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Characterising the spatial distribution of fish schools with a point process approach: a first application on sonar recordings

by

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Pelagic fish schools occur in clusters of schools. The number of these clusters, their dimensions, the number of schools in them and the biomass per school are the major paramaters that influence both the catchability in a perse seine fishery and the precision of acoustic abundance survey estimates. At present, little is known on the variability of clustering parameters and in particular on their relation with the population abundance and the environment. Acoustic surveys give precise information on the location, the dimensions and the biomass of schools. It is thought that the cluster point process methodology should enable to characterize the spatial structure of schools. This study is an attempt to apply a marked point process approach to the occurrence of schools. As each school has some characteristics (dimension or biomass) the process considered is a marked point process where for each point, we have a value.

We used sonar image recordings stored on videotape. The sonar was omni-directional with a range of 2400m. The research vessel was stopped and the schools recorded during 4 hours. The video was stopped at fixed intervals and several measurements were made on the schools projections. Each school projection center was localised. Elliptical surface of each school projection was measured. The centers of the school projections were considered to be the points of the process and the school projection surfaces the marks of the point process.

The structural function L(h) showed that the schools were more regularly distributed than for a Poisson process for distances lower than 400m. Mark variogram functions showed in half of the cases that the surfaces of school projections were correlated between neighbouring schools up to the distance 1000m. Larger schools had on average less neighbours than smaller schools. This first attempt is considered successfull both methodologically and biologically as it also gives a statistical base for discussing how schools behave and interact.

Introduction

It is expected that in a near future, acoustic data will be sampled with multibeam sonars and multifrequency echosounders and that image analysis will play an important role in the statistical analysis. We have made a prospective study, using sonar images of schools as mapped point fields. We have used Point Process structural tools to characterise spatial structure of schools. Results are promising as they give insight on the relations between schools.

Such study is made to answer a major preocupation in pelagic fisheries and acoustic surveys: the influence of aggregative behaviour on the acoustic biomass estimate of fish stocks and on the catchability of the fish. In acoustic surveys, high density values are often very few and also possibly located close to poor densities. These two factors (few high values and important discontinuity in the spatial distribution when they occur) increase the variance on the biomass estimate of fish stocks. Biologically, such high values occur because of the fish aggregative behaviour (schooling or shoaling). Thus, the variance on the biomass estimate is indicative of our abilitty to predict the occurence of rich schools. Improvement in acoustic survey estimates is thought to come from adequate modeling of schooling. Fish aggregative behaviour (schooling and shoaling) potentially changes with time (day/night), environment, species assemblages and exploitation pattern. Thus, when coming back to a dense spot, the same biomass if it has stayed stationary may be structured in another biological form. For instance, one may not observe a few dense schools but many small ones or a dispersed layer. Assuming that no fish is missed, this does not affect the echointegration value but it highly affects the variance. It is also probable that the biological structure of the biomass (school, shoal, layer, dispersed) affects the acoustic estimate because fish reaction differs.

When the fish is in schools, these generally occur in clusters of schools. The biomass per school, the number of schools in the clusters, the number of clusters and their dimensions determine both precision in acoustic surveys and catchability in the fishery. In this paper we give primary results on school clustering which we have measured by sonar and attempted to characterise statistically using a Point Process approach.

1. Material and Methods

1.1. Survey

The R/V "Antea" of ORSTOM (the French Institute of Scientific Research for the Developement in Cooperation) performed an acoustic survey along the coast of Senegal in february-march 1996 in collaboration with CRODT (the Senegalese Oceanographic Research Center in Dakar). This survey is part of the programme "Varget" of ORSTOM designed to study the spatio-temporal variability of aggregative behaviour. The survey was designed in two parts. First an acoustic prospection with echointegration was performed (Fig.1). Secondly several experiments were performed on schools using sonar in areas that the prospection enabled to select. We used the sonar SIMRAD SR240 which is a long range multi beam sonar. The sonar has [redacted] beams of [redacted] each and is thus able in the omni direction mode to sample the 360° around the boat. The species were identified by trawling with a pelagic trawl.

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Species present were Sardinella aurita and S. maderensis (Clupeids) and also Trachurus trecae and Decapterus rhonchus (Carangids). Average lengths for the four species varied between 20-30cm and individuals were mature. We here concider only one experiement.

1.2. Sonar experiment and data

The vessel was stopped during 4 hours on february 7, just before and after dawn (6am-10am) in an area where schools had been previously observed, ie near latitude 14° on the coastal side of the transects were depths varied between 20-40m (Fig.1). We used the sonar in omni directional mode. The beams thus constitue a 360° umbrella. We used a tilt angle for all beams which varied between 5-10°. Thus the umbrella is not totally opened (Fig.2). Near the boat, schools not positioned in the sub-surface will not be detected where as away from the boat all schools in the water column will be detected. We assumed that schools were homogeneously distributed in the water column and did not considered the effect of the beam on the probability of detection of a school. The sonar range used was 2400m. This is smaller than the average correlation range (5Nm) observed on variograms in the area (Petitgas and Levenez 1996). Thus the spatial distribution of schools is observed here at small scale, inside clusters of schools.

The sonar screen was recorded on video tape via a camera connected to a magnetoscope. The sonar system enables to display on the screen fixed geographic points referenced by GPS. Such points on the sonar screen allow compute later the position of each recorded school trace. The tape was then sampled every 12mn and 20 still-pictures were analysed by drawing the school traces on transparencies. The number of schools varied during the 4 hours: it increased then decreased. For the purpose of the present study, we selected 5 still-pictures where the schools were in sufficient number to perform a statistical analysis for each image. On each image, the position of the center of each school trace was determined and the dimensions of the school traces along and across the beam were measured. We applied beam correction on the across beam dimensions as in Misund (1990). We applied no pulse length correction on the along beam dimension. We then estimated the elliptical surface of each school projection as in Misund (1990).

Let C_a be the apparent across beam dimension, C the corrected across beam correction and L_a the apparent along beam dimension. Let α be the beam angle (α=1.4°) and R the distance of the school trace center to the boat. The surface of the school projection is denoted m (the mark associated to the point materialising the school center). We have:
$C = C_a - 2R\,tg(\alpha/2)$ and
$m = CL_a\pi/4$

For each image, we worked on the marked point process made of the school trace centers where each point was attributed the value of the school projection elliptical surface (Figures 3, 4, 5, 6). The 4 sonar images are coded SI 3, SI 4, SI 5, SI 6. The number of schools per image is:

	SI 3	SI 4	SI 5	SI 6
School number	26	30	32	29

1.3.3. Relation between number of points and value of marks

The mark values for all images were regrouped and 4 classes were defined as follows:

	Class 1	Class 2	Class 3	Class 4
minimum (m^2)	0	247	668	970
maximum (m^2)	247	668	970	1542

We computed the average number of points in a disc neighbourhood around each point for each class of mark. This was performed for each image with a radius of 600m. The relation was linear and similar for all sonar images. We then repeated the computation for different radii and averaged the number of schools for all images. We took the linear regression line and presented how these lines vary with disc neighbourhood radii.

2- Results

The L- functions for the sonar images have been supperposed on Figure 7. All curves have a similar behaviour. They are under the diagonal Poisson line for distances smaller than 400m, then cross the line and stay above and close to it for larger distances. The fact that all curves show a similar behaviour is interpreted by us as significative. For small distances, schools would tend to be distributed more regularly than the random Poisson case. In other words, around an arbitary school, there is on average less schools than what a pure random process would generate.

The mark variogram functions are on Figures 8 and 9. For sonar images SI 4 and SI 5, we observe a clear correlation and a range of approximately 1000m. For sonar images SI 3 and SI 6, no correlation is clear. On Figures 4 and 5, we see areas of small schools and larger schools are somewhat out side of these areas. On Figures 3 and 6, big schools occur near smaller schools.

Figure 10 shows a clear linear relation between mark classes and the average number of schools. The average is computed for each sonar image in neighbourhoods (discs) of 600m of diameter centered around each school of the mark class. All sonar images have a similar relation. Figure 11 shows linear regression lines computed over all sonar images, for different values of the disc neighbourhood radius. Influence of the school surface on the number of neighbours is clear for radii greater than 400m. No computations were performed for radius lower 400m.

Discussion

The L- functions of the different sonar images supperposed well. This means that we may consider each sonar image as a realistion of the same underlying point process. There was time lag between each sonar image and each had very similar total school numbers. This means that there is reproductibility in the way schools are spatially organised and that this organisation possibly depends on the number of schools. The different sonar images also showed similarity in the relation between the number of neighbours and the school surface dimension. On the contrary, the spatial correlation between school dimensions was less reproductible. We believe that this non reproductibility is due to the relative position of the schools. Therefore, the correlation would be a fortuitous consequence and not a model parameter. There might be correlation for some realisations and not for others. On Figure Figure 12 we give a visual representation of our interpretative model.

The driving parameter seems to be the school dimension at the scale of the study, ie inside a cluster of schools. If we wanted to generate a point field having the characteristics observed, we would use a sequential procedure. First generate a random point with its random dimension which determines its "vital domain". Then take at random a new dimension for a new point. Then the random position of this new point is accepted if it lies outside all "vital domains" and if its "vital domain" does not intersect another one. Depending on the positions of big and small schools we may have correlation of school dimbnsions or not. Simulations could enable to test such assumption.

The statistical results obtained lead to behavioural interpretations. For distances lower than 400m, schools would interact and the consequence would be that a school has a certain "vital domain" around itself. The interaction can be either aggregation of schools in one or repulsion of schools. Noise can be advocated as a cause of interaction as Olsen (1976) has proved that fish in schools are able to detect sound several hundred of meters from the source (up to 400m) and react. Chemical reception could also be an important cause of interaction, also detectable on several hundreds of meters (Soria 1994 and references there in).

Larger schools have on average more emptiness around them than small schools. This would be compatible with the hypothesis of a population of schools being made of elementary unit schools. Schools would thus be the aggregation of elementary schools.

In the study of the relation between the number of neighbours and school dimension, more work is needed on the standardisation of the statistics by the school intensity for classes of marks.

It is possible that some bias exist in the sonar images (Fig.13). The number of detected schools per unit area decreased as the distance to the boat increased. We interpret this result as due to sound propagation and beam effect. A slight increase in the school surface with distance to the boat have also to be addressed. Corrections made are probably not enitrely sufficient. We don't know how these effects have influenced the present results.

Finally, analysis of school spatial distribution on sonar images with Point Process methodology seems very promissing. More analyses are needed and are programmed.

Ackonwledgments:

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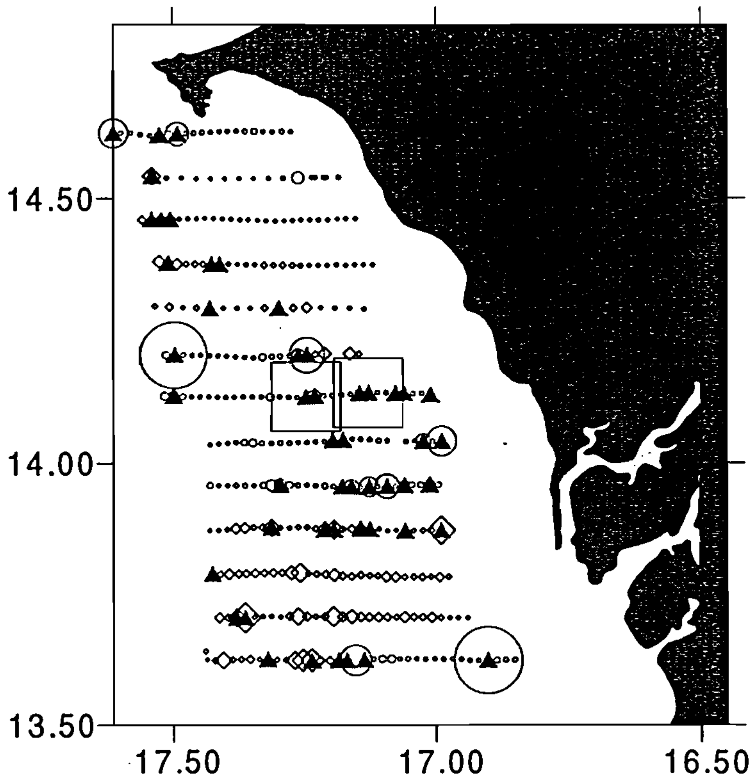


Figure 1: Acoustic prospection south of Dakar with proportional representation of backscattered energy per ESDU. (March 1996 - R/V "Antéa"). ESDU is1Nm long. Circles and diamonds indicate respectively day and night values. Squares represent very large values outside the range of other values. Black triangles indicate presence of large schools in the ESDUs. Sonar experiments were undertaken in the area around the point 17°W and 14°N where most schools and high densities were observed.

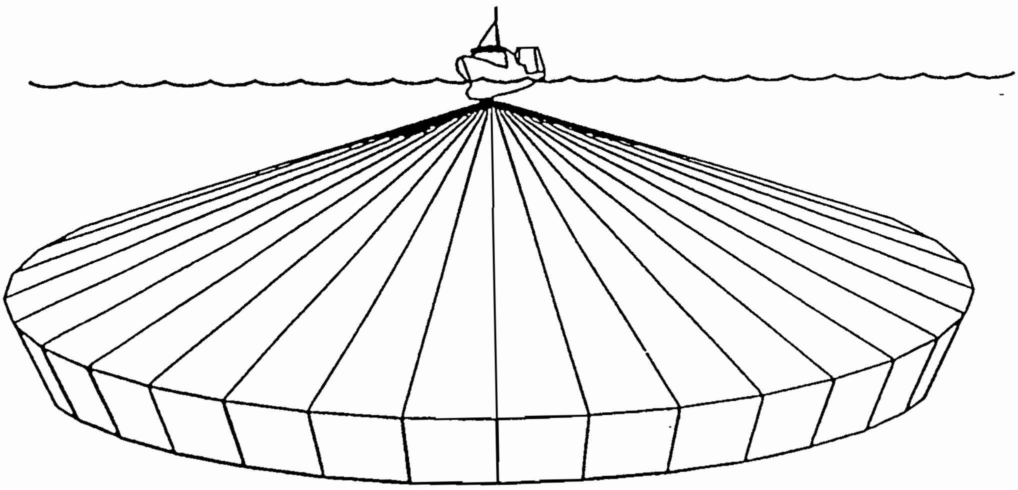


Figure 2: Representation of the 360° umbrella sampling volume of the sonar SIMRAD SR 240. The sonar has 256 beams of 1.4° angle. The sonar was used in omni direction mode. The boat was stopped drifting on depths of 30-40m. The sonar range was 2400m. The tilt angle for all beams varied between 5-10°.

Figure 3: Sonar image SI 3. Marked point field representing the school positions with proportional circles for the elliptical surface of the schools. The middle cross represents the position of the Research Vessel.

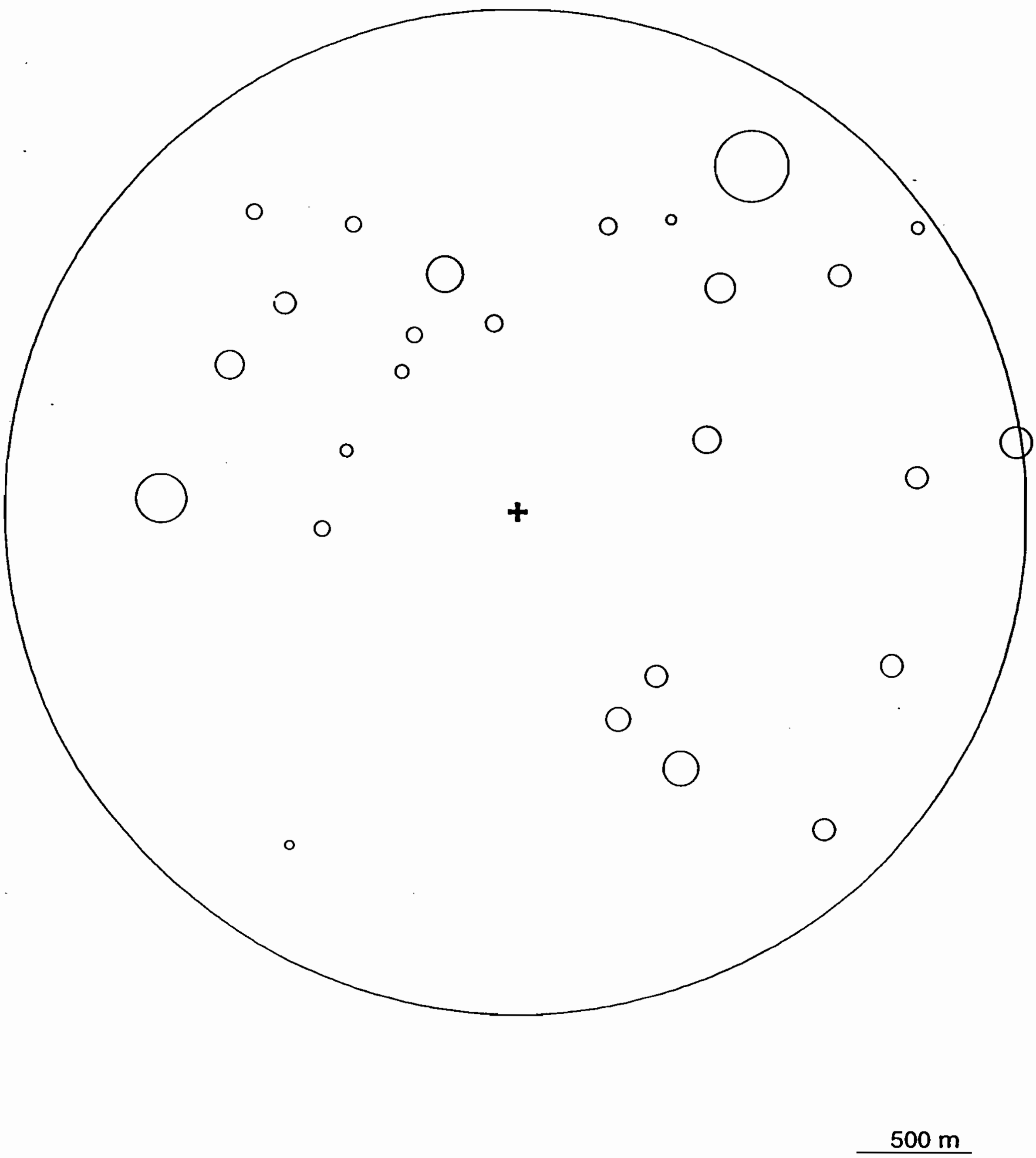


Figure 6: Sonar image SI 6. Marked point field representing the school positions with proportional circles for the elliptical surface of the schools. The middle cross represents the position of the Research Vessel.

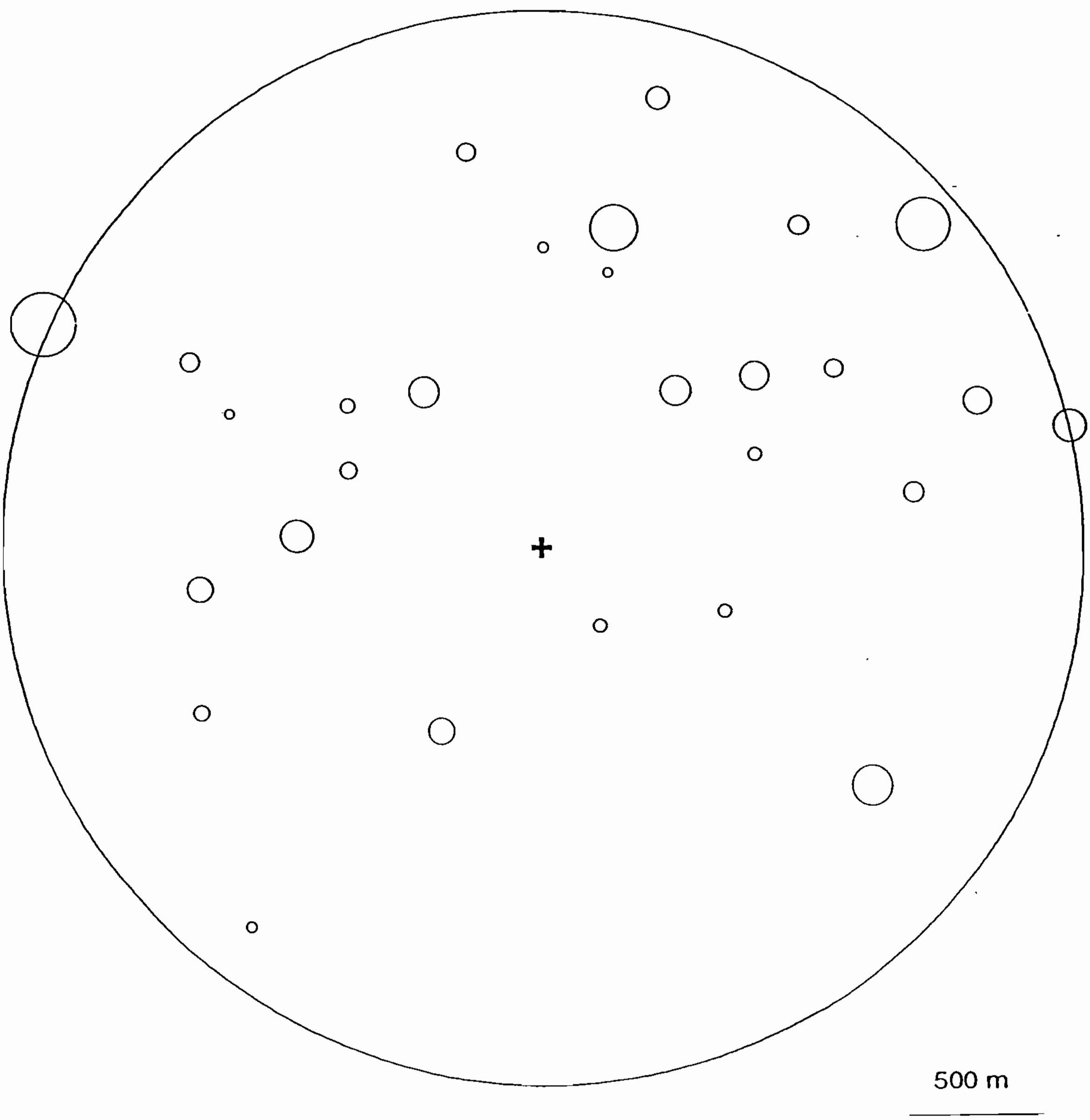


Figure 7: L- functions for the different sonar images. The diagonal dash line represents the L-function for a Poisson point process.

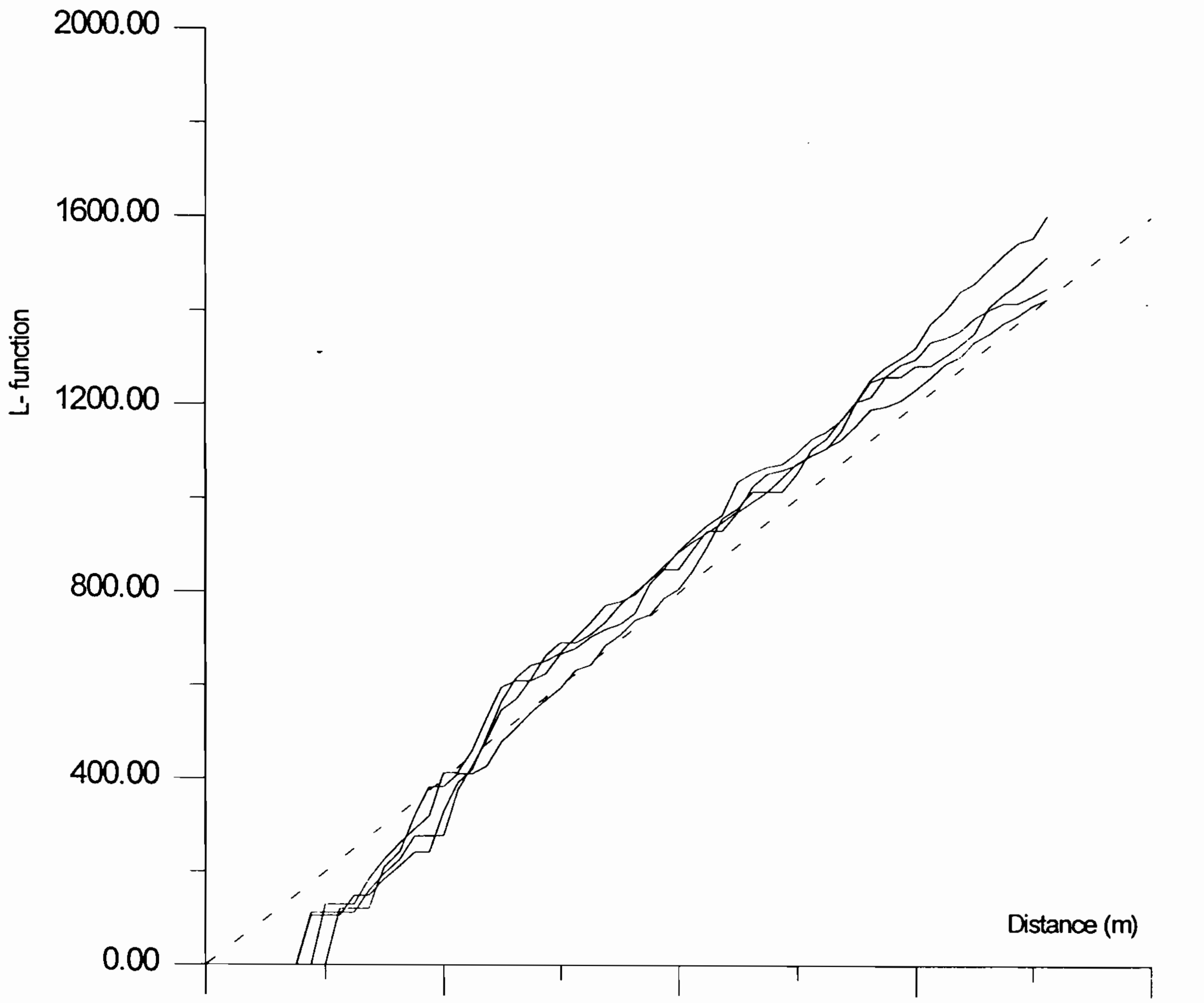


Figure 8: Mark Variogram functions for sonar images SI 4 and 5.

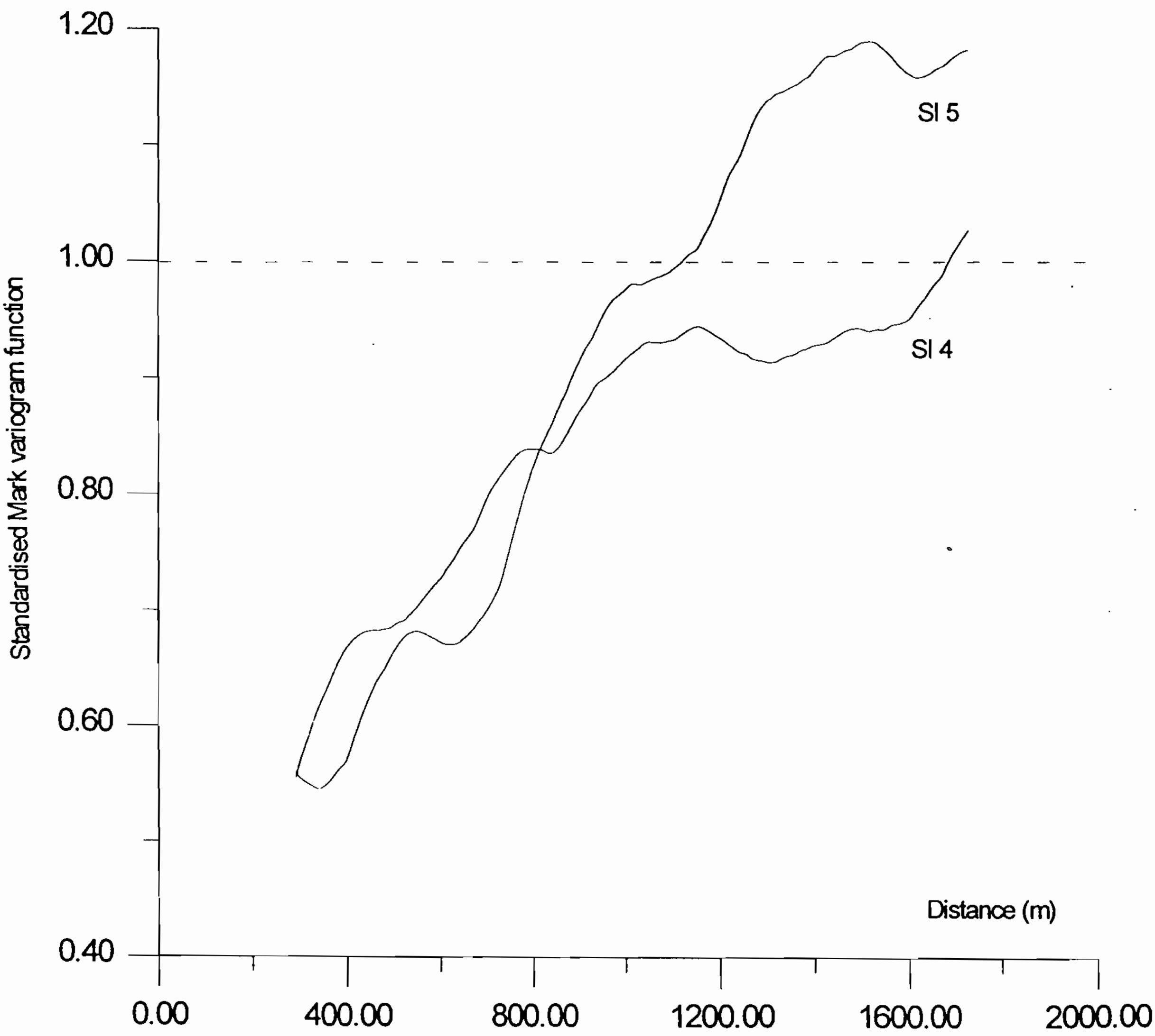
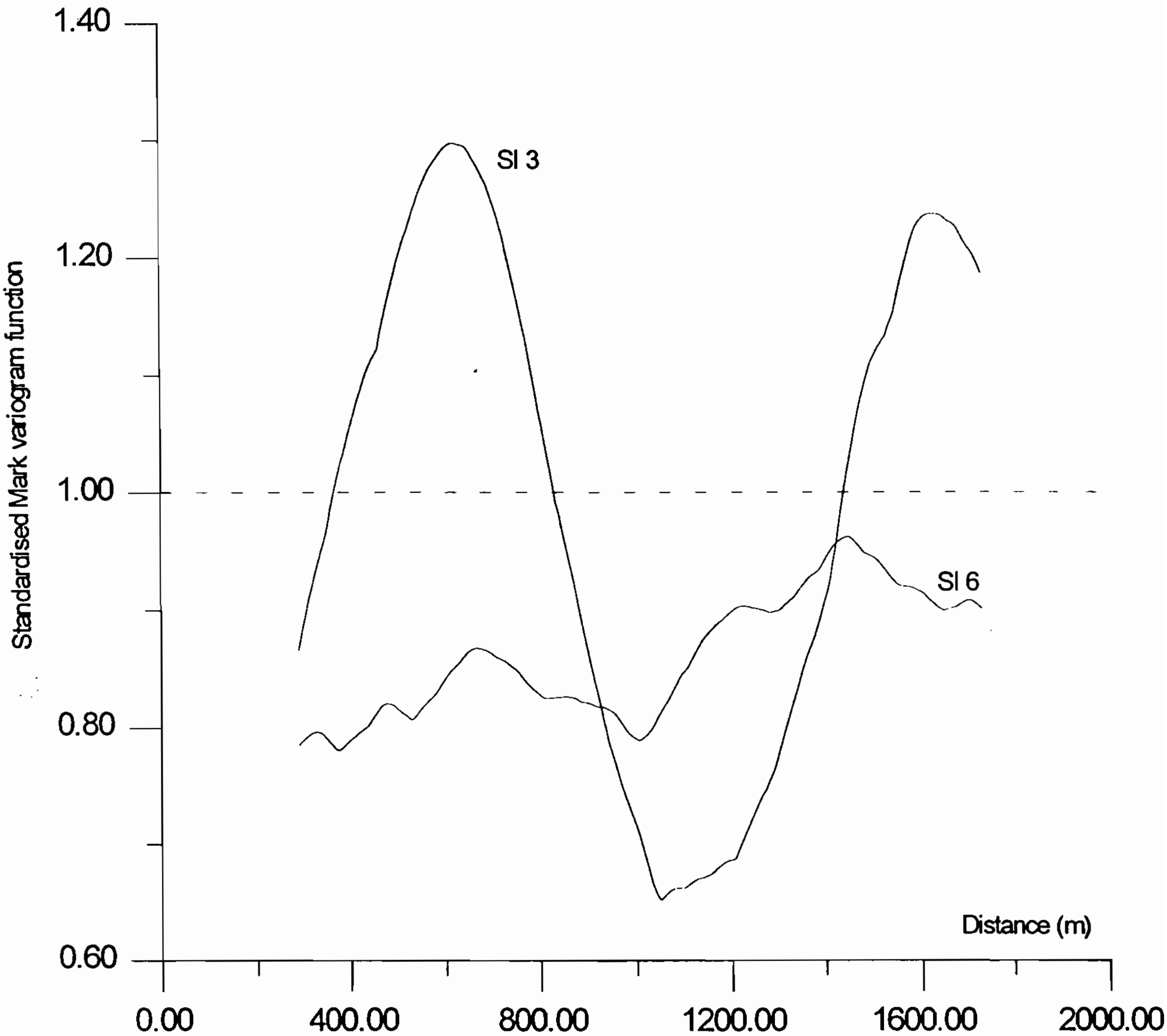


Figure 9: Mark Variogram functions for sonar images SI 3 and 6.



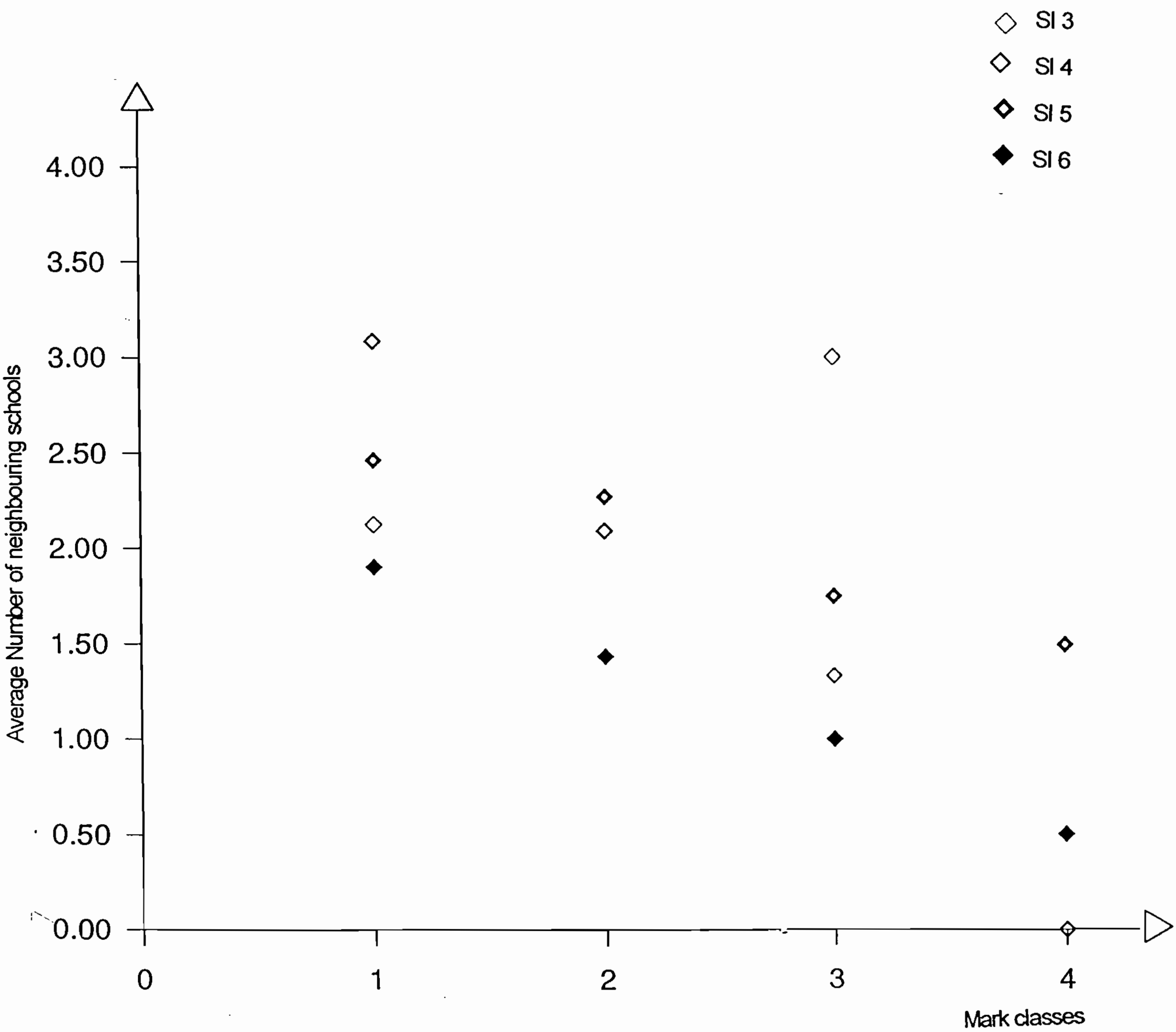


Figure 10: Relation between the school dimension and its average number of neighbours. Neighbours are counted in discs of diamater 600m. Mark classes are (m^2): 0-247, 247-668, 668-970, 970-1542.

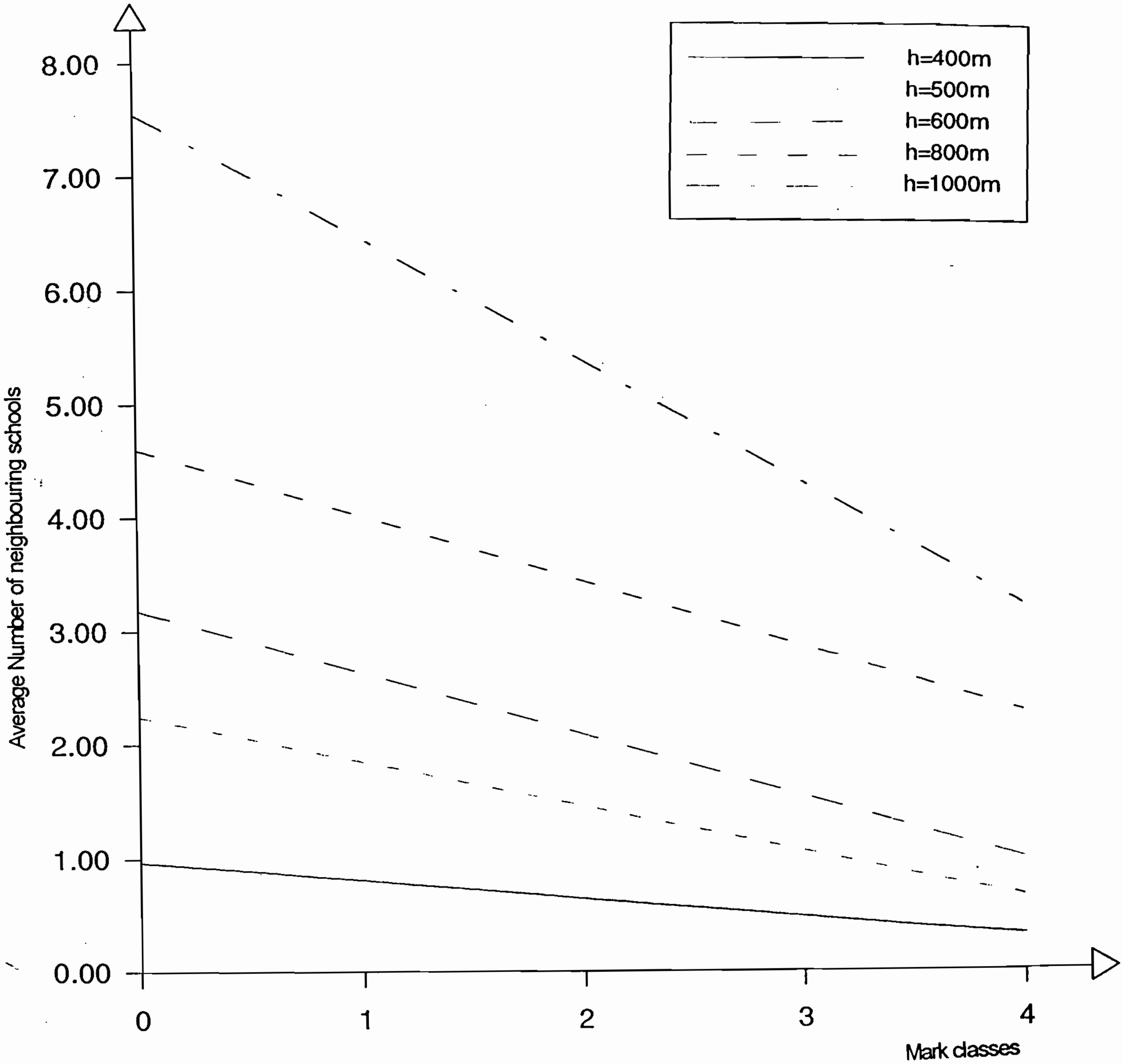
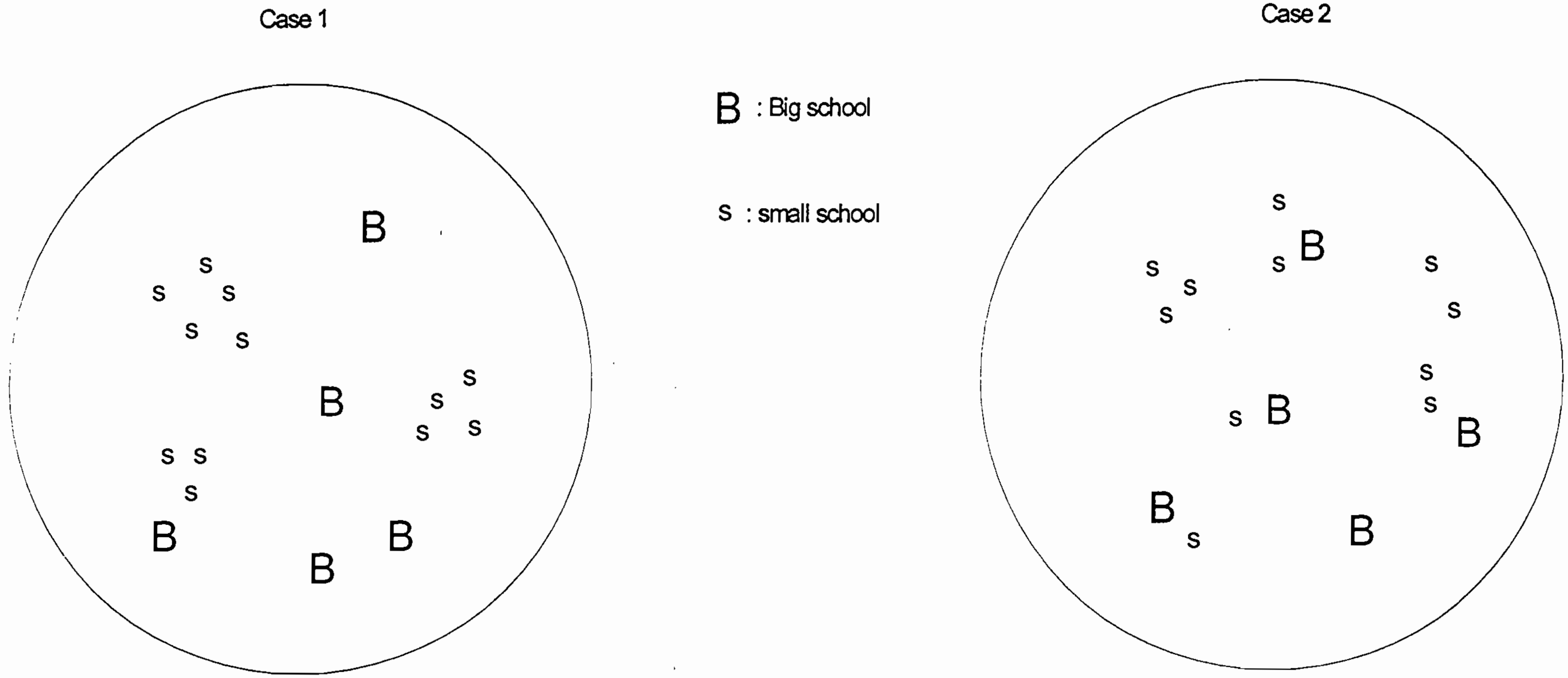


Figure 11: Regression lines of the number of neighbours on the dimension of a school, for different diameters, h, of disc neighbourhoods. Mark classes are (m^2): 0-247, 247-668, 668-970, 970-1542.



Cases 1 and 2 have the same L- function and the same relation between number of neighbours and school dimension but case 1 will have a structured Mark variogram function where as in case 2 there will be no structure.
Correlation between school dimension (ie areas where school dimensions tend to be alike) depends on school positions.
Relative position of points depends on school dimension.

Figure 12: Interpretative model proposed where the driving parameter is the school dimension. Case 1 and 2 represent 2 realisations of the model.

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