These decreses in both zones was primarily the fact of cohorts IV , which dropped there to **less than 32%** of its 1991 biomass (Table 2D), and to cohorts V-VI+, which dropped to **57-53%** (Table 2E). In zone 3 cohort III also contributed to the general decrease but it increased in the other zones. The zone 2 did not show such large fluctuations; a notable increase in cohort V-VI+ in 1992 is however worth mentioning as well as a substantial drop in cohort III in 1991.

CONCLUSION

In conclusion, the northern shrimp biomass in the gulf of St.Lawrence, considered as a whole, was globally stable in 1990 and 1991, but regionally and locally variable, with possible movements and exchanges of biomass between zones. In 1992, an important decrease in the overall biomass occurred, because of a substantial weakening in cohort VI and V-VI+ in Esquiman channel and Sept-Iles area compared to the abundant year 1991. The cause of this drop will be investigated further elsewhere.

ACKNOWLEDGMENT

We thank Louise Savard, Sylvain Hurtubise, for having made available the data analysed here. The contribution of many other colleagues to different steps of the study is also acknowledged.

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Table 1. Trawl samples collected in the Gulf of St.Lawrence during research surveys for estimating the northern shrimp biomass at the end of the summer.

YEAR	VESSEL	TRAWL TYPE	NO OF SAMPLES DAY	NIGHT
1990	FRV/Alfred-Needler (50m)	URI 81-114	130	61
1991	FRV/Alfred-Needler (50m)	URI 81-114	162	88
1992	FRV/Alfred-Needler (50m)	URI 81-114	163	77

Table 2. Estimated mass of shrimp (t) in the study region for 4 management units and for the whole Gulf resulting from discrete summation of the kriging block estimates (kg/km^2) of the grid (Fig. 6), for the chosen kriging models (Annexe 1). The relative errors SE = σ_D/total biomass are computed from equation (1).

YEAR	ZONE 1 (A=37015 km^2)			ZONE 2 (A=25959 km^2)			ZONE 3 (A=23315 km^2)			ZONE 4 (A=4567 km^2)			TOTAL (A=90856 km^2)		
	mean kg/km^2	× A = mass t	SE %	mean kg/km^2	× A = mass t	SE %	mean kg/km^2	× A = mass t	SE %	mean kg/km^2	× A = mass t	SE %	mean kg/km^2	× A = mass t	SE %
A: ALL SHRIMP															
1990	744	27539	9.8	664	17237	11.5	710	16554	13.0	516	2357	36.8	701	63690	6.4
1991	1001	37052	6.4	498	12928	15.9	810	18885	8.4	220	1005	86.2	769	69868	5.1
1992	548	20284	13.1	632	16406	11.1	349	8137	18.7	577	2635	32.9	523	47518	7.5
B: 10-14 CL SHRIMP*															
1990	2	74	>	2	52	>	0	0	>	4	18	>	2	182	>
1991	2	74	>	2	52	>	3	70	>	0	0	>	2	182	>
1992	6	222	72.7	2	52	>	0	11	>	0	0	>	3	273	80.5
C: 14-18 CL SHRIMP															
1990	19	703	64.0	46	1194	27.7	32	746	48.1	7	32	>	30	2726	15.3
1991	71	2628	15.0	15	389	88.5	28	653	40.8	2	9	>	41	3725	16.0
1992	74	2739	16.2	56	1454	21.9	12	280	91.3	22	100	>	51	4634	12.8
D: 18-23 CL SHRIMP															
1990	226	8365	19.8	279	7243	16.9	231	5386	24.4	179	817	65.6	240	21805	11.4
1991	273	10105	14.4	235	6100	20.9	303	7064	14.0	16	73	>	257	23350	9.5
1992	87	3220	50.8	177	4595	25.9	84	1958	48.7	35	160	>	109	9903	22.2
E: 23-30 CL SHRIMP															
1990	501	18545	11.4	290	7528	20.7	438	10212	16.6	316	1443	47.3	415	37705	8.4
1991	643	23801	7.8	237	6152	26.4	471	10981	11.4	192	877	77.8	460	41794	6.7
1992	372	13770	15.2	387	10046	14.3	252	5875	26.4	523	2389	28.6	353	32072	8.7

*: Too few data (< 30 samples) larger than 0 kg/km^2 to compute a meaningful variogram, a random model (nugget=σ^2) was assumed.
>: SE > 100%

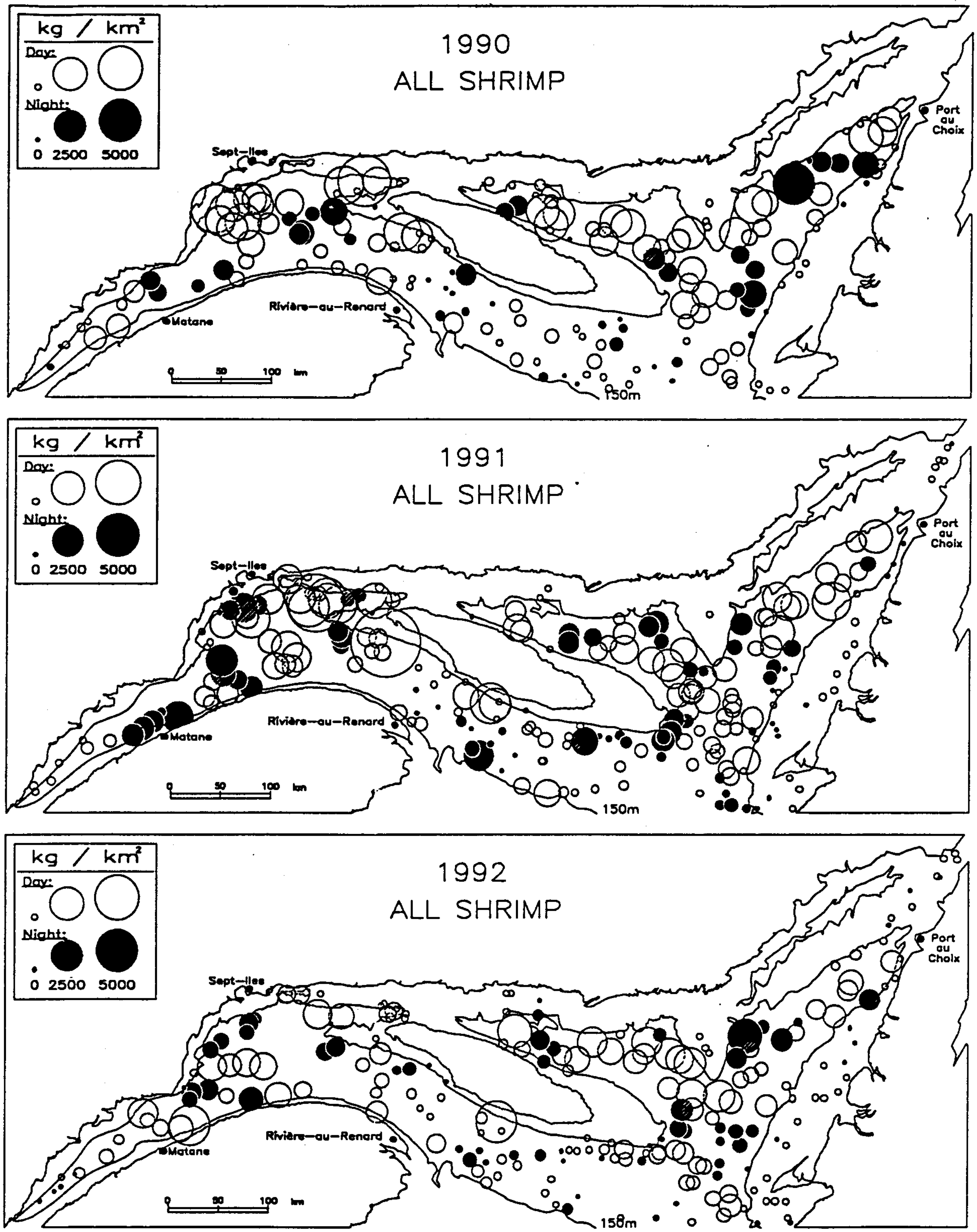
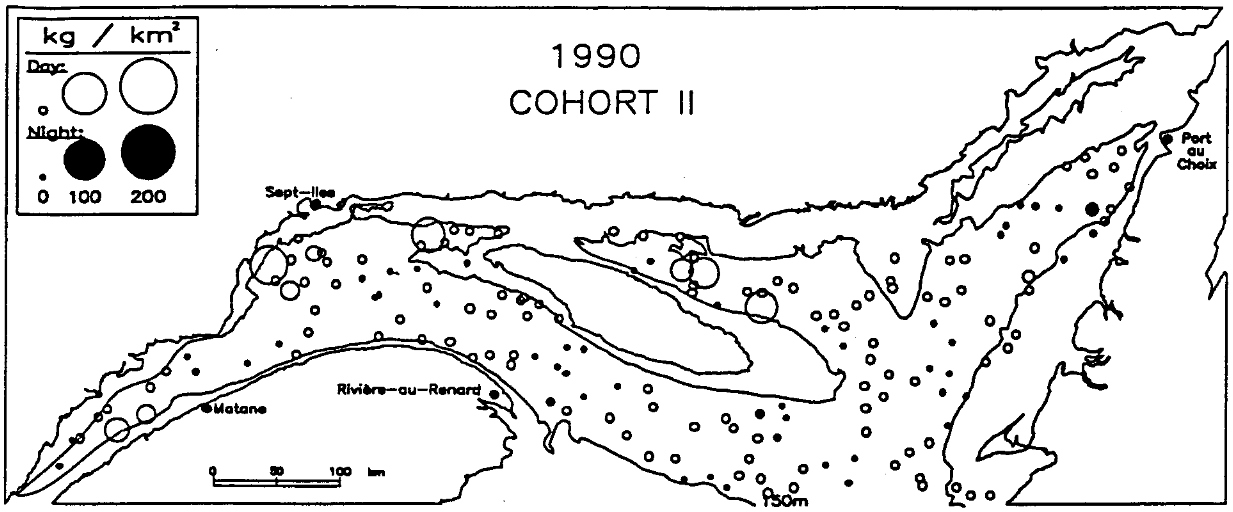
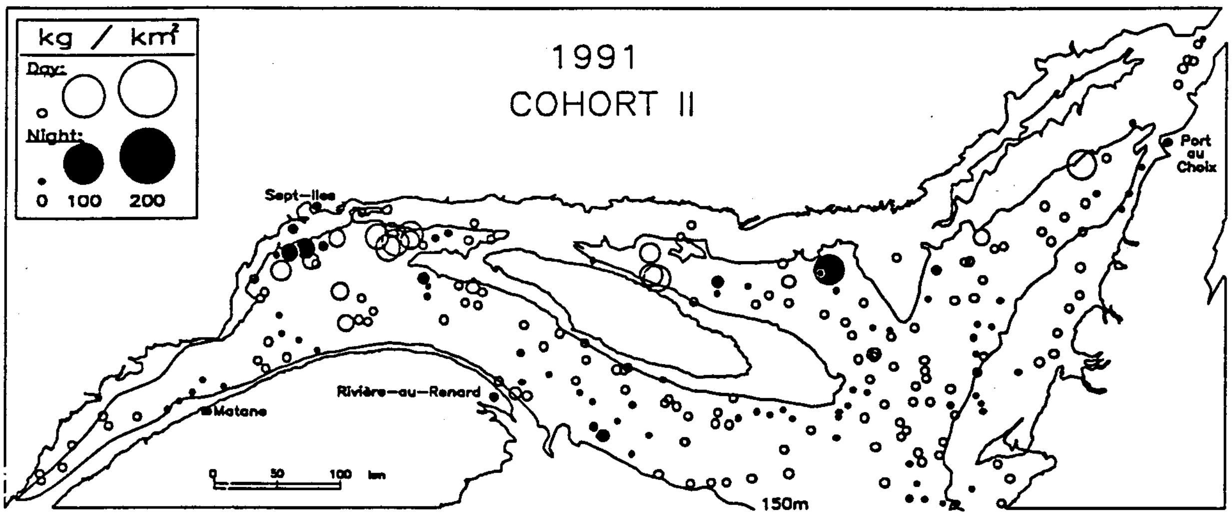


Figure 1. Trawl stations and northern shrimp catch during the surveys. Symbol size proportional to the square root of shrimp weight per km^2.





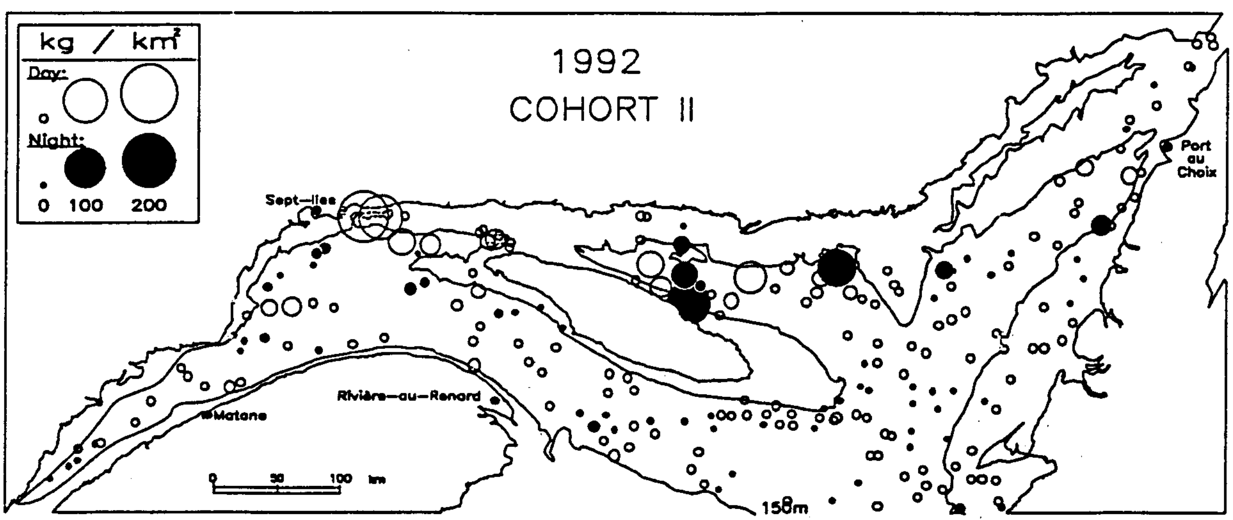


Figure 2. Trawl stations and 10–14mm (CL) northern shrimp catch during the surveys. Symbol size proportional to the square root of shrimp weight per km².

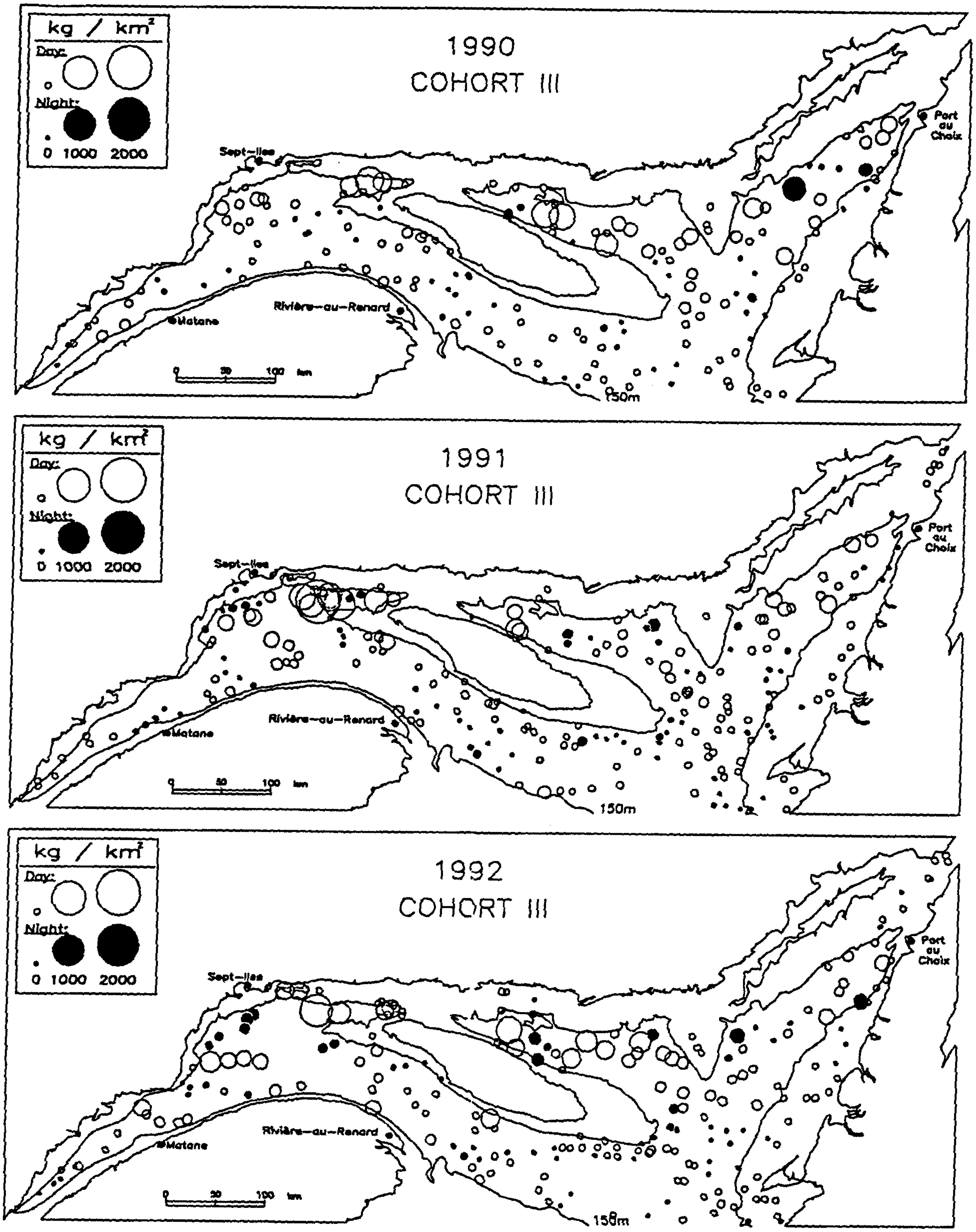


Figure 3. Trawl stations and 14–18mm (CL) northern shrimp catch during the surveys. Symbol size proportional to the square root of shrimp weight per km².

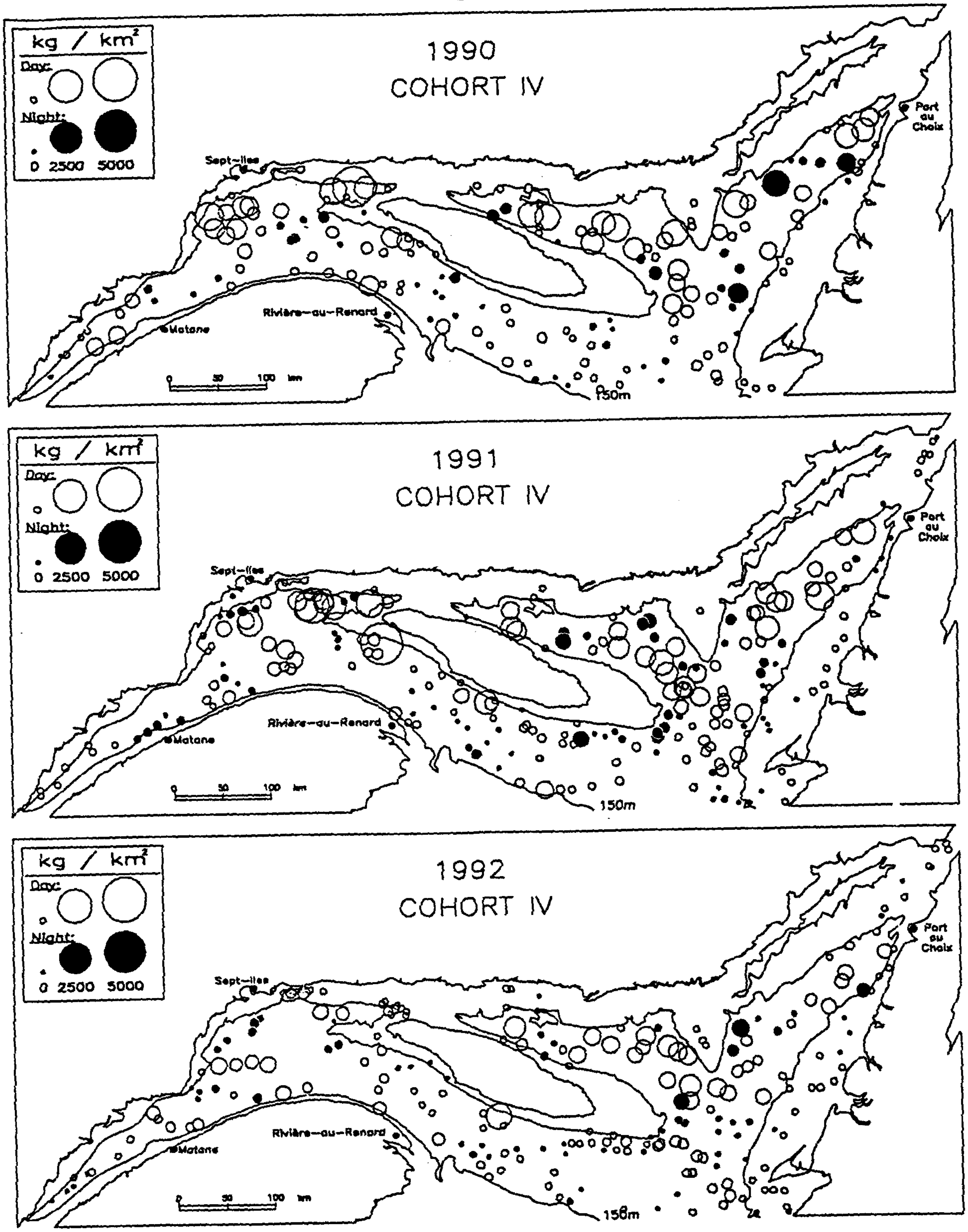


Figure 4. Trawl stations and 18–23mm (CL) northern shrimp catch during the surveys. Symbol size proportional to the square root of shrimp weight per km^2.

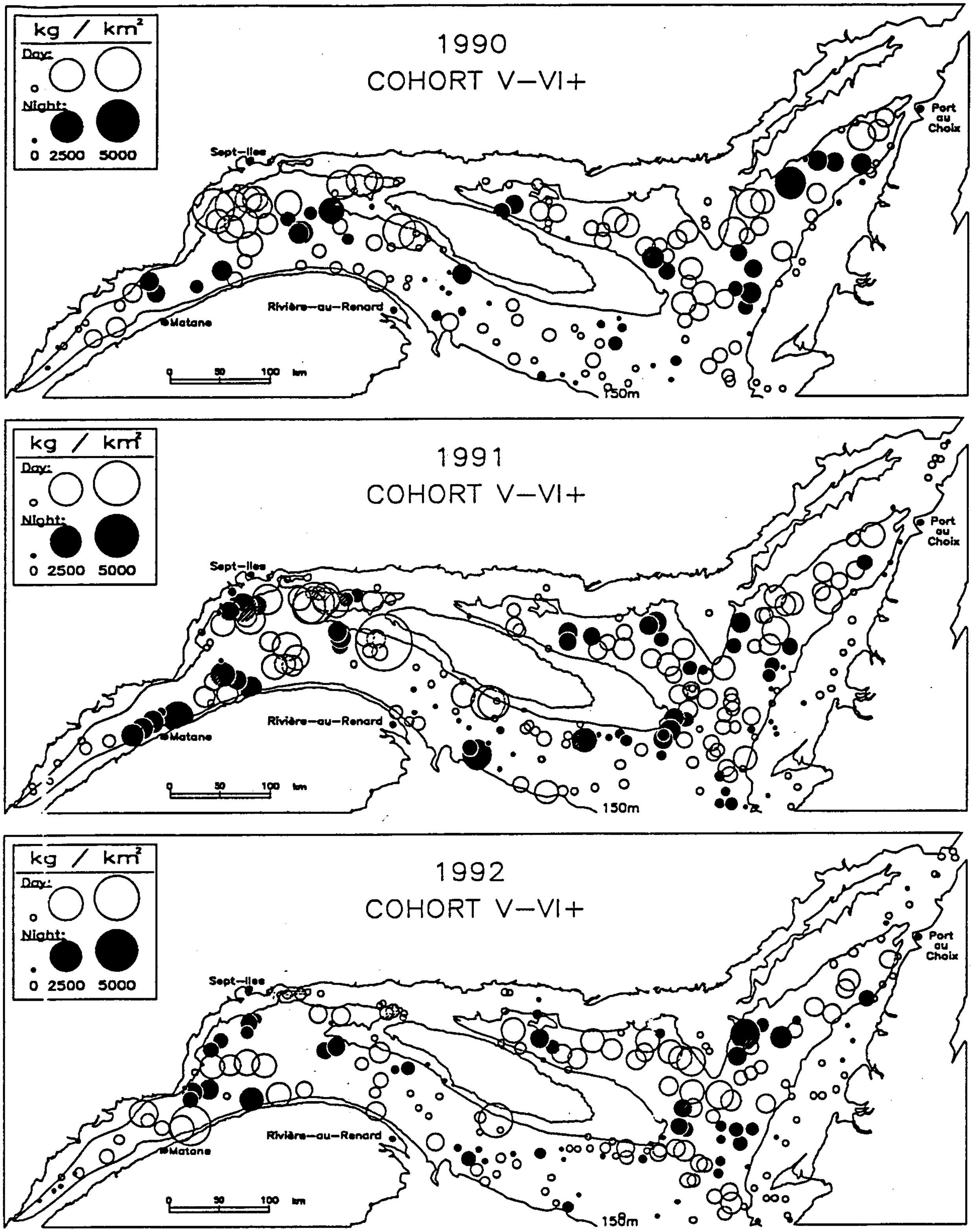


Figure 5. Trawl stations and 23–30mm (CL) northern shrimp catch during the surveys. Symbol size proportional to the square root of shrimp weight per km².

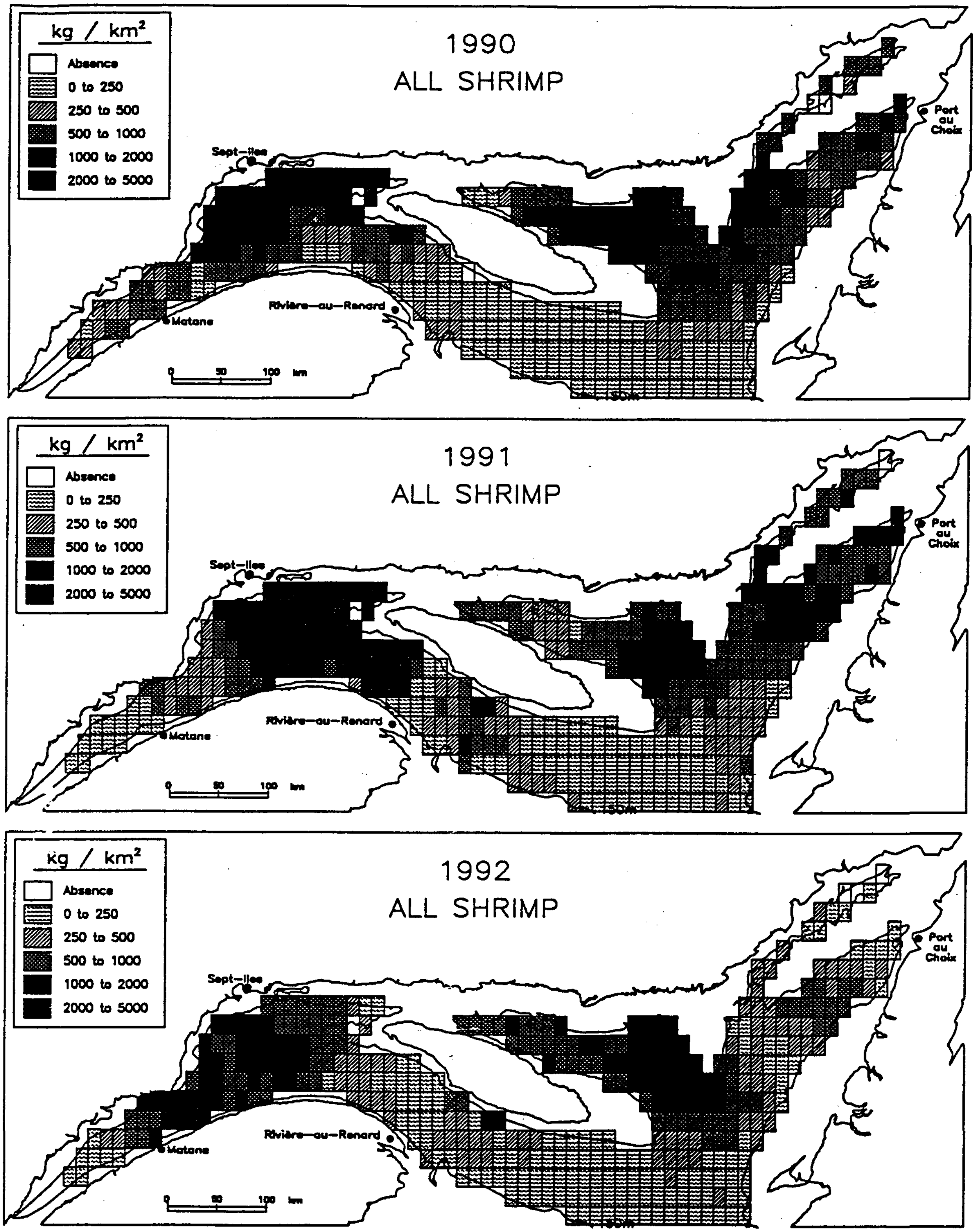


Figure 6. Hatch maps of the kriged blocks of northern shrimp biomass (kg / km²) during the surveys.

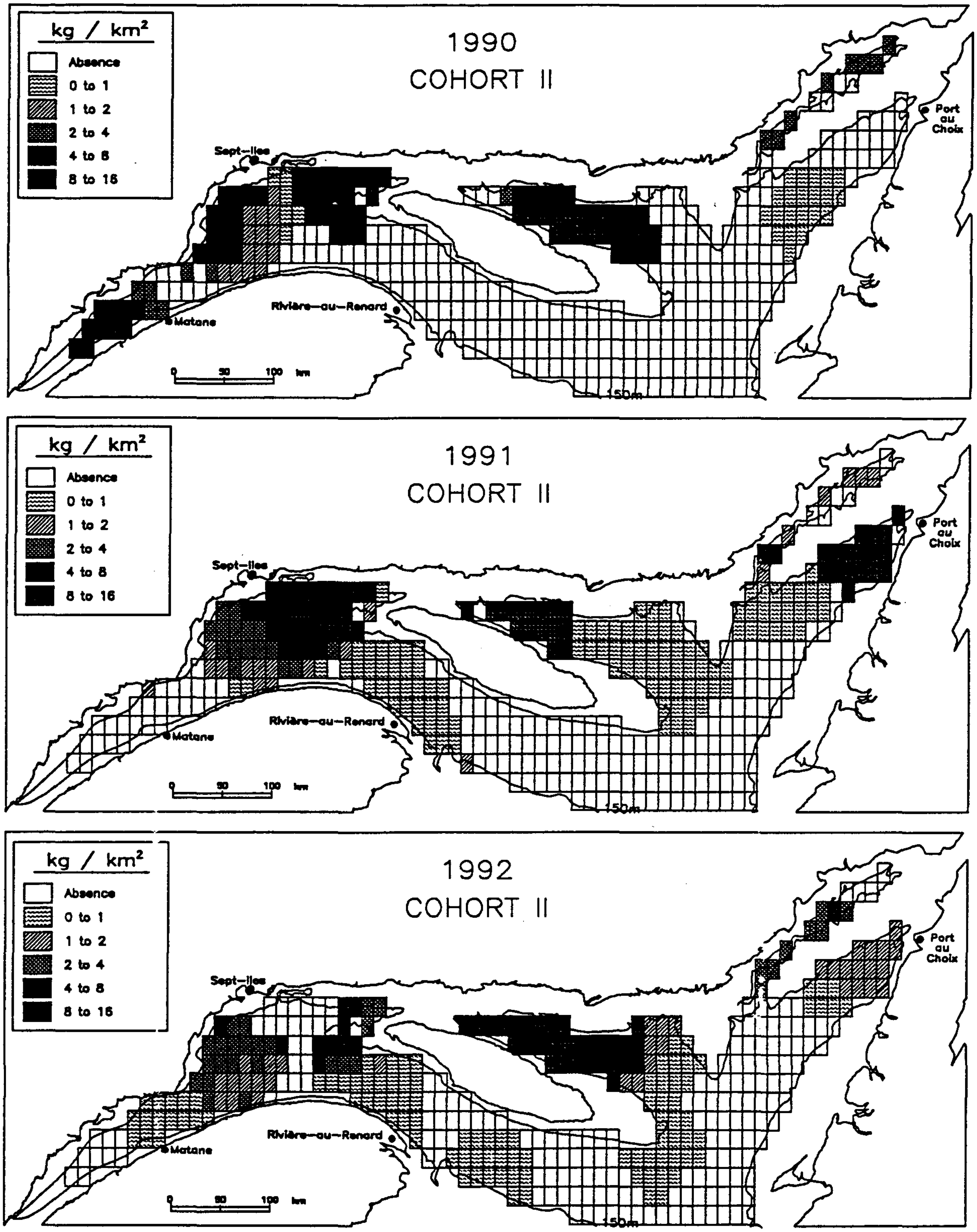


Figure 7. Hatch maps of the kriged blocks of 10–14mm (CL) northern shrimp biomass (kg / km^2) during the surveys.

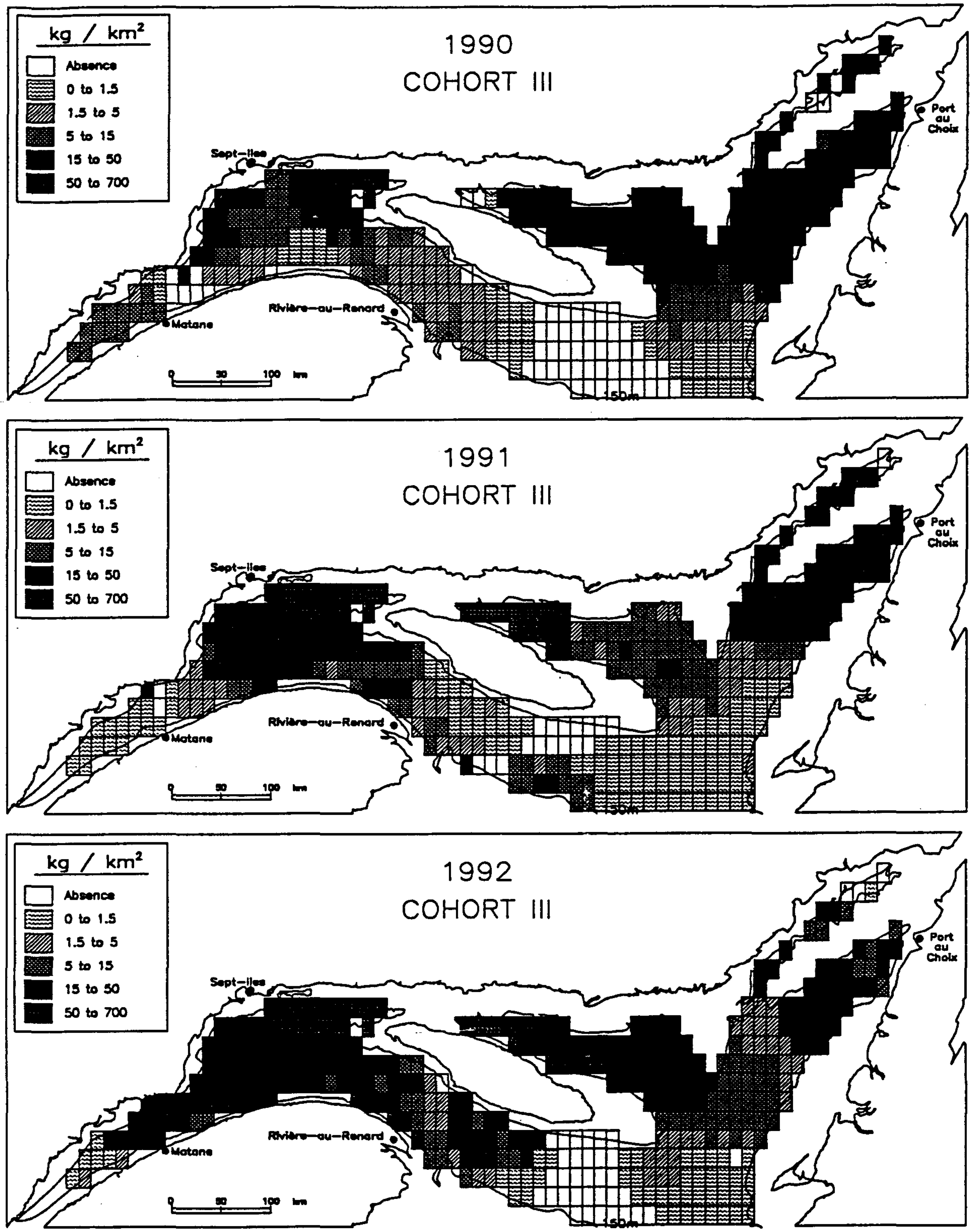


Figure 8. Hatch maps of the kriged blocks of 14–18mm (CL) northern shrimp biomass (kg / km²) during the surveys.

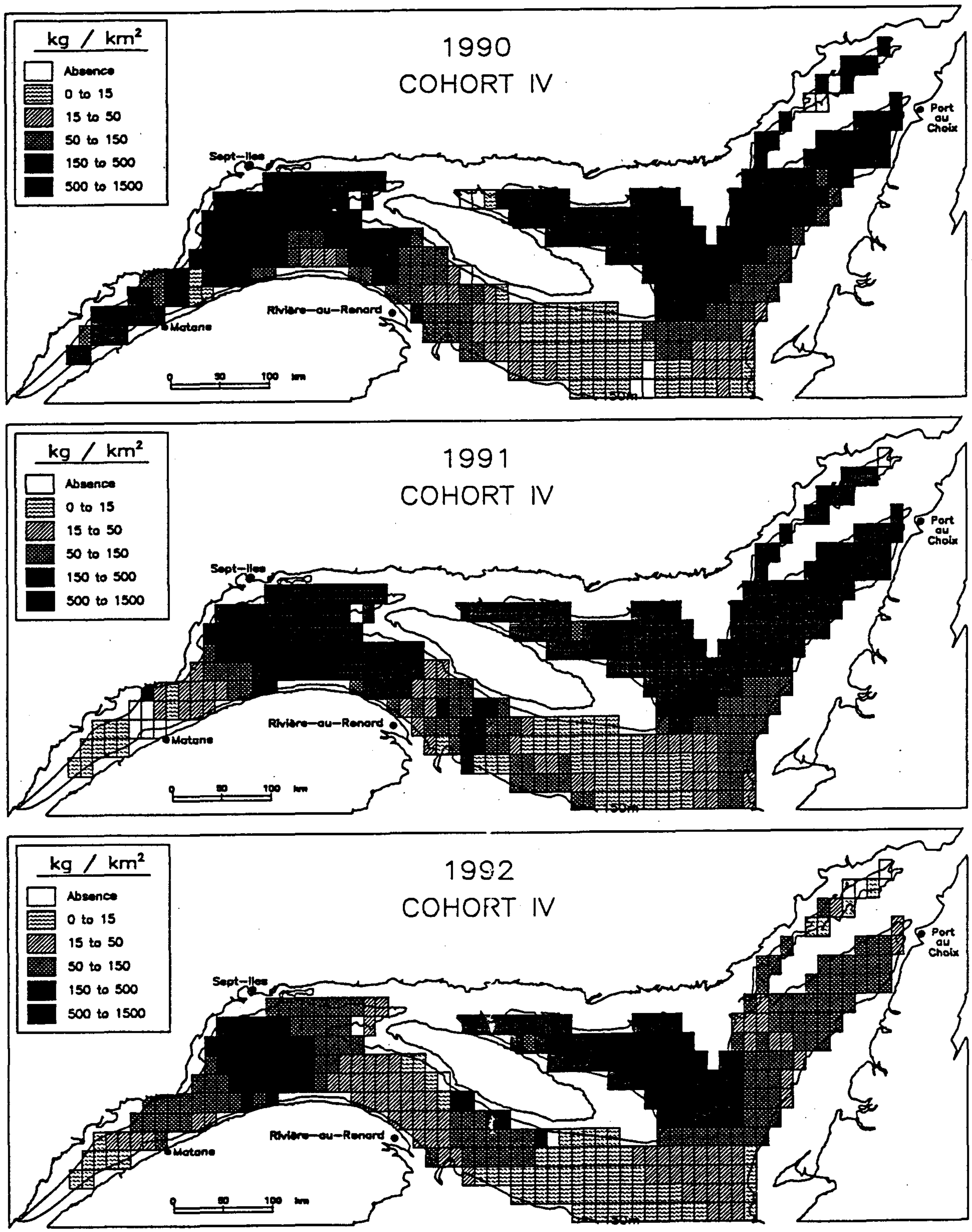


Figure 9. Hatch maps of the kriged blocks of 18–23mm (CL) northern shrimp biomass (kg / km²) during the surveys.

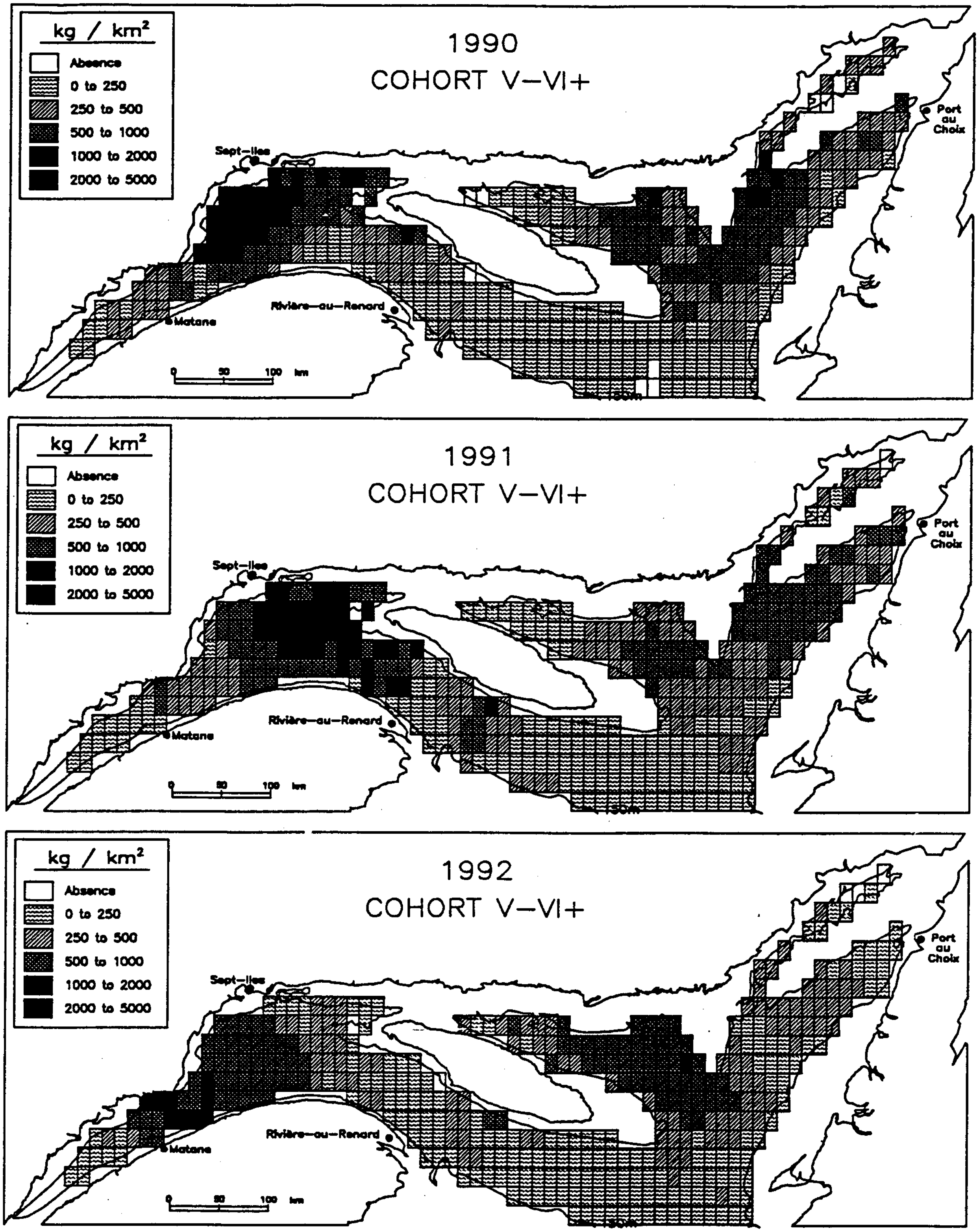


Figure 10. Hatch maps of the kriged blocks of 23–30mm (CL) northern shrimp biomass (kg / km²) during the surveys.

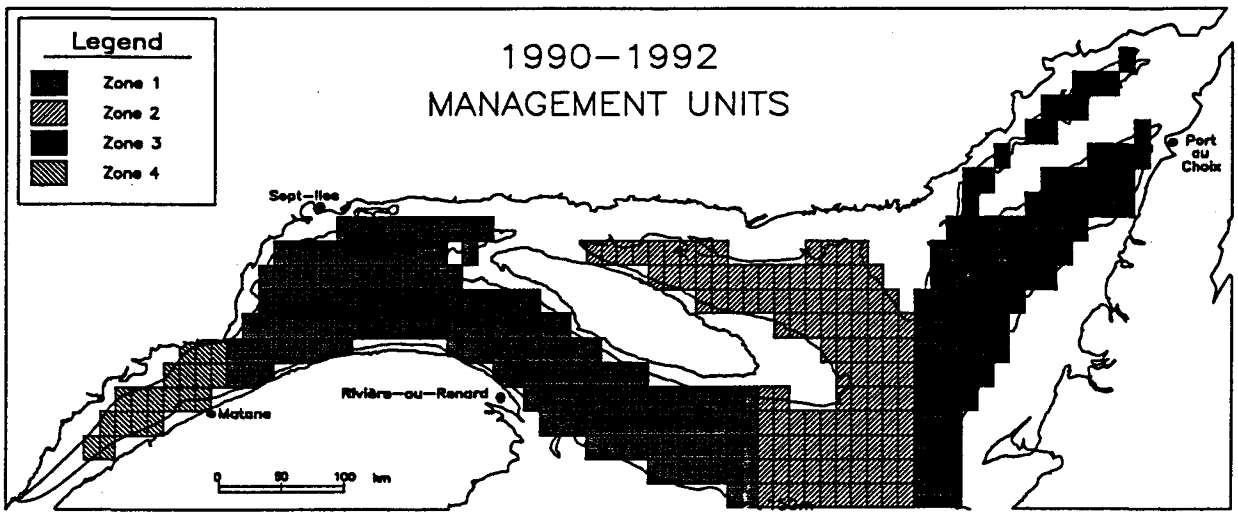


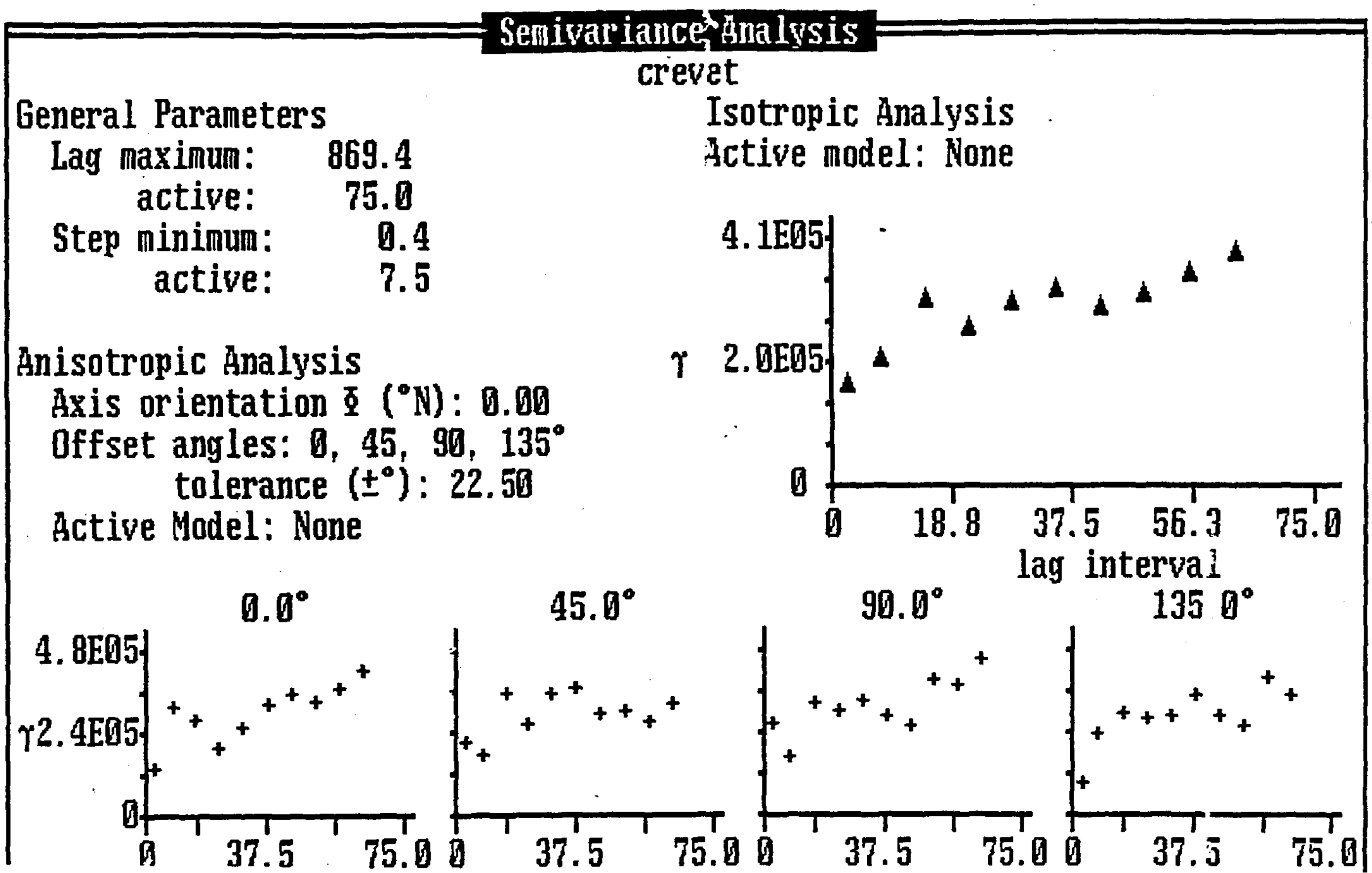
Figure 11. Map of the four management units of the northern shrimp and the kriged blocks from which the global biomass estimates are computed.

ANNEXE 1

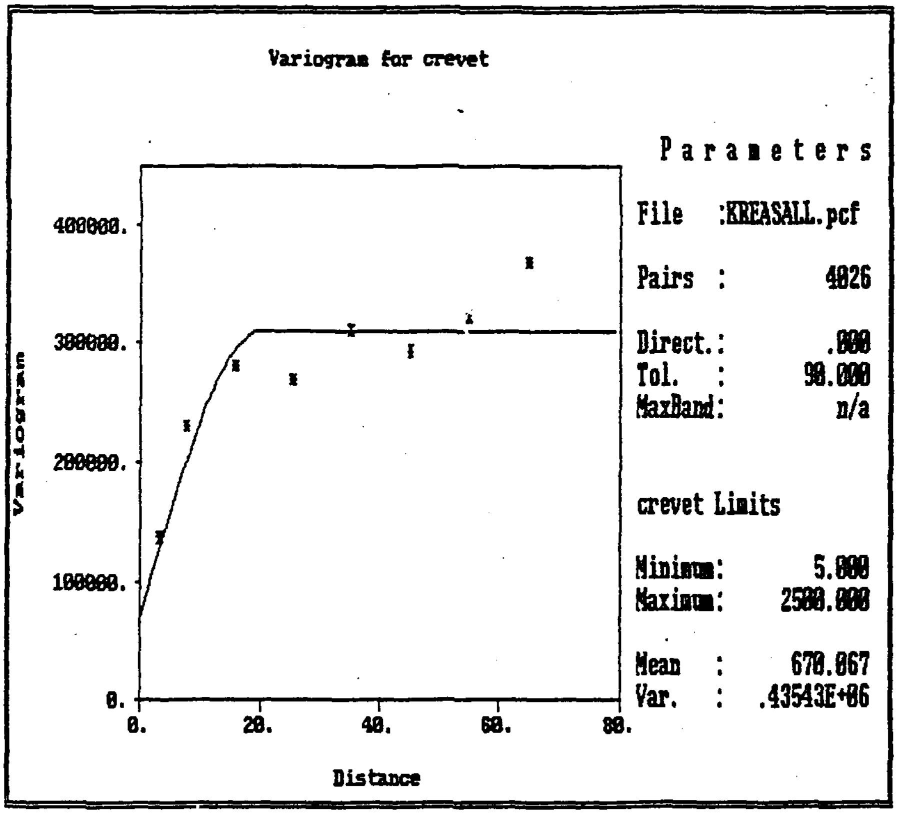
Multi-years variograms of the shrimp biomass (kg/km^2) used for kriging for all sizes together and for each size group larger than 14 mm CL separately.

ALL SHRIMPS

ANISOTROPY STUDY



ALL SHRIMPS



MODEL

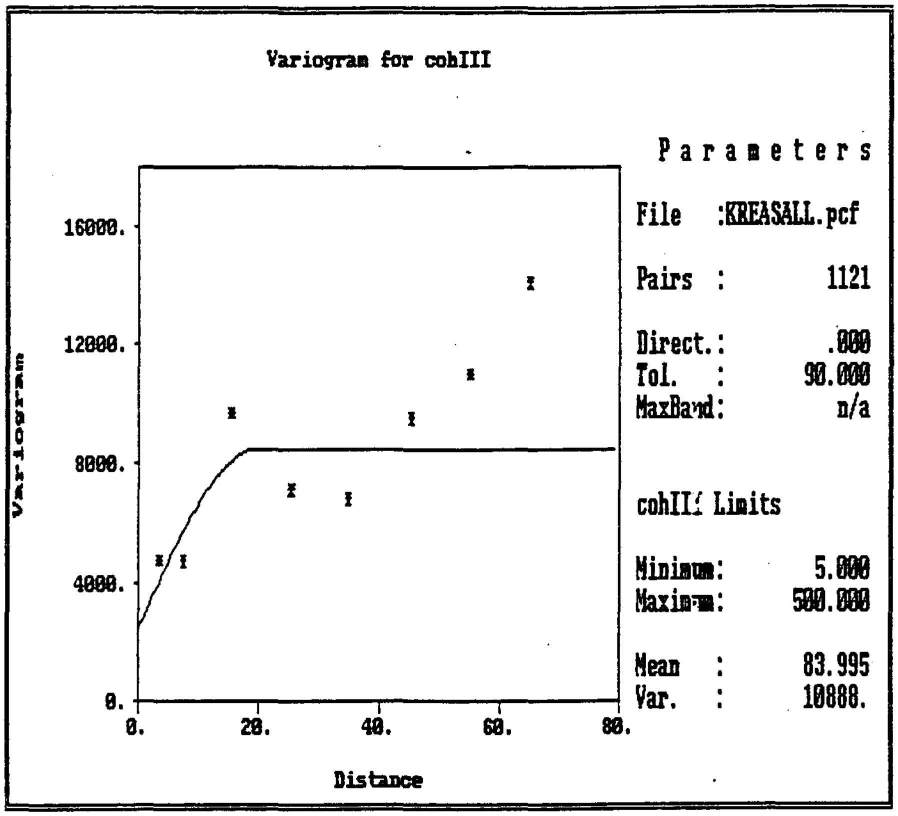
	Pairs	Avg Distance	Value
1	40	3.145	137392.800
2	114	7.716	230927.000
3	402	15.721	281244.900
4	563	25.206	269832.100
5	627	35.105	311239.200
6	732	45.122	293714.200
7	743	55.041	322983.100
8	805	64.962	368346.200
9			
10			
11			
12			
13			
14			
15			
16			
17			
18			
19			
20			
21			
22			
23			
24			

Model

Nugget : 70000.000

Type	Sill	Range
Spherical	240000.000	20.000

COHORT III



MODEL

	Pairs	Avg Distance	Value
1	20	3.418	4768.599
2	34	7.512	4717.579
3	121	15.576	9720.561
4	161	25.356	7137.514
5	174	34.655	6820.532
6	196	45.157	9528.255
7	194	55.082	11028.260
8	221	64.954	14094.190
9			
10			
11			
12			
13			
14			
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16			
17			

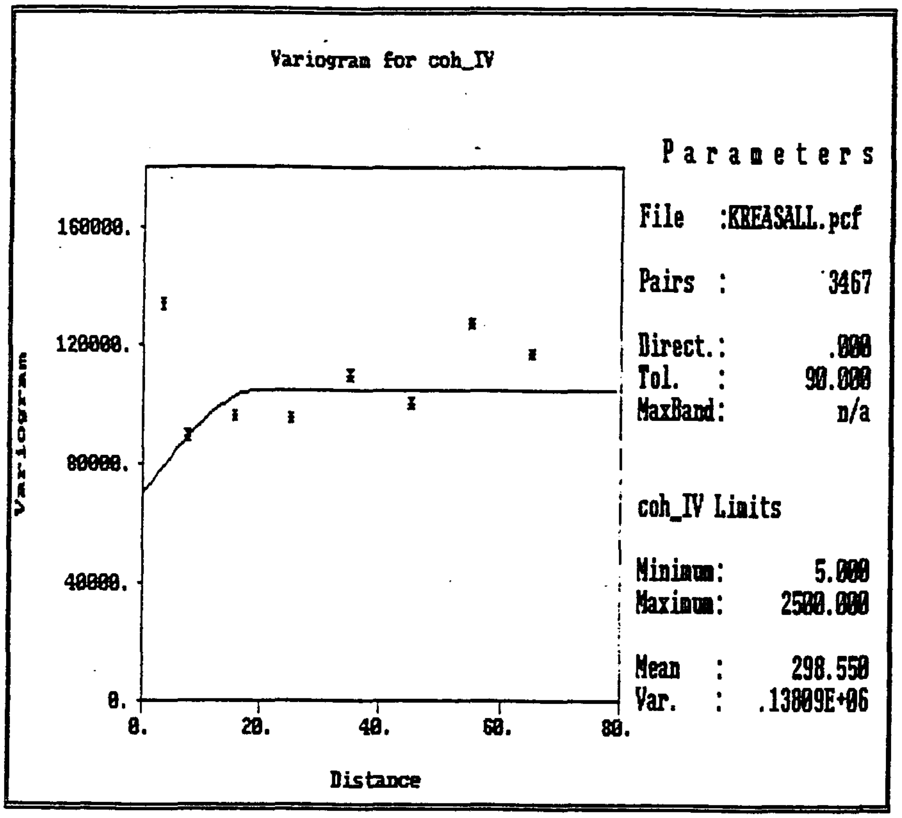
	Pairs	Avg Distance	Value
18			
19			
20			
21			
22			
23			
24			

Model

Nugget : 2500.000

Type	Sill	Range
Spherical	6000.000	20.000

COHORT IV



MODEL

	Pairs	Avg Distance	Value
1	34	3.319	133892.900
2	106	7.645	89587.270
3	359	15.625	96409.100
4	484	25.144	95598.340
5	536	35.052	109685.800
6	636	45.008	100403.900
7	622	54.923	127294.900
8	690	64.957	117220.600
9			
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	Pairs	Avg Distance	Value
18			
19			
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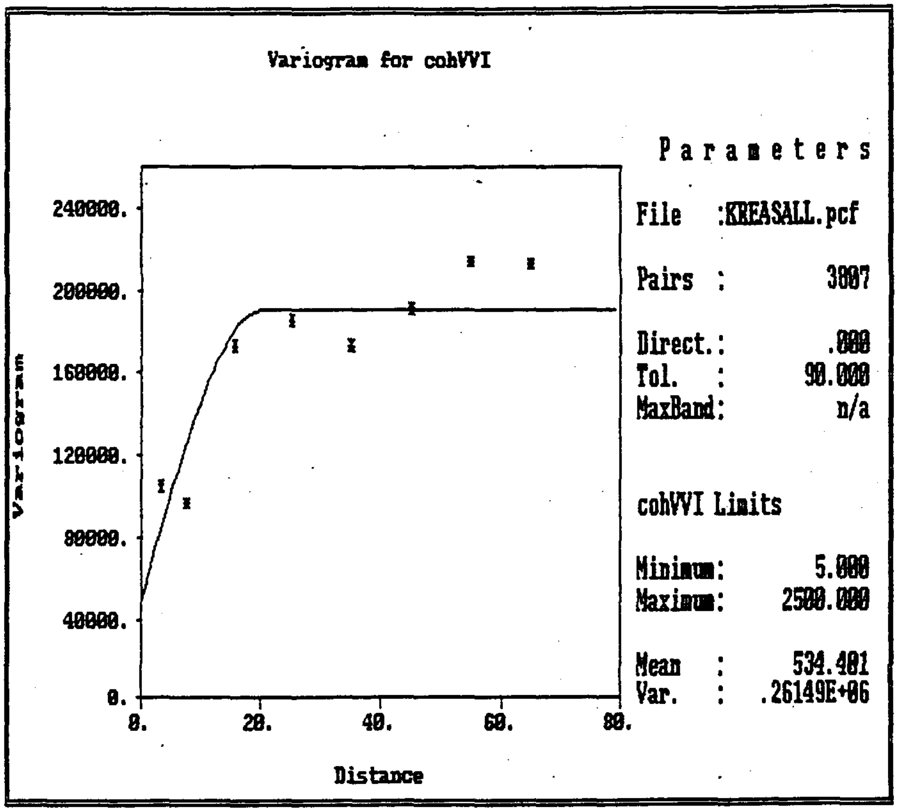
24			

Model

Nugget : 70000.000

Type	Sill	Range
Spherical	35000.000	20.000



COHORT V-VI+

MODEL

	Pairs	Avg Distance	Value
1	37	3.336	105327.800
2	117	7.670	96543.760
3	400	15.611	172912.900
4	540	25.140	185408.100
5	584	35.020	172908.100
6	686	45.034	191093.600
7	693	54.981	213991.600
8	750	64.918	212857.500
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23			
24			

Model

Nugget : 50000.000

Type	Sill	Range
Spherical	140000.000	20.000