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Executive summary

The **Joint AcousMed project/ICES WGACEGG Workshop on Geostatistics** (WKACUGEO), chaired by Pierre Petitgas, France and Marianna Giannoulaki, Greece met from 20-21 November 2010 at Palma de Mallorca, Spain. The workshop allowed gathering most of the European acoustic surveys on anchovy and sardine in ICES and Mediterranean waters. The objectives of the workshop were to standardize data analysis methods for the evaluation and optimization of survey design.

Documents and formats were developed to prepare data, apply basic geostatistics and report results, which allowed standard applications to the many case studies. The framework of linear geostatistics was flexible and robust enough to allow analyse all case studies, extract the underlying spatial correlation structure, estimate survey precision for the current survey design and evaluate other designs. Appropriate geostatistical tools (ToR a) were applied in each case study, based on the peculiarities of the acoustic data in each area, in order to evaluate the precision of abundance estimates (ToR b). The precision of abundance estimates was estimated for different survey designs (ToR c) as well as under the current survey design and taking into account different autocorrelation range values concerning the spatial structure of fish populations (ToR c). For harmonization purposes, the data were prepared following common guide lines; common software was used in the analyses and case study results reported with a common reporting format.

In total 11 Case Studies (five Case Studies from the Mediterranean Sea, five Case Studies from the Atlantic waters and one from Tasmanian waters) were analysed and results reported. The target variable to analyse was left at the appreciation of each case study leader. The precision of the global mean estimate for that variable was estimated to characterize survey precision, using standard linear geostatistics. The underlying spatial correlation range modelled from the survey data were close in value to the inter-transect distance. Survey precision lied in the range 0.05 – 0.19 per cent of the mean estimate. Survey precision was often a non-linear function of inter-transect distance. Therefore, decreasing survey effort had a negative effect on survey precision while increasing it had a moderate positive affect.

The workshop concentrated on spatial error because of survey coverage only. But acoustic surveys have other sources of error in addition to area coverage. The full variance of species abundance at length or age was not considered. For that purpose, the use of more elaborate geostatistics would be necessary. A future perspective could be an ICES training course as well as a permanent ICES geostatistics sharepoint to follow up on applications and build a community of practitioners.

1 Introduction, opening of the meeting, and adoption of the agenda

The workshop was the opportunity to standardize data analysis methods for anchovy and sardine acoustic surveys in ICES and Mediterranean waters. The interest in a joint Atlantic and Mediterranean workshop was to encompass the majority of the European case studies on anchovy and sardine acoustic surveys. A general need to improve anchovy and sardine acoustic survey designs had been identified by members of the EU-funded project AcousMED and ICES WGACEGG and to this purpose geostatistics was considered an appropriate tool. Being involved in Spanish surveys in both Atlantic (ICES) and Mediterranean waters, the acoustic survey team of IEO in Palma de Mallorca was well positioned to host the Workshop.

The co-Chairs (Pierre Petitgas, France and Marianna Giannoulaki, Greece) opened the meeting. The Workshop was attended by 18 scientists from six countries (Annex 1). The group was welcomed by the local host Dr Magdalena Iglesias (IEO) who expressed her delight that the group was meeting in Palma and highlighted the facilities that were available to the group throughout the workshop.

A draft agenda was circulated in advance of the meeting. The adopted agenda is presented in Annex 2.

The Terms of Reference addressed by the group were (Annex 3):

a) Apply geostatistical tools on case studies;

b) Evaluate the precision of abundance estimates using geostatistics for a list of MEDIAS- and ICES-coordinated acoustic surveys;

c) Suggest how survey designs can be optimized.

2 Approach followed

To address the Terms of Reference the work was organized as explained below. Standard linear geostatistics were used to characterize the underlying spatial autocorrelation in the data and compute the estimation variance of the mean estimate over the survey area. Briefs on acoustic survey errors (Section 1.1) and geostatistics methods (Section 2.2) were presented and a list of basic geostatistics references was provided (Annex 4). Also prior to the meeting a tutorial was provided to WK participants with software and R scripts and an example case study together with guide lines for preparing the data case study files (Section 2.3). A format was agreed for presenting case study key information relevant to the analyses (Section 2.4). Finally a reporting format was agreed to present the results (Section 2.4).

2.1 Sources of error in acoustic surveys

Using geostatistics we will analyse how spatial error due to survey coverage affects the precision of the global mean survey estimate. But acoustic surveys bear other sources of error, which have been well documented elsewhere (e.g. Simmons and MacLennan, 2005; Rivoirard *et al*., 2000).

Acoustic surveys are made of two sampling processes (e.g. Simmonds and MacLennan, 2005). The acoustic part of the survey is dedicated to spatial coverage by recording echotraces along-transect lines. The biological part of the survey is dedicated to fishing echotraces at stations. Fishing serves to i) identify echotraces to species and ii) perform biological measurements by species (length, age, maturity). When designing a survey the total sampling effort must be partitioned into time for fishing operations and acoustic spatial coverage. The two processes are often considered uncorrelated although fishing stations are opportunistic and often located conditionally to observed echotraces.

The species-specific fish density estimate in a particular ESU (elementary distance unit) along an acoustic transect is derived by combining different sources of information: the echointegrated acoustic density of the unidentified echotraces (echo sA value or NASC), the part of the NASC allocated to the target species, the species length and the species target strength at length (TS). The spatial error is often dominated by the spatially aggregated echotraces. But the identification error can be as large as the spatial error in mixed species ecosystems (e.g. Petitgas *et al*., 2003). To access to the full error variance of the estimate, geostatistical simulations are useful to combine the error in the different variables of the different sampling processes (e.g. Woillez *et al*., 2009).

Here, we have been concerned by the spatial error only; due to the area coverage of the acoustic transect lines. Depending on the variable considered in the analysis, the other sources of error are implicitly considered or not. If working on total fish NASC per ESU (not partitioned into species) one will analyse spatial variability only. In contrast, working NASC or abundance by species, other sources of error contribute implicitly to the data variability and will be analysed here as spatial variability.

2.2 Geostatistical methodology

Geostatistics links the sample locations with the underlying population spatial correlation structure to compute the precision of the mean estimate (Matheron, 1971). Therefore geostatistics can be used whatever the survey design. In the fisheries context, geostatistics has been useful to evaluate / discuss survey design (Rivoirard *et al*., 2000).

How to design a homogeneous survey over an area can be thought of in geometrical terms. In particular for acoustic surveys of pelagic schooling fish a major question is how to calibrate the inter-transect distance to patches of high values. This can be answered by taking indicators of high values and characterizing their average patch dimension. Or we can consider the underlying spatial correlation structure, which applies to all ranges of values. The inter-transect distance should be close to patch dimension or the correlation range for regularly spaced transects to encounter enough patches. Here we considered homogeneous survey designs (not adaptive sampling) and linear geostatistics (intrinsic case: Matheron, 1971). In this approach, the structural tool is the variogram. The variogram measures how on average in the area the variance between pairs of points increases with increasing vector distance between them. We considered evaluating survey precision using the precision of the mean survey estimate.

The mean estimate over a given area V, Z_V, is estimated by a linear combination of sample values $Z_V^* = \sum_\alpha \lambda_\alpha Z_\alpha$. The weights λ_α that sum to unity will ensure unbiasedness of the estimate by filtering a constant mean. The geostatistical estimation variance $Var[Z_V - Z_V^*] = E[Z_V - Z_V^*]^2$ develops in three terms (Matheron, 1971), which writes simply when the estimate is the simple data average as:

$$\sigma_E^2 = 2\bar{\gamma}(\alpha,V) - \bar{\gamma}(V,V) - \bar{\gamma}(\alpha,\beta) \qquad [1]$$

The term $\bar{\gamma}(\alpha,\beta)$ is the average variogram value between all pairs of sample points (double summation of the γ). It depends on the variogram and how the samples are positioned relative to each other. The term $\bar{\gamma}(V,V)$ is the average variogram value between all pairs of points in V (double spatial integration of γ over V). It depends on the variogram and the geometry of V. The term $\bar{\gamma}(\alpha,V)$ is the average variogram value between sample locations and all points in V. It depends on the variogram and how the samples are positioned in the area V.

Equation [1] is key for comparing survey designs and estimating their precision. It states that the estimation variance depends on the data locations, the geometry of the area V and the variogram (underlying population spatial correlation structure), but not on the data values themselves. Therefore the precision of the mean estimate can be computed using different survey designs by generating data locations without knowing the data values but considering that other designs would provide data that would allow estimating a similar variogram (underlying structure) as that used.

Equation [1] can be computed for a variety of survey designs, whether random, random stratified, regular, zig-zag (e.g. Petitgas, 2001). For simple regular designs, approximation formulae were developed and the estimation variance charted as a function of grid mesh dimension and correlation range (Matheron, 1971).

In the case of parallel transects regularly spaced, we considered the following 2D estimation configuration. The estimate of the global mean is the weighted sum of strata means where the strata are the rectangles of influence around each transect. Each acoustically sampled transect is the continuously sampled mid-line of its rectangle of influence. There is no estimation error along the line. The mean rectangle value is estimated by the mean along the transect. The estimation errors between rectangles are considered uncorrelated. The estimation variance of the global mean is a linear combination of elementary estimation variances:

$$\sigma_E{}^2=\sum_i w_i{}^2\sigma_i{}^2 \ ; \ w_i=l_i/\sum_i l_i$$

where i is the index of transects, l_i the length of transect i, and $\sigma_i{}^2$ is the estimation variance in the rectangle of influence of transect i. The estimation variance $\sigma_i{}^2$ is computed using equation [1].

This 2D estimation configuration leads to similar estimation results as a 1D configuration obtained by summing the transect values and performing the estimation in 1D on the sequence of regularly spaced transect sums along a line (Petitgas, 1993).

In the case of zig-zag transects, equation [1] can be applied over the entire surveyed area, with the transects considered as continuously sampled with no estimation error along the track.

The software EVA (Petitgas and Lafont, 1997) allows estimating the variogram from survey data, model it and compute the estimation variance for a variety of designs, including regular designs (approximation formulae), zig-zag transects, scattered individual sampling points.

2.3 Software and data files

Prior to the meeting documentation on geostatistics was posted on sharepoint with a reference list (Annex 4). A Software and an R script were posted on sharepoint with an example case study for the participants to get acquainted prior to the meeting with the technicalities of geostatistical computations that allowed to address the ToRs. The R script was designed to serve as tutorial for the analyses to be carried out during the workshop. The software used were EVA (Petitgas and Lafont, 1997) and the R script used the R library RGeoS (Renard and Bez, 2008).

Data files were prepared prior to the meeting following the instructions below.

Data file: text format with separators '\t' or ';' (the decimal symbol is '.')

Col.1=year or survey code

Col.2=longitude (decimal degrees)

Col.3=latitude (decimal degrees)

Col.4=variable to be analysed (sA value or biomass of target species)

Col.5,…n = any other variable (for another species or environment)

Polygon file: text format with separators '\t' or ';' (the decimal symbol is '.')

Col.1=longitude (decimal degrees)

Col.2=latitude (decimal degrees)

Columns contain the coordinates along long and lat of the polygon vertices. The polygon is closed: first and last lines are the same.

Polygon for selecting the data to be analysed may differ from that for mapping.

Grid file: text format with separators '\t' or ';' (the decimal symbol is '.')

Line.1: x0,y0: coordinates (decimal degrees) of the lower left corner

Line.2: dx,dy: mesh size (decimal degrees) along x and y

Line.3: nx, ny: number of grid cells along x and y

The file contains 2 columns and 3 lines.

Survey design file: EVA2 format. See Section 4.3.1 in document ICES CM 1997/Y:21. An empty formatted file can be created using EVA2 (file/create Eva data file).

Line.1 : comments or nothing

Line.2 : comments or nothing

Line.3 : header

Line.4,…n : data

Depending on the case study, the requirement is to fill with values Cols.1,2 (x,y : 2D analysis for regular parallel transects) or Col.4 (lg tr. : 1D analysis for regular parallel transects : transect lengths) or Cols.15,16 (rtex,rtey : zig-zag survey). If polygons are considered, Cols. 5–6, …, 13–14 (px1 py1, … px5, py5 : closed polygon vertices) need be valued. If problems with EVA in selecting survey points inside polygon, Col.3 should be valued.

The survey design file (data locations only) will serve to estimate the precision of the survey mean estimate, given a variogram model. Different survey designs (i.e. files) can be constructed and their precision compared.

Transformation of coordinates: In order to compute distances longitude need be transformed so that the same unit along x and y correspond to the same distance. A simple projection is to multiply the longitudes by the cosine of the survey area mid-latitude.

2.4 Workshop case studies

Also prior to the meeting a working group member was assigned as the lead for each Case Study. He/her provided a brief outline of the acoustic survey analysed in each Case Study. The presentations followed a format agreed prior to the meeting:

- Brief on survey series: name, target species, period of life cycle, number of days at sea, number of years in the series
- Data to be analysed (year, long, lat, target variable) + time-series of box-plots (one boxplot per survey) showing variability of values in each year and across years
- Bubble plot maps: one map for average, low and high biomass along the series, to evaluate density-dependence in the spatial distributions
- A list of other important sources of error than spatial variability
- A list of problems encountered so far when applying geostatistics and software used

Workshop case studies were:

Mediterranean waters

- Mediterranean Spanish waters (Annex 5) – Pilar Tugores and Magdalena Iglesias (IEO)
- Gulf of Lions (Annex 6) – Jean Louis Bigot and Mathieu Doray (Ifremer)
- Sicily Channel (Annex 7) – Marco Barra (CNR IAMC)
- Adriatic Sea (Annex 8) – Andrea De Felice and Fabio Campanella (CNR ISMAR)
- North Aegean Sea (Annex 9) – Marianna Giannoulaki (HCMR)

Atlantic waters

- Mediterranean Spanish waters (Annex 10) – Marian Peña and Magdalena Iglesias (IEO)
- Bay of Biscay French shelf (Annex 11) – Mathieu Doray and Pierre Petitgas (Ifremer)
- Celtic Sea (Annex 12) – Jeroen Van Der Kooij (Cefas)
- Bay of Biscay, juvenile surveys (Annex 13) – Guillermo Boyra (AZTI)

Australian waters

- Tasmanian waters (Annex 14) – Tim Ryan (CSIRO)

Acoustic survey characteristics are summarized in Tables 2.1 and 2.2. Figure 2.1 shows a map with the location and extent of ICES and Mediterranean coordinated acoustic surveys whose target species are sardine and anchovy.

Table 2.1. Summary table of case studies in the Mediterranean Sea.

Survey Identity	Greece - Aegean Sea	Italy - Adriatic Sea	Italy – Sicily Channel	France - Gulf of Lions	Spain - Iberian Coast
Geographic area	northern Aegean Sea	Western side (Italy + Slovenia)	Strait of Sicily	Gulf of Lions	Spanish Mediterranean Sea (continental shelf)
Size of Area covered (NM2)	9 000 NM2	About 16 500 nm2	2 680 nm2	3 300 nm²	6 922 nm²
Days at sea	40	41	10	20	31
Period of survey	June-July	July - September	July	July	November-December
Echo sounder	Biosonic DTX (Split-beam)	Simrad EK60 (Split-beam)	Simrad EK60 (Split-beam)	Simrad ER60 since 2006 (Split-beam)	Simrad EK60 (Split-beam) since 2006
Frequency for assessment (kHz)	38	38	38	38	38 kHz
Threshold for assessment (dB)	-70	-70	-60	-60	-60 dB
Survey design					
Transects design	Perpendicular to bathymetry, zig-zag inside the gulfs	Parallel grid, perpendicular to the coastline/bathymetry	Parallel transects and perpendicular to bathymetry	Perpendicular to the coastline/bathymetry	Perpendicular to the coast
Inter-transect distance (nm)	10 NM	10 NM and 8 NM in narrow shelf areas	4–8 NM	12 NM	8 NM in wide continental shelf, 4 NM in narrow shelf
Transect length (min – max)	10 – 70 nm	5–40 nm			
Time of day for acoustic sampling	Daytime	Daytime & night-time	Daytime & night-time	Daytime	Daytime
EDSU (NM)	1 NM	1 NM	1 NM	1 NM	1 NM
Min Bottom depth sampled(m)	10 m	10 m	10 m	10 m	30 m
Echo sounding depth (m) recording.	230	250	300	200	200–220

Survey Identity	Greece - Aegean Sea	Italy - Adriatic Sea	Italy – Sicily Channel	France - Gulf of Lions	Spain - Iberian Coast
Vessel speed	7 kn	9–10 kn	9–10 kn	8 kn	10 kn
Echo partitioning into species	Echo trace classification based on echogram visual scrutinisation and allocation on account of representative fishing station	Frequencies comparison, catch of pelagic trawl, TS analysis when needed	Visual analysis of echogram and from results of control trawl	Echo trace classification based on echogram visual scrutinisation and allocation on account of representative fishing station	Allocation on account of representative fishing station (sometimes direct allocation).
Abundance indices estimated	Total fish NASC per EDSU Anchovy, Sardine NASC per EDSU	Total fish NASC per EDSU Anchovy, Sardine NASC per EDSU	Total fish NASC per EDSU Anchovy, Sardine NASC per EDSU	Pelagic biomass and biomass per species, Biomass per nautical mile	Total fish NASC per EDSU Anchovy, Sardine NASC per EDSU
Target species	Anchovy Sardine	Anchovy, sardine	Anchovy and Sardine	Anchovy and Sardine	Sardine, anchovy
Other species	Horse mackerel Mackerel Gilt sardine	Sprat, atl. mackerel, horse mackerel, chub mackerel, bogue, gilt sardine	Mackerel, Sardinella, Horse mackerel	All pelagics	Trachurus mediterraneus, bogue, sardinella, Scomber colias & Scomber scombrus.

Table 2.2. Summary table of case studies in the Atlantic and Tasmania.

Survey Identity	Gulf of Cadiz - IEO	Atlantic - AZTI	PELACUS - IEO	Bay of Biscay PELGAS - Ifremer	Cefas	Tasmania - CSIRO
Geographic area	Gulf of Cadiz	Bay of Biscay	Atlantic Spanish waters and Cantabrian Sea	Bay of Biscay French shelf	Western Channel - Celtic Sea	Tasmania
Area covered (NM2)	3618 nm2	40000 nm2	6614 nm2	~30000 nm²	~50000 nm2	
Days at sea	10–15	30	20–25	30–40	22	60
Survey period	June-July	Autumn	March-April	Spring	May-June	June-August
Echo sounder	Simrad EK60 (Split-beam)	Simrad EK60 (Split-beam)	Simrad EK60 (Split-beam)	Simrad ER60 since 2006 (Split-beam)	Simrad EK60 (Split-beam)	Simrad ES60, ES38B 7 degree split-beam transducer
Frequency for assessment (kHz)	38	38	38	18, 38, 70, 120, 200 + multibeam (70 to 120)	38	38
Survey design						
Transects design	systematic grid with tracks perpendicular to coast	Parallel grid, perpendicular to the coastline/bathymetry	Parallel transects and perpendicular to bathymetry	Perpendicular to the coastline/bathymetry	Transects, perpendicular to coastline/bathymetry, stratified	Many opportunistic grid surveys of localized schools and 1–2 broadscale surveys of entire 100 NM spawning grounds
Inter-transect distance (nm)	8 NM	17 NM (2003 – 2005) and 15 NM (since 2006)	8 NM	12 NM	10 and 20 NM	Adaptive, typically between 0.3 and 1 NM
Transect length (min – max)	4- 21 nm	30- 100 nm	4- 27 nm	25 – 95 nm	16–150 NM	3–5 NM
Time of day for acoustic sampling	Daytime	Daytime	Daytime	Daytime	Daytime	Day and Night
EDSU (NM)	1 NM	0.1 NM	1 NM	1 NM	1 NM	0.1 NM
Min Bottom depth sampled (min, m)	20 m	15 m	10 m	20 m	15m	300 m

Survey Identity	Gulf of Cadiz - IEO	Atlantic - AZTI	PELACUS - IEO	Bay of Biscay PELGAS - Ifremer	Cefas	Tasmania - CSIRO
Echo sounding depth (max, m) recording.	200	200	300	200	200	700 m
Vessel speed	10 kn	7 – 10 kn	10 kn	10 kn	10kn	10 kn
Echo partitioning into species	Allocation on account of representative fishing station (sometimes direct allocation).	Allocation on account of representative fishing stations, area stratification based on the homogeneity of the aggregations	Allocation on account of representative fishing station (sometimes direct allocation).	Allocation on account of representative fishing stations and echo types, area stratification based on the homogeneity of the aggregations	Unknown survey will be in 2011.	Visual classification of schools, then assume school regions contain 100% blue grenadier
Abundance indices estimated	- Total fish NASC per EDSU - Anchovy, Sardine NASC per EDSU	Biomass of anchovy juveniles per EDSU	Total fish NASC per EDSU Anchovy, Sardine NASC per EDSU	Nasc and biomass/esdu/length class/age		Biomass for each survey, maximum biomass in each year then used in assessment
Target species	Anchovy	Anchovy juveniles	Sardine	Anchovy, Sardine	Sardine, Anchovy	
Other species	All pelagics	All pelagics (since 2010)	All pelagics	All pelagics	All pelagics	Blue grenadier (Macruronus novaezelandia)

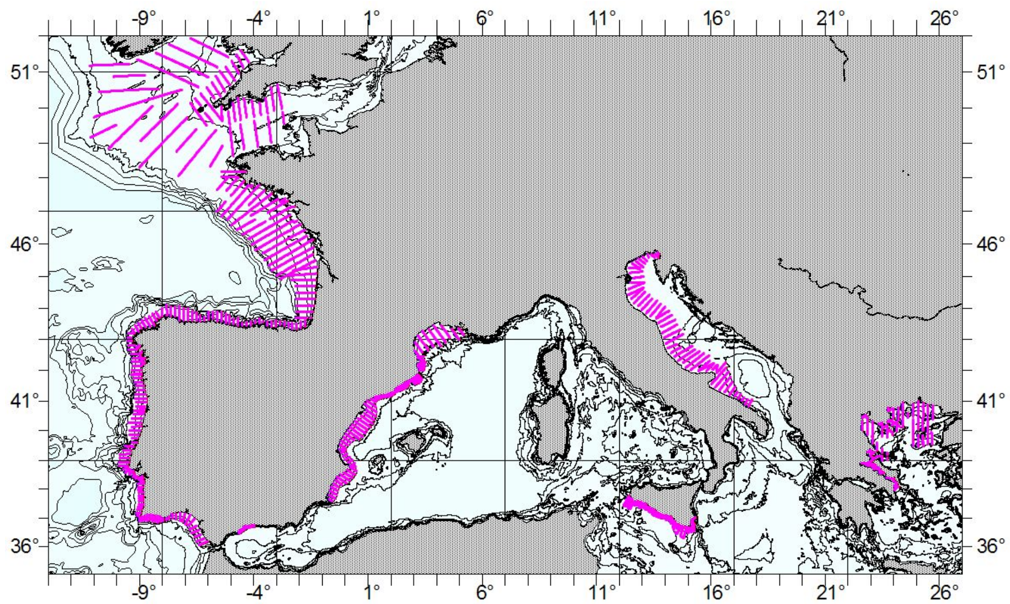


Figure 2.1. Survey designs (acoustic transects) used in the acoustic surveys in Mediterranean and Atlantic waters.

2.5 Reporting format

Reporting was at least for one year, one species and included the following items.

Data visualization:

Basic statistics: histogram, mean, CV

Bubble plot of z(x) and Ln(1+z(x)), with coast and estimation polygon

Variogram:

Experimental + model

Comments explaining the structure

Estimation variance:

Geostatistical estimation coefficient of variation (CVgeo) for survey

Optimization of design:

Curve of the estimation variance as a function of different survey designs

If different years are considered, an average variogram can be used

Table 2.3. Reporting format for case studies.

ITEMS TO REPORT ON	TOOLS TO USE
Data: basic data statistics: histogram, mean, CV	RGeoS or EVA
Data: bubble plot maps of z(x) and Ln(1+z(x)) with coast and estimation polygon	RGeoS or EVA
Variogram: Experimental + model	RGeoS or EVA
Estimation variance: CVgeo for survey analysed	Scattered points: RGeoS or EVA Parallel regularly spaced transects: EVA Zig-zag transects: EVA
Survey design: Curve Var.estim = func(different survey designs) using variogram model	Scattered points: RGeoS or EVA. Generate new sample locations Parallel regularly spaced transects: EVA. Generate new transect lengths (col.4 Eva data file) Zig-zag transects: EVA. Genereate new zig-zags (cols.15,16 Eva data file)

3 Progress on the Terms of Reference

3.1 ToR a) Apply geostatistical tools on case studies

Geostatistics was applied to all case studies, which encompassed a diversity of situations. A diversity of approaches has been used.

3.1.1 Variable analysed

The target variable to analyse was left at the appreciation of each case study leader. The precision of the global mean estimate for that variable was estimated to characterize survey precision.

For most case studies the target variable analysed was the NASC attributed to a species (anchovy or sardine) per ESU (elementary sampling unit) along the acoustic transect lines. The survey precision for that variable will then highlight the ability of the survey to effectively estimate the mean NASC of the species. The data values will contain other sources of error in addition to spatial error. If the NASC is attributed to species by expert scrutiny of the echogram (see Section 1.1) the additional error will be that of echogram scrutiny. If the total fish NASC is split into species based on acoustic proportions of species as observed in the trawl hauls (Simmonds and MacLennan, 2005, chap. 9) the additional error will be a mix of errors on the species TS, spatial distribution of species and mean length of species.

In contrast, in two case studies we used the total fish NASC value that was not partitioned into species (Bay of Biscay Pelgas surveys and Adriatic Sea surveys). The survey design was then tested for its ability to sample echotraces irrespective of species. The surveys are ecosystemic and provide abundance estimates for all pelagic species.

In other case studies species abundance was used. The abundance variable incorporated all survey errors in addition to spatial variability. In the Gulf of Lions case study (Pelmed surveys) the abundance was expressed in tonnes per nmi^2 while in the Catalan sea case study (Ecomed surveys) it was in numbers of individual fish. In the

Juvena surveys it was the abundance of age-0 anchovy (tonnes per 1.5 nmi^2). The variable incorporated in addition errors in the age determination.

In the case of the Celtic Sea, a future survey was examined. We tested a hypothetical, optimal survey design that would provide adequate coverage and precision. As no acoustic data were available, we used an *a priori* variogram resembling one based on a multiyear Bay of Biscay model, which was the nearest available relevant survey.

3.1.2 Geographical setting: survey design, estimation polygon, ESU length

Unlike other research survey case studies, the Tasmanian surveys examined had been performed by a commercial vessel. The surveys prospected along the shelf break for fish concentration in canyons (blue grenadier). When a concentration was encountered sampling effort was increased by performing a small-scale survey with parallel regularly spaced transects. The estimation polygon was thus reduced to particular concentrations. The analysis tested the ability of the small-scale surveys to estimate the abundance of a fish concentration.

Often, the total survey area has been divided into subareas and a geostatistical analysis performed by subarea. The survey design in each subarea was adapted to the complexity of the geographical setting (coastline orientation, islands, bays, shelf width) by modifying the orientation of transects or using zig-zag transects. In case studies where the shelf width was small, the design was either zig-zag or parallel transects. In the Adriatic Sea, both parallel and zig-zag designs had been performed and were compared. In the North Evoikos gulf, the survey design was a combination between zig-zag and parallel transects. In the Juvena and Pelacus surveys, the analysis concentrated on one subarea, the Cantabrian Sea, where all transects had similar orientation. In the Sicily strait case study, the part of the survey analysed was that where parallel transects were performed.

In the Catalan Sea, the shelf width is small. The inference of the spatial structure along the transects with an ESU length of 1 nautical mile is therefore uneasy. In that case, the data were summed along the transects and a 1d-geostatistical analysis performed on transect sums. This approach was compared to the 2d one. When the shelf width is small, a possibility could be to integrate the NASC over an ESU length shorter than 1 nautical mile.

In all case studies the ESU was fixed, being 1 nautical mile except for the Tasmanian small-scale surveys where it was 80 m and the Juvena surveys were it was 185 m (0.1 nautical mile). The Juvena NASC values had been integrated for a range of ESU lengths (0.1 to 4 nautical miles) and for that case study the change in the variogram with increasing ESU was studied.

3.1.3 Time series of surveys

Because surveys are undertaken yearly, each case study contained a time-series of surveys. In most case studies, the analysis was performed year by year. A small number of years were selected in each case study. The selection criterion was that the year was either a typical situation or on the contrary showed low or high abundance.

In addition, in the North Aegean Sea case study, the average per year variogram was computed over the series of surveys. Also, to provide the Celtic Sea case study with a hypothetical yet sensible variogram (i.e. a variogram that can be expected), an average per year variogram was computed on the NASC values of the Biscay Pelgas series.

3.1.4 Structural tools and methods used

In most case studies, the variogram was estimated on the raw NASC values using the classical estimator, which is the average square difference between pairs of values at vector distance h apart. In some situations though this estimator is unable to extract the structure in the data due to the high differences between pairs of values at short distance. In that case, log transforming the data were helpful (Ecomed, Pelacus and Juvena case studies). In the Sicily strait case study, the largest value was omitted when computing the variogram to extract the underlying structure.

In the North Aegean Sea case study, the variograms showed high nugget value and short range. Therefore, in order to obtain a better visualization of the geometry and the size of fish patches along-transect we applied omnidirectional indicator variograms at different percentiles (25%, 50% and 75%) of the data. In this case, the survey was tested for its ability to encounter particular patches and estimate the occurrence probability of these patches. In the Pelacus series, the analysis was performed on the raw data and also on the log transformed data, which showed a longer range structure.

Also used was the non centred covariance for estimating the variogram (option in EVA), which was used in the Juvena case study. In effect, the Juvena survey data analysed showed small patches of high values surrounded by many zeroes, a situation where the small structure in the data is best evidenced with the non centred covariance (Rivoirard *et al*., 2000).

In all cases except one, we considered the 2d-data with coordinates in latitude and longitude. In the EcoMed case study though, the transects being very short and containing a few high values, the approach used was to sum the values along the transects and perform the estimation in 1d on the transect sums with the 1d-transitive method (option in EVA). In that approach the structural tool was not the variogram but the transitive covariogram. Results are similar using a 2d or a 1d-transitive approach (Section 2.2; Petitgas, 1993; Tugores *et al*., 2010).

3.2 ToR b) Evaluate the precision of abundance estimates using geostatistics for a list of MEDIAS- and ICES-coordinated acoustic surveys

In each case study, for the variable and year chosen, the variogram was estimated and modelled. The precision of estimating the mean over the survey area by the data arithmetic mean was computed for the survey design currently in use. Results are summarized in Table 3.1. The different approaches allowed to deal with particular data characteristics and infer the underlying spatial structure from the data. In all, the inter-transect distance was of the same order of magnitude than the correlation range of the underlying distribution. The survey precision as characterized by the coefficient of variation of the mean estimate (CVgeo) lied between 0.05 and 0.19 across all case studies and was thus satisfactory. In the North Aegean study, the indicator variable chosen represented the positive area of the fish spatial distribution. It can therefore be concluded that these surveys estimated the area of fish presence with high precision.

It should be noted that spatial variation and time variability during the survey were confounded in the data and analysis performed. In particular the across-transect spatial structure may not always be accessible due to time variability during the survey (ICES, 1997; Rivoirard *et al.*, 2000). It was unclear how time variability could have affected the inference of the correlation range.

Table 3.1. Summary table documenting for each case study: the variable used its spatial correlation structure, the survey design and the precision of the mean estimate.

Survey series	Area	Survey design	Variable analysed	Correlation Range 1	Correlation Range 2	Ratio nugget/sill	Inter-transect distance	CV geo	Method used
Annex 5: ECOMED	Catalan Sea (autumn)	Parallel transects	Nb.Fish Transect sums Anchovy 2003	88 n.mi.	120 n.mi.	0.09	8 n.mi.	0.12	EVA software plan A 1D-transitive
			Nb.Fish Transect sums Anchovy 2004	72 n.mi.	120 n.mi.	0.01	8 n.mi.	0.07	EVA software plan A 1D-transitive
Annex 6: PELMED	Gulf of Lions (summer)	Parallel transects	Biomass Anchovy 2003 (t./n.mi.2)	10 n.mi.		0.29	12 n.mi.	0.12	EVA software plan A 2D-intrinsic
			Biomass Sardine 2003 (t./n.mi.2)	10 n.mi.		0.57	12 n.mi.	0.19	EVA software plan A 2D-intrinsic
Annex 7: Strait of Sicily	Sicily South West coast (summer)	Parallel transects	NASC Anchovy 2002	27 n.mi.		0.40	5 n.mi.	0.09	EVA software plan A 2D-intrinsic
Annex 8: Adriatic Sea	Italian part of Adriatic Sea (summer)	Zig-zag transects	NASC Total fish 2005	18 n.mi.		0.31	10 n.mi.	0.05	EVA software plan D 2D-intrinsic
Annex 9: North Aegean Sea	Thermoïkos gulf (summer)	Parallel transects	NASC Anchovy Indicator of 0.25 percentile	9.5 n.mi. (multiyear variogram)		0.68 (multiyear variogram)	10 n.mi.	0.01	EVA software plan A 2D-intrinsic
	Thracian Sea (summer)	Parallel transects	NASC Anchovy Indicator of 0.25 percentile	10 n.mi. (multiyear variogram)		0.68 (multiyear variogram)	10 n.mi.	0.01	EVA software plan A 2D-intrinsic
	North Evoïkos gulf (summer)	Zig-zag + parallel transects	NASC Anchovy Indicator of 0.25 percentile	14 n.mi. (multiyear variogram		0.15 (multiyear variogram)	Zig-zag + parallel transects	0.01	EVA software plan D 2D-intrinsic

Table 3.1 (continued)

Survey series	Area	Survey design	Variable analysed	Correlation Range 1	Correlation Range 2	Ratio nugget/sill	Inter-transect distance	CV geo	Method used
Annex 10: PELACUS	Cantabrian Sea (spring)	Parallel transects	NASC Sardine 2008	6 n.mi.		0.06	8 n.mi.	0.18	EVA software plan A 2D-intrinsic
Annex 11: PELGAS	Bay of Biscay French Shelf (spring)	Parallel transects	NASC Total fish 2010	6 n.mi.	100 n.mi.	0.45	12 n.mi.	0.08	EVA software plan A 2D-intrinsic
Annex 12 : PELTIC	Celtic Sea (spring)	Parallel transects: design planned	No data	7 n.mi. (from average Pelgas vario)		0.50 (from average Pelgas vario)	20 n.mi.	0.12	EVA software plan A 2D-intrinsic
Annex 13 : JUVENA	Catabrian Sea (autumn)		Biomass 2009 age-0 anchovy (t./1.5n.mi.2)	2 n.mi.		0.96	15 n.mi.	0.11	EVA software plan A 2D-intrinsic
Annex 14: Tasmania	Small-scale fish aggregation (strata 3)	Parallel transects	NASC 2005 blue grenadier	350 m (average from anisotropy)		0.17	227 m	0.08	EVA software plan A 2D-intrinsic

3.3 ToR c) Suggest how survey designs can be optimized

The optimization of the design was evaluated in terms of the spatial coverage of the acoustic transects only (see Section 2.1 where all sources of error are discussed). The estimation variance for other designs than the one currently in use was calculated as well as for the same design but other efforts (e.g. number of transects), depending on the case studies. These computations were possible because the estimation variance (eq. 1, Section 2.2) depends on the variogram model and the sampling configuration only, not on the data values. Therefore, once we have accessed to the underlying variogram model, different sampling designs can be generated and their corresponding estimation variance estimated. The assumption made is that different survey designs would have allowed to model the underlying variogram.

For most of the survey series, the design was made of parallel regularly spaced transects. We then explored the effect of increasing / decreasing the number of transects and inter-transect distance. In the Adriatic Sea, the design was changed from zig-zag transects to parallel ones. We tested how that change affected survey precision. In the North Evoikos gulf, the design was a mix between zig-zag and parallel transects due to the complexity of the coastline. Different combinations of zig-zag and parallel transects were generated and their precision evaluated. In computing survey precision (CVgeo) for different survey designs, the variogram models and procedures used were the same as for computing the CVgeo of the design currently in use (Table 3.1).

The case study results reported in Annexes 5 to 14 are compiled below. The contribution of the nugget (pure random spatial component) to the survey precision increased with increasing sampling effort as the structural component gets more and more resolved by the survey spatial coverage. Survey precision was often not a linear function of inter-transect distance and therefore, decreasing survey effort had a large negative effect on survey precision while increasing it had a moderate positive affect.

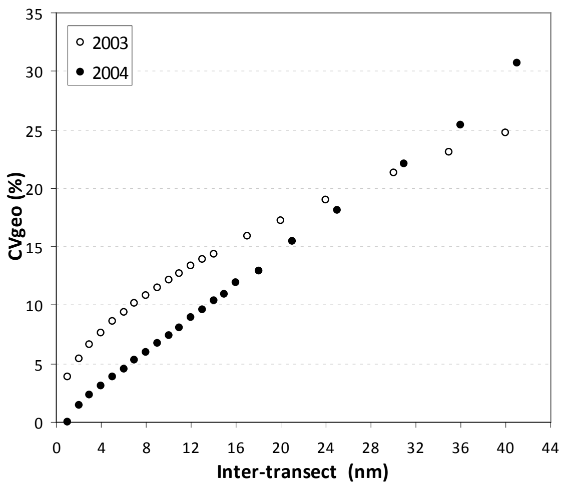
Annex 5: ECOMED surveys, Catalan Sea

Current design: Parallel transects regularly spaced. Inter-TR = 5 nautical miles

Design tested: Inter-TR from 1 to 40 nautical miles

Variable: anchovy, 2003, 2004, transect sums of nb of fish

CVgeo as a function of designs tested:



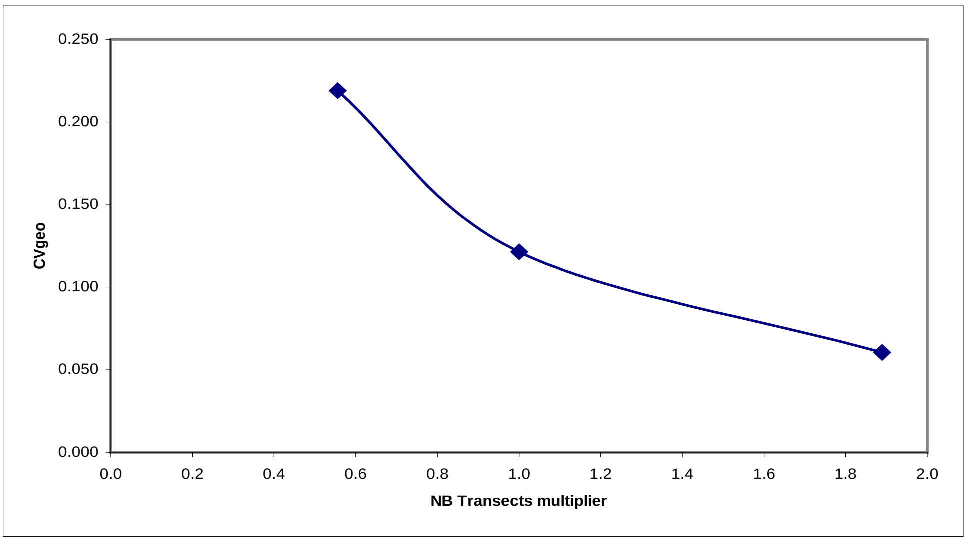
Annex 6: PELMED surveys, Gulf of Lions

Current design: Parallel transects regularly spaced. Inter-TR = 12 nautical miles

Design tested: doubling / halving the nb of TR and inter-TR distance

Variable: anchovy biomass (t./nmi2), 2003

CVgeo as a function of designs tested:



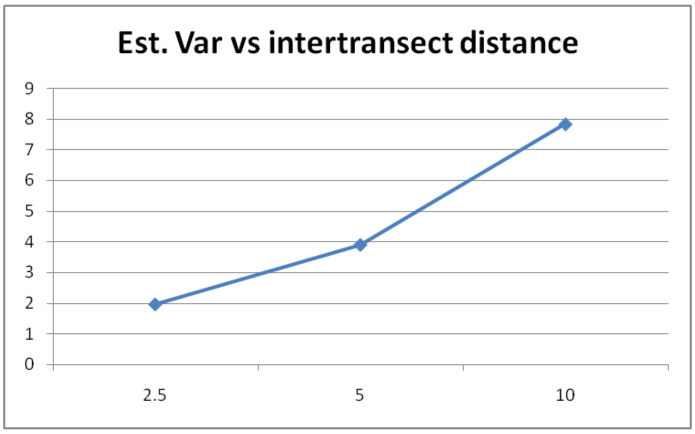
Annex 7: Strait of Sicily

Current design: Parallel transects regularly spaced. Inter-TR = 5 nautical miles

Designs tested: doubling / halving the nb of TR and inter-TR distance

Variable: NASC anchovy, 2002

CVgeo as a function of designs tested:



Annex 8: Adriatic Sea

Design of reference (2005): zig-zag transects

Designs tested (2008): Parallel transects regularly spaced. Inter-TR = 10 nautical miles

Variable: NASC total fish

CVgeo as a function of designs tested:

CVgeo (zig-zag)= 0.048

CVgeo (parallel)= 0.036

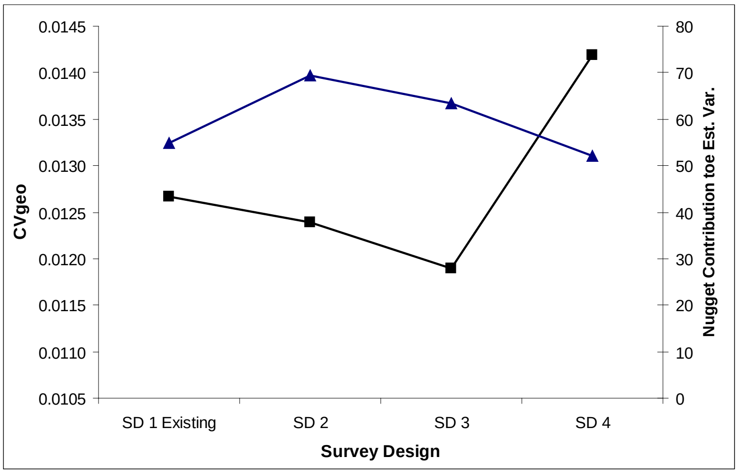
Annex 9: North Evoikos gulf (North Aegean Sea)

Current design: SD1, zig-zag abd parallel transects mixed

Designs tested: various combinations of zig-zag and parallel transects to accommodate coastline: SD 2, 3 and 4

Variable: NASC anchovy, indicator of 0.25 percentile

CVgeo as a function of designs tested: (black squares: CVgeo; bleu triangles: nugget contribution (%))



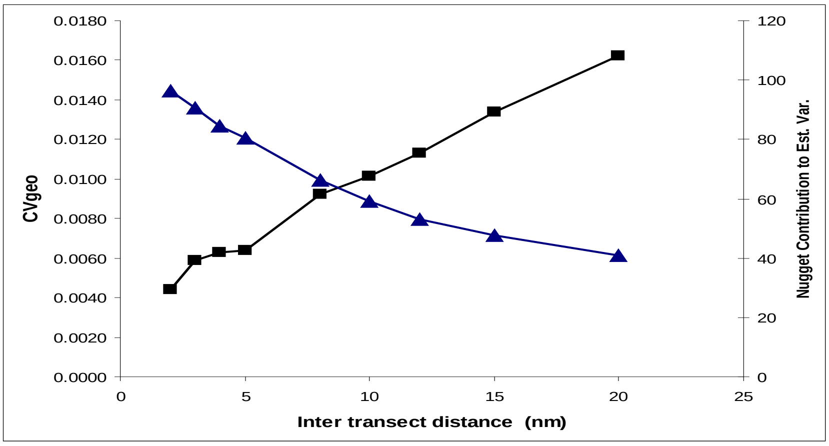
Annex 9: Thermaikos Gulf (North Aegean Sea)

Current design: Parallel transects regularly spaced. Inter-TR = 10 nautical miles

Designs tested: nb of TR and inter-TR distance varied from 2 to 20 nautical miles

Variable: NASC anchovy, indicator of 0.25 percentile

CVgeo as a function of designs tested: (black squares: CVgeo; bleu triangles: nugget contribution (%))



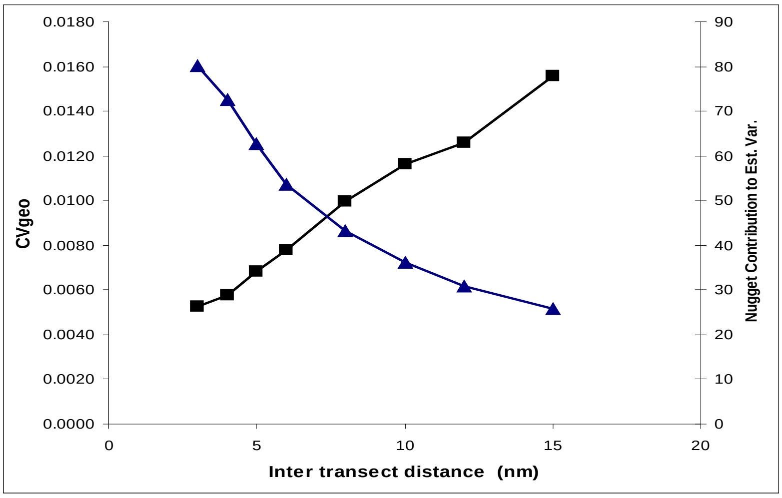
Annex 9: Thracian Sea (North Aegean Sea).

Current design: Parallel transects regularly spaced. Inter-TR = 10 nautical miles

Designs tested: nb of TR and inter-TR distance varied from 3 to 15 nautical miles

Variable: NASC anchovy, indicator of 0.25 percentile

CVgeo as a function of designs tested: (black squares: CVgeo; bleu triangles: nugget contribution (%))



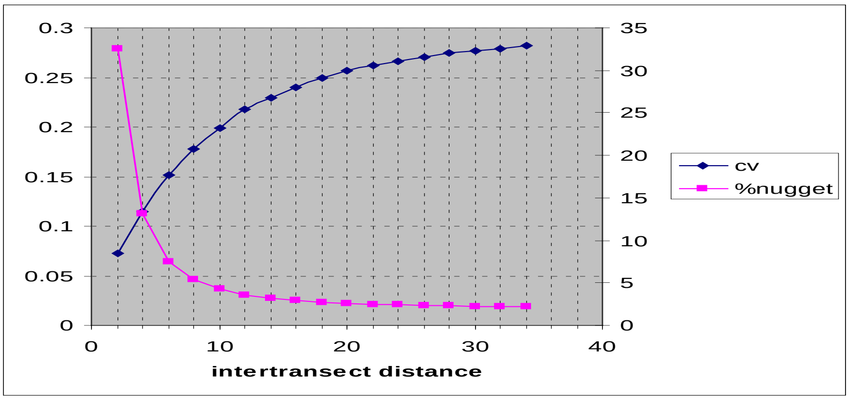
Annex 10: PELACUS surveys, Cantabrian Sea

Current design: Parallel transects regularly spaced. Inter-TR = 8 nautical miles

Designs tested: Inter-TR from 2 to 34 nautical miles

Variable: NASC sardine, 2008.

CVgeo as a function of designs tested:



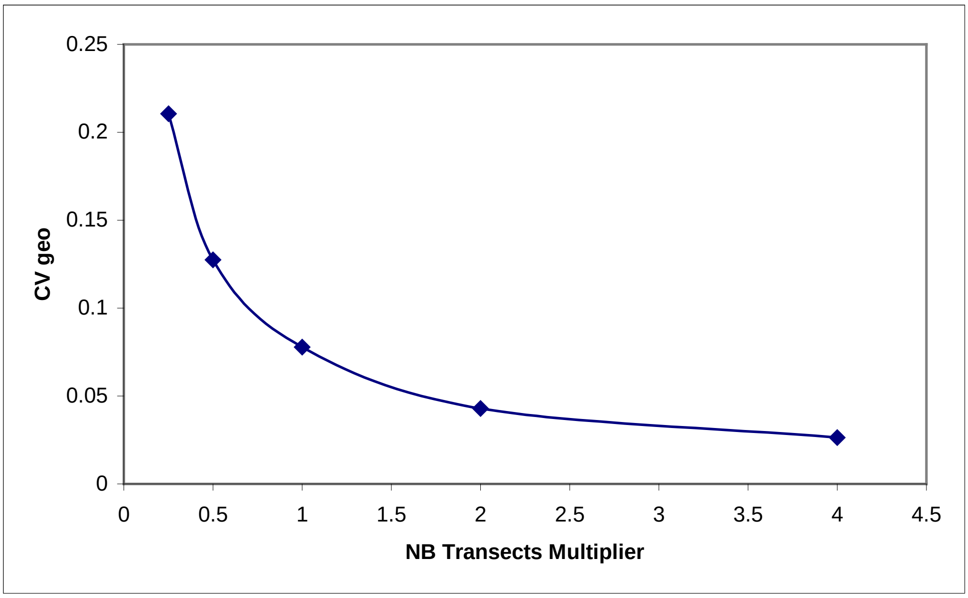
Annex 11: PELGAS surveys, French shelf of Bay of Biscay

Current design: Parallel transects regularly spaced. Inter-TR = 12 nautical miles

Designs tested: double and half inter-transect distance and transect number

Variable: NASC total fish.

CVgeo as a function of designs tested:



Annex 12: PELTIC survey, Celtic Sea

Current design: none, survey series to begin

Reference design: Parallel transects regularly spaced. Inter-TR = 20 nautical miles

Designs tested: double and half inter-transect distance and transect number

CVgeo as a function of designs tested:

Reference: CVgeo(ref)=0.12 ; CVgeo(double)=0.04; CVgeo(half)=0.29

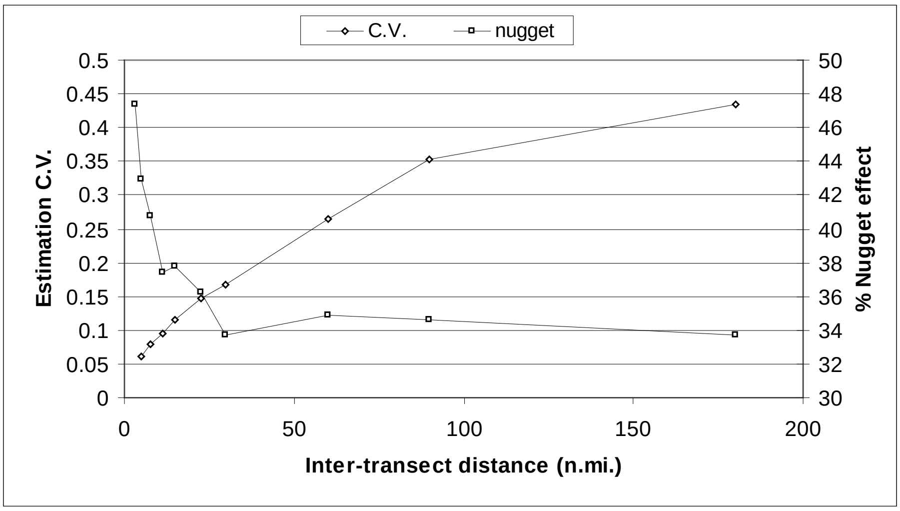
Annex 13: JUVENA surveys, Cantabrian Sea

Current design: Parallel transects regularly spaced. Inter-TR = 15 nautical miles

Designs tested: inter-transect distance varied

Variable: age-0 anchovy biomass 2009 (t./1.5nmi2)

CVgeo as a function of designs tested:



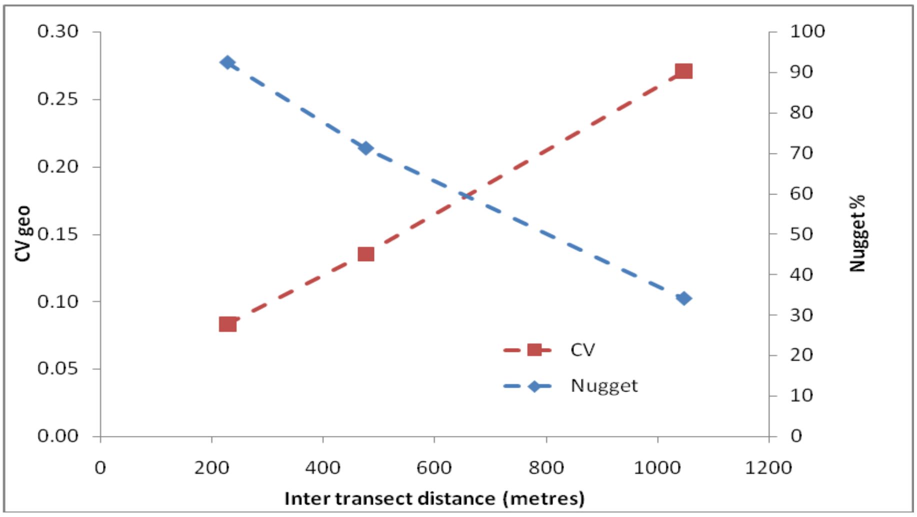
Annex 14: Tasmanian blue grenadier small-scale surveys

Current design: Parallel transects regularly spaced. Inter-TR = 227 m

Designs tested: half and quarter inter-transect distance with increased nb of transects

Variable: NASC blue grenadier, 2005, strata 3

CVgeo as a function of designs tested:



4 Discussion and Recommendations

The framework of linear geostatistics was flexible and robust enough to allow analyse all case studies, extract the underlying spatial correlation structure, estimate survey precision for the current survey design and evaluate other designs. Acoustic survey series in 11 different areas were analysed during the workshop.

In most cases, only one correlation range (one spatial component) was modelled on the variogram. But in others (Table 3.1), two components were identified. The shorter correlation range was often close in value to the inter-transect distance. As a consequence the survey designs seemed adapted to the underlying spatial correlation range.

Although common formats to all case studies were established for data analysis and reporting, the variable analysed was left to the appreciation of the practitioner. An indicator approach could be proposed to all case studies for achieving greater standardization of the workshop exercise. The interest in doing so would be that the survey design would be formulated in terms of geometry of fish aggregations and probability to encounter patches of high values. The drawback would be that survey precision of the mean estimate would not be accessed.

The workshop concentrated on spatial error due to survey coverage only. Acoustic surveys have other sources of error in addition to area coverage. The full variance of species abundance at length or age was not considered. For that purpose, other geostatistics tools than used at the workshop would be necessary such as mapping, combining maps, and simulations.

The workshop developed documents and formats to prepare data, apply basic geostatistics and report on results. This allowed standard applications to the many case studies. A more in-depth knowledge of geostatistical practice was gained by the participants, leading to a growing interest in the method. During the workshop a small part of geostatistical methods was used only, which was sufficient to estimate survey precision. But for instance, no mapping (kriging) was involved. Therefore an ICES training course is recommended in which a broader range of geostatistical tools could be presented and tutorial applications provided (Annex 3).

Also it was felt by workshop participants that an e-forum would be useful: questions could be posed, answers given at regular intervals, expertise exchanged as well as code. It is suggested that a permanent geostatistics sharepoint be established to serve as the ICES Fisheries Geostatistics e-forum. It would certainly structure a growing community of practitioners (Annex 3).

5 References

ICES. 1997. Report of the Workshop on Time Variability and Space-Time Interaction in Fisheries Acoustic Surveys. pp. 35–43, *In:* WGFAST report. ICES CM1997/D:5.

Matheron, G. 1971. The theory of regionalized variables and their applications. Les Cahiers du Centre de Morphologie Mathématique, Fasc. 5. Fontainebleau, Ecole Nationale Supérieure des Mines de Paris.

Petitgas, P. 1993. Geostatistics for fish stock assessments: a review and an acoustic application. ICES Journal of Marine Science, 50: 285–298.

Petitgas, P. 2001. Geostatistics in fisheries survey design and stock assessment: models, variances and applications. Fish and Fisheries, 2: 231–249.

Petitgas, P., Massé, J., Beillois, P., Lebarbier, E. and Le Cann, A. 2003. Sampling variance of species identification in fisheries acoustic surveys based on automated procedures associating acoustic images and trawl hauls. ICES Journal of Marine Science, 60: 437–445.

Petitgas, P., and Lafont, T. 1997. EVA2: estimation variance version 2 - a geostatistical software on windows95 for the precision of fish stock surveys. ICES CM 1997/Y:22.

Renard, D., and Bez, N. 2008. RGeoS: Geostatistical package. http://www.cg.ensmp.fr/rgeos/

Rivoirard, J., Simmonds, J., Foote, K., Fernandes, P., and Bez, N. 2000. Geostatistics for estimating fish abundance, Blackwell Science.

Simmonds, J., and MacLennan, D. 2005. Fisheries acoustics: theory and practice. Blackwell Science, Oxford. 2nd Edition.

Tugores, P., Iglesias, M., Díaz, N., Oñate, D., Miquel, J., and Giráldez, A. 2010. Latitudinal and interannual distribution of the European anchovy (*Engraulis encrasicolus*) and sardine (*Sardina pilchardus*) in the western Mediterranean, and sampling uncertainty in abundance estimates. ICES Journal of Marine Science, 67: 1574–1586.

Woillez, M., Rivoirard, J., and Fernandes, J. 2009. Evaluating the uncertainty of abundance estimates from acoustic surveys using geostatistical simulations. ICES Journal of Marine Science, 66: 1377–1383.

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Annex 2: Agenda

Joint AcousMed project/ICES WGACEGG Workshop on Geostatistics (WKACUGEO)

Saturday 20 November

9:00 Opening, adoption of agenda, House-keeping and support arrangements

Presentation of surveys in each area

9:15 Spanish Mediterranean waters (IEO, Pilar Tugores, Magdalena Iglesias)

9:30 Gulf of Lions (Ifremer, Jean Louis Bigot)

9:45 Sicily Channel (CNR IAMC, Angelo Bonanno, Marco Barra)

10:00 Adriatic Sea (CNR ISMAR, Andrea DeFelice, Fabio Campanella)

10:15 Aegean Sea (HCMR, Marianna Giannoulaki)

10:30 Gulf of Cadiz (spring IEO, Fernando Ramos)

10:45 Bay of Biscay (spring Ifremer, Mathieu Doray)

11:00 Coffee Break

11:15 Atlantic Spanish waters & Cantabrian Sea (spring IEO, Magdalena Iglesias)

11:30 Atlantic – Bay of Biscay (autumn AZTI, Guillermo Boyra)

11:45 Atlantic -Western English Channel- Cefas (spring, Jeroen Van Der Kooij)

12:00 Opportunistic acoustic surveys of Tasmanian west coast blue grenadier using commercial fishing vessels (CSIRO, Tim Ryan)

12:15 Precision of acoustic surveys and geostatistics (Pierre Petitgas)

12:45 Discussion on technical issues, planning and organization of work by case study

13:00 Lunch Break

14:00 Practical Session: Geostatistical applications on case studies

16:00 Coffee Break

16:15 Geostatistical applications on case studies

18:00 Wrap up of the day work, Closing

Sunday 21 November

9:00 Geostatistical applications on case studies

11:00 Coffee Break

11:15 Geostatistical applications on case studies

12:00 Definition of a common format for reporting Case Studies

13:00 Lunch Break

Evaluation of case studies: presentation of results, problems, solutions

14:00 Spanish Mediterranean waters

14:20 Gulf of Lions

14:40 Sicily Channel

15:00 Adriatic Sea

15:20 Aegean Sea

15:40 Atlantic IEO (spring)

16:00 Coffee Break

16:20 Atlantic Ifremer (spring)

16:40 Atlantic Cefas (spring)

17:00 Atlantic AZTI (autumn)

17:20 Tasmania CSIRO

17:40 Suggestions for future work and analysis, format of report

18:30 Closing

Annex 3: Recommendations

RECOMMENDATION	FOR FOLLOW UP BY:
1. To organize a training course on basic and advanced geostatistics for applications to fisheries surveys	SSGESST, SCICOM
2. To set up a permanent ICES Fisheries Geostatistics sharepoint to serve as an e-forum and structure a community of practicioners	SSGESST, SCICOM

Annex 4: List of basic references in geostatistics and their applications to fisheries survey data

Bez, N., and Rivoirard, J. 2001. Transitive geostatistics to characterise spatial aggregations with diffuse limits: an application on mackerel ichtyoplankton. Fisheries Research, 50: 41–58.

Chilès, J.-P., and Delfiner, P. 1999. Geostatistics: modelling spatial uncertainty. New York, John Wiley and Sons.

Journel, A., and Huijbregts, C. 1978. Mining geostatistics. London, Academic Press.

ICES. 1992. Acoustic survey design and analysis procedure: a comprehension review of current practice. ICES Cooperative Research Report, 187.

ICES. 1993. Report of the workshop on the applicability of spatial statistical techniques to acoustic survey data. ICES Cooperative Research Report, 195.

ICES. 2004. Report of the Workshop on Survey Design and Data Analysis (WKSAD). ICES CM 2004/B:07.

Lantuéjoul, C. 2002. Geostatistical simulations: models and algorithms. Berlin, Springer-Verlag.

Matheron, G. 1971. The theory of regionalized variables and their applications. Les Cahiers du Centre de Morphologie Mathématique, Fasc. 5. Fontainebleau, Ecole Nationale Supérieure des Mines de Paris.

Matheron, G. 1989. Estimating and choosing: an essay on probability in practice. Berlin, Springer-Verlag.

Petitgas, P. 1993. Geostatistics for fish stock assessments: a review and an acoustic application. ICES Journal of Marine Science, 50: 285–298.

Petitgas, P. 1996. Geostatistics and their applications to fisheries survey data. Computers in Fisheries Research. B. Megrey and E. Moksness, Chapman and Hall: 113–142.

Petitgas, P. 2001. Geostatistics in fisheries survey design and stock assessment: models, variances and applications. Fish and Fisheries, 2: 231–249.

Petitgas, P. 2009. Geostatistics and their applications to fisheries survey data: a history of ideas, 1990–2007. Computers in Fisheries Research. B. Megrey and E. Moksness, Springer Netherlands: 191–224.

Petitgas, P., and Lafont, T. 1997. EVA2: estimation variance version 2 - a geostatistical software on windows95 for the precision of fish stock surveys. ICES CM 1997/Y:22.

Rivoirard, J. 1994. Introduction to disjunctive kriging and non-linear geostatistics. Oxford, Clarendon Press.

Rivoirard, J., Simmonds, J., Foote, K., Fernandes, P., and Bez, N. 2000. Geostatistics for estimating fish abundance, Blackwell Science.

Wackernagel, H. 1995. Multivariate geostatistics: an introduction with applications. Berlin, Springer-Verlag.

Woillez, M., Rivoirard, J., and Fernandes, J. 2009. Evaluating the uncertainty of abundance estimates from acoustic surveys using geostatistical simulations. ICES Journal of Marine Science, 66: 1377–1383.

Annex 5: Mediterranean Spanish waters – ECOMED surveys (Pilar Tugores and Magdalena Iglesias, IEO)

Survey characteristics

Area covered: Spanish Mediterranean continental shelf from the French border till the Strait of Gibraltar. 6922 nmi^2

Period of the year: Mid November – mid December

Target species: anchovy (*Engraulis encrasicolus*) recruitment and start of spawning of sardine (*Sardina pilchardus*)

Echosounder: Simrad EK500 (2003, 2004 and 2005) and Simrad EK60 (2006)

Research vessel: Cornide de Saavedra 67 m length

Survey design: 128 parallel equidistant transects with 4 or 8 nm inter-transect distance depending on continental shelf width

Acoustic sampling: from dawn till dusk and from 30 m depth till 200 m depth, with 1 nm ESDU; pulse length: 1 ms; vessel speed 10 knots

Mid-water pelagic fish trawls ~12 m vertical opening net, during the night; vessel speed: 3–4 knots

Data analysed

Anchovy sA ($m^2\,nm^{-2}$) in 2003 and 2004 (geostatistical method: intrinsic in 2D)

Anchovy abundance (nº individuals) in 2003 and 2004 (geostatistical method: transitive in 1D)

2003 corresponds to a high abundance year while 2004 was a year with average abundance

Area: the Northern Spanish Mediterranean waters surrounding Ebro river delta, referred to as Southern subarea, SS (Figure 1).

Number of transects in the area: 15 transects

Inter-transect: 8 nm

Narrow continental shelf: maximum width aprox. 60,000m (~33 nm)

Diagonal distance: 220,000 m (~119 nm)

Data visualization

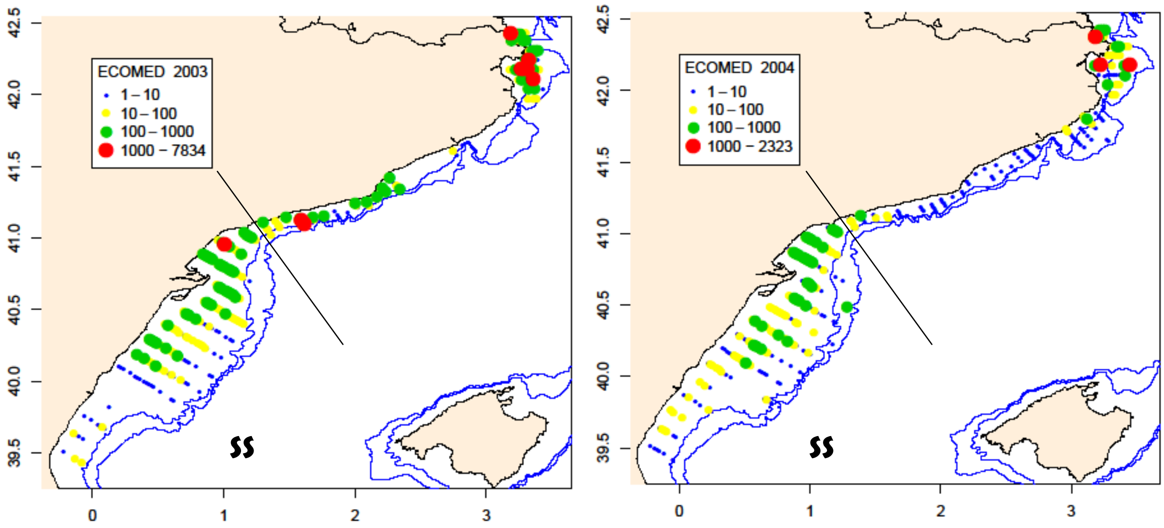


Figure 1. Anchovy sA (m² nm⁻²) in 2003 (left) and 2004 (right), zero anchovy sA values are not plotted.

Basic statistics

Table 1. Basic statistics of the analysed data.

Year	Subarea	N	Min	Max	Mean	Var	CV (%)
2003	SS	357	0	1816	42.09	17645	316
2004	SS	355	0	749	35.18	9730	280

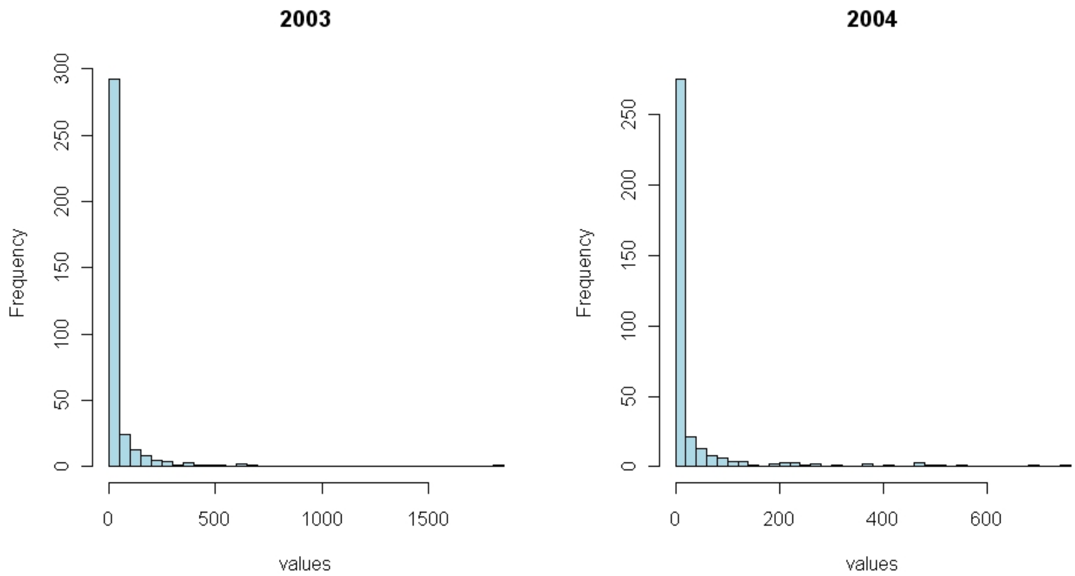


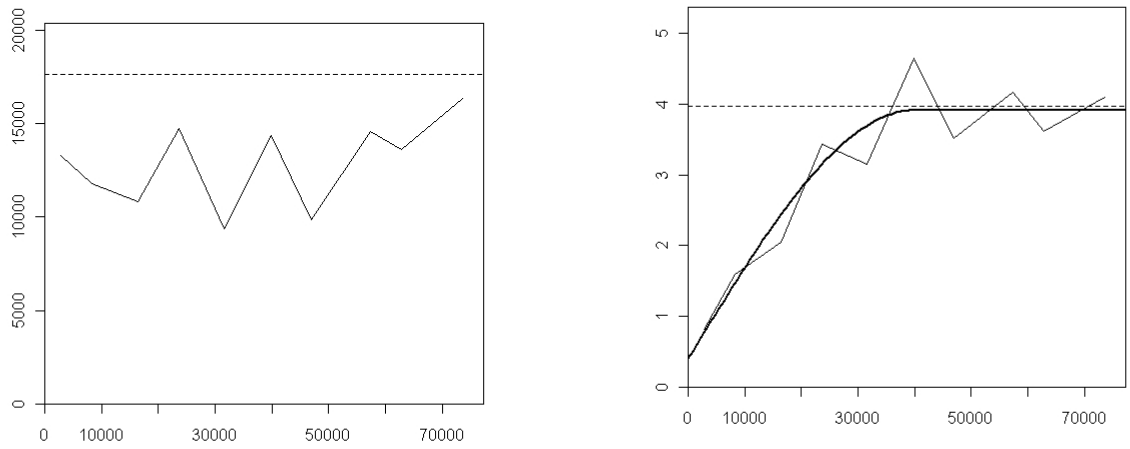
Figure 2. Histogram of anchovy sA (m² nm⁻²) in the SS.

Variograms (2D)

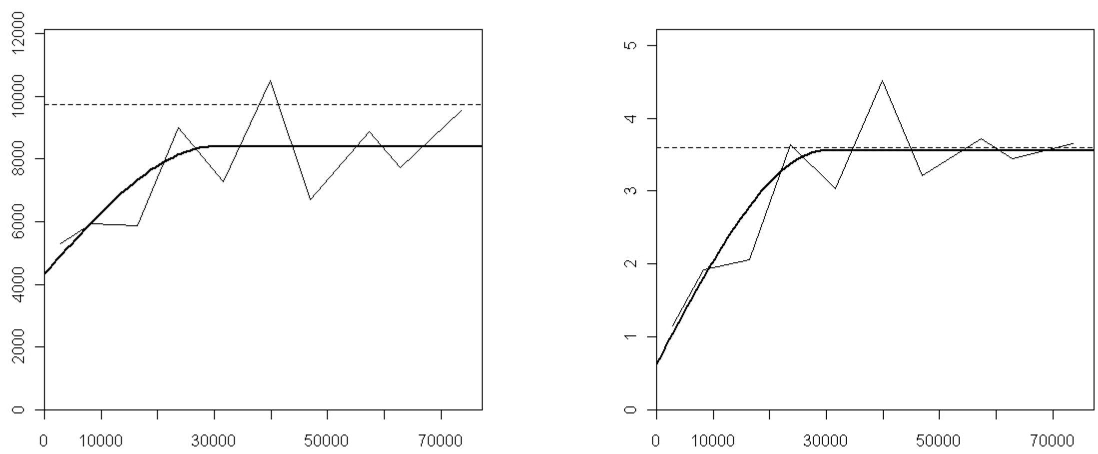
Omnidirectional experimental variograms: Lag width: 8000 m (4.32 nm); N lags: 10

(A)

Raw data (x) **Log (x+1)**



(B)

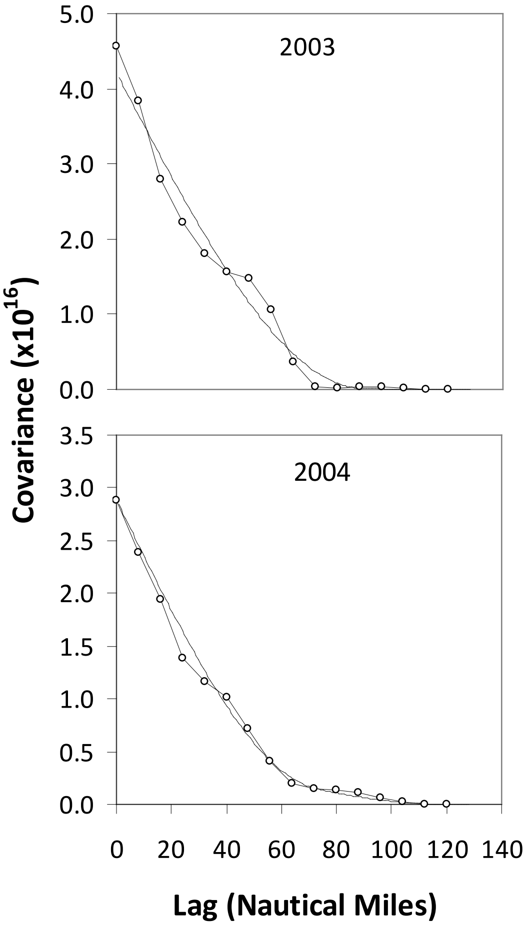


Distance (m)

Figure 3. Semivariogram of anchovy sA (m^2 nm^{-2}) and fitted models in (A) 2003 and (B) 2004, for the raw untransformed data (left) and for the log-transformed data (right) in the SS.

Covariograms (1D)

1D covariogram across transects computed on transect sums



	2003		
	Sph	Sph	nug
Range (nm)	120	88	-
Sill ($x10^{16}$)	0.15	4.00	0.41
VarE	0.5	18.1	81.4

	2004		
	Sph	Sph	nug
Range (nm)	120	72	-
Sill ($x10^{16}$)	7.0	21.4	0.3
VarE	12.1	58.2	26.0

Figure 4. Covariogram of anchovy sA in SS in 2003 and 2004 (reproduced from Tugores *et al.*, 2010)

Comments about the spatial structure

Anchovy sA showed spatial structure both in 2003 and 2004 with a range of correlation at about 35000 m (~19 nm) although in the year 2003 the spatial structure was only observable for the log scaled data (Figure 3). In the covariograms of anchovy biomass in 1D (Figure 4) two ranges of correlation are observed one encompassing the maximum distance across transects (120 nm) and the other one of about ½ of the maximum distance (72–88 nm). This is also observed in the bubble plots as anchovy seems to be more or less continuously distributed in all the analysed area.

Estimation variance

Table 2. Total estimated variance, CV and % of nugget on the total variance.

	Intrinsic 2D						Transitive 1D		
	sA			ln (sA+1)			Abundance		
	CVgeo (%)	Varmean	Nugget (%)	CVgeo (%)	Varmean (x 10–3)	Nugget (%)	CVgeo (%)	Varabundance (x 1015)	Nugget (%)
2003	-	-	-	3.92	4.65	15.57	11.98	40.27	81.4
2004	13.33	21.68	58.48	4.87	5.92	36.89	6.57	7.69	26.0

Optimisation of sampling design

Using the transitive 1D models, estimated variance and CV have been computed for different inter-transect distances. Results are shown as graphs (Figure 5) and tabulated (Table 3).

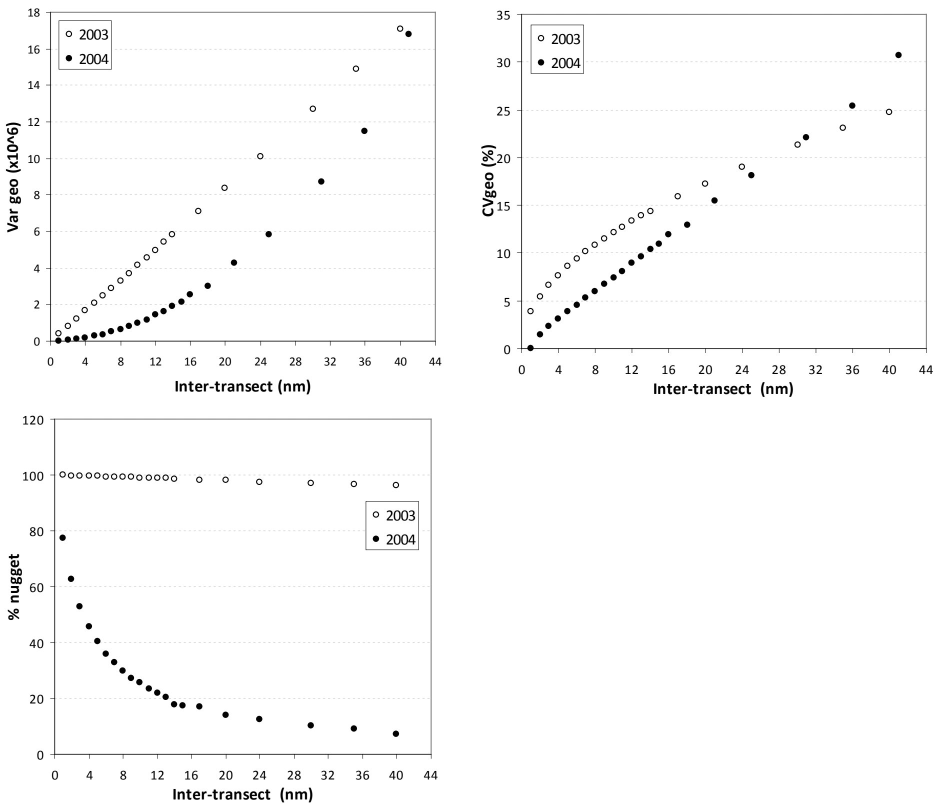


Figure 5. Geostatistical variance, geostatistical coefficient of variation and % of nugget in relation to inter-transect distance in 2003 (white circles) and 2004 (dark circles).

Annex 6: Gulf of Lions – PELMED surveys (Jean Louis Bigot and Mathieu Doray, Ifremer)

Area: Gulf of Lions

Target species: anchovy and sardine

Sampling design. Parallel transects regularly spaced perpendicular to isobaths. Area covered in 4 weeks with RV "L'Europe". Number of transects: 9. Inter-transect distance: 12 nautical miles Period: summer (July).

In this study coordinates were converted to nautical miles, longitudes were multiplied by the cosine of the mean latitude. Unit coordinates are in nautical miles.

Anchovy: tonnes per nautical mile square

Data

mean=8.48 ; nb.samples=269 ; CV= 1.58

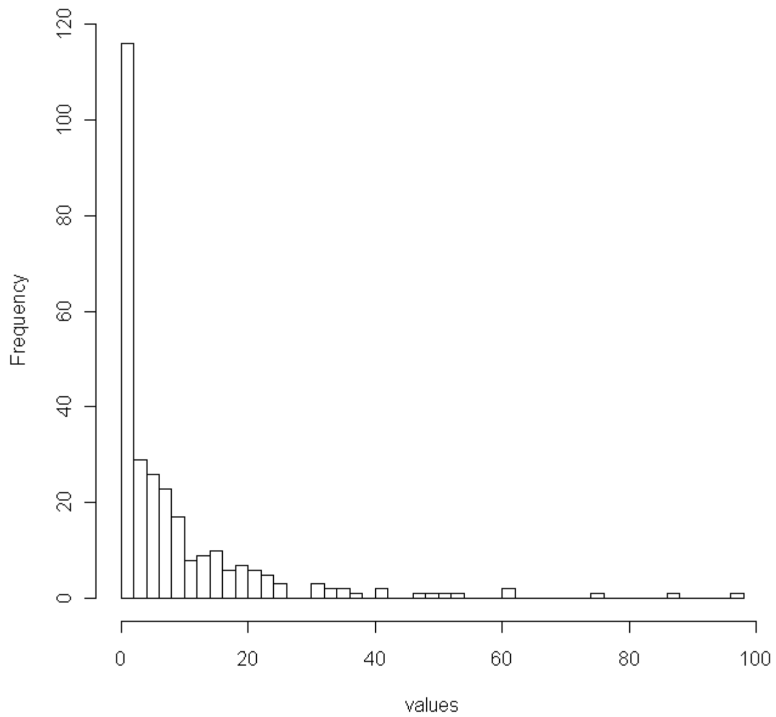


Figure. Anchovy. Histogram of raw data (tonnes per nautical mile²).

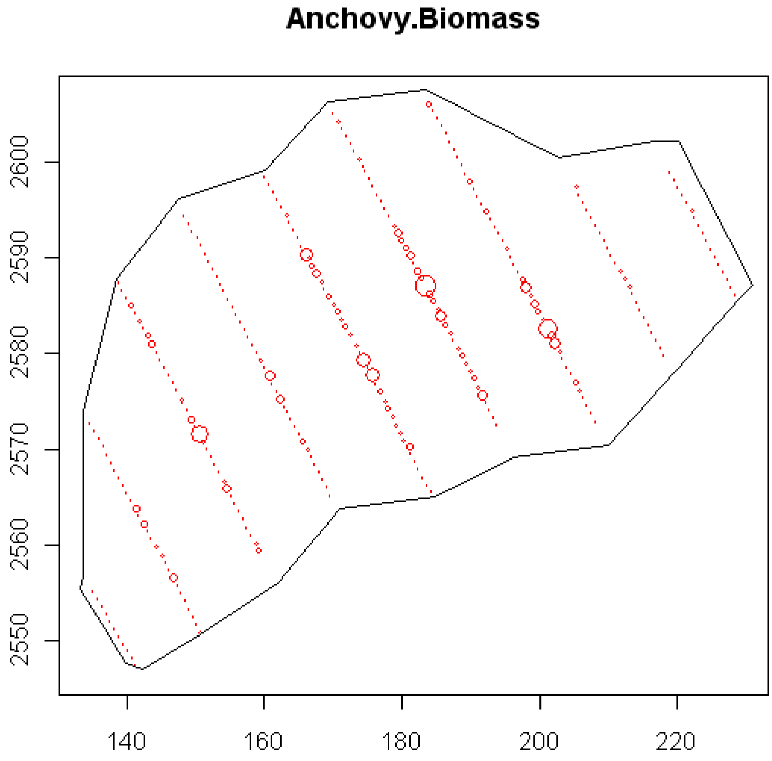


Figure. Bubble plot of raw data inside estimation polygon.

Variography

No isotropy detected: variogram in direction across transects is flat and at variance level. Omnidirectional variogram computed with lag 1 nautical mile

Variogram first modelled by eye and parameters entered as input for automatic sill fitting of nugget and sill using RGeoS software.

Model retained: nugget(sill=58)+ exponential(sill=142, practical range=10)

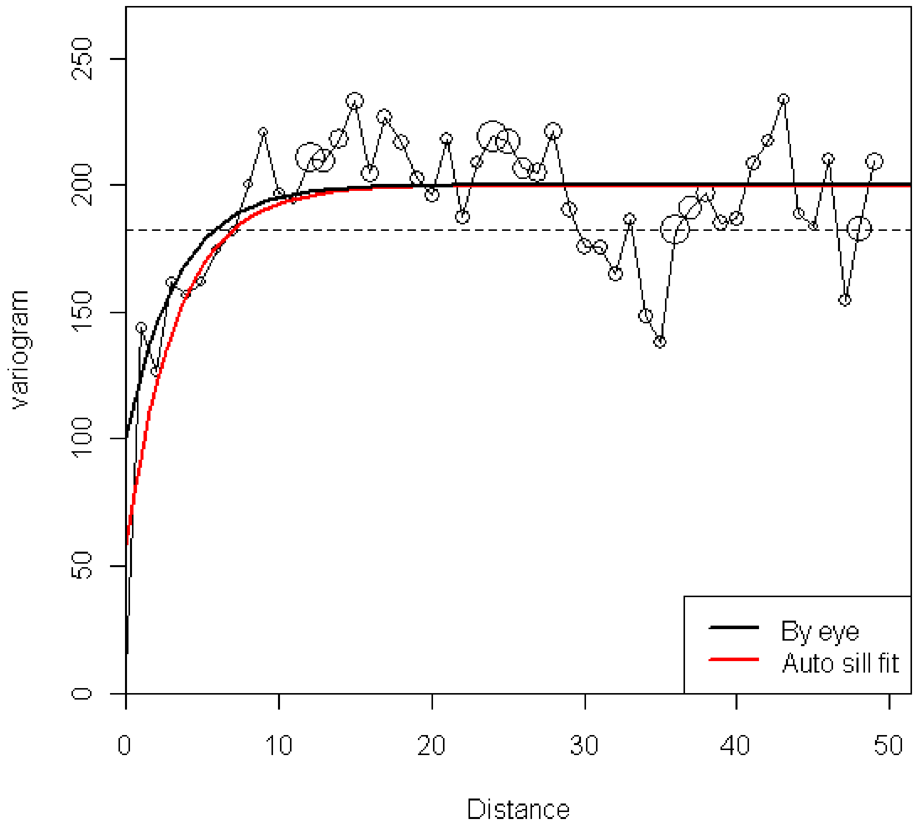


Figure. Anchovy. Omndirectional variogram with model fit. Bubbles are proportional to the number of pairs at lag.

The geostatistical estimation variance σ^2_{geo} was computed using the software EVA, Plan A: continuously sampled parallel transects regularly spaced. The calculation was performed for the current survey design. To evaluate other survey effort the Nb of transects was multiplied by 2 and halved.

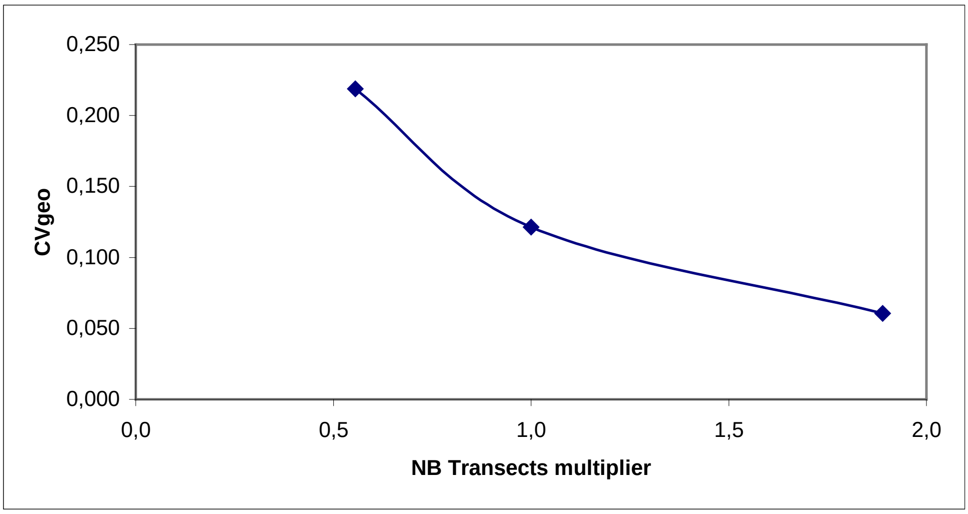


Figure. Anchovy. Evolution of the estimation precision with sampling effort.

Nb Transects Mulitplier	Nb Transects	Inter Transect Distance (n.mi.)	CV geo	Per cent nugget
0,5	5	24	0.22	0.11
1	9	12	0.12	0.20
2	17	6	0.06	0.41

The present design is satisfactory. Increasing the number of transects does not seem necessary.

Sardine: tonnes per nautical mile square

Data

Mean=33.16; nb.samples=269 ; CV=2.82

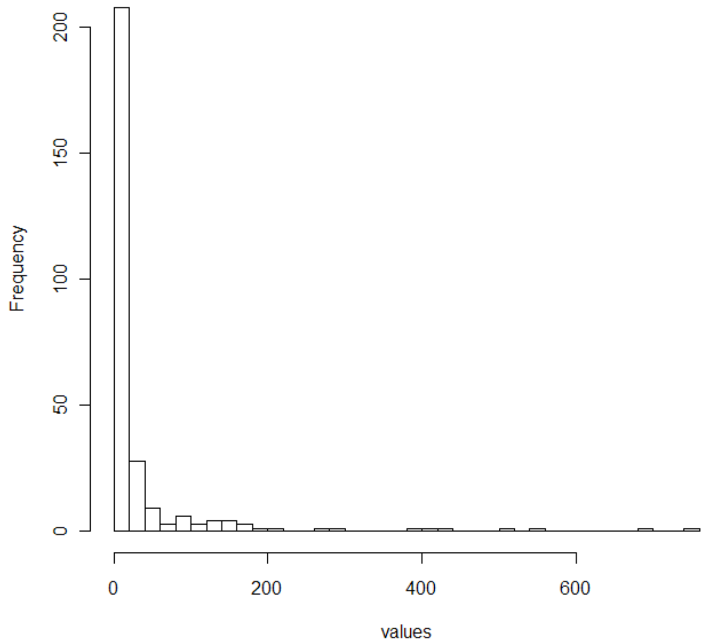


Figure. Histogram of raw sardine density values (tonnes per n.mi.²).

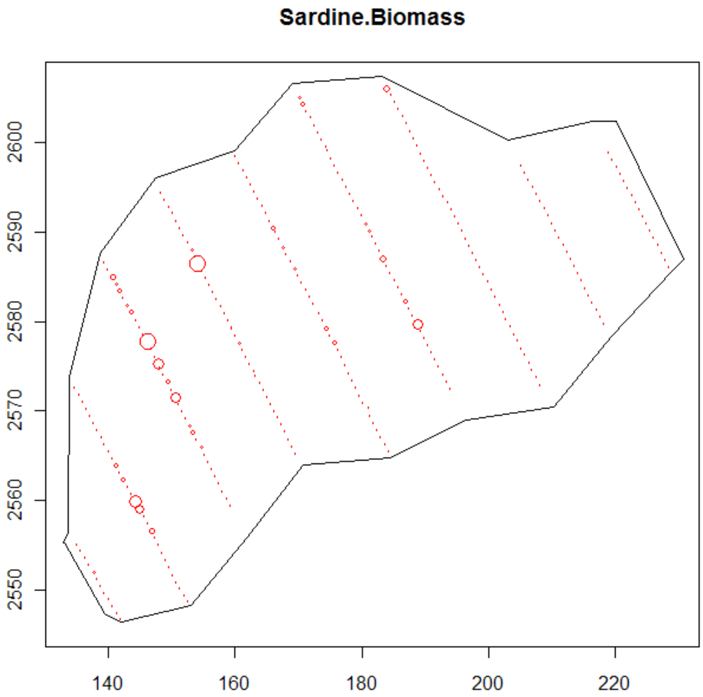


Figure. Bubble plot of raw data inside estimation polygon.

Variography

No isotropy detected: variogram in direction across transects is flat and at variance level. Omnidirectional variogram computed with lag 1 n.mi.

Variogram first modelled by eye and parameters entered as input for automatic sill fitting of nugget and sill using RGeoS software.

Model retained: nugget(sill=4918)+ exponential(sill=3732, practical range=10)

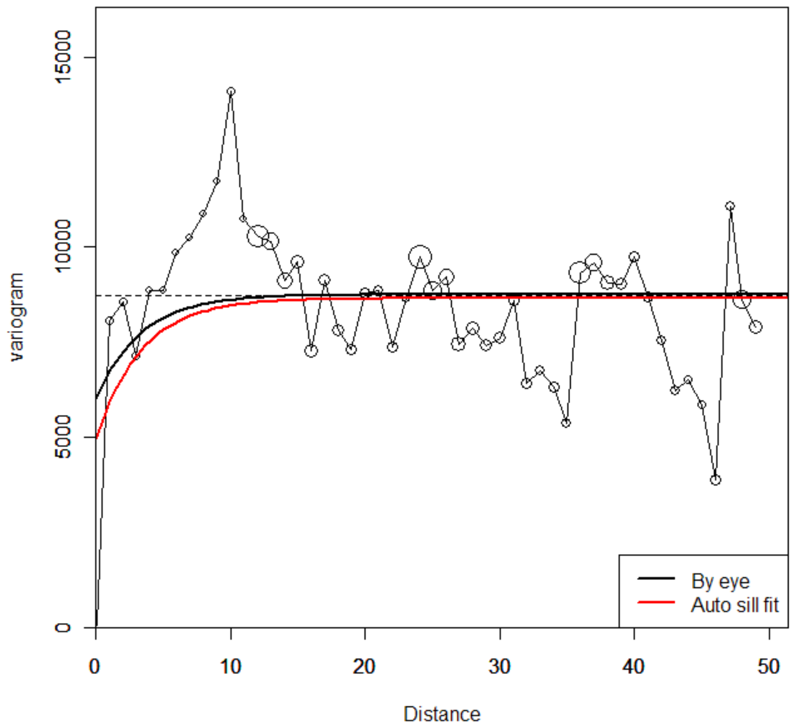


Figure. Sardine. Omndirectional variogram with model fit. Bubbles are proportional to the number of pairs at lag.

The geostatistical estimation variance σ^2_{geo} was computed using the software EVA, Plan A: continuously sampled parallel transects regularly spaced. The calculation was performed for the current survey design. To evaluate other survey effort the Nb of transects was multiplied by 2 and halved.

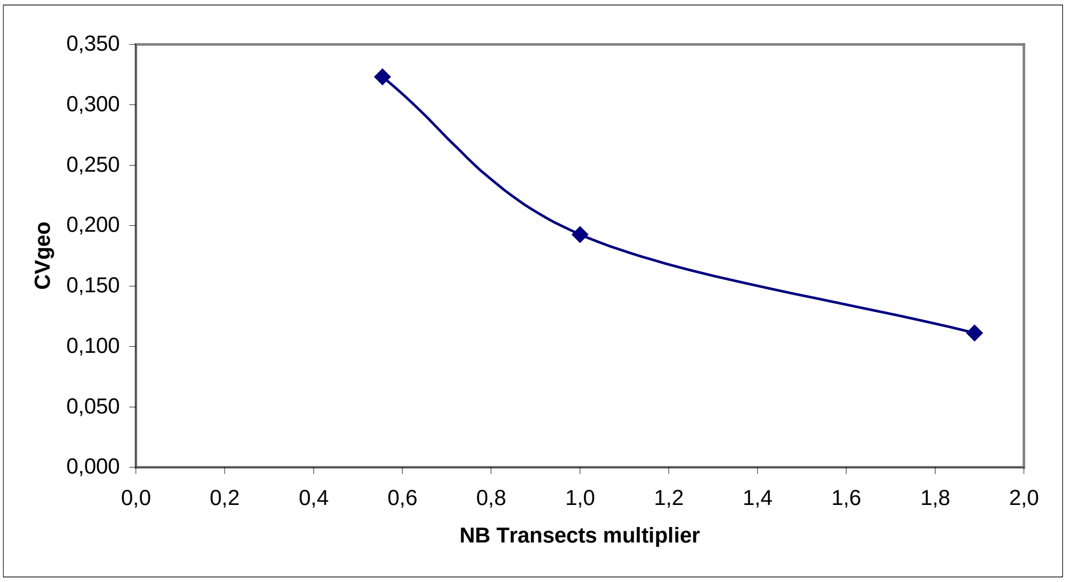


Figure. Sardine. Evolution of survey precision with survey effort

Nb Transects Mulitplier	Nb Transects	Inter Transect Distance (n.mi.)	CV geo	Per cent nugget
0,5	5	24	0.323	0.29
1	9	12	0.193	0.45
2	17	6	0.111	0.69

In comparison to anchovy, sardine shows higher spatial variance and nugget and therefore the precision of the abundance estimate is higher. A lower inter-transect distance (e.g. 8 nautical miles) could provide a more precise sardine estimate.

Annex 7: Strait of Sicily (Marco Barra, CNR-IAMC)

Survey series

Composite design with a regular transect part and a zig-zag part. Inter-transect distance of 5 nautical miles

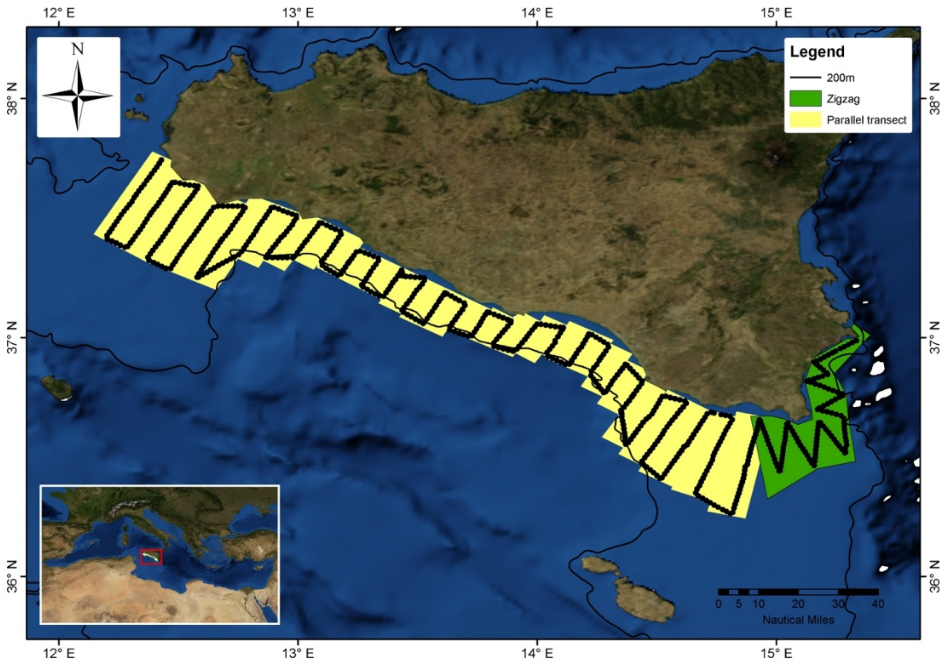


Figure 1. Survey design.

Data:

- NASC Sardine and NASC Anchovy (2002, 2003, 2004)
- Biomass density (t/ NM^2; 2005, 2006)

Geostatistical analysis

Software used: EVA2

Parallel transect, Year 2002, species anchovy and sardine

Distance units: meters

Anchovy NASC, 2002

Basic Statistics

Year=2002 Descriptive						
	Valid N	Mean	Minimum	Maximum	Variance	Coef.Var.
NASCanch	311	21,07	0,00	388,65	2620,21	2,42
Ln_NASCANCH	311	1,58	0,00	5,96	2,61	1,02

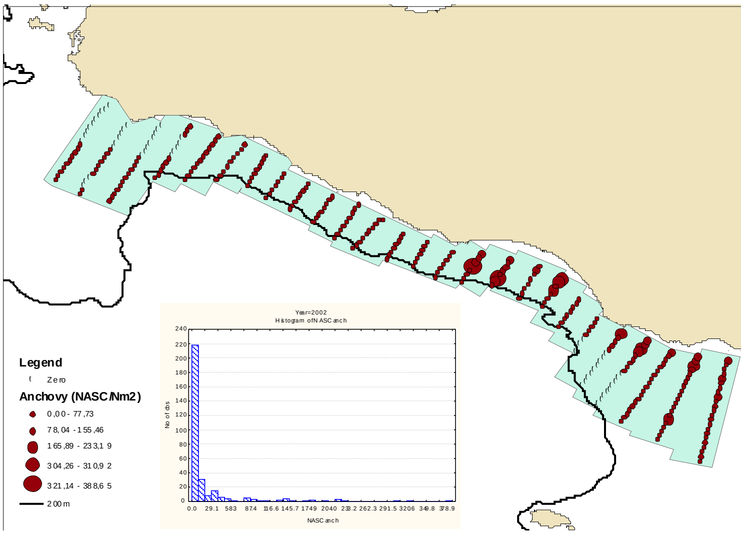


Figure 2. Bubble plot map of untransformed values.

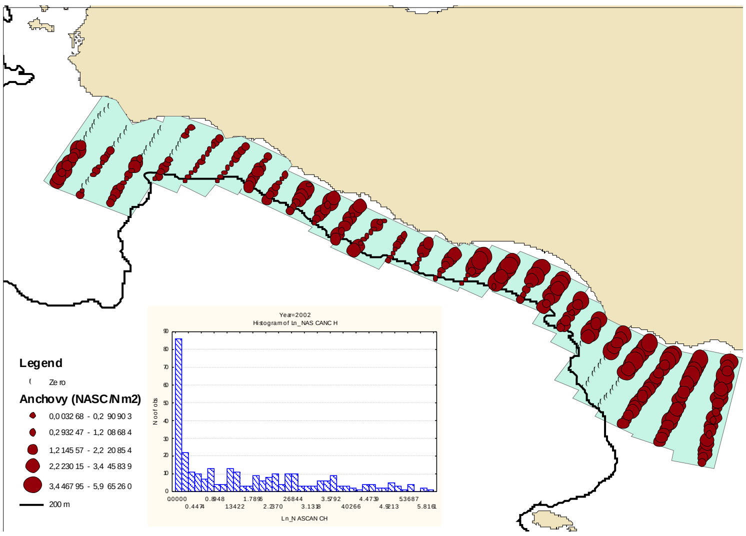


Figure 3. Bubble plot map of Log transformed values.

Variography

Raw data were used as spatial structure was clear enough

Experimental variogram	Model Parameters
• 2d – 60° and 150° • N Lags 35 • Lag 4000 • Tol. Ang. 22	• Model: Sph • Nug 1150 • Sill 1700 • Range 65000 • coeffX 1.9 • coeffY 1

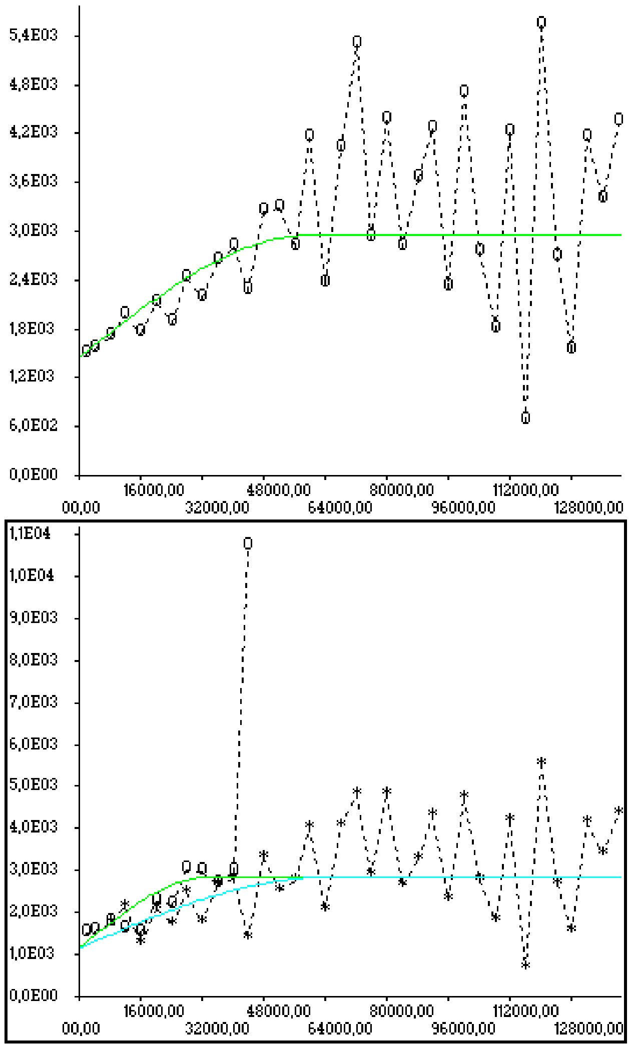
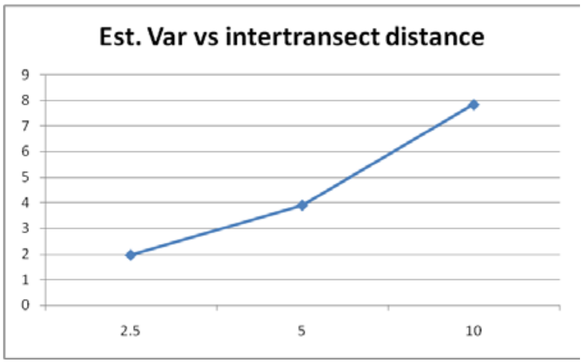


Figure 4. Isotropic and directional variograms and directional model retained.



Est. Var vs. intertransect distance			
Intertransect (NM)	Nug	Est. Var	CVgeo
2.5	98.5	1.97	0.064681
5	95.9	3.91	0.091123
10	96.5	7.84	0.129032

Figure 5. Estimation variance as a function of inter-transect distance.

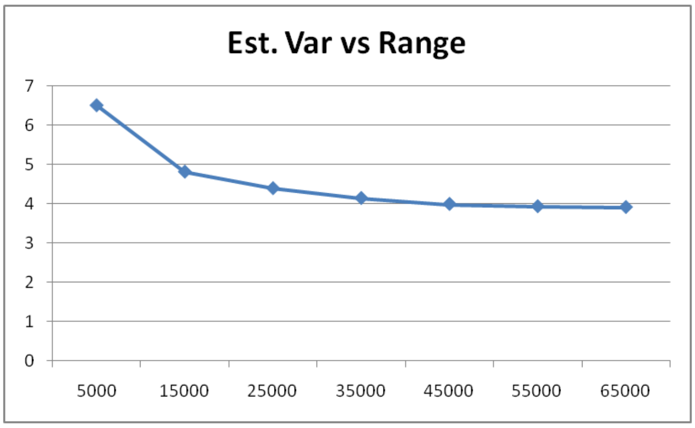


Figure 6. Estimation variance (ordinate) as a function of variogram range (abscissa in meters) for the current inter-transect distance (5 n.mi.).

Sardine NASC, 2002

Basic statistics

Year=2002 Descriptive						
	Valid N	Mean	Minimum	Maximum	Variance	Coef.Var.
NASCSard	310	41,5	0,00	931,59	11560	2,58
NASCSard (filtered ext. val. >52)	258	5,35	0	51,9	126,5	2,1
Ln_NASCSard	311	1,54	0,00	6,83	4,03	1,3

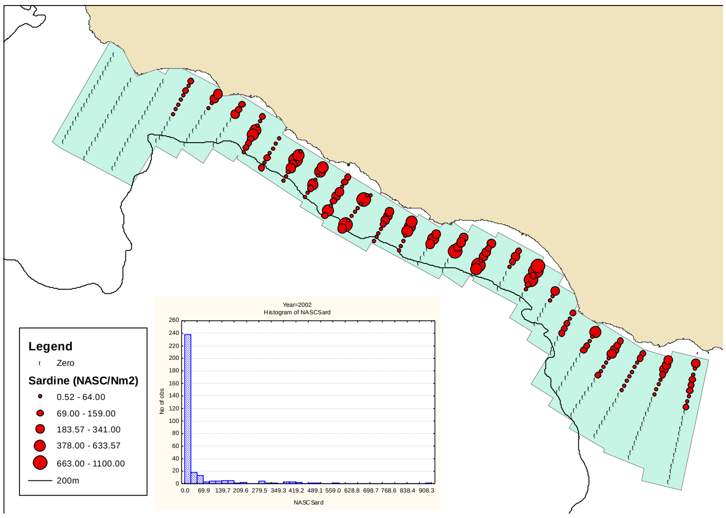


Figure 7. Bubble plot map of untransformed values.

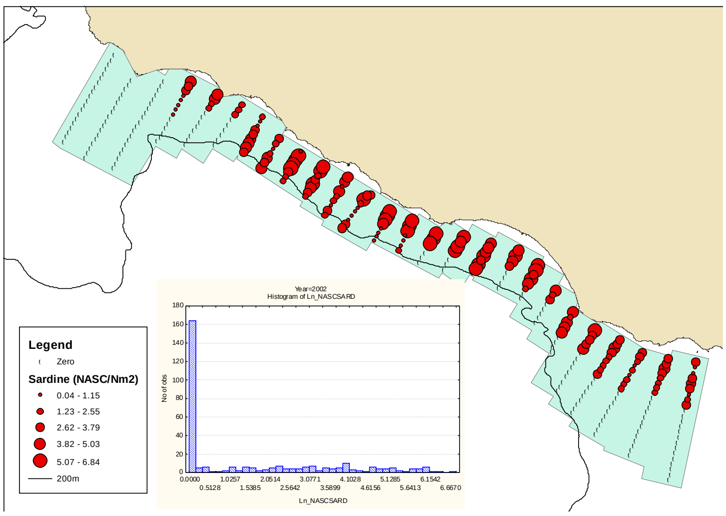


Figure 8. Bubble plot map of Log transformed values.

Variography

Raw data were used, but extreme values were filtered to get a clearer variogram.

EXPERIMENTAL VARIOGRAM	MODEL PARAMETERS
• 2d – 60° and 150°	• Model: Exp
• N Lags: 35	• Nug : 27
• Lag : 4000	• Sill : 140
• Tol. Ang. : 22	• Range : 65000
	• coeffX : 1.9
	• coeffY : 1

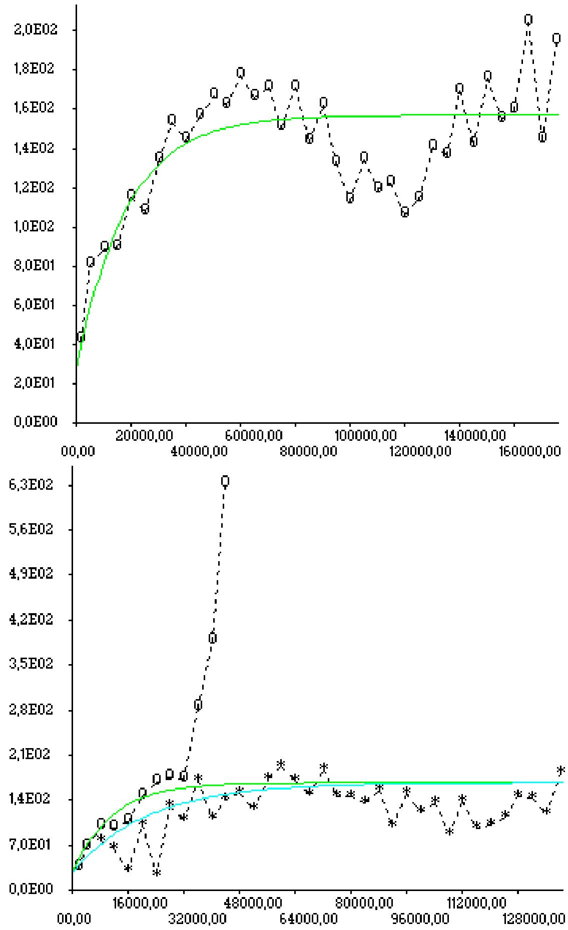
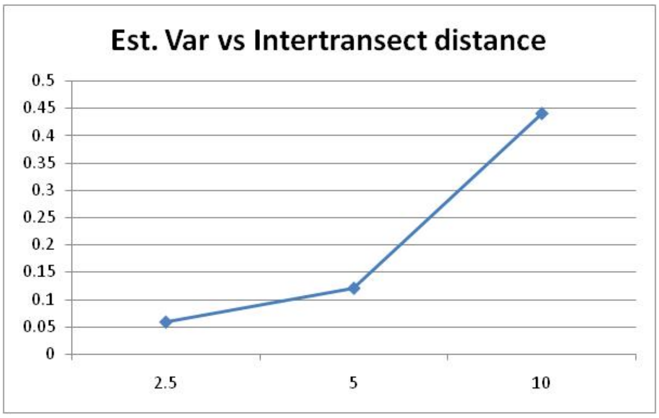


Figure 9. Sardine. Isotropic and directional variograms and directional model retained.



EST. VAR VS. INTERTRANSECT DISTANCE			
Intertransect (NM)	Nug (%)	Est. Var	Cvgeo
2.5	78.5	0.058	0.0450153
5	71.8	0.12	0.0647496
10	40	0.44	0.123986

Figure 10. Sardine. Estimation variance as a function of inter-transect distance.

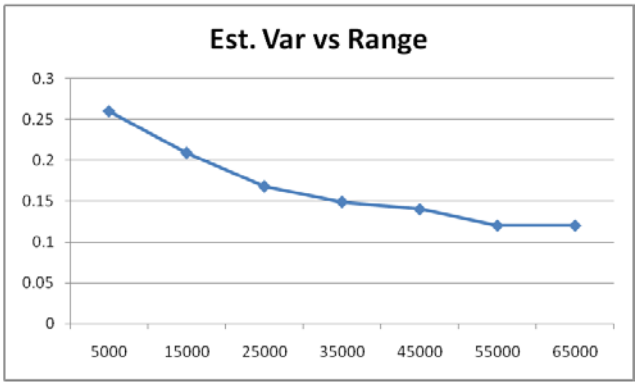


Figure 11. Sardine. Estimation variance (ordinate) as a function of variogram range (abscissa in meters) for the current inter-transect distance (5 n.mi.).

Annex 8: Adriatic Sea (Andrea de Felice, CNR-ISMAR)

Survey series

- Study area : Adriatic Sea
- Target species: *Engraulis encrasicolus, Sardina pilchardus*
- Split-beam Simrad Echosounder EK 500 – EK 60 at 38 – 120 – 200 kHz
- TS and Sv thresholds set to -80 dB for data logging and -70 dB (-60 dB depending on kind of echogram) for data processing
- 8 - 10 nm inter-transect distance
- EDSU was 1 nm
- Min Bottom Depth 10m
- Vessel speed : 9.5 knots
- Data collection: Day and night
- Myriax Echoview for Echogram analysis

Data available

Year	Area	Area sampled	Inter-transect distance	Sampling design	Data
2002	Central-south Adriatic	around 7000 nm^2	10 nm in average	Zig-zag	NASC fish, anchovy NASC, sardine NASC.
2004	North Adriatic	around 8000 nm^2	10 nm in average	Zig-zag	NASC fish, anchovy NASC, sardine NASC
2005	entire western Adriatic	around 15000 nm^2	10 nm in average	Zig-zag	NASC fish, anchovy NASC, sardine NASC
2006	entire western Adriatic	around 15000 nm^2	10 nm in average	Zig-zag	NASC fish, anchovy NASC, sardine NASC
2007	entire western Adriatic	around 15000 nm^2	10 nm in average	Zig-zag	NASC fish, anchovy NASC, sardine NASC
2008	entire western Adriatic	around 15000 nm^2	0 nm, 8 nm in narrow area	parallel grid	NASC fish, anchovy NASC, sardine NASC
2009	entire western Adriatic	around 15000 nm^2	0 nm, 8 nm in narrow area	parallel grid	NASC fish, anchovy NASC, sardine NASC, anchovy and sardine biomass per mile

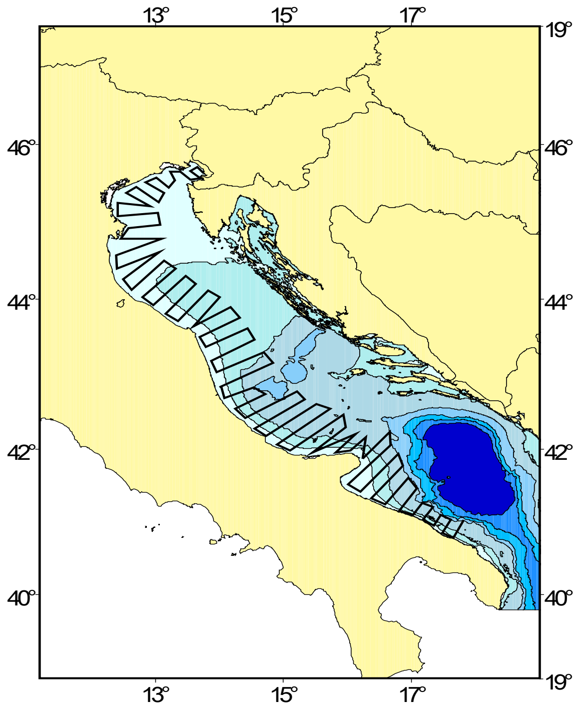


Figure 1. Survey design from 2008.

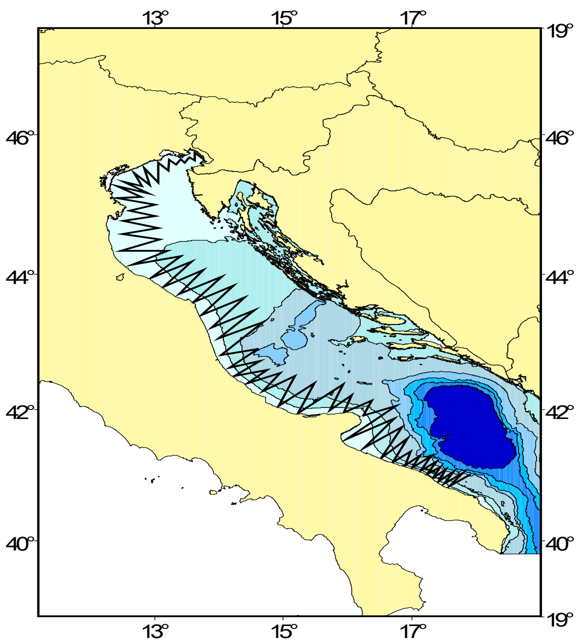


Figure 2. Survey design until 2007.

Case study

Data: Raw NASC total pelagic without log transformation

Year: 2005

Area: North Adriatic

Coordinate transformation: Projected UTM33 Northing and Easting metrical coordinates.

Units of distances: Nautical miles

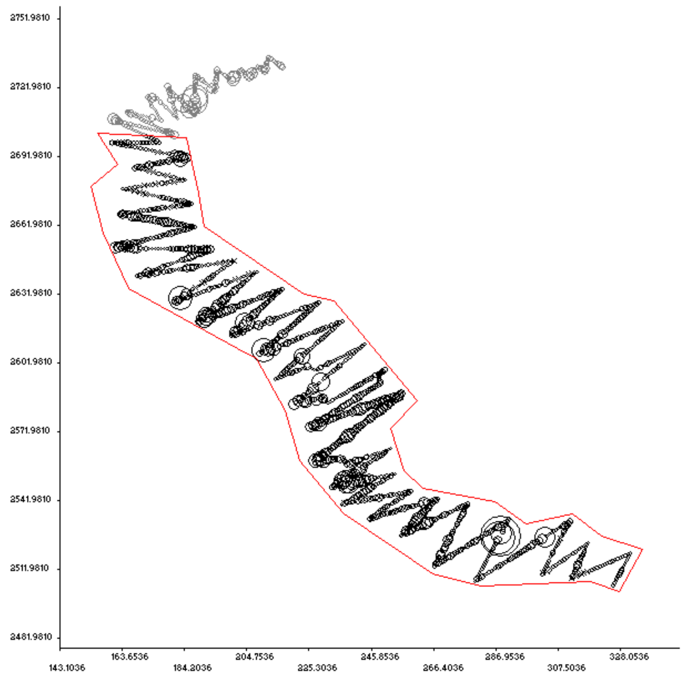


Figure 3. Bubble plot for the raw NASC values.

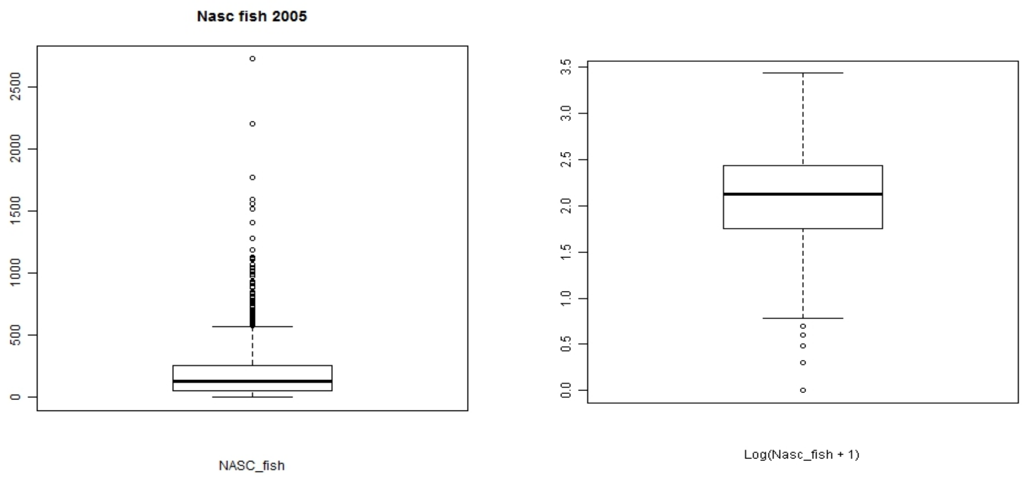


Figure 4. Boxplots for the raw NASC values (left) and log transformed NASC (right).

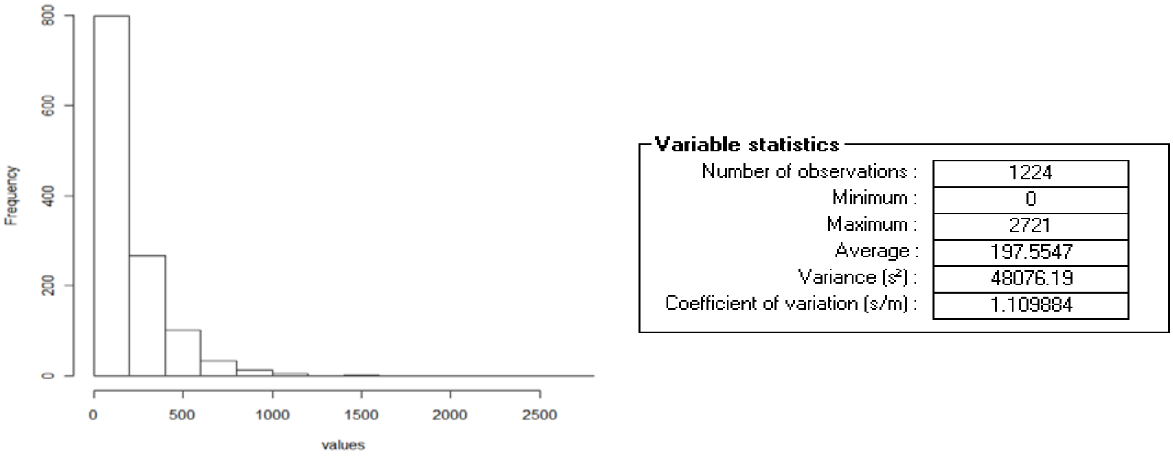


Figure 5. Hystogram and basic statistics of raw NASC values.

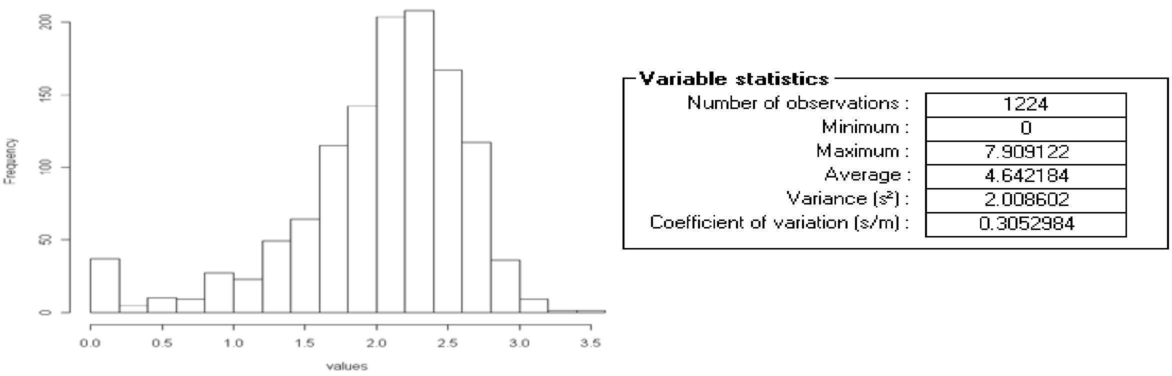
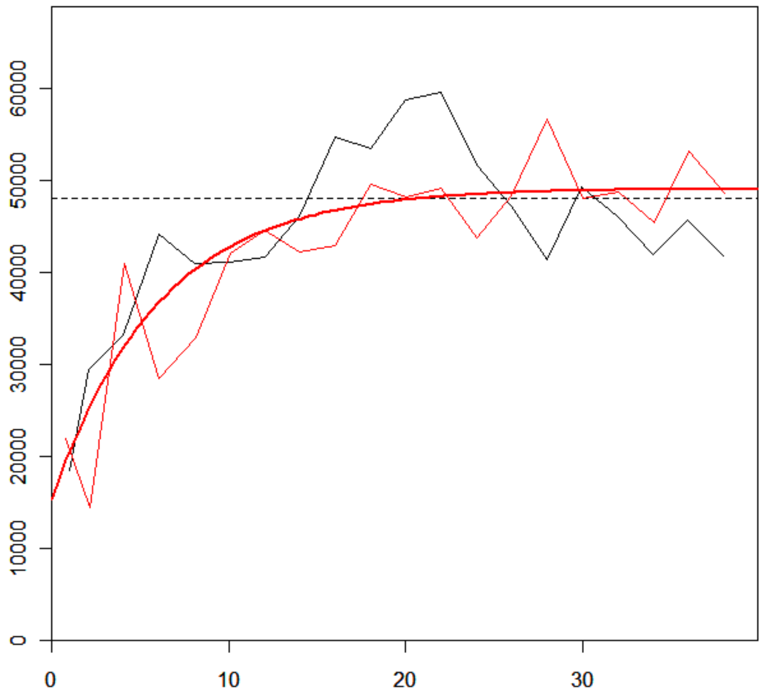


Figure 6. Hystogram and basic statistics of log transformed NASC values.



Lag	N° lags	Nugget	Sill	Range
2 nmi	20	15235	33895	18

Figure 7. Variogram for the raw total pelagic NASC.

Year	Estimation variance	Nugget	Model	CVGeo
2005 (zig zag transect)	91.46	86.6%	13.4%	0.048
2008 (parallel transect)	52.64	66.6%	33.4%	0.036

Figure 8. Variance comparison between 2005 zig-zag design and 2008 parallel design.

Annex 9: North Aegean Sea (Marianna Giannoulaki, HCMR)

- Name of the survey: Anchovy
- Target species: anchovy and sardine
- Period: Summer (June)
- About 30-40 days at sea
- Temporal series: 5 years (2003–2008)
- Geostatistical exercise on Thracian Sea (open area), Thermaikos Gulf (semi closed gulf) and North Evoikos Gulf (closed gulf)
- Daytime survey, daytime and night-time hauls
- Pelagic trawl
- Transect lengths 10–60 nautical miles
- ESDU 1 nautical mile
- Data: biomass of anchovy and sardine

The surveyed area is divided into subareas (Thermaikos Gulf, Thracian Sea and north Evoikos Gulf: Figure 1) based on existing topography and the different characteristics of fish aggregations. Therefore geostatistical analysis was applied separately per subarea and different survey designs were tested per subarea.

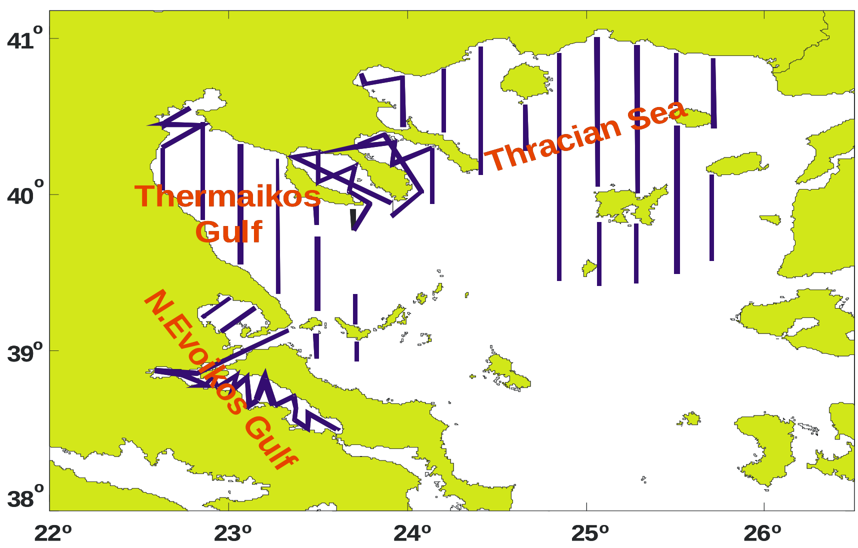


Figure 1. Current survey design in Northern Aegean Sea.

Thermaikos Gulf

Existing survey design is consisted of parallel transects with 10 nm inter transect distance and two zig-zagged transects in the northwestern part of the gulf. For analysis purposes an area covering only parallel transects was selected in order to facilitate the application of different survey designs.

RGEOS package was used for the application of geostatistical analysis. Raw NASC anchovy values in the along-transect direction were used for the application of intrinsic omnidirectional variograms. However raw NASC values presented highly skewed distribution and the respective annual variograms indicated low autocorrealation: high nugget value and short range (less than 3 nm, Figure 4, Table 2).

This is most likely attributed to the highly patchy and compact anchovy aggregations located mainly in the coastal waters of the north and northeastern part of the gulf (i.e. presenting high NASC values at short distances). Therefore in order to obtain a better visualization of the geometry and the size of fish patches along-transect at different density levels we applied omnidirectional indicator variograms at different percentiles (25%, 50% and 75%) of the raw NASC values Table 3, Figure 5). The cut off points were selected based on the available data from the entire time-series.

A progressive loss of structure with an increase in the nugget values and a reduction in the autocorrelation range was observed towards the higher percentiles, however because the aim of the acoustic survey in this area was to adequately capture the large spatial structures of fish aggregations the 25% indicator variogram was modelled and used for testing survey design. The average variogram for all years in the time-series was estimated and modelled (Table 4, Figure 6) and revealed the existence of mesoscale spatial structures in anchovy aggregations presenting autocorrelation range at 9.5 nm.

Evaluation of different survey designs

Based on the model of the average indicator variogram of the 25% percentile different survey designs corresponding to different values of inter transect distance were applied and the geostatistical variance was estimated as well as the nugget contribution to the variance. Results are presented in Table 5, indicating a reduction in the geostatistical variance with a reduction in the inter-transect distance thus better estimation at smaller inter-transect distance. Current survey design at 10 nm of inter – transect distance is close to the size (9.5 nm) of the autocorrelation structure based on the average indicator variogram.

Test of different autocorrelation range

The use of an average variogram infers that a spatial pattern is persistent from one year to another. However, the spatial structure of anchovy aggregations can present considerable annual variability. So, we tested different based values of autocorrelation range under the current survey design and based on the model of the average indicator variogram of the 25% percentile in order to estimate the geostatistical variance when the fish structure changes from short to large ranges.

Table 1.1. Thermaikos Gulf: Basic Statistics of anchovy NASC values in June 2008.

	No of samples	Mean	Variance	CV
Raw data	162	508.07	2529151	3.13
Ln (Z(x)+1)	162	1.642	8.89	1.81

Table 1.2. Thermaikos Gulf: Model Variogram fitted results for the raw data in 2008

Nugget	Exponential model Sill	Range
1640264.80 (67.38%)	793787.759 (32.61%)	2.3 nm
Est Variance	Variance geo	CV geo
13390.81	9.091717	0.017895

Table 1.3. Thermaikos Gulf: Indicator variograms description.

%Q: Contribution to the mean, % V: contribution to the variance

	Cut off value	No of samples	P	%Q	%V
25%	1.06	162	0.247	1	0.923
50%	67.85	162	0.222	0.997	0.921
75%	492.46	162	0.148	0.961	0.918
95%	1726.27	162	8.6419E-02	0.828	0.904

Table 1.4. Thermaikos Gulf: Model fitted results on the average indicator variogram at 25% cut off level of all years.

Nugget	Exponential model Sill	Range
0.17 (62%)	0.08 (38%)	9.5 nm

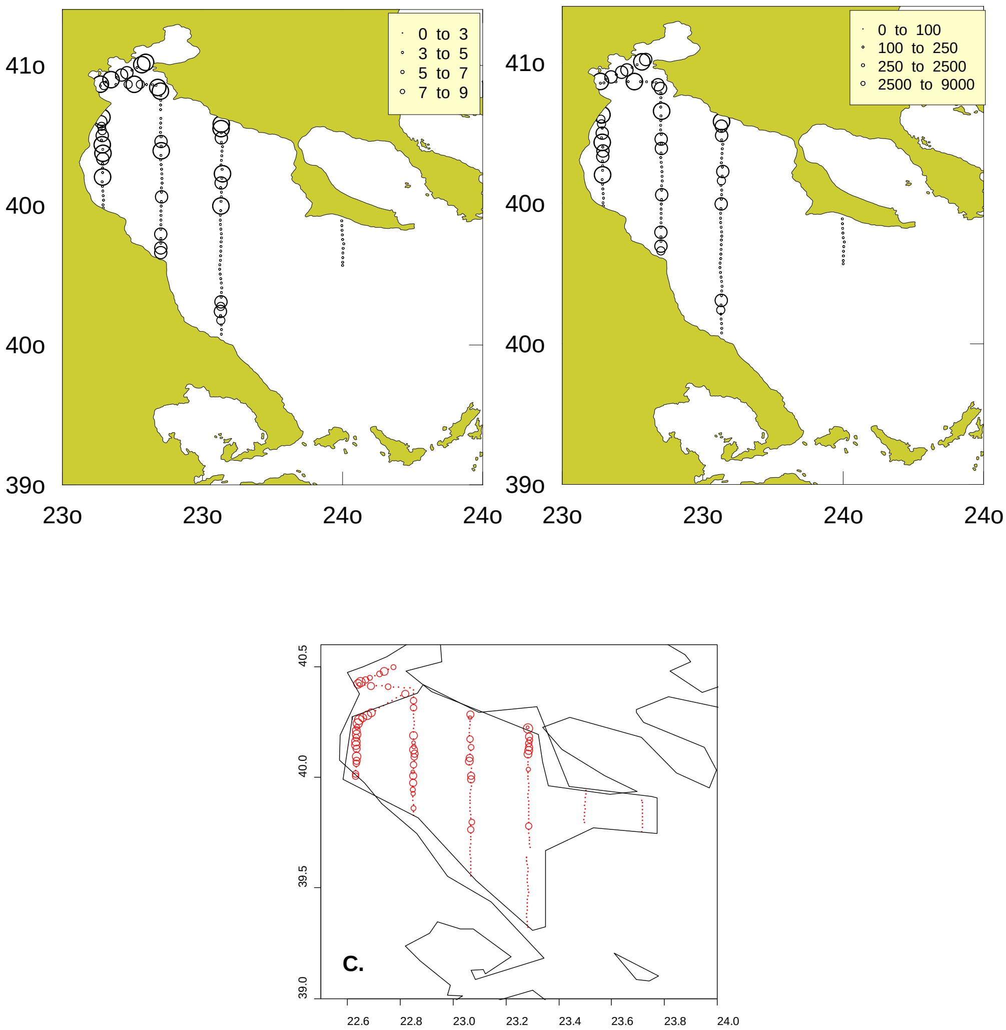


Figure 1.2. Thermaikos Gulf: Anchovy spatial distribution in June 2008 (A) raw NASC values (B) Ln (1+z(x)) transformed NASC values (C) Polygon used for analysis.

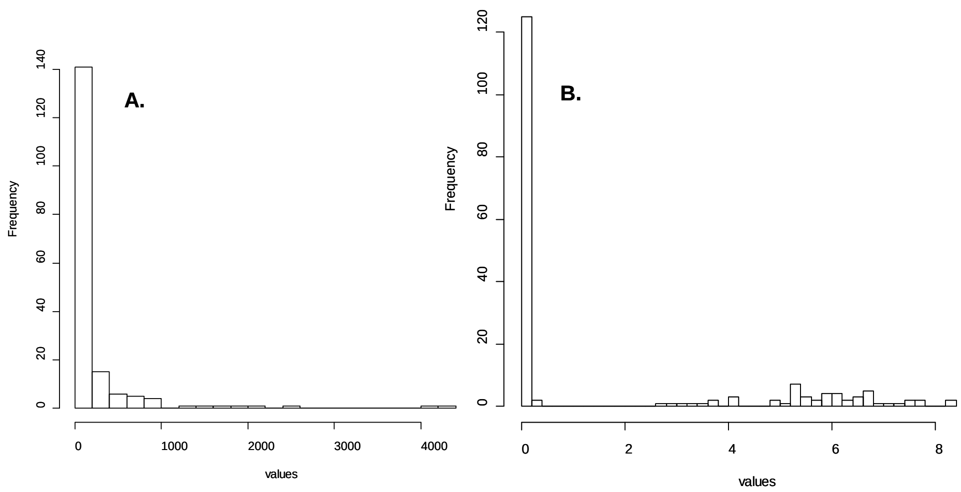


Figure 1.3. Thermaikos Gulf: Histogram of anchovy NASC values in June 2008 (A) raw NASC values (B) Ln (1+z(x)) transformed NASC values.

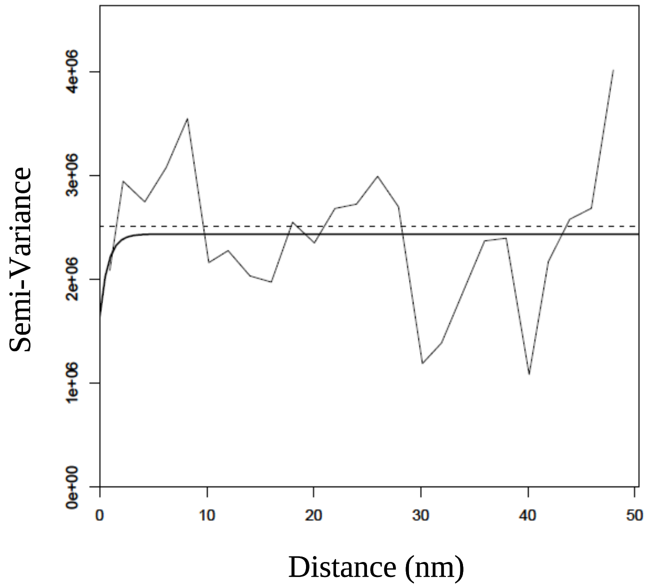


Figure 1.4. Thermaikos Gulf: Omnidirectional variogram of raw NASC anchovy values using lag=2 nm, Nlags=25, angle tolerance=90°.

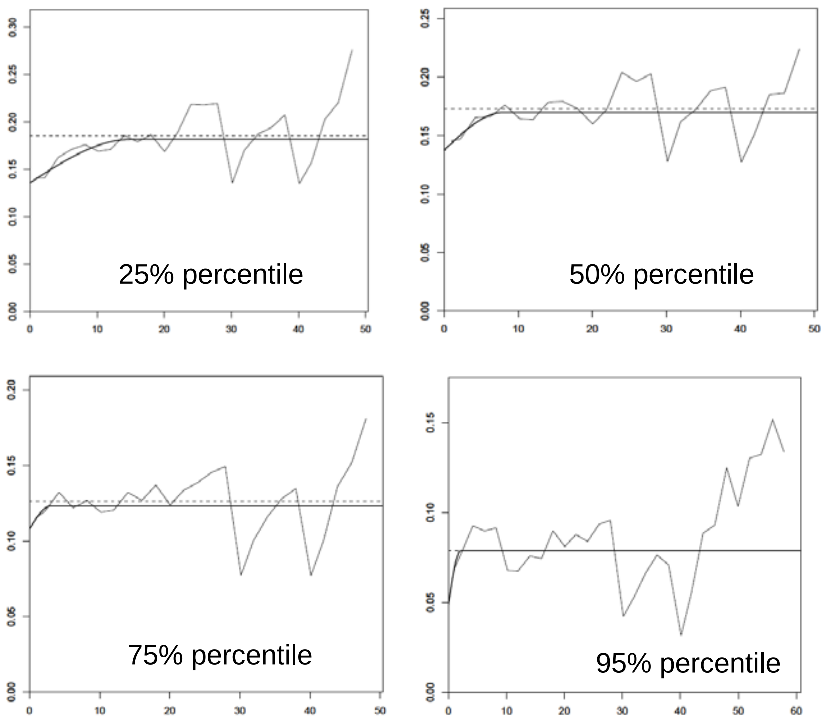


Figure 1.5. Thermaikos Gulf: Omnidirectional indicator variograms of anchovy NASC in 2008.

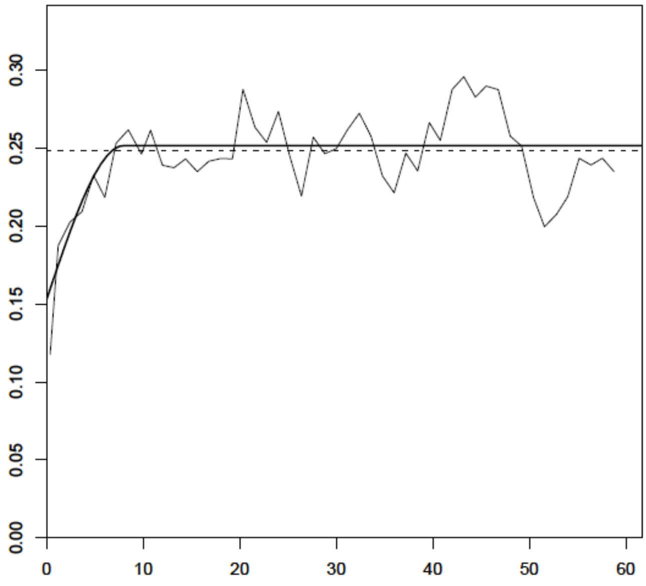


Figure 1.6. Thermaikos Gulf: Average omni directional indicator variogram of the 25% for June 2003–2008.

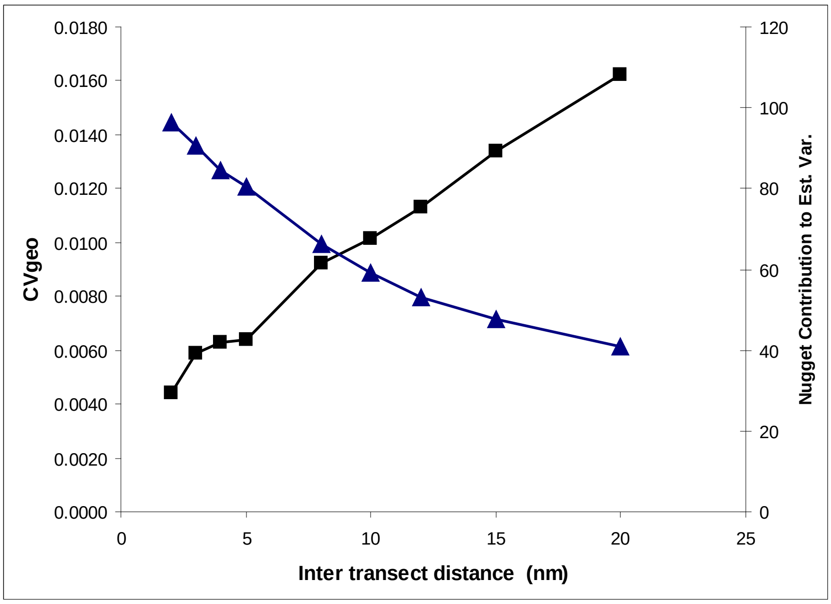


Figure 1.7. Thermaikos Gulf: Variance estimates and nugget contribution to the estimated variance under different survey designs corresponding to different values of inter transect distance.

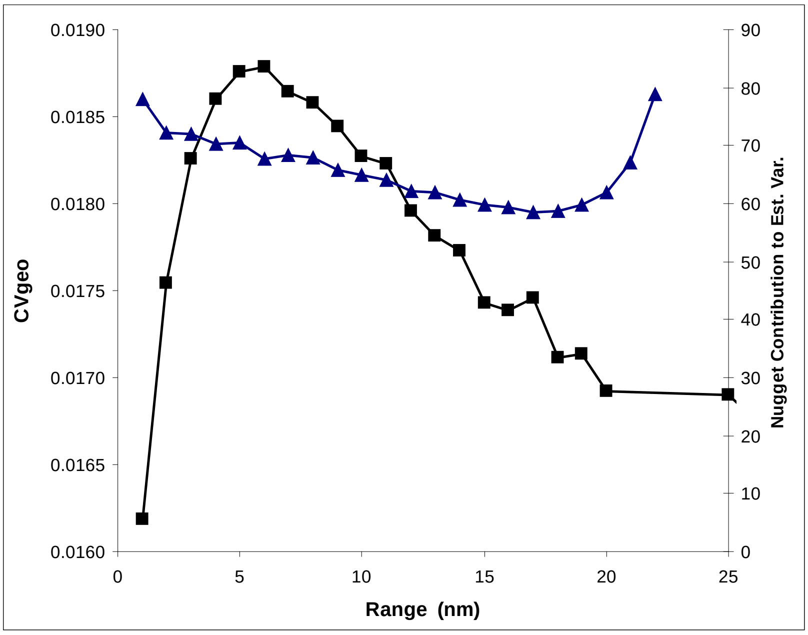


Figure 1.8. Thermaikos Gulf: Variance estimates and nugget contribution to the estimated variance under different autocorrelation range values.

Thracian Sea

Existing survey design is consisted of parallel transects with 10 nm inter transect distance. RGEOS package was used for the application of geostatistical analysis. Raw NASC anchovy values in the along-transect direction were used for the application of intrinsic omnidirectional variograms. Raw NASC values presented highly skewed distribution and the respective annual intrinsic variograms indicated an autocorrelation range around 5–11 nm (depending on the year) concerning anchovy aggregations in the along-transect direction. Data concerning 2005 are presented in Figure 4, Table 2.

In order to obtain a better visualization of the geometry and the size of fish patches along-transect at different density levels we applied omnidirectional indicator variograms at different percentiles (25%, 50% and 75%) of the raw NASC values Table 3, Figure 5). The cut off points were selected based on the available data from the entire time-series. Because the aim of the acoustic survey in this area was to capture the large spatial structures of fish aggregations the 25% indicator variogram was modelled and used for testing survey design. The average variogram for all years in the time-series was estimated and modelled (Table 4, Figure 6) and revealed the existence of mesoscale spatial structures in anchovy aggregations presenting autocorrelation range at 10 nm.

Evaluation of different survey designs

Based on the model of the average indicator variogram of the 25% percentile different survey designs corresponding to different values of inter transect distance were applied and the geostatistical variance was estimated as well as the nugget contribution to the variance. Results are presented in Table 5, indicating a reduction in the geostatistical variance with a reduction in the inter-transect distance thus better estimation at smaller inter-transect distance. Current survey design at 10 nm of inter – transect distance approximates the size (10 nm) of the autocorrelation structure based on the average indicator variogram.

Application of different autocorrelation ranges

The use of an average variogram infers that a spatial pattern is persistent from one year to another. However, the spatial structure of anchovy aggregations can present considerable annual variability. So, we tested different based values of autocorrelation range under the current survey design and based on the model of the average indicator variogram of the 25% percentile in order to estimate the geostatistical variance when the fish structure changes from short to large ranges.

Table 2.1. Thracian Sea: Basic Statistics of anchovy NASC values in June 2005.

	No of samples	Mean	Variance	CV
Raw data	138	266.54	790302.5	3.335
Ln (Z(x)+1)	138	1.582	7.326	1.710

Table 2.2. Thracian Sea: Model Variogram fitted results for the raw data in June 2005.

Nugget	Exponential Model Sill	Range
320000 (59.4%)	470000 (40.6%)	11 nm
Est Variance	Variance geo	CV geo
6310.773	6.762	0.025

Table 2.3. Thracian Sea: Indicator variograms description. %Q: Contribution to the mean, % V contribution to the variance.

	Cut off value	No of samples	P	%Q	%V
25%	6.26	138	0.275	1	0.934
50%	104.8	138	0.196	0.982	0.929
75%	513.6	138	0.108	0.910	0.928

Table 2.4. Thracian Sea: Model fitted results on the average indicator variogram at 25% cut off level of all years.

Nugget	Exponential Model Sill	Range
0.17 (62%)	0.08 (38%)	10 nm

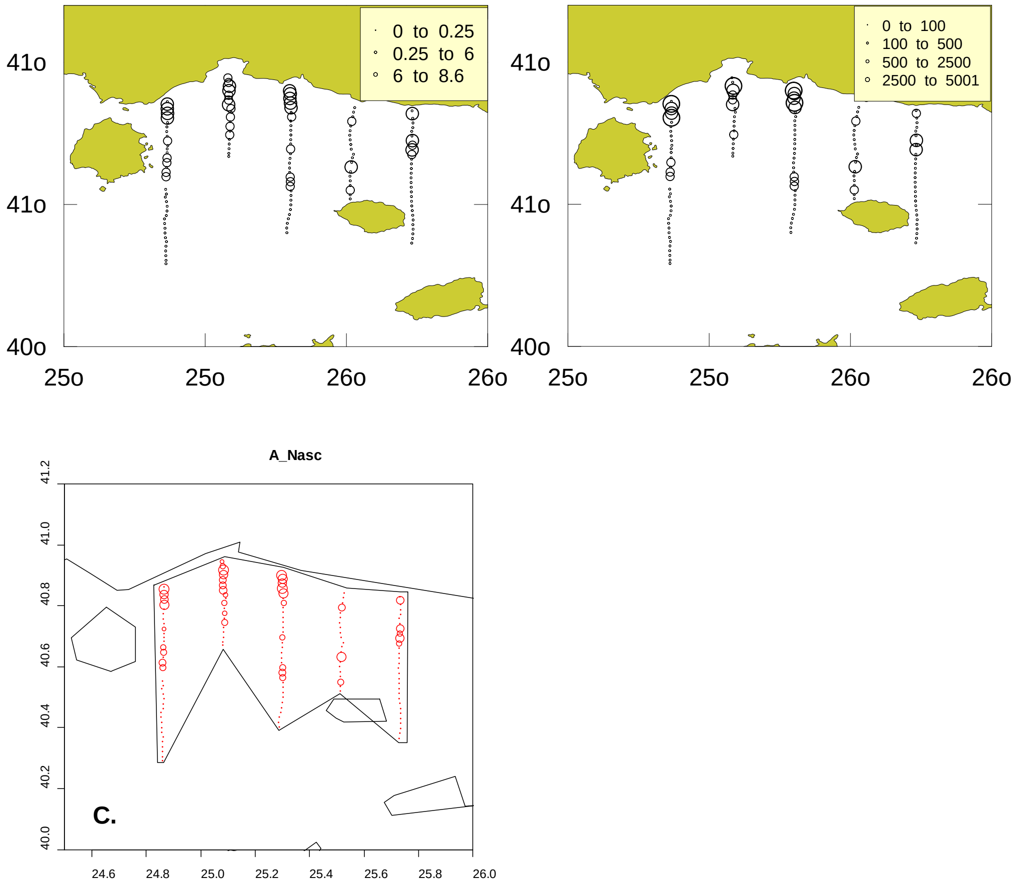


Figure 2.2. Thracian Sea: Anchovy spatial distribution in June 2005 (A) raw NASC values (B) Ln (1+z(x)) transformed NASC values (C) Polygon used for analysis.

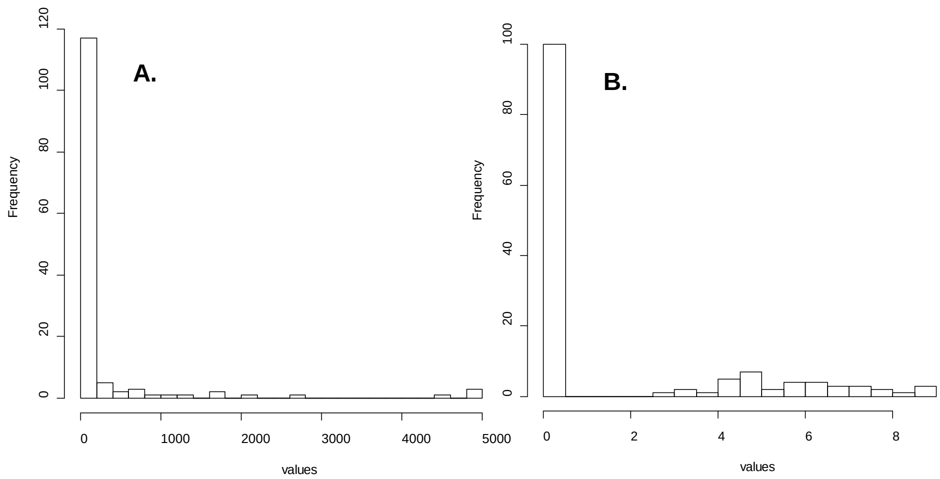


Figure 2.3. Thracian Sea: Histogram of anchovy NASC values in June 2005 (A) raw NASC values (B) Ln (1+z(x)) transformed NASC values.

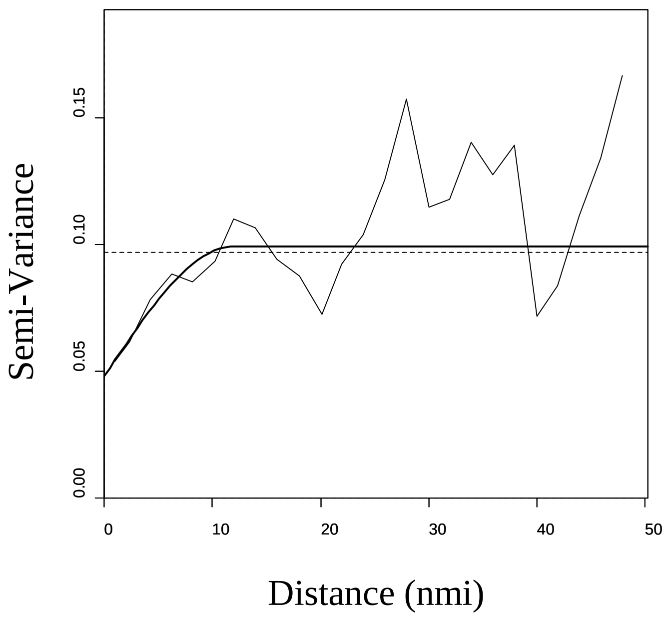


Figure 2.4. Thracian Sea: Omnidirectional variogram of raw NASC anchovy values using lag=2 nm, Nlags=24, angle tolerance=90º.

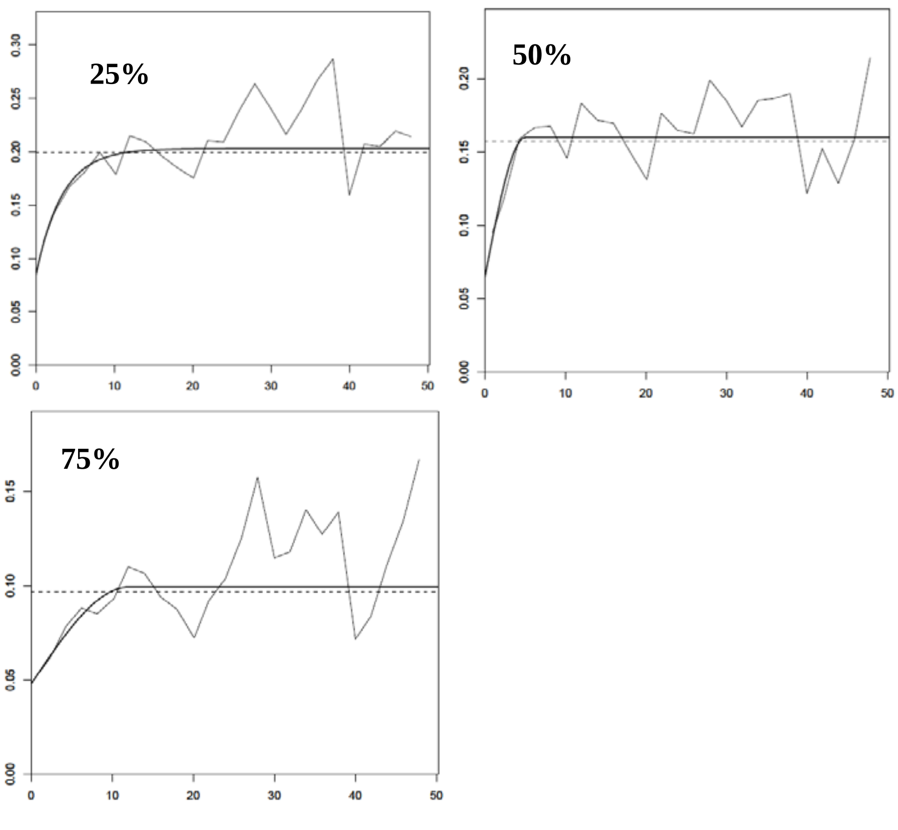


Figure 2.5. Thracian Sea: Omnidirectional indicator variograms of anchovy NASC in June 2005.

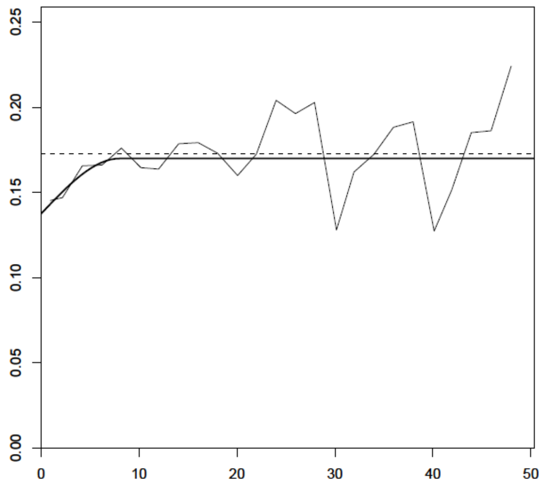


Figure 2.5. Thracian Sea: Average Indicator variogram of 25% cut off anchovy NASC values for June 2003–2008.

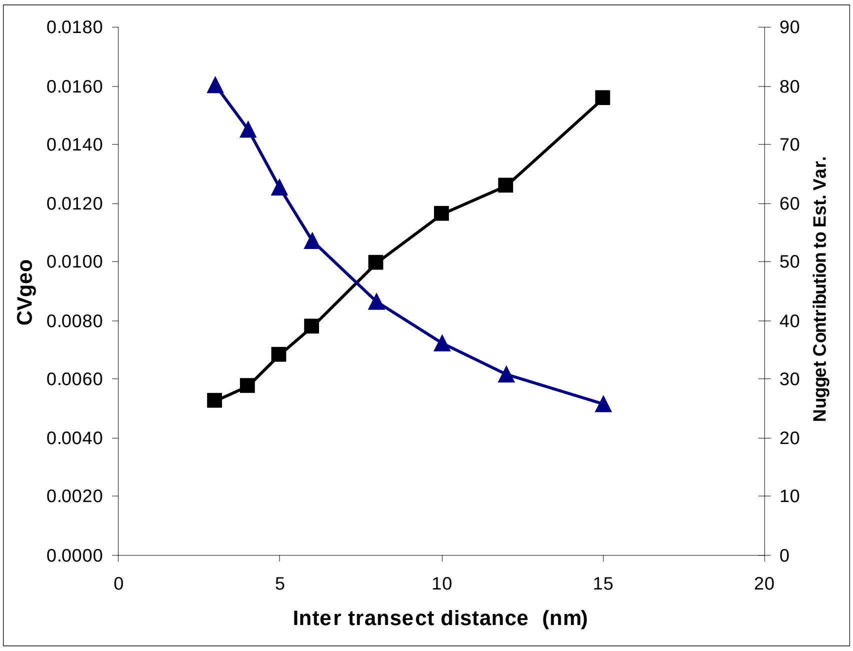


Figure 2.7. Thracian Sea: Variance estimates and nugget contribution to the estimated variance under different survey designs corresponding to different values of inter transect distance.

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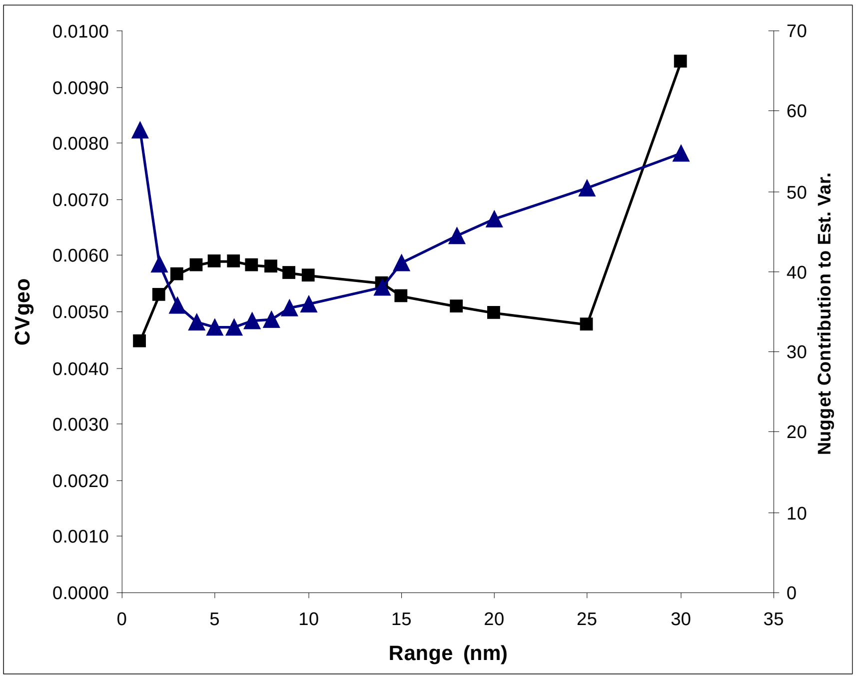


Figure 2.8. Thracian Sea: Variance estimates and nugget contribution to the estimated variance under different autocorrelation range values addressing potentially the annual variability in the spatial structure of anchovy aggregations.

North Evoikos Gulf

Existing survey design is consisted of zig-zagged transects. For testing different survey designs EVA software was used, points were generated outside and imported into the software for analysis purposes.

RGEOS package was used for the application of geostatistical analysis in NASC anchovy values obtained within the 2008 survey. Raw NASC anchovy values in the along-transect direction were used for the application of intrinsic omnidirectional variograms. However raw NASC values presented highly skewed distribution and the respective annual indicated autocorrelation range at 13 nm and nugget values at xx (Figure 4, Table 2). Similarly the histogram of the ln (x+1) values is indicated.

Therefore in order to obtain a better visualization of the geometry and the size of fish patches along-transect at different density levels we applied omnidirectional indicator variograms at different percentiles (25%, 50% and 75%) of the raw NASC values Table 3, Figure 5). The cut off points were selected based on the available data from the entire time-series.

No loss of structure or reduction of the autocorrelation range was observed towards the higher percentiles. All estimated and modelled variograms (Table 4, Figure 6) revealed the existence of mesoscale spatial structures in anchovy aggregations presenting autocorrelation range at 12–13 nm. Therefore, the raw data variogram was used for testing different survey designs.

Evaluation of different survey designs

Based on the model of the raw data different survey designs were applied:

SD1: Current survey design

SD2. More intense sampling with dense zig-zag in the north part of the gulf along with parallel transects in the south part with 2–3 nm inter transect distance

SD3: Existing survey design in the north part of the gulf along with parallel transects in the south part with 2–3 nm inter transect distance

SD4: Existing survey design in the north part of the gulf along with parallel transects in the south part with 5 nm inter transect distance

The geostatistical variance was estimated as well as the nugget contribution to the variance. Results are presented in Table 5, indicating

Application of different autocorrelation ranges

The use of an average variogram infers that a spatial pattern is persistent from one year to another. However, the spatial structure of anchovy aggregations can present considerable annual variability. So, we tested different based values of autocorrelation range under the current survey design and based on the model of the raw data in order to estimate the geostatistical variance when the fish structure changes from short to large ranges.

Table 3.1. North Evoikos Gulf: Basic Statistics of anchovy NASC values in 2008.

	No of samples	Mean	Variance	CV
Raw data	205	569.65	2659339	2.86
Ln (Z(x)+1)	205	1.48	8.97	2.02

Table 3.2. North Evoikos Gulf: Model Variogram fitted results for the raw data in 2008.

Nugget	Exponential Model Sill	Range
1200000 (45.1%)	1400000 (54.9%)	13 nm
Est Variance	Variance geo	CV geo
10669.12	7.21	0.013

Table 3.3. North Evoikos Gulf: Indicator variograms description.

%Q: Contribution to the mean, % V: contribution to the variance.

	Cut off NASC value	No of samples	P	%Q	%V
25%	24.3	205	0.205	1	0.902
50%	211.3	205	0.180	0.994	0.901
75%	891.1	205	0.127	0.951	0.899

Table 3.4. North Evoikos Gulf: Model fitted results of the indicator variograms at different cut off levels in 2008.

Cut off level	Nugget	Exponential Model Sill	Range
25%	0.030	0.170	14.0 nm
50%	0.040	0.140	13.5 nm
75%	0.045	0.075	11.5 nm

Table 3.5. North Evoikos Gulf: Geostatistical variance estimates and nugget estimates under different survey designs based on the raw data fitted variogram.

Survey Design	Var. estim. geo	CVgeo	% nugget
SD1	7.214	0.0126	54.9
SD2	7.059	0.0124	69.5
SD3	6.777	0.0119	63.4
SD4	8.081	0.0142	52.1

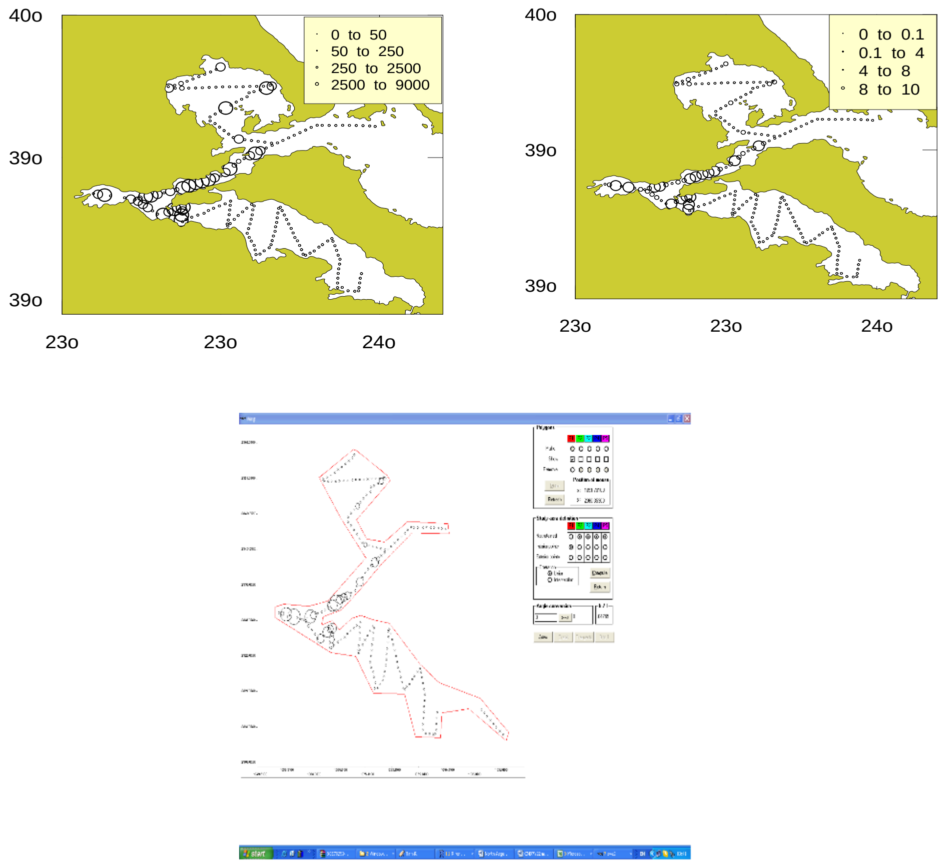


Figure 3.2. North Evoikos Gulf: Anchovy spatial distribution in June 2008 (A) raw NASC values (B) Ln (1+z(x)) transformed NASC values and (C) the polygon used for variance estimates.

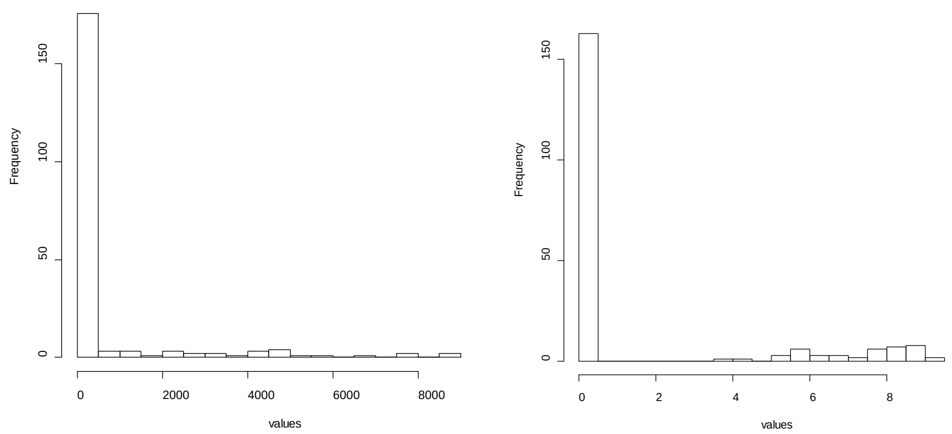


Figure 3.3 North Evoikos Gulf: Histogram of anchovy NASC values in June 2008 (A) raw NASC values (B) Ln (1+z(x)) transformed NASC values.

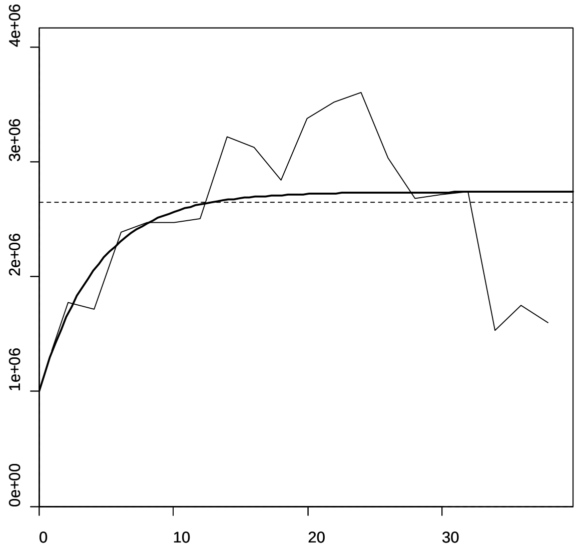


Figure 3.4. North Evoikos Gulf: Omnidirectional variogram of raw NASC anchovy values using lag=2 nm, Nlags=20, angle tolerance=90°.

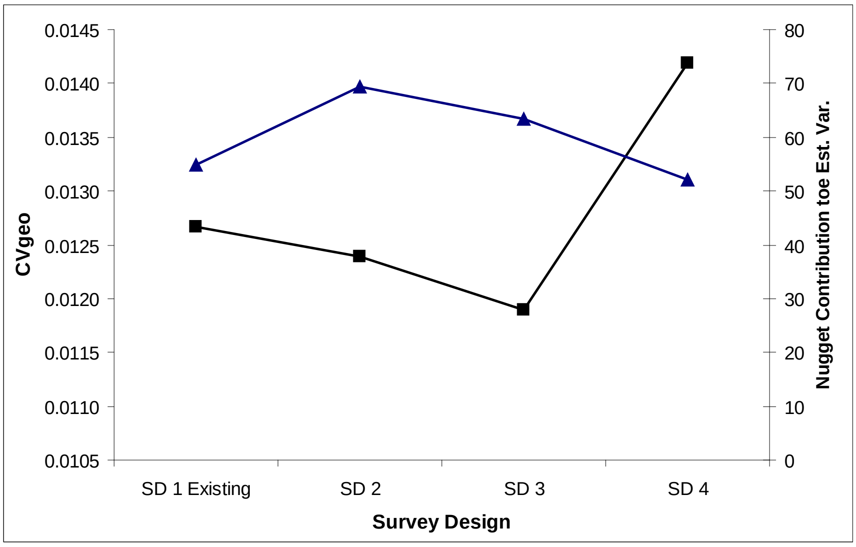


Figure 3.5. North Evoikos Gulf: Variance estimates and nugget contribution to the estimated variance under different survey designs corresponding to different values of inter transect distance.

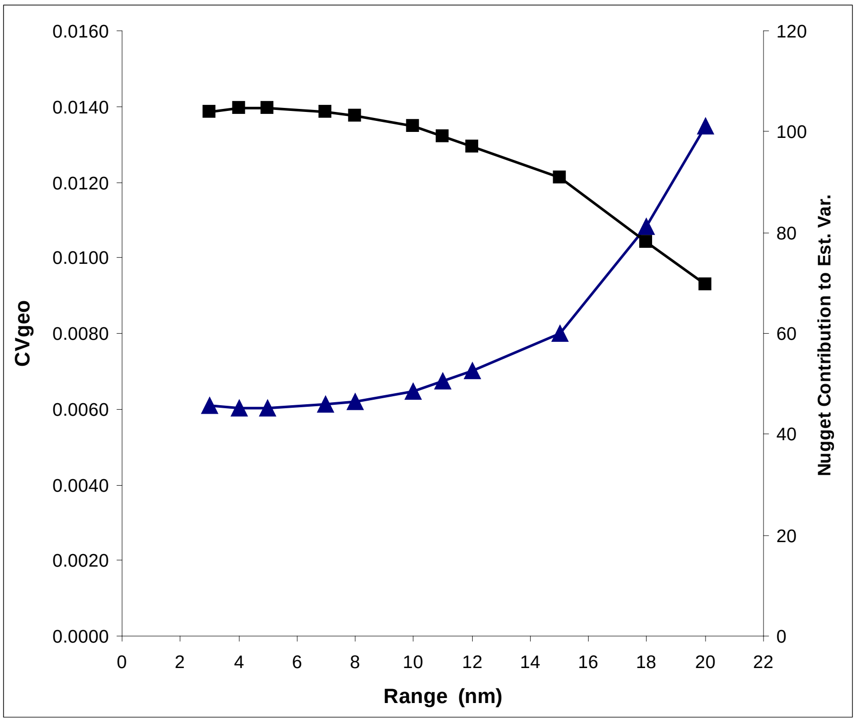


Figure 3.6. North Evoikos Gulf: Variance estimates and nugget contribution to the estimated variance under different autocorrelation range values addressing potentially the annual variability in the spatial structure of anchovy aggregations.

Annex 10: Atlantic Spanish waters - Pelacus surveys (Marian Peña and Magdalena Iglesias, IEO)

Geostatistical analyses were applied to the PELACUS survey data; the current survey design (Figure 1), covers from the North Portugal waters to the South French waters. Both Sardine and anchovy are target species (see Table 1), but as the latest has dramatically reduced its distribution in these waters in the last few years, we consider only sardine for this study. 2008 has been selected as the year with an average distribution of sardine, considering the whole Pelacus series; since then, both abundance and distribution have decreased. As a first approach we consider the radials in the Cantabrian coast with a North direction (see red polygon in Figure 1); the reason for that is two folded: a change in the survey design (radial direction due to change in coast direction) may imply a different spatial structure, and second, since 2008 the sardine distribution has been reduced to Cantabrian coast and the Galician waters.

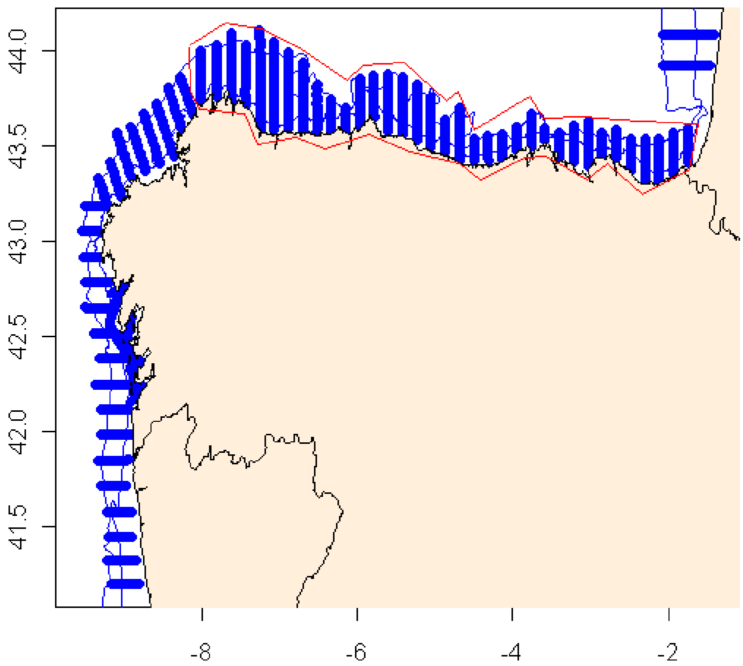


Figure 1. 2008 survey design for the PELACUS survey with estimation polygon shown (red line).

Table 1. Data series characteristics.

- **Study area:** Spanish North Atlantic waters
- **Surveyed area (NM²):**
  - Selected polygon: 13742
- **Target species:** Sardine
- **Sampling period** March – April
- **Life stage:** spawning

- **Data collection:** day
- **Echo sounder**
  - Simrad EK60
- **ESDU** 1NM
- **Sampling design:** parallel transect (inter transect distance 8NM)
- **Software** Echoview

Basic Statistics (within the polygon)

Table 1a. Statistics for the selected polygon data

Year=2008 Descriptive						
	Valid N	**Mean**	**Minimum**	**Maximum**	**Variance**	**Coef.Var.**
SA	536	73.45	0,00	5724	87968	4.03
Log SA	536	0.94	0,00	3.758	0.79	0.94

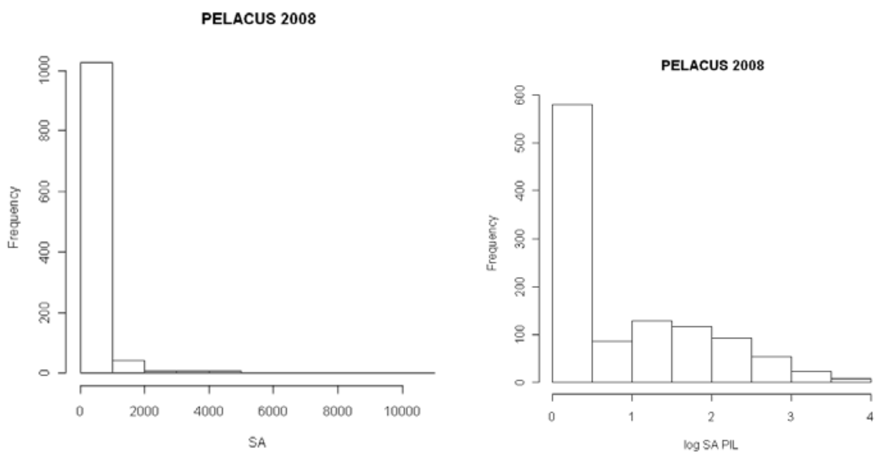


Figure 2. Sardine histograms for the raw SA values (left) and log transformed SA (right).

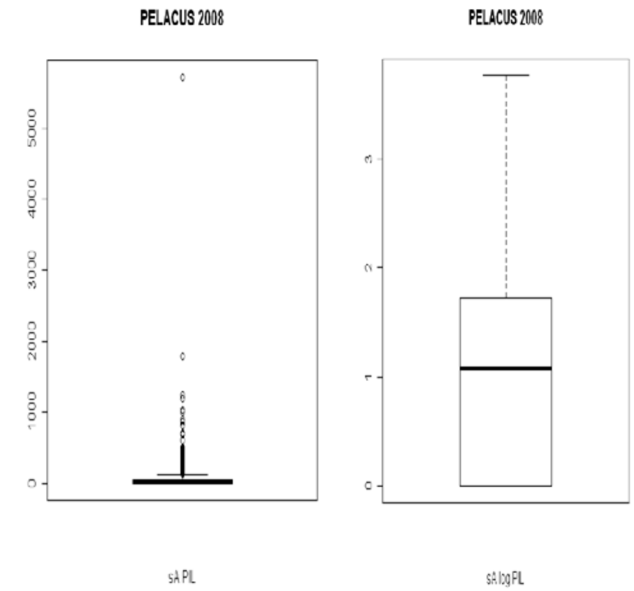


Figure 3. Sardine boxplots for the raw SA values (left) and log transformed SA (right).

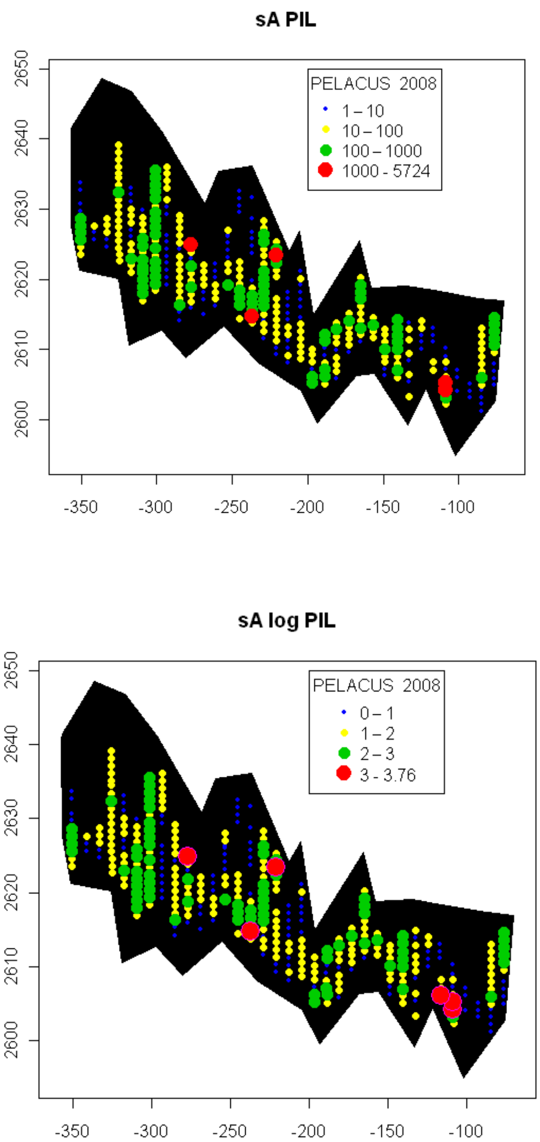


Figure 4. Sardine bubble plots for the raw SA values (top) and log transformed SA (bottom).

Variogram Analysis

Omnidirectional intrinsic variograms were evaluated both for raw and transformed data.

Raw data:

Table 2. Variogram analysis for the sardine raw data.

Experimental variogram	Model Parameters
• N Lags60 • Lag 1 • Tol. Ang. 5	• Model: expon • Nug 0.5e04 • Sill 8e04 • Range 6 • coeffX 1 • coeffY 1

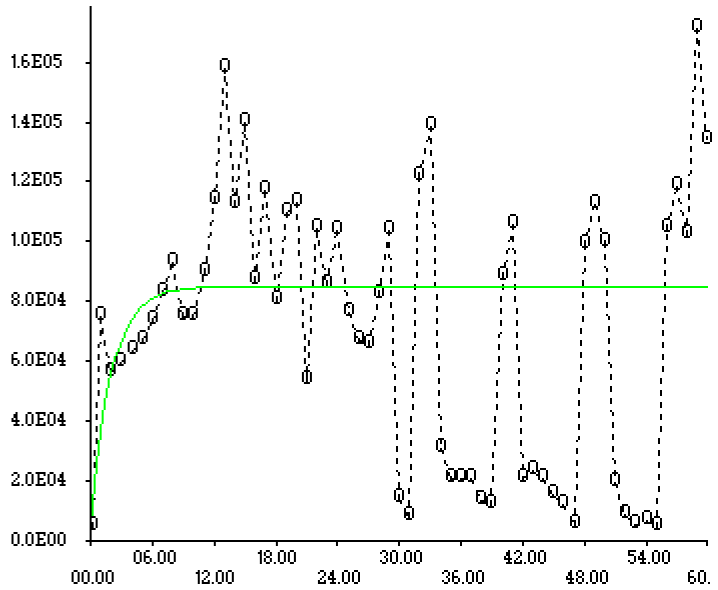


Figure 5. Variogram for the sardine raw data.

Spatial structure:

The variance around the sill is much shorter until a bit less than 30MN distance, that is the radial longest distance; and then a much bigger variance between transects with the 8MN intertransect distance well marked in the variogram. A few outliers in the border (always at the end of radials), but they don't seem to have much influence on the variogram.

The range obtained is similar to the one modelled for the same survey for the period 1991–1993 (Porteiro *et al*., 1996).

Survey design:

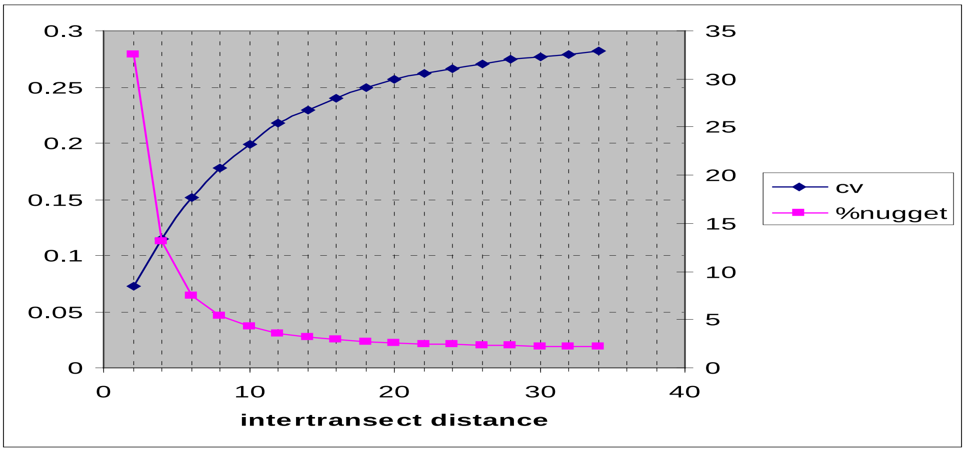


Figure 6. CV and percentage of nugget for different survey designs.

Coefficient of variation and percentage of nugget were calculated for different intertransect distances (Figure 6). The variance (cv) increases with distance, while the percentage of nugget reduces. Current survey design is 8 NM, which is close to the correlation range for this average variogram (6NM).

Log transformed data:

Table 4. Variogram analysis for the sardine raw data.

Experimental variogram	Model parameters
• N Lags 60 • Lag 1 Tol. Ang. 5	• Model: expon • Nug 0.1 • Sill 0.7 • Range 13 • coeffX 1 • coeffY 1

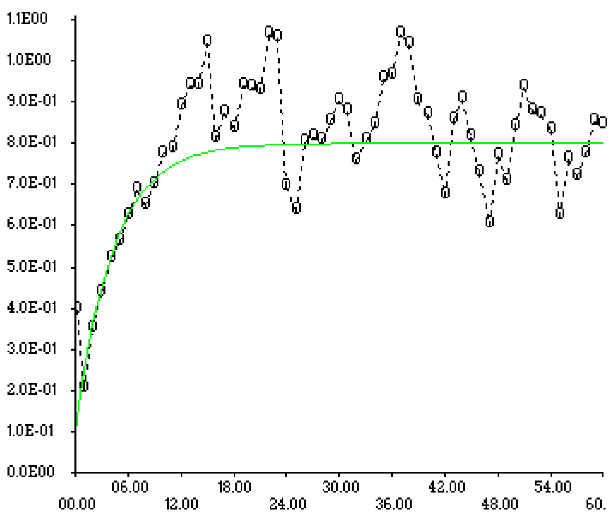


Figure 7. Variogram for the sardine raw data.

Spatial structure:

Results for log transformed data are shown in Figure 7 and Table 4. The variance around the sill is reduced both at short and long distance. The range however increases from 6 to 12–13 NM.

Survey design:

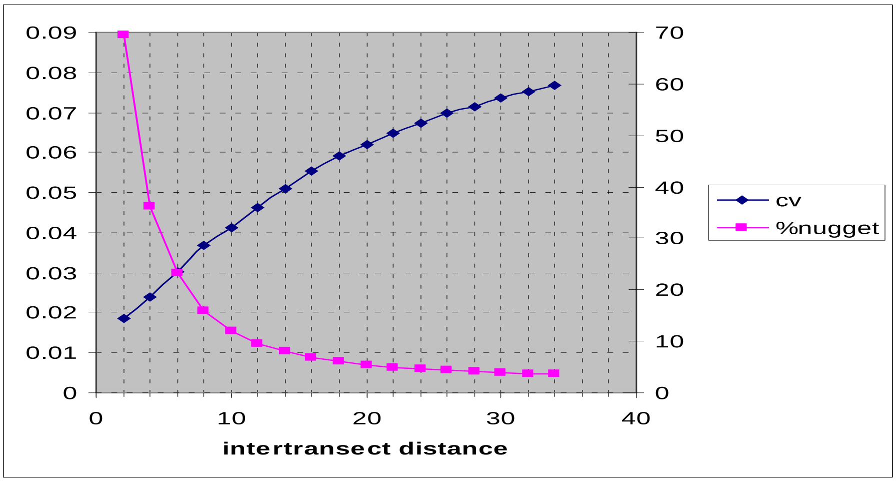


Figure 8. CV and percentage of nugget for different survey designs.

Annex 11: Bay of Biscay, spring, French shelf – Pelgas surveys (Pierre Petitgas and Mathieu Doray, Ifremer)

Sampling design

Parallel transects perpendicular to isobaths. The areas is covered in 4 weeks with 26 transects. Inter-transect distance: 12 nautical miles. The survey is an ecosystem pelagic survey coordinated with the surveys of IEO and IPIMAR, making one international pelagic survey from Cadiz to Brest.

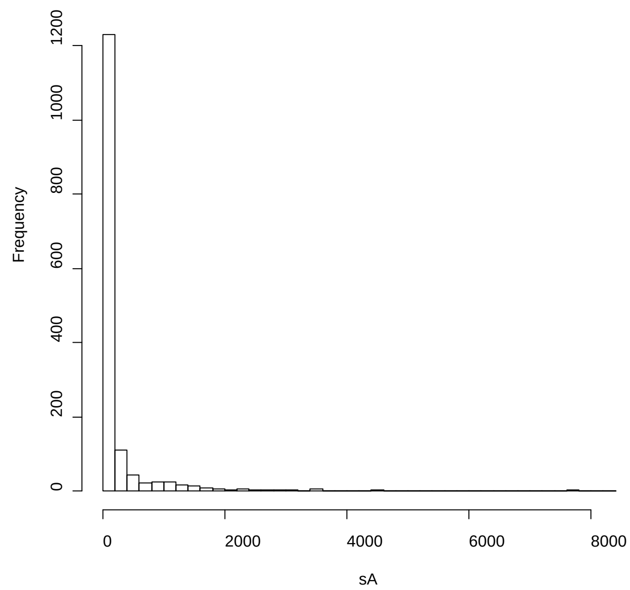
Target variable analysed: total fish sA values.

In the evaluation procedure the total sA is disaggregated into species based on the scrutinizing of the echogram and the fishing hauls. The acoustic sampling applies to total sA and the biological trawl haul sampling to species. We here consider total sA only.

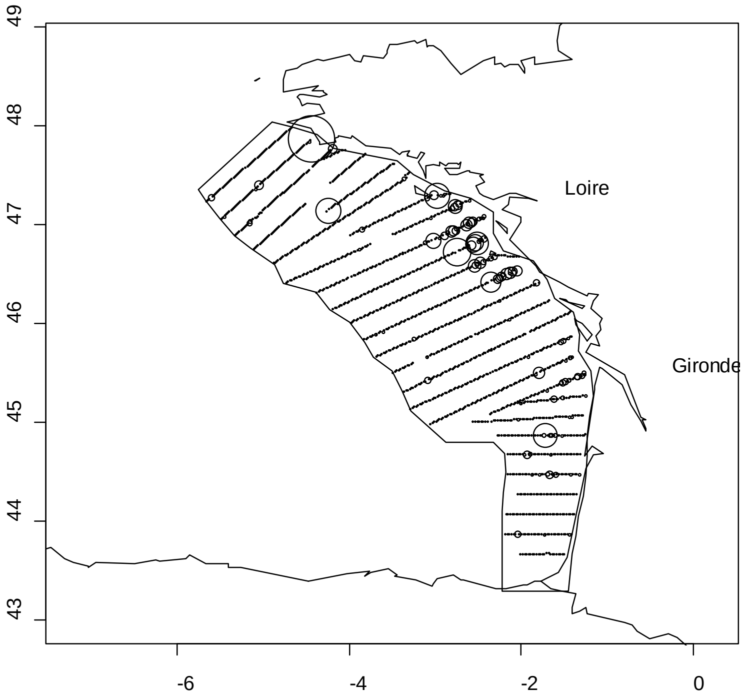
Analysis of PelGas 2010

Data basic statistics

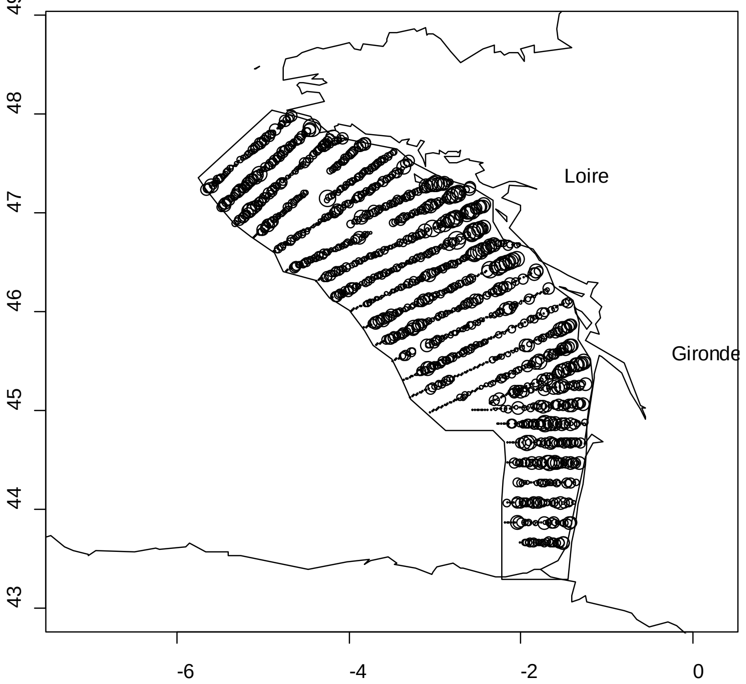
Inside polygon : mean= 245.6 ; nb ESUs= 1724 ; CV= 3.05 n0= 304



Data visualization

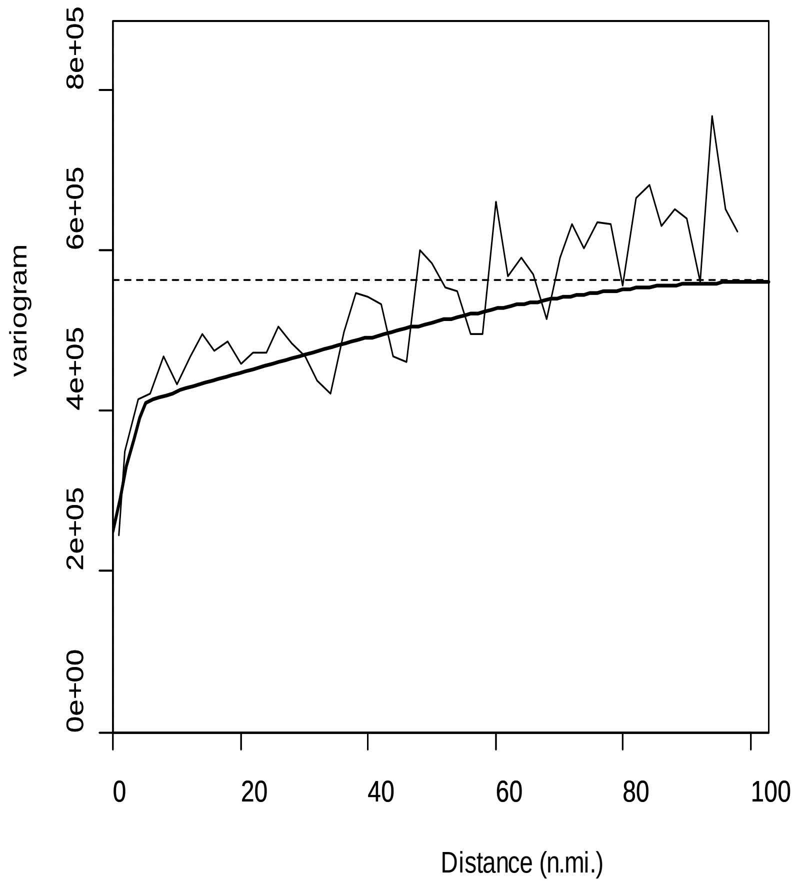


Bubble plot of sA values (arithmetic scale)



Bubble plot of log-transformed sA values (Log(sA+1))

Variography



omnidirectional variogram of raw sA values

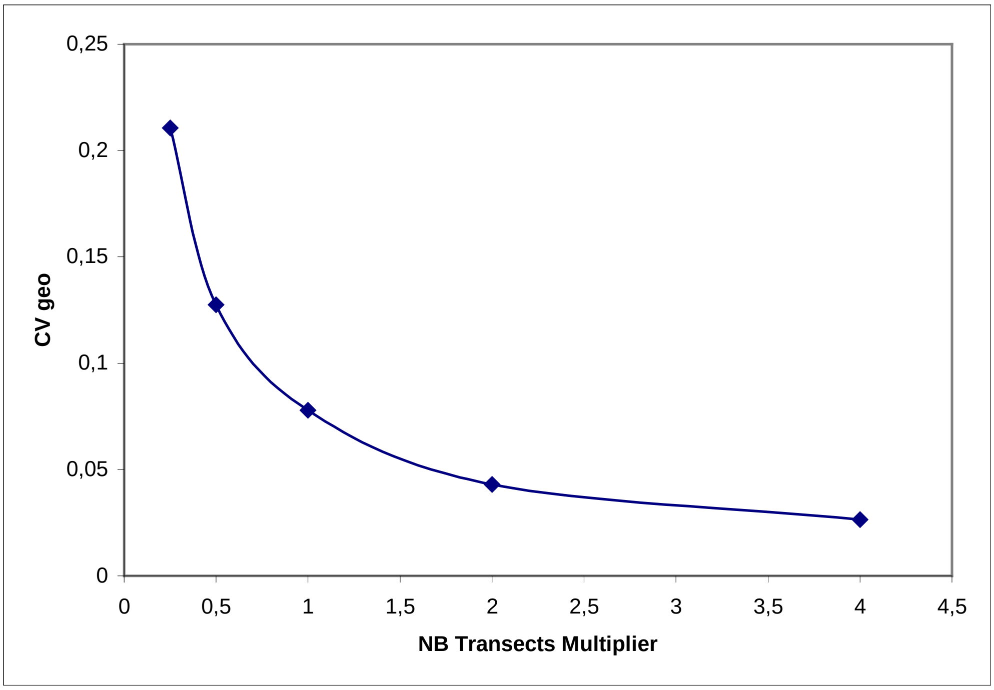
Computation: Lag=2 nautical mile, 50 lags

Model:

nugget(sill=250e3)+ spherical(sill=150e3,range=6)+spherical(sill=160e3,range=100)

The geostatistical estimation variance σ^2_{geo} was computed using the software EVA, Plan A: continuously sampled parallel transects regularly spaced. Each transect is the middle line of a rectangle of influence. In the computation of the estimation variance the estimation errors in the different rectangles are considered uncorrelated. The procedure corresponds to the chart of Matheron (1971, p. 96).

The estimation variance depends on the variogram and the sampling configuration only, not on the data sample values. Therefore, different sampling designs can be generated and their corresponding estimation variance computed. The assumption made is that different survey designs would have allowed to model the same variogram.



Nb Transects Mulitplier	Nb Transects	Inter Transect Distance (n.mi.)	CV geo	Per cent nugget
0,25	7	48	0.211	0.22
0,5	13	24	0.128	0.29
1	26	12	0.078	0.40
2	51	6	0.043	0.67
4	101	3	0.026	0.89

The present design is satisfactory. Increasing the number of transects does not seem necessary.

Multiyear variography : PelGas 2000–2010

We computed the variogram in each year, scaled it to unity by dividing by the data variance and estimated the average scaled variogram across all years, 2000–2010. This per year scaled average variogram showed a high nugget (75% of sill), a small range structure between 5 and 10 nautical miles and a longer range structure around 40 nautical miles.

Therefore, to test the design of the PELTIC survey we advised to use a variogram range between 5 and 10 nautical miles and a nugget to sill ratio between 50 and 80 per cent.

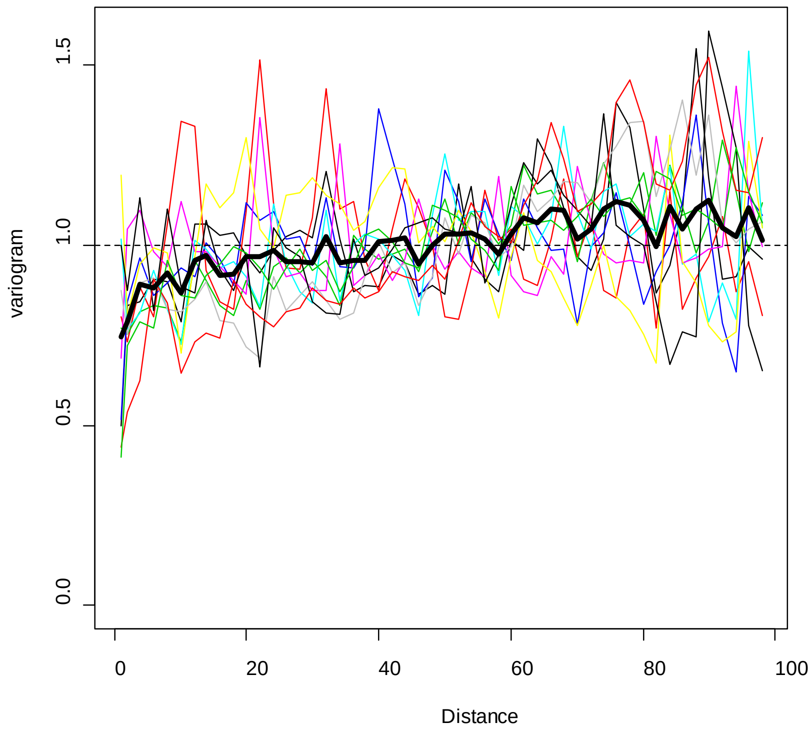


Figure. Scaled omnidirectional variograms 2000–2010 with average variogram in bold.

Annex 12: Celtic Sea, spring – Peltic surveys (Jeroen van der Kooij, Cefas)

An a *priori* geostatistical assessment of the design of a new survey: acoustic survey on sardine and anchovy in the Celtic Sea, Northeastern Atlantic.

Recent publications in both the scientific and grey literature, have suggested that southern species such as anchovy and sardines have been increasing in the northern limits of their distribution including Celtic, Irish and North Seas. Several reasons such as climate change and/or expansion of existing spawning populations have been suggested, but there is no information available about the basic biology of these species in this area, nor are there any existing surveys that could provide this. Recently a reconnaissance survey was undertaken using chartered fishing vessels, to explore the distribution and spawning areas of these species, and the preliminary results suggest that sardine is widespread across the shelf edge during their spring/summer spawning season.

Following the 2010 exploratory survey Cefas (UK) will undertake an acoustic survey in 2011 to explore the population dynamics of the pelagic species in the western Channel and the Celtic Sea shelf area. The proposed survey is the first dedicated multidisciplinary field programme focussing on the dynamics, abundance and identity of sardine and anchovy populations in the area. Acoustics are combined with species information from trawls to extract continuous along track data on the distribution and abundance of these species. Additional plankton and egg samples will be collected to assess the spawning areas, and oceanographic data will provide important information on the environmental conditions.

The current survey is timed to coincide with the peak spring/summer spawning period of sardine. A large part of the spawning population of sardine appears to be distributed across the shelf area, which makes them more easy to sample compared to later in the year when they are thought to be moving inshore. The survey is aimed to run parallel with a series of existing sardine and anchovy surveys, from Gibraltar to Brittany, providing coverage of most of the distribution of these species in the Northeastern Atlantic. To be able to explore the combined data of these surveys, they are standardized as much as possible, coordinated by the ICES Working Group on Acoustic and Egg surveys on sardine and anchovy (WGACEGG).

Case study

Given the large size of the area of interest and the limited available time (<22 days) we tested the optimal survey design that would provide adequate coverage. As no acoustic data were available, we used an *a priori* variogram resembling one based on a multiyear Bay of Biscay model, which was the nearest available relevant survey.

Two variogram models were considered with a total sill scaled to 100: nugget representing 50 and 80 per cent of the total sill added to a spherical model with range of 7 nautical miles. These hypotheses were based on the average per year variogram computed on the PelGas survey series, 2000–2010 (Annex 11).

The original survey design consisted of 25 regularly spaced transects, with an inter-transect distance of 20 nautical miles (Figure 1). We generated two alternative survey designs, both based on the original but one with half the number of transects as the original (and twice the inter-transect distance) and one with double the transects (and half the transect distance). We estimated the survey precision for all three transect scenarios using a nugget sill ratio of 20:80% and 50:50% (Table 1, Figure 2).

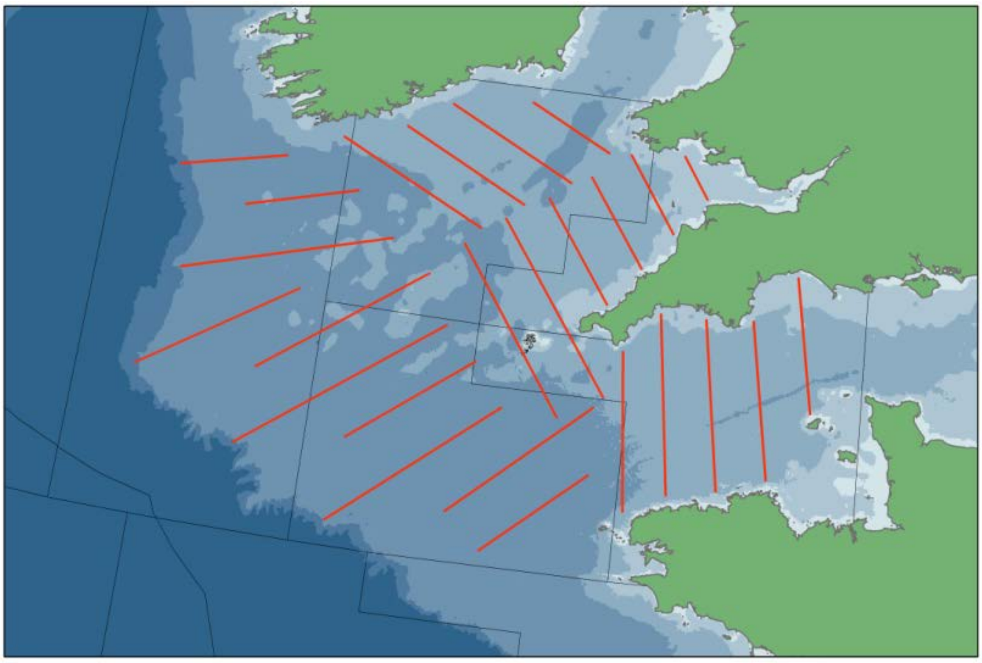


Figure 1. Overview of the Celtic Sea shelf and western Channel area, with in red the proposed acoustic survey transects.

Table 1. CV estimates generated by applying the variogram model based upon approximate Bay of Biscay survey data, on three inter-transect distance scenarios each with two nugget sill ratios.

	Inter-transect distance	Nb transects	Nb ESUs	Nugget Sill ratio	Nugget contrib.	Model contrib.	CV
Double nb.	10	46	3536	20/80	12.0	88.0	0.05
Transects				50/50	35.2	64.8	0.04
Original	20	25	1986	20/80	51.5	48.5	0.08
design				50/50	20.8	79.2	0.12
Half nb.	40	13	988	20/80	5.0	95.0	0.40
Transects				50/50	17.5	82.6	0.29

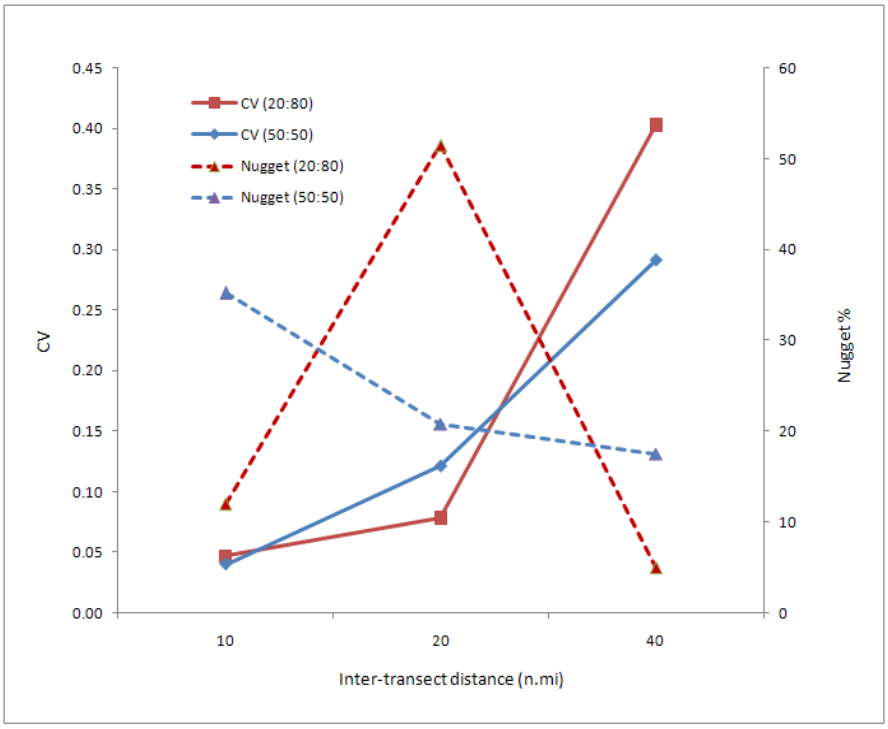


Figure 2. Plot of CV estimate (Left y-axis) and nugget contribution (Right y-axis) for three survey designs.

Annex 13: Bay of Biscay – Juvena autumn surveys (Guillermo Boyra, AZTI)

- Name of the survey: JUVENA
- Target species: juvenile anchovy (age-0)
- Period: Autumn (September), about 4 months after spawning season
- About 30 days at sea
- Temporal series: 8 years (2003–2010)
- Geostatistical exercise on offshore area 2009
- Daytime survey, mostly daytime hauls
- Purse seiners plus pelagic trawler
- Transect lengths 30–100 nautical miles
- ESDU 0.1 nautical mile
- Data: biomass of age-0 anchovy (tones per 1.5 n.mi.^{2})

Data description

The project JUVENA aims at estimating the abundance of the anchovy juvenile population and their growth condition at the end of summer in the Bay of Biscay. The long-term objective of the project is to be able to assess the strength of the recruitment entering the fishery the next year. The project is conducted annually since 2003 (Figure 1).

For this case of study, data from year 2009 was used (Figure 1). The data correspond to the offshore part of anchovy population in the Cantabrian Sea (Figure 3). The year and area were chosen because it is a large and geographically regular area composed of mainly pure isolated juvenile anchovy distributed close to the surface (from 10 to about 40 m depth) in the typical offshore juvenile aggregations. The value used for variance estimation was biomass instead of NASC because, due to the pure composition of the hauls, the species assignation wasn't expected to cause a significant increase in the error estimates. The data unities are, thus, metric tonnes of pure juvenile anchovy.

Data interpretation

The exploration of the data showed the typical strongly skewed distribution of fisheries acoustic data (Figures 4 and 5). The variogram was rather noisy, with little structure and a small range (Figures 6 and 7). The use of the log variogram showed a nested structure with two ranges, the small one visible in linear scale at about 1 nautical mile and a larger one at 5.5 nautical miles (Figure 8).

The computation of the geostatistical estimation variance was higher than the classical estimation variance for the area of study. This is considered to be caused by the type of structure showed by the juveniles' aggregations: of high stationarity and small spatial structure. The estimation variance was also obtained in log scale, but the value was not considered due to the difficulty of interpreting it in terms of abundance estimation error.

The experimental variogram based on the non-centered covariance seemed to be more stable for this type of data, being able to show clearly the internal structure of the data (Figure 9). The estimated range from this variogram was 2 nautical miles, similar to the square differences-based variogram, but the variance estimated set to 11% C.V (Figure 10), again, the geostatistically calculated variance was higher than the classical one. Given the small range presented by these data compared with the large inter-transect distance; no attempt was made of trying to fit an anisotropic variogram, being the isotropic covariogram considered a conservative approach for this case.

Optimization of design

Using the obtained structure, an additional exercise was conducted to illustrate the variation of the estimated variances with the change of the inter-transect distance, according to the modelled structure of the data. The results showed an increasing trend of the variance with the increasing inter-transect distance (Figure 11). Conversely, the decrease of the inter-transect distance produced the decrease also of the variance, along with an increase of proportion in the variance of the nugget effect.

To analyse the incidence of the support in the variance estimation, the 0.1 nautical mile ESDU data were averaged in ESDU lengths of 0.25, 0.75, 1, 2 and 4 nautical miles, plus the consideration of the average value of each transect (Figure 12). Experimental variograms were computed based on both the non centered covariances (nccv, see Figure 13) and on the square differences (sqdv, see Figure 14). The computation of the variances showed consistently higher geostatistics than classic variances when computing the nccv. The differences were gradually reduced and the percentage of nugget increased while increasing the ESDU (Figure 15). In the full transect average, the inter-transect distance was higher than the spatial structure, showing a pure nugget effect.

When computing the variance based on the sqdv, the geostatistical cv showed a decreasing trend with the increasing ESDU length (Figure 15). For ESDU lengths larger than 1 n.mi, the classic cv were higher than the geostatistical ones. This was interpreted as a consequence of the increase of the support to sizes larger than the size of the spatial structure. Yet, it should be noted that the variograms were fitted independently for each ESU length. The models may therefore not conform to the mathematical relationship linking them.

For each ESDU length, the value of the dispersion variance was compared with the weighted average of the variogram (Figure 16). In the case of the sqdv, the discrepancies were small and rather constant. But in the case of the nccv, the discrepancies increased with the ESDU length. This led us to propose, as a compromise between variogram stability and variance consistency, the nccv for ESDU lengths 0.1–1 nautical mile and the sqdv for ESDU length > 1 nautical mile for the calculation of the estimation variance (Figure 16).

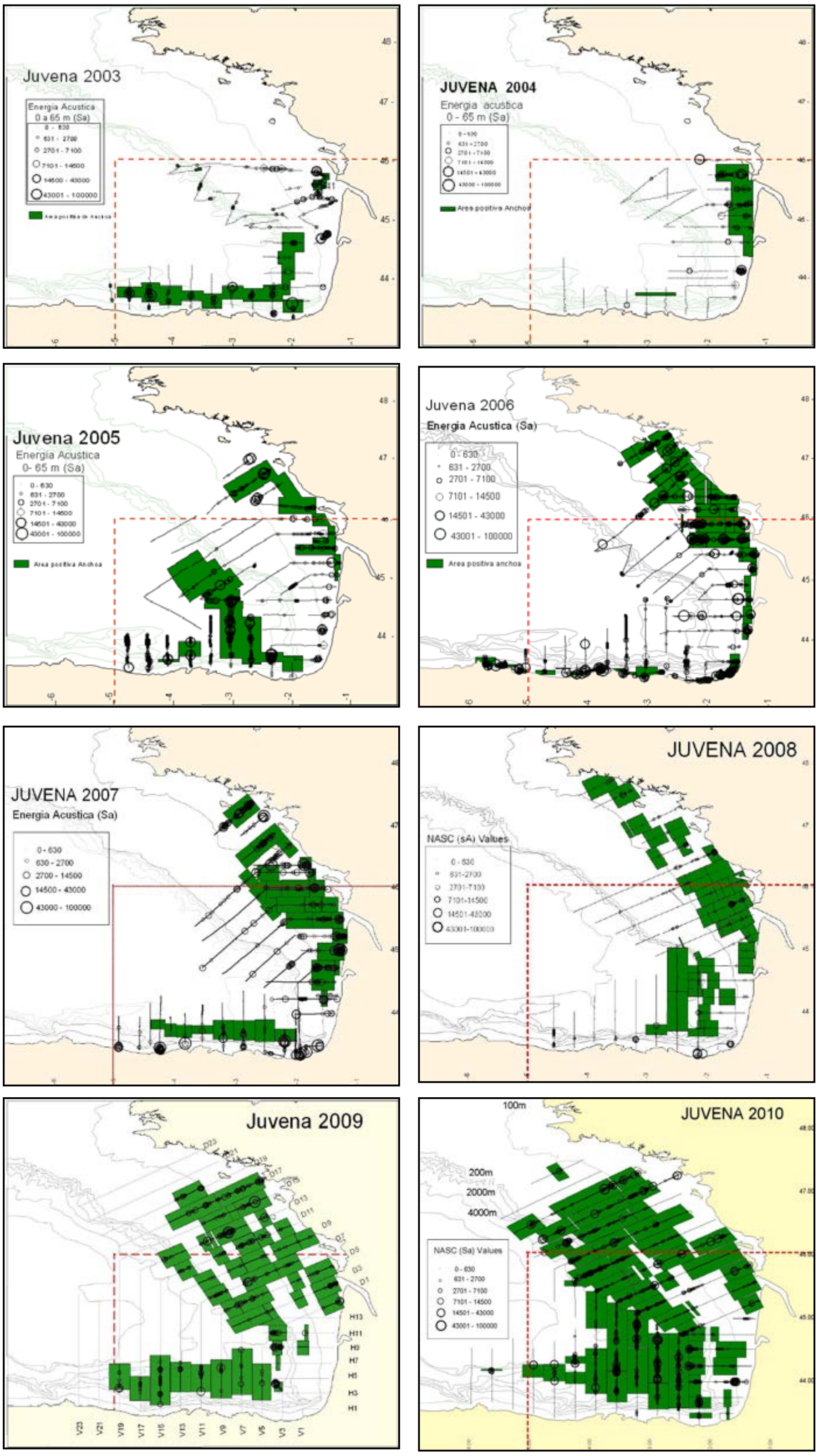


Figure 1. Temporal series of the JUVENA Survey. Positive anchovy areas in green. Bubbles represent NASC values attributed to anchovy.

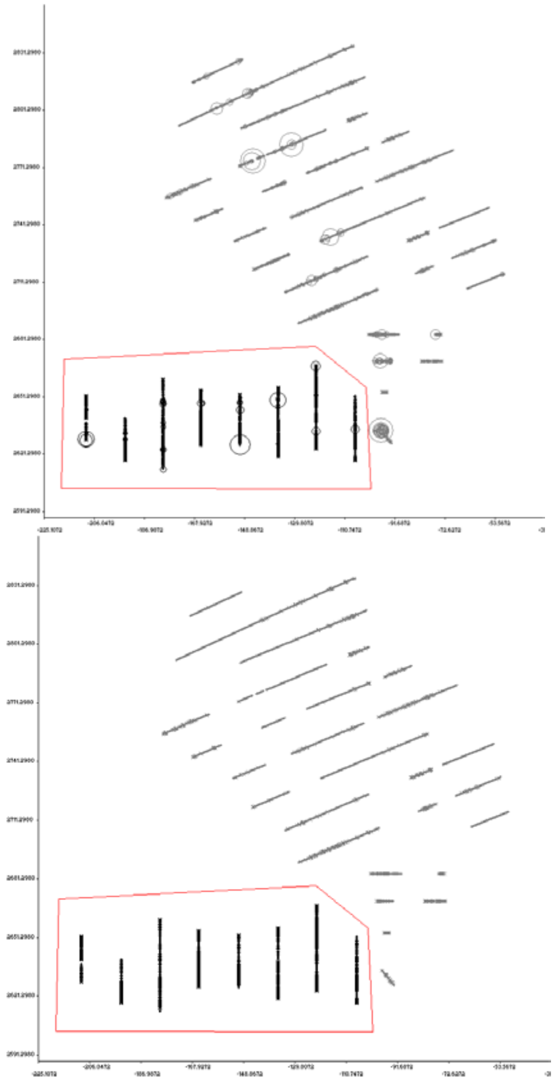


Figure 3. Year 2009 buuble plot of NASC anchovy values in the area offshore-south (polygon) in arithmetic scale (up) and log scale (down).

Variable statistics	
Number of observations :	2577
Minimum :	0
Maximum :	2300.58
Average :	20.68153
Variance (s^2) :	8815.859
Coefficient of variation (s/m) :	4.539935

Variable statistics	
Number of observations :	2577
Minimum :	0
Maximum :	7.741351
Average :	1.272027
Variance (s^2) :	2.599237
Coefficient of variation (s/m) :	1.267437

Figure 4. Basic statistics of the data in linear and log scales.

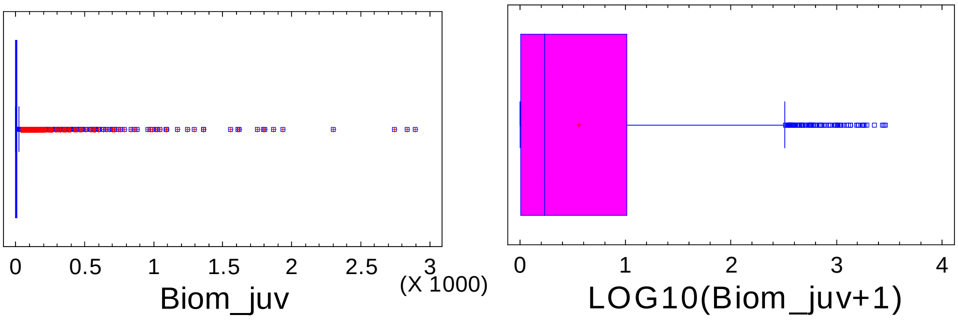


Figure 5. Linear and log boxplots of the data.

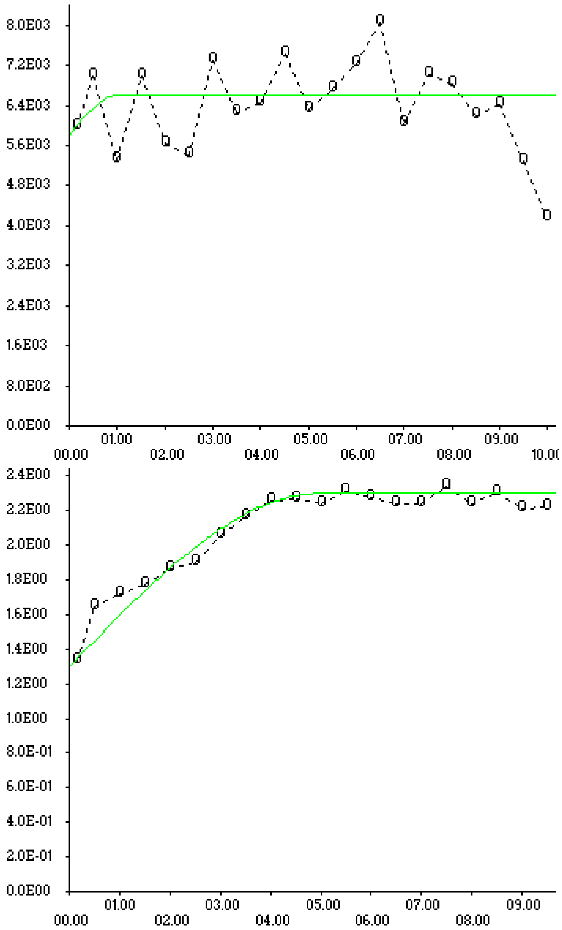


Figure 6. Linear and log variograms.

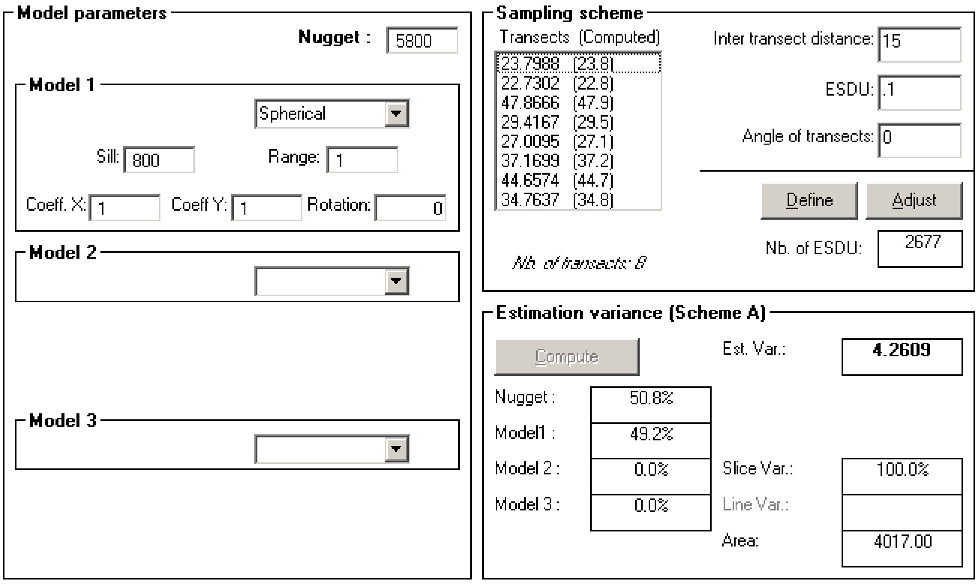


Figure 7. Model parameters and variance estimation for offshore-south area in linear scale. The calculated c.v. was: sqrt(4.2609)/20.68153= 0,1

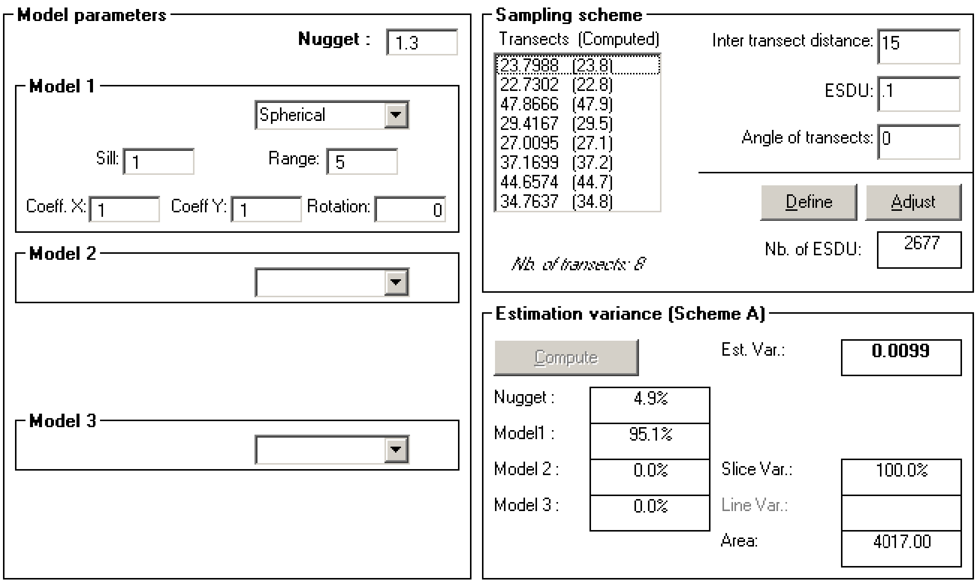


Figure 8. Model parameters and variance estimation for offshore-south area in log scale. The calculated c.v. was difficult to interpret in terms of abundance estimation unless undo the transformation.

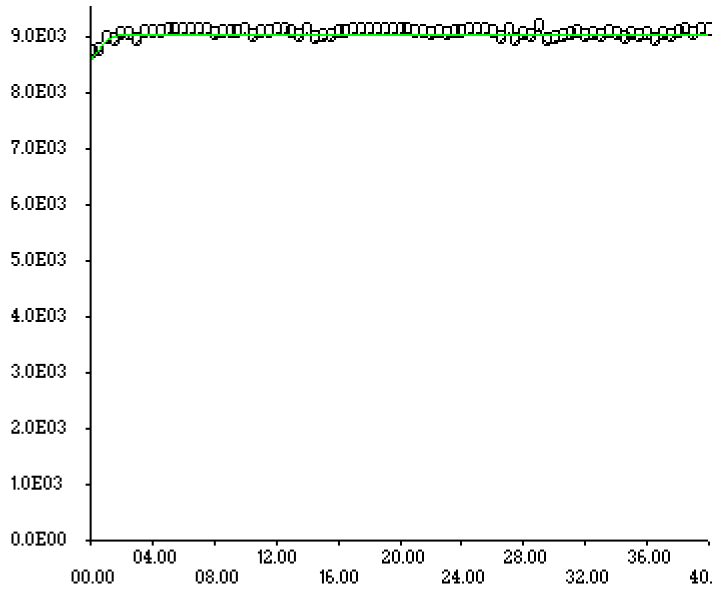


Figure 9. Variogram estimated based on non-centred covariance and its model (green line).

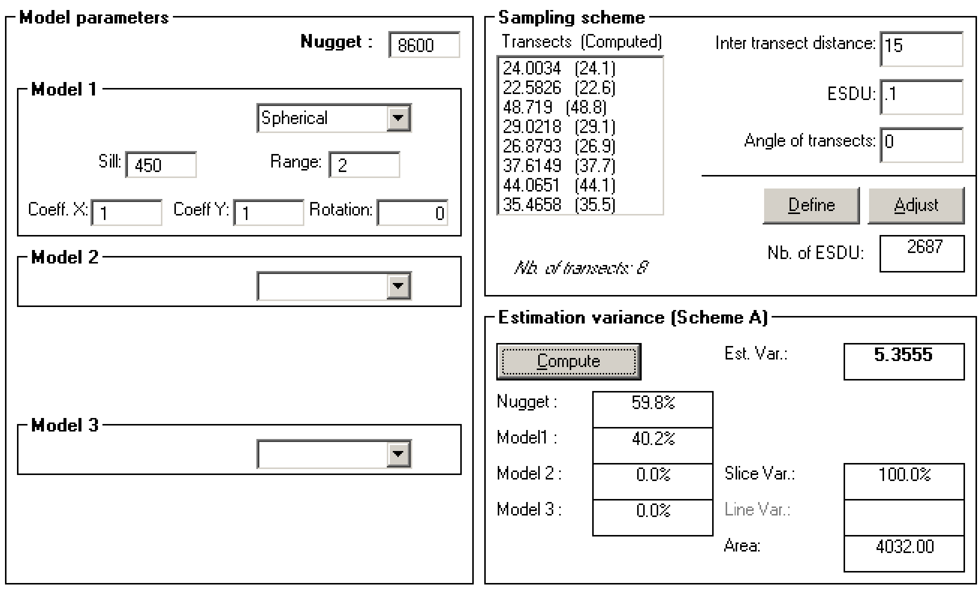


Figure 10. Model parameters and variance estimation for the model fitted to the covariogram.

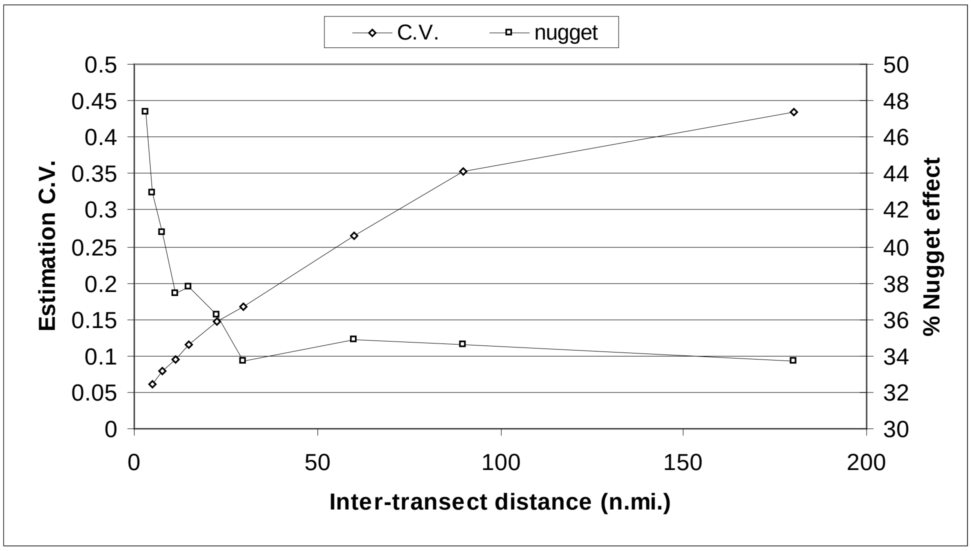


Figure 11. Change of the coefficient of variation of the estimation with the simulated change of inter-transect distance.

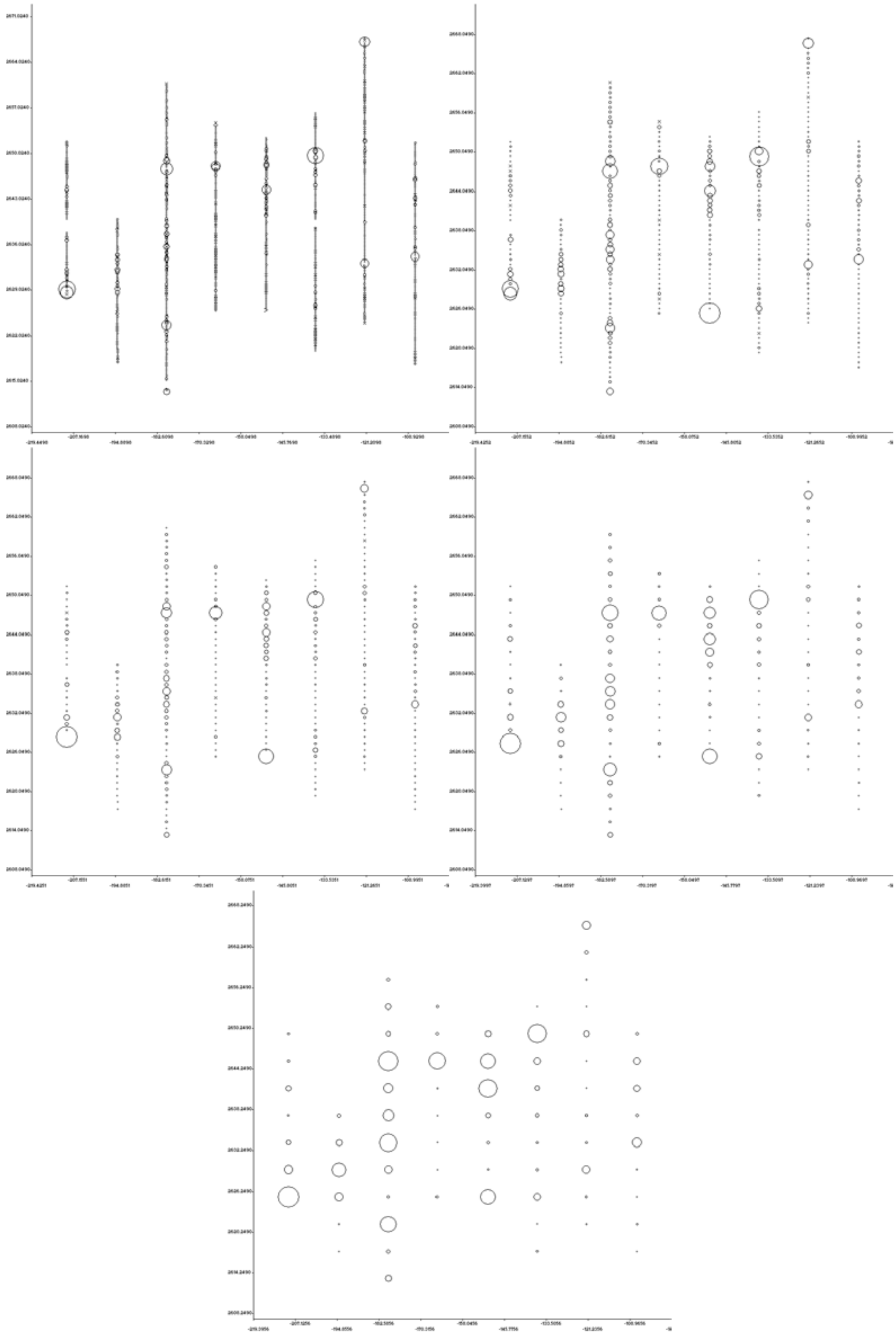


Figure 12. Bubble maps for different ESDU lengths (0.25, 0.75, 1, 2 and 4 n.mi.).

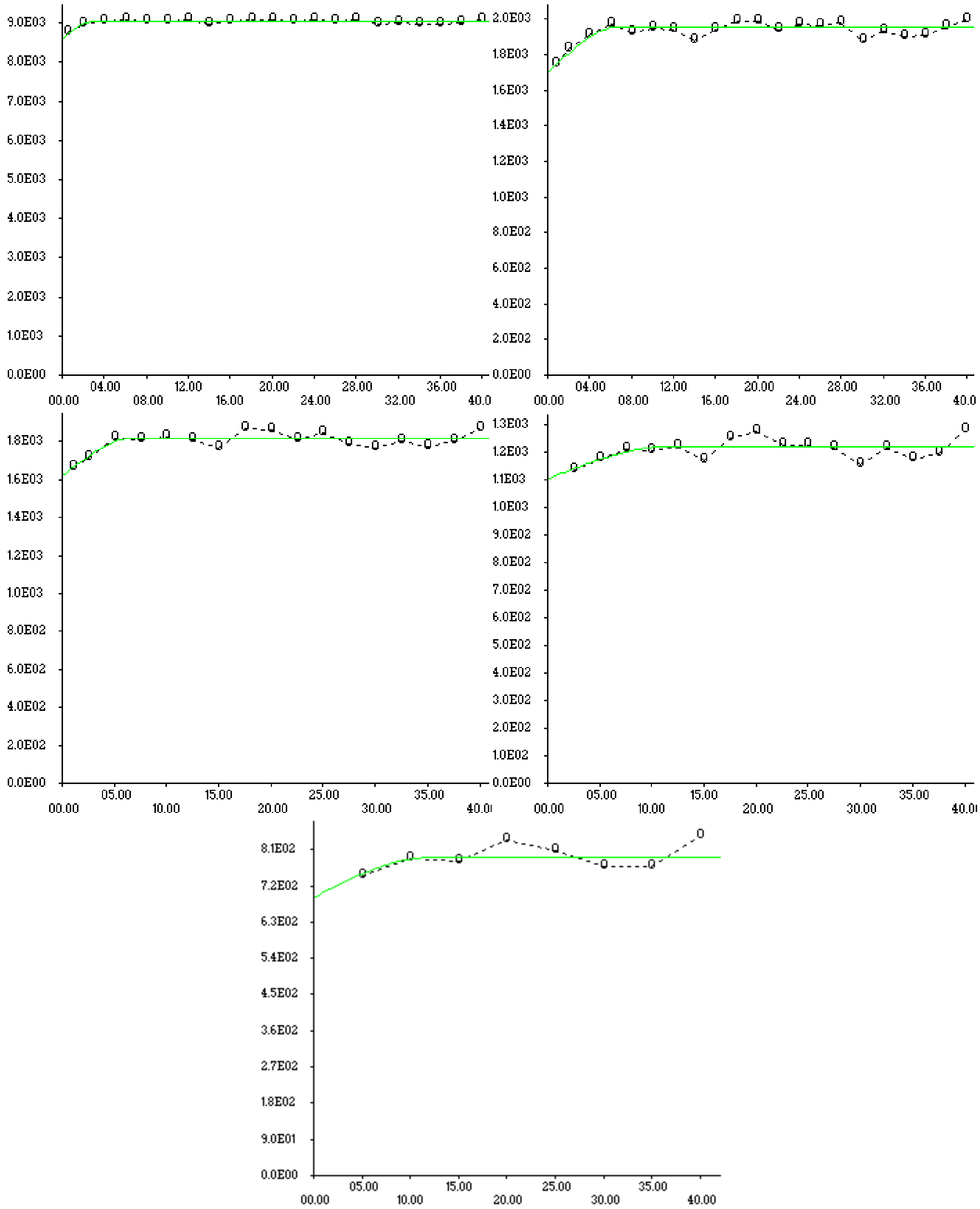


Figure 13. Experimental variograms based on the non centred covariances for ESDU lengths of 0.25, 0.75, 1, 2 and 4 n.mi. Variograms were fitted independently for each ESU length.

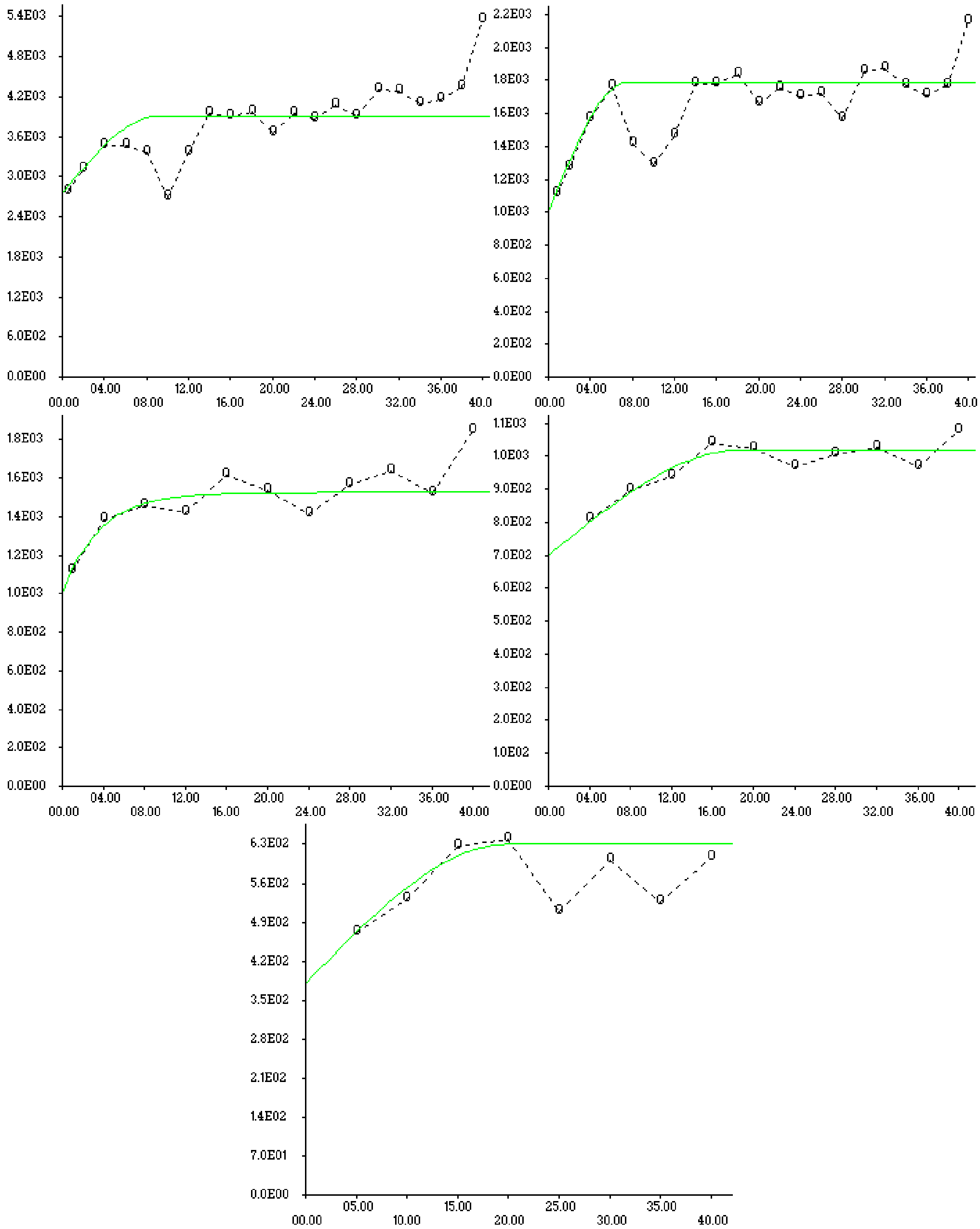
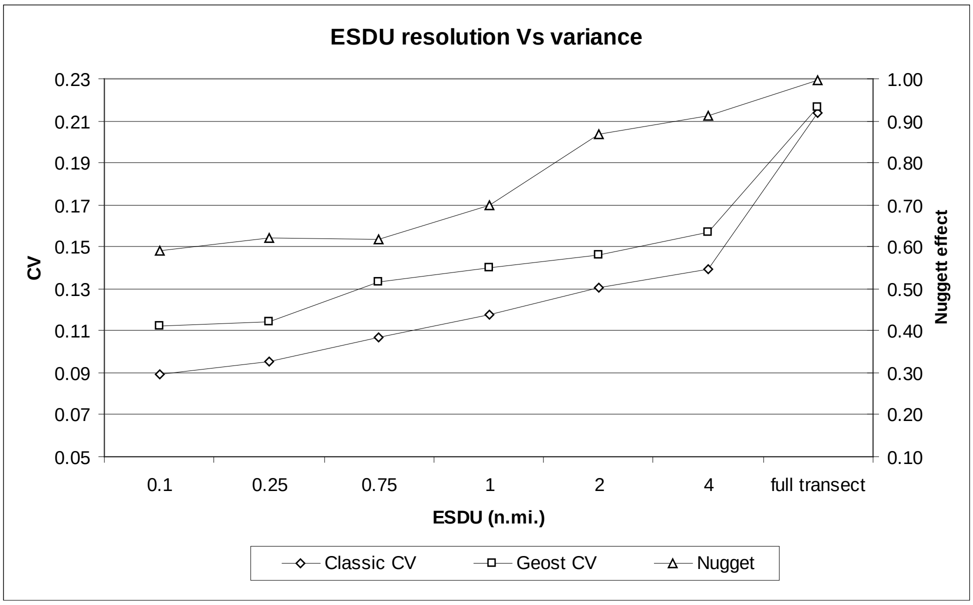


Figure 14. Experimental variograms based on the square differences for ESDU lengths of 0.25, 0.75, 1, 2 and 4 n.mi. Variograms were fitted independently for each ESU length.



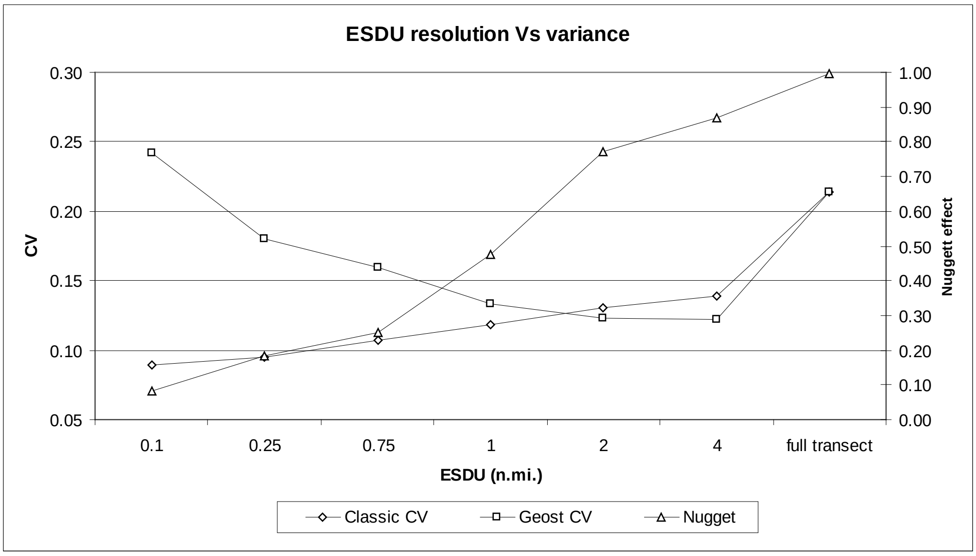
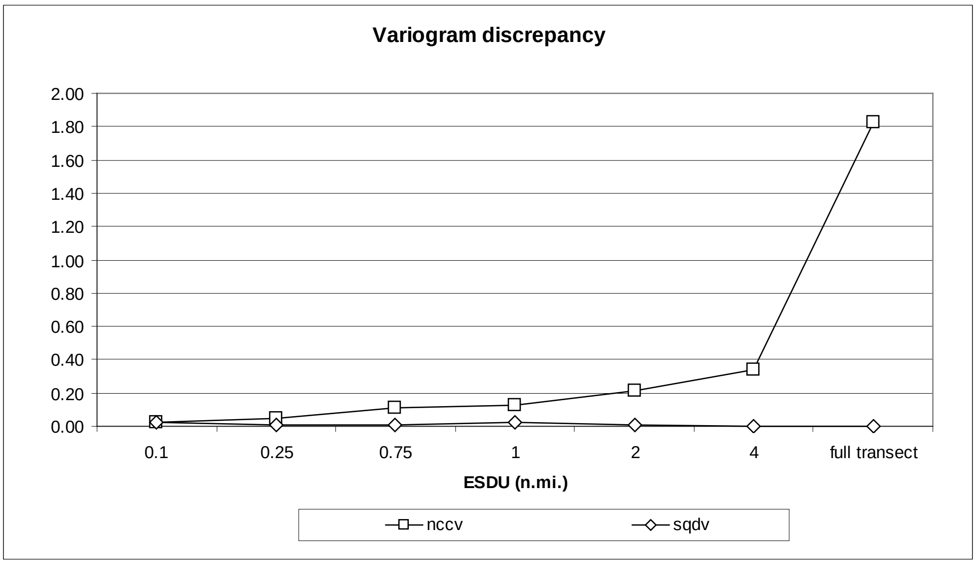


Figure 15. Geostatistical and classical variances calculated for different ESDU lengths. Top: The variances were calculated using the non-centred covariance based variogram (nccv). Middle: The variances were calculated using the square differences based variogram (sqdv). Bottom: The variances were calculated with the nccv for ESDU lengths 0.1–1 n.mi and with the sqdv for ESDU lengths > 1 n.mi. The variogram models being fitted independently for different ESU lengths, they may not conform to the mathematical relationships linking them.



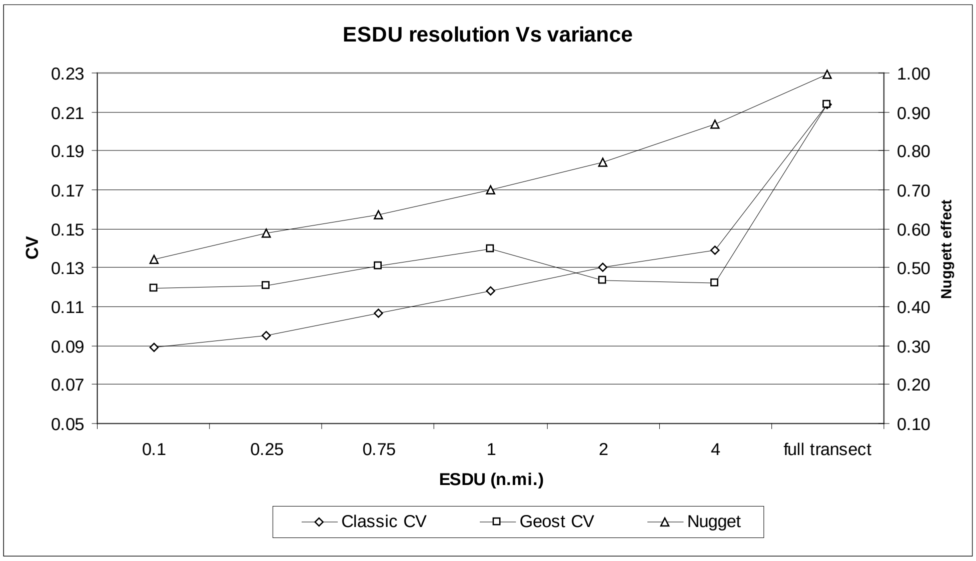


Figure 16. Top: Variogram discrepancy for both types of variogram used in this case of study. Bottom: Geostatistical and classical variances calculated for different ESDU lengths. The variances were calculated with the nccv for ESDU lengths 0.1–1 n.mi and with the sqdv for ESDU lengths > 1 n.mi. The variogram models being fitted independently for different ESU lengths, they may not conform to the mathematical relationships linking them.

Annex 14: Tasmanian west coast blue grenadier surveys (Tim Ryan, CSIRO)

Application of geostatistics to low cost industry acoustic surveys of Tasmanian west coast blue grenadier (*Macruronus novaezelandia*).

Overview

In the austral winter commercial fishing of Tasmanian west coast blue grenadier (*Macruronus novaezelandia*) takes place during their two-month spawning period. Here schooling aggregations of semi-demersal blue grenadier are found between seabed depths of 300–600 m along the continental shelf edge. The narrow spawning grounds extend north–south for approximately 100 nautical miles while the steep shelf constrains the east-west extent to 3 to 5 nautical miles. The terrain consists of a number of canyon features that are connected by easily trawl-able sandy seabed. In some years substantial quantities of blue grenadier will be caught from the relative small canyon features but in other years fishing effort will focus across a much broader area in order to maintain catch rates.

In partnership with the majority quota holders, CSIRO has overseen seven annual acoustic biomass estimation surveys since 2003. Depending on the available quota, one to three factory freezer vessels will have been fishing commercially and participating in the survey program. The surveys are carried out by the ships officers using the vessel's calibrated commercial echosounder (Simrad ES60 38 kHz). There are two main survey modes. Localised grid surveys occur opportunistically during the 6–8 hours of fish processing time that follows a successful trawl (O'Driscoll ref). These surveys will have a close grid spacing (0.3 to 1 n. mile) and time constraints dictate that the survey typically extends for just a few nautical miles along the contour. The survey designs are adaptively devised by the ships officers following CSIRO guidelines. A key objective is that the ships officers ensure that the extent of the school is bound by the survey grid. Over a two month season between 10–30 localized grid surveys may be completed. During the post-voyage analysis phase, a review of localized surveys is made and only those that measured substantial schools are selected for full analysis. The second survey mode is a broadscale design that covers the entire north–south extent of the spawning grounds. The broadscale design consists of a combination of rectangular grid transects at canyon features and connecting stratums of zig-zag transects at a lower sampling intensity. From the set of analysed surveys (either localized of broadscale) the maximum biomass for that year is input into the stock assessment model.

Case study. Year 2005 survey – strata 3 – closely spaced parallel transects.

As a case study Strata 3 within the 2005 broadscale survey has been chosen (Figure 1). The survey sequence for the broadscale survey was a rectangular grid across a cayon feature (Strata 1 - historically large amount of fish caught here). A less intensive zig-zag pattern then followed (Strata 2). Upon encountering reasonable school marks the ship's officer adaptively changed the survey pattern into a rectangular grid with very close spaced transects (Strata 3). The close spaced transects proved to be time consuming, motivating a doubling of the inter-transect distance (Strata 4). Finally a wide spaced zig-zag pattern (Strata 5) was adopted when schools ceased to be observed towards the end of Strata 4. Of interest in this analysis is to explore the consequences that wider transect spacings would have had on the survey cv for Strata 3.

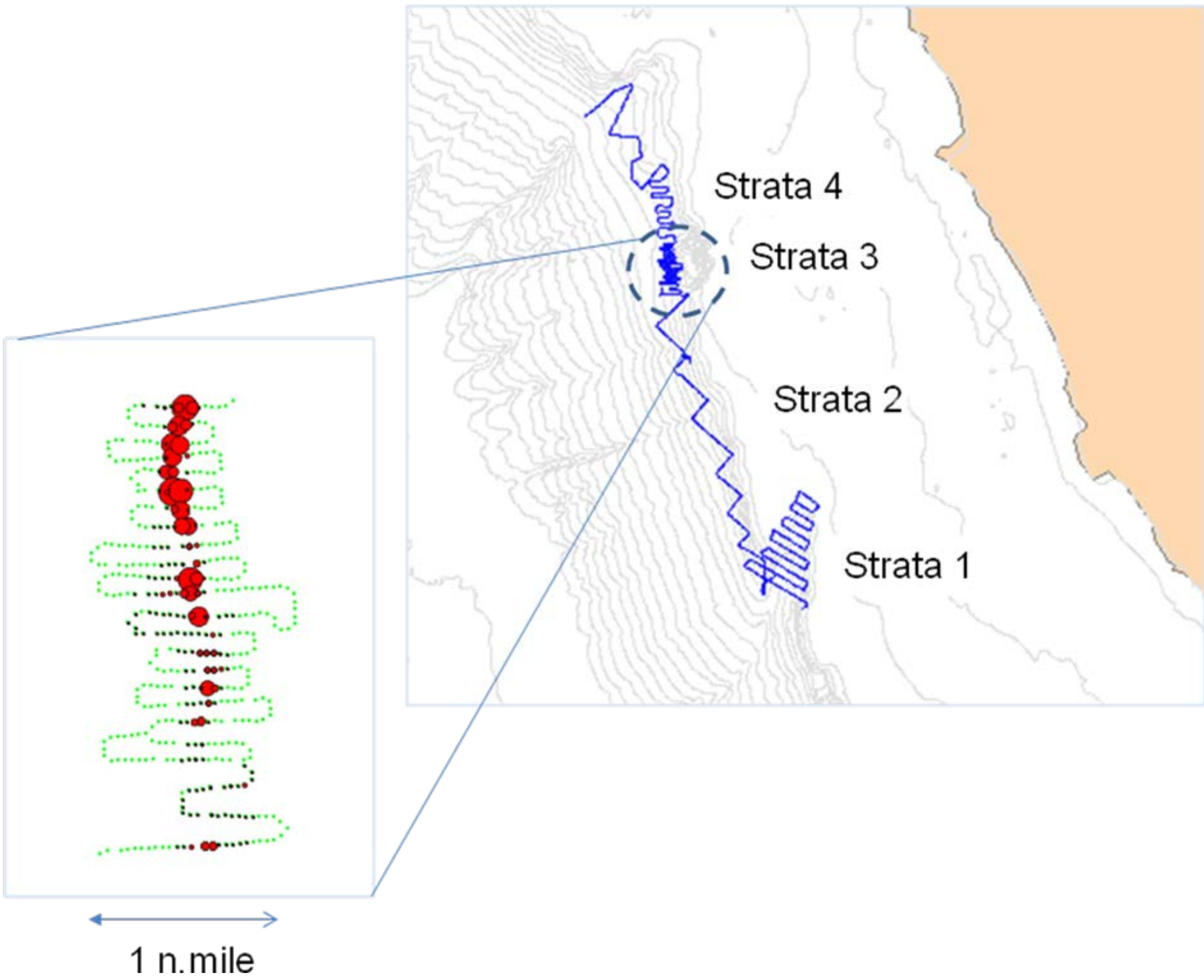


Figure 1. Bubble plot of Year 2005 Strata 3 survey. Circle size is proportional to the NASC value.

Basic summary statistics and a histogram of NASC values are given in Table 1 and Figure 2 respectively.

Table 1. Basic summary statistics for NASC data.

PARAMETER	VALUE	UNITS
Min	0	m2 n.miles-2
Max	111933	m2 n.miles-2
Mean	6096	m2 n.miles-2
Variance	2.74E+08	2.74E+08
CV	2.71	2.71
Number of samples	420	420
North-South extent	2.9	n. miles
East-West extent	1.0	n. miles
ESDU	80	meters
Number of transects	24	24

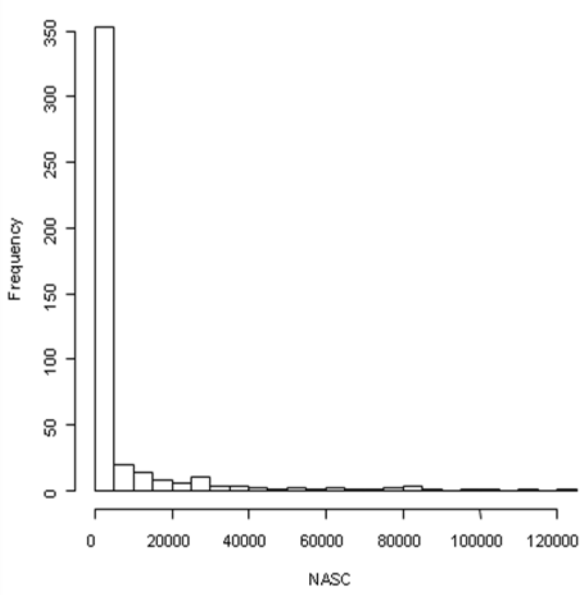


Figure 2. Histogram of NASC values.

The experimental variogram for untransformed NASC values and model estimates were generated using EVA2 (Figure 3, Table 2). Two dimensional variograms were necessary to describe the observed anisotropy. The experimental variogram indicates a larger range in the north–south direction (stars) compared to the east-west direction (open circles). This anisotropy is in keeping with our experience that blue grenadier often show a strong along-contour affinity but a limited cross contour distribution as they are constrained to their preferred depth range by the narrow and steeply sloping shelf.

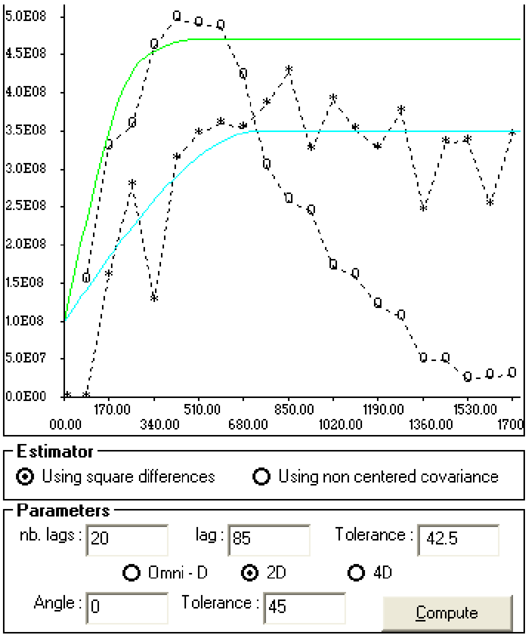


Figure 3. Experimental variogram with model estimations. Open circles and green line depict the variogram and model respectively for the east-west direction. Stars and blue line depict the variogram and model respectively for the north–south direction. Model parameters are given in Table 2.

Table 2. Model parameters for 2005 Strata 3.

Nugget	1e8				
Model 1	Spherical				
Sill	2.5e8				
Range	300				
Coeff X	1	Coeff Y	0.4	Rotation	0
Model 2	Spherical				
Sill	1.2e8				
Range	500				
Coeff X	1	Coeff Y	0	Rotation	0

To explore the effect of different inter-transect distances, the variogram model was applied to the original transect spacing, a survey design with half and a quarter the number of transects respectively.

Table 3. CV estimates generated by applying the variogram model based upon Strata 3 survey data for three inter-transect distances.

Parameter	Original survey transect spacing	Half number of transects	Quarter number of transects
Number of transects	24	12	6
Inter-transect dist (m)	227	476	1048
Mean (m2 n.mile-2)	6096	6096	6096
Variance	257469	679904	2722759
CV	0.08	0.14	0.27
Nugget contribution	92.1	71.1	34
Model 1 contribution	7.8	28.3	66
Model 2 contribution	-0.1	0.7	-0.5

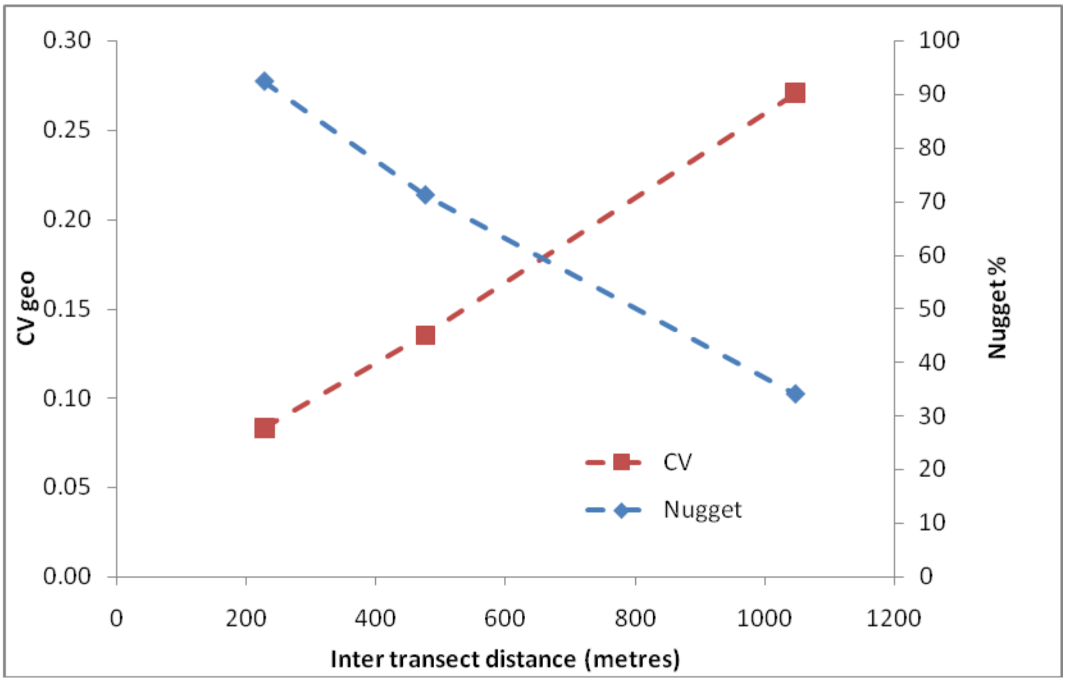


Figure 4. Plot of CV estimate (LHS axis) and nugget contribution (RHS axis) for three survey designs.