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A Multivariate Approach to Study the Variability and Structure of Length-frequency Distributions: an Example with the Gulf of St. Lawrence Northern Shrimp Population

by

Y. Simard and L. Savard

Fisheries Research Division, Dept. of Fisheries and Oceans, Maurice-Lamontagne Institute
P. O. Box 1000, Mont-Joli, Quebec, Canada G5H 3Z4

INTRODUCTION

For population dynamics study , precise estimates of lengths and numbers at ages are needed. In northern shrimp populations, these estimates are obtained from LFDs and, generally, they exhibit significant variations from sample to sample. Attempts to reduce variability by summing up LFDs on a regional basis or on depth intervals have been disappointing, the cohort characteristics extracted changing unpredictably with the arbitrary chosen integration unit (depth interval, strata, etc.). This stressed the need of an integrated study on the causes the variability which can be taken into account while sampling and analysing LFD information for population dynamics modeling. Specific objectives were: (1) to test for the presence and persistence of spatial patterns and to describe the patterns if any, (2) to measure the residual level of variability and the scales of organization in space and along depth gradients, (3) to extract ecological information on the local population evidenced by the LFD structure and (4) to suggest strategies to take the structure into account when sampling and analysing LFDs for population dynamics modeling.

METHODS

Description of spatial patterns: Cluster analysis

The LFDs (from 500-1500 shrimps per sample) from trawl sampling were divided in 24 classes of carapace lengths, from 8 mm to 32 mm. Considering the LFD as a multivariate with 24 dimensions given by the length-classes, a Bray and Curtis (1957) dissimilarity index (d) between the n samples of each year was first computed. The symmetric matrix ($D_{n \times n}$) obtained gave the LFD dissimilarity between all pairs of combinations of the n samples. Hierarchical clustering using the complete linkage algorithm was then used to sort the samples according to their similarity. Then, the resulting 4 to 5 clusters corresponding to the most important branches of the grouping tree were mapped, to look at their spatial organization, and their mean LFD were computed (Fig. 2).

Analysis of structures: Mantel tests, variograms and correlograms

To test for non-random spatial organization, to analyze and to determine the type of spatial structure present (mosaic of patches, gradients, etc.) the Bray and Curtis dissimilarity matrices, $D_{n \times n}$, were submitted to Mantel tests (Mantel 1967, Sokal 1979a) using the normalized Mantel statistic (r, Smouse et al. 1986) for comparisons with two model matrices, $Y_{n \times n}$, representing the geographic distances or the depth separations between stations. This spatial statistic is analog to a Pearson correlation coefficient calculated between the paired elements of the two matrices. It ranges from -1.0 to 1.0. Its probability was obtained from comparison to a Monte Carlo null distribution, computed from 250 random permutations of the rows and columns of one matrix. Mantel correlograms (Sokal 1986, Oden and Sokal 1986) were obtained by computing and plotting r for various scales (Figs. 3-4). The degree of LFD similarity at various scales was computed and plotted (Figs. 3-4), giving dissimilarity variograms (Mackas 1984).

RESULTS AND DISCUSSION

Spatial patterns of LFDs and time variations

The cluster analysis identified five different LFD assemblages (a to e) every year, characterized by a gradual disappearance of the young individuals to the profit of old ones (Fig. 2). In general, the distribution of the assemblages reflected the regional bathymetry: the LFDs with the highest proportions of small individuals and with the smallest modal mean lengths were found in the shallower depths at the channel borders, and conversely for the deeper parts. This spatial organization was ascribed to the ontogenic horizontal migration of the shrimps to deeper grounds. The relative proportion of the modes in each group exhibited however important interannual variations (Fig. 2, Table 1), likely reflecting important fluctuations in recruitment and/or survivorship, some of them presenting a regional component (ex. the singularity of assemblage b in 1984).

Variations of LFD similarity with distance and depth

Mantel correlograms and dissimilarity variograms (Figs. 3-4) showed that: 1) the unresolved residual variability of LFD was stable over the regions and from year to year; 2) above this small-scale background variability, LFDs were never randomly organized but structured by persistent monotonic gradients, largely - but not exclusively - related to the particular bathymetric shape of the regional basins sampled; 3) the range of influence of LFDs on each other extended to the whole depth range (70-110 m) and space (120-170 km) sampled in each region, except one. 4) From detailed analysis of the spatial structures and LFD assemblages, inferences on the migration were derived: speeds, routes, enhanced growth along the migration routes (c.f. Table 1). 5) The information from the variograms can be used to optimize sampling density to take the structure into account when deriving information from LFDs, similarly to univariate kriging.

The analysis clearly showed that population dynamics modeling of northern shrimps in the Gulf of St.Lawrence requires adequate consideration of spatial processes.

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Table 1. Parameters of the modal components of the mean LFDs of the groups of samples classified with the cluster analysis (Fig. 3). Mean carapace length; 95% range (R) of the normal distribution, % (P) of total numbers according to Macdonald and Pitcher (1979). M: males (nos. are not ages); F: females.

GROUPS		MODES			
		M1	M2	M3	F
1984-a	M	11.1	15.7	19.2	23.3
	95% R	9.3-12.9	13.2-18.2	17.0-21.4	18.8-27.8
	P	0.02	0.50	0.24	0.24
1984-b	M		16.0	19.7	24.6
	95% R		13.8-18.2	17.7-21.7	21.1-28.1
	P		0.16	0.59	0.25
1984-c	M		16.7	20.6	25.9
	95% R		13.8-19.6	17.3-23.9	22.0-29.8
	P		0.29	0.37	0.34
1984-d	M		16.2	20.5	25.0
	95% R		14.0-18.4	17.4-23.6	21.1-28.9
	P		0.03	0.56	0.41
1984-e	M		17.6	21.5	26.5
	95% R		14.9-20.3	19.0-24.0	23.2-29.8
	P		0.10	0.31	0.59
1985-a	M	11.0	15.5	19.1	23.7
	95% R	9.0-13.0	13.1-17.9	17.3-20.9	20.2-27.2
	P	0.12	0.35	0.22	0.31
1985-b	M	13.2	16.0	19.4	24.1
	95% R	10.5-15.9	14.2-17.8	16.3-22.5	20.0-28.2
	P	0.08	0.16	0.46	0.30
1985-c	M	13.4	16.7	20.2	24.7
	95% R	11.0-15.8	14.5-18.9	17.7-22.7	20.8-28.6
	P	0.05	0.14	0.35	0.46
1985-d	M		17.2	21.3	26.5
	95% R		12.7-21.7	17.6-25.0	23.4-29.6
	P		0.08	0.24	0.68
1985-e	M		16.1	20.6	25.4
	95% R		13.2-19.0	17.3-23.9	21.7-29.1
	P		0.04	0.42	0.54
1987-a	M	11.1	15.6	20.8	24.3
	95% R	9.3-12.9	12.7-18.5	16.9-24.7	21.0-27.6
	P	0.24	0.56	0.12	0.08
1987-b	M	11.5	16.8	21.0	25.3
	95% R	9.3-13.7	14.1-19.5	17.9-24.1	21.8-28.8
	P	0.03	0.60	0.17	0.20
1987-c	M	13.3	18.4	21.3	25.6
	95% R	10.9-15.7	15.5-21.3	18.9-23.7	22.5-28.7
	P	0.05	0.51	0.26	0.18
1987-d	M	11.4	17.5	21.0	24.9
	95% R	9.4-13.4	14.4-20.6	18.3-23.7	21.6-28.2
	P	0.02	0.39	0.14	0.45
1987-e	M		18.2	21.3	26.3
	95% R		14.9-21.5	18.0-24.6	23.4-29.2
	P		0.26	0.32	0.42

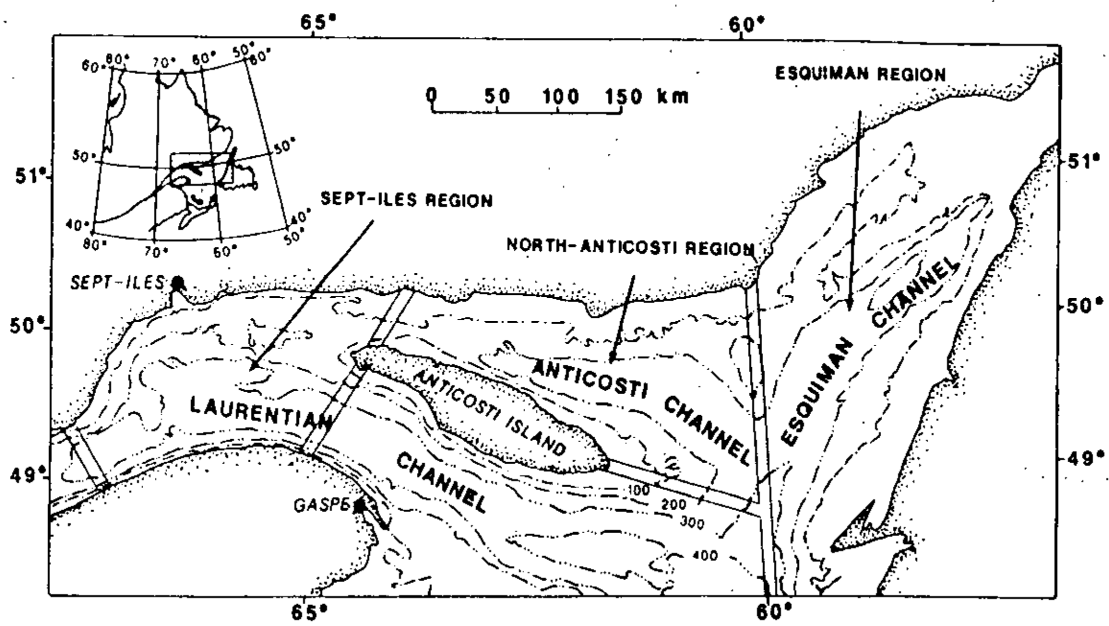

Figure 1. Map of the Gulf of St.Lawrence showing the three channels and the regions sampled. Boundaries divide the 5 management units to which a stratified random subsampling design was applied. Depth contours in meters.

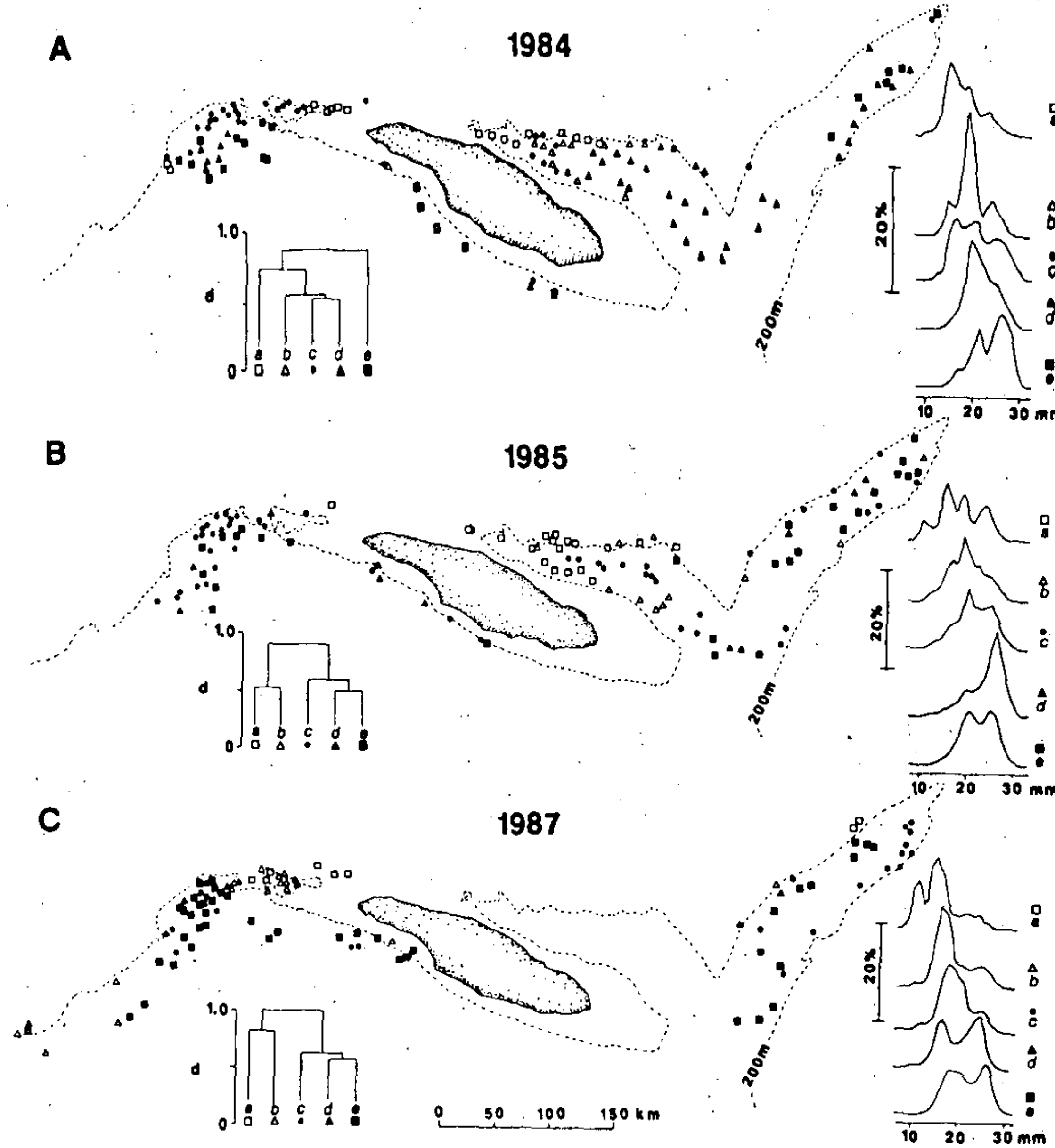

Figure 2. Results of the cluster analysis showing the spatial organization of similarity of the LFDs in early fall of 1984, 1985 and 1987 in the Gulf of St.Lawrence. Mean LFDs of the 5 most important branchs (a to e) of the dendograms. Carapace length in mm, frequency in percent.

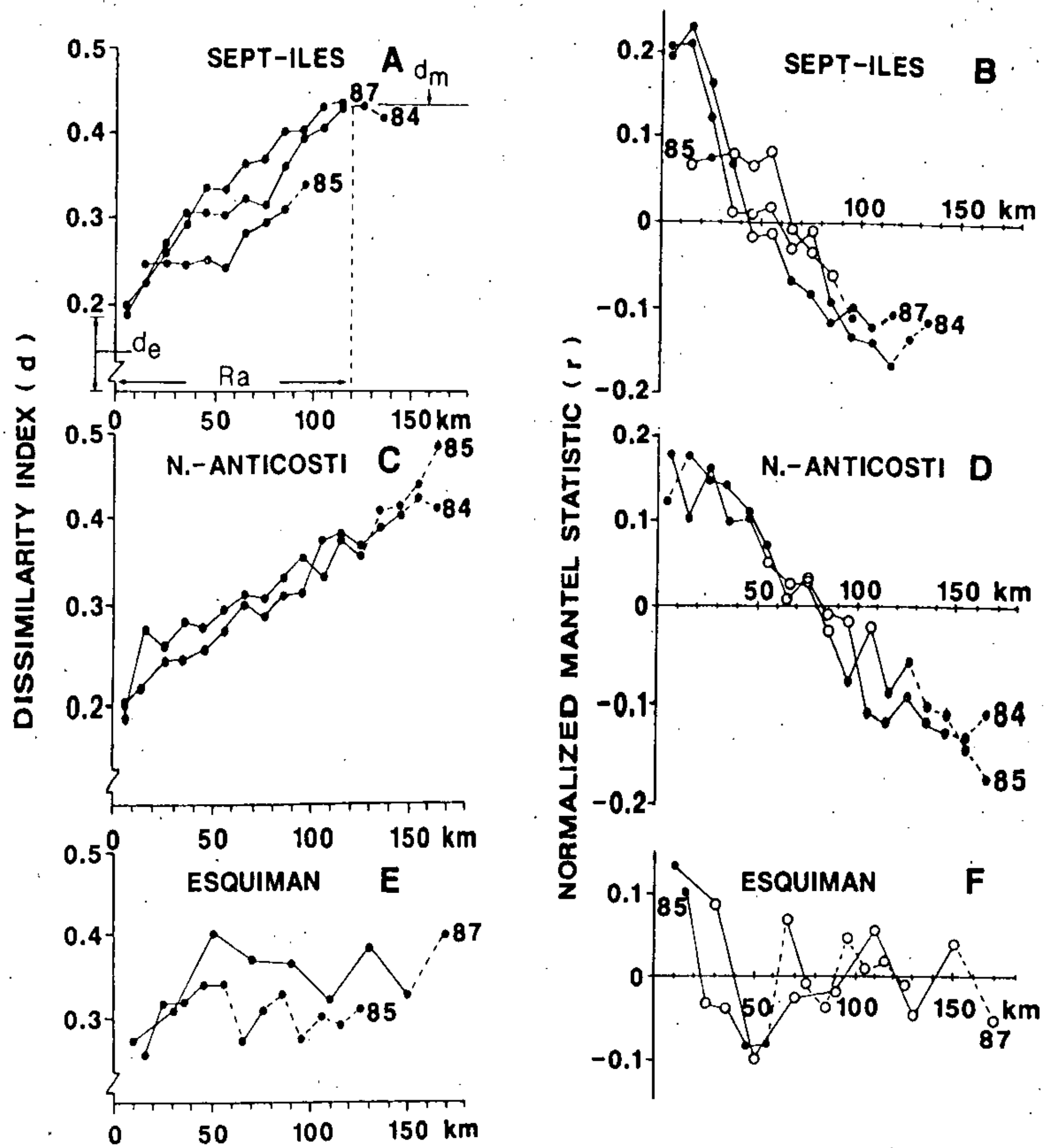

Figure 3. Spatial variograms (A,C,E) and correlograms (B,D,F) of similarity of LFDs for the three regions in the Gulf of St.Lawrence. Dotted lines indicate low n (20 < n < 30); open circles in correlograms are not significant (p > 0.01). Ra: range of influence of autocorrelation; d_m: maximum dissimilarity observed, d_e: residual variability of dissimilarity.

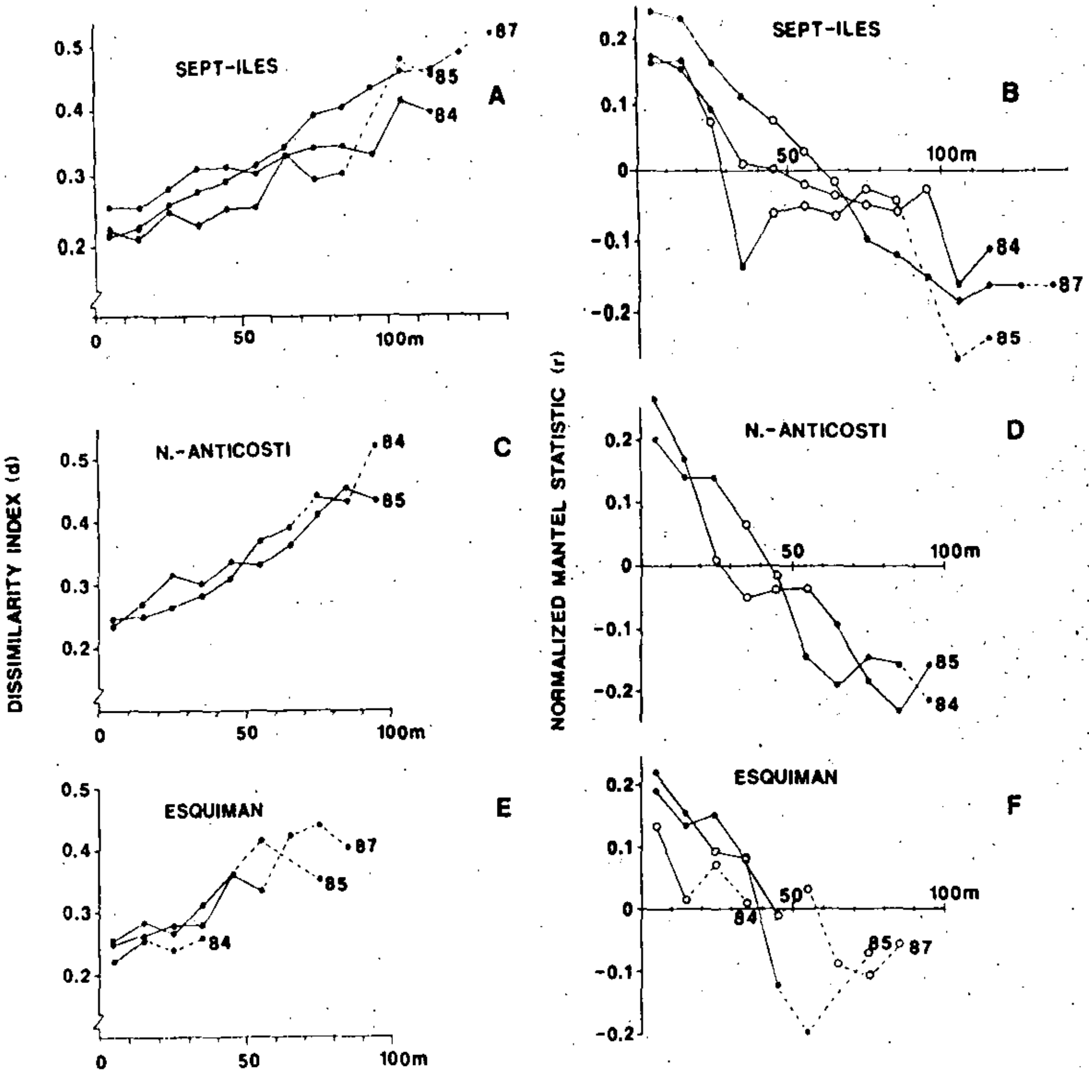

Figure 4. As in Fig. 3 but with depth separations between stations as X axis.