Quality control and preparation of acoustic survey data for treatment by spatial analysis techniques. Experiences from using integrated visualization software tools.

by

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ABSTRACT

Based on real survey data, cases are presented of the common data preparation steps, which are required for bringing the voluminous acoustic survey data into a form amenable for treatment by spatial analysis techniques. These are correction of erroneous georeferences, removal of unrepresentative sections from the survey tracks, visual apprehension of spatial structure in the data, and stratification. Spatial manipulation software has been devised to perform these steps operationally on board the surveying vessel. The software delivers an interface of programmable objects. These objects expose results of the visual selections in the form of simple data structures, which are accessible for use by standard data analysis software. An application of the visual tools and programmable objects in abundance estimation work is demonstrated.

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INTRODUCTION

Regularly conducted acoustic abundance surveys provide basis for estimates of fish stocks. They use scientific echo sounders like the SIMRAD EK-500 echosounder and the onboard software systems for echo interpretation like the Bergen Echo Integrator (BEI; Foote et al. 1993). Results from the echo classification in BEI are stored in a database. This database contains measures of acoustic density allocated to the target species, encountered along a vessel's path. Postprocessing of survey data exploit the content of that database. The postprocessing steps involve: (1) quality-control procedures, (2) data preparation, and (3) data analysis. For standard abundance surveys, data postprocessing methodologies are well established and applied consistently to each new investigation. For such surveys, it is practical to automate those postprocessing methodology by means of software. The processing automated by software will be more effective than a manually executed process: processing times will be shortened; quality-control will become more thorough; and higher resolutions of the processed data will be attained.

The Survey Viewer (SV) is a Windows-based application for postprocessing and analysis of survey data using a geostatistical approach. The SV is a visual and interactive system. It automates acoustic data postprocessing steps after the echo interpretation on the BEI. The software has been applied to support data quality-control, preparation, and analysis during the acoustic surveys of the stock of Norwegian spring spawning herring (Foote et al. 1996, 1997). In this paper, the author introduces the SV software, and describes experiences in using it to support the on board data processing operations according to the methodology developed for those surveys.

1. SOURCE OF ACOUSTIC DATA

The prerequisites of development of the SV system have been: existence of an established survey methodology and a standardized source of acoustic data. These topics are outlined in this section.

1.1 Survey design

Norwegian spring-spawning herring (*Clupea hagenus*) wintering in fjords of northern Norway has been the target of annual research surveys since 1992. Since 1987 the spawning component of that stock has been found wintering in Ofotfjord and Tysfjord and Vestfjord. Between 1987 and 1994 the main concentrations were found in the inland fjords: Ofotfjord and Tysfjord. More recently, the bulk of the stock has been encountered in the more exposed to the ocean - the inner part of Vestfjord. Systematic acoustic abundance surveys, supplemented with trawl hauls have been employed to determine spatial distribution and abundance of the stock. That survey effort has been documented in a series of reports presented at the ICES annual science conferences: (Foote 1993, Røttingen et al. 1994, Foote and Røttingen 1995, Foote et al. 1996, 1997).

The survey design was determined by a number of factors: geometry fjord boundaries, bathymetry, navigational impediments, results of trawl sampling, and spatial extent of the stock itself. Zigzag and parallel designs were favored in the open areas of the fjords, while ad hoc designs were employed in the navigationally difficult, narrow branches of Ofotfjord and Tysfjord. Regions of the occurrence of major concentrations were covered several times.

Acoustic registration and data storage was conducted continuously during the whole cruise (lasting two to three weeks), including the periods of supplementary measurements (trawl sampling and CTD stations) and auxiliary studies.

1.2 Acoustic measurements and echo interpretation

Acoustic measurements were made with the SIMRAD EK500 scientific echo sounder (Bodholt et al., 1989). Echo interpretation was preformed on BEI. The following briefly illustrates a typical echo recording-interpretation cycle: a surveying vessel makes measurements of acoustic density along transects crossing the survey region. Data on acoustic density are recorded by means a scientific echo sounder, and these data are supplemented with positions from Global Positioning System (GPS). An operator scrutinizes the recorded data, displayed in the form of an interactive echogram on the computer screen. Based on the appearance of this echogram, which indicates the degree of concentration and position in the water column of the stocks, and using biological information from trawl hauls the operator allocates acoustic samples to the target fish species - in this case, to the herring. With allocation completed, the resulting measures of acoustic density of the herring are stored in an attached database. The stored data are separated to 10-meter depth layers, extending from the surface to 500-meter depth, and to 0.1-nautical mile distance intervals. Attached to each distance interval are ancillary data such as geographical location, bottom depth, and time of sampling. With the given resolution, the number of stored acoustic data per nautical mile is 500 and that yields, with the typical 2000 nautical miles sailed, the size of the cruise database of the order of 10^5 acoustic samples.

2. THE PROCESSING REQUIREMENTS OF THE SV SYSTEM

The data from the acoustic surveys of the stock of Norwegian spring spawning herring are processed according to a well-established methodology, first introduced by Foote (1993). The SV design goal was to automate the postprocessing steps pertaining to that methodology. This section outlines the two aspects of the aforesaid methodology: computational procedures and data postprocessing steps.

2.1 Computational procedures

There are four groups of computations in the analysis of data from the concerned surveys (Foote 1993). These include (1) derivation of acoustic density, (2) abundance estimation, (3) variance estimation, and (4) cumulative estimates.

Derivation of acoustic density The quantity that is analyzed is the area backscattering coefficient (denoted s_A) referenced by geographical location. s_A-values are obtained from the BEI database in two steps. First, each 10-meter depth layer is corrected forextinction according to a standard algorithm (Foote, 1991). Subsequently, the extinction-corrected values are added over all 10-meter depth intervals yielding a single s_A-value for each 0.1-nautical mile interval.

Abundance estimation Abundance estimation proceeds in strata. For each stratum, mean value of area backscattering coefficient s_A is computed from all s_A-values located within its boundaries. The conversion to fish density is achieved through the fundamental equation of echo integration:

$$\rho_A = s_A / \sigma_b \quad , \tag{1}$$

where ρ_A is the mean area fish density expressed as number of fish per square nautical mile, and σ_b is the backscattering crossection. Multiplying ρ_A by the stratum area gives total number of fish in the stratum. The value of σ_b is derived from the standard equation for herring (Foote, 1987):

$$TS = 20 \log l - 71.9 = 10 \log (\sigma_b / 4\pi) \quad , \tag{2}$$

where TS is average target strength for a herring of RMS mean length l.

Estimation variance Estimation variance is a measure of uncertainty in the estimation of the mean of a stratum, which takes into account geometry of surveyed stratum, distribution of transects, and spatial structure of the encountered fish aggregations. Estimation variance is computed by a standard geostatistical procedure in three steps.

(1) Experimental variogram Assuming isotropy in the stratum, the two dimensional experimental variogram is computed according to the formula,

$$\gamma(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} \left[z(x_i) - z(x_i + h) \right]^2 \quad , \tag{3}$$

where h is the separation vector, and $z(x_i)$ is datum at location x_i; $N(h)$ is the h-dependent number of samples.

(2) Variogram modeling Variogram is modeled by a nugget term and a linear combination of the positive definite function:

$$\gamma(h) = A_N N(h) + \sum_{i=1}^{n} A_i \gamma_i(h) \quad , \tag{4}$$

where A_N is a non-negative amplitude, $N(h) = 0$ for $h = 0$ and 1 for $h > 0$; $\gamma_i(h)$ is a model function, and A_i is an associated amplitude. Most widely used model functions are the following:

$$spherical(h) = 1.5\frac{|h|}{a} - 0.5\left(\frac{|h|}{a}\right)^3 \qquad |h| \le a \quad , \quad 1 \; for \quad |h| > a$$

$$exponential(h) = 1 - e^{-\frac{3|h|}{a}}$$

$$gaussian(h) = 1 - e^{-\frac{3|h|^2}{a^2}}$$

$$linear(h) = h \qquad ,$$

where a is range of the modeled variogram.

(3) <u>Estimation variance</u> is computed from the following formula:

$$\sigma_E^2 = 2\gamma(V,s) - \gamma(V,V) - \gamma(s,s) \quad , \qquad\qquad (5)$$

where $\gamma(V,s)$, $\gamma(V,V)$, and $\gamma(s,s)$ denote mean values of the variogram models integrated over the respective set of points V and s; V being a total stratum area, and s are the data sampled along the acoustic transects. Estimation variance is typically normalized by the mean value, forming the ratio σ_E/s_A. It may be than compared with non-geostatistical measure of uncertainty, namely, s_E/s_A, where s_E denotes standard error.

Cumulative estimates Given the estimates of abundance and estimation variance for the individual strata, the total fiord estimates are obtained by simple addition.

2.2 Steps of the data postprocessing process

Having completed data allocation of the echo to target species in the BEI, a sequence of further preprocessing steps are initiated. These are: (1) extraction of acoustic surveys; (2) data verification and correction; (3) removal of redundant track pieces; (4) delineation of strata. *Extraction of acoustic surveys* involves retrieval from the continuous survey record those data subsets that comprise exclusively the systematic acoustic coverages of the surveyed fjords; the subsequent processing steps will pertain only to these subsets. The aim of *data verification and correction* is to ensure that: all data have been scrutinized, data values are consistent, and registered positions do not offset from the executed survey track. During *elimination of redundant track pieces*, statistically unrepresentative sections of survey track are removed: these include transect endpieces and loops of vessel's maneuvers during trawling. *Delineation of strata* divides further the data subsets extracted in Stage (1) in a process of stratification. The division to strata is based on the following criteria: degree of acoustic coverage, which is depended on fiord geometry and navigational hazards; biological composition, which is inferred from physical capture of fish; and distribution of acoustic density itself.

Having completed the above postprocessing steps, computations of abundance and variance are pursued for each delineated stratum. They include: basic statistic of a stratum (mean s_A-value, variance, coefficient of variation and standard error normalized to mean s_A), computation of a variogram, derivation of the variogram model and computation of estimation variance.

The final postprocessing step is the collation of final results in a publication quality format. The results from each stratum are assembled in a tabular form. Prepared are visualizations with spatial distributions of fish along the survey tracks (Figure 7 and 8).

3. INTRODUCING THE SV SYSTEM

3.1 User interface

A view of the SV system is presented in Figure 1. An SV application is contained in a single window named "Application Window". Within that window are additional windows, which are called "Survey Windows". Survey Window is a workspace for visualization and postprocessing operations on the data subsets retrieved from the acoustic database. It comprises map of a survey area, and, given the data have been loaded, distribution plots of the data. Survey Windows can be moved, sized and exploded within the confines of Application Window, while their content may be zoomed and panned. The downloaded data, visualized in a Survey Window are named "Datasets". The Datasets may be visualized as constant-sized points, or using one of the proportional transforms: square, linear, square root, or logarithmic; the points may be described by their respective alues. This basic type of the visualisation in the SV, which includes a map of the survey area and displays distribution of point-data from database, is conveniently termed the Pin Map. The visualized data may be processed, given they have been first enclosed in a polygon, or "Stratum". The Strata are created interactively, by drawing the polygonal boundaries on the map with the mouse. The data enclosed in a stratum may be used in two ways: they may be send to other applications by means of file or clipboard transfer, or they may be analyzed with the built-in tools. All opened in the SV objects, namely, Survey Windows, Datasets and Strata form a hierarchy, which may be accessed by the user through a schema window, seen in the upper-left corner in Figure 1. The window is called "Survey Hierarchy Tree". The Survey Hierarchy Tree has two pages: one for Datasets, another for Strata. Both pages comprise hierarchical lists of their respective object active in the SV application. The lists behave as a standard directory tree on Windows: by selecting a tree item, the user expands or contracts the hierarchy graph; by applying the mouse right button he invokes actions pertaining to the selected item. One such action, pertaining to Stratum item, opens the Variography Tool Window, seen in the lower-left corner in Figure 1. That window contains a series of notebook pages for guiding the user through stages of the geostatistical analysis according to the methodology outlined in Section 2.1.
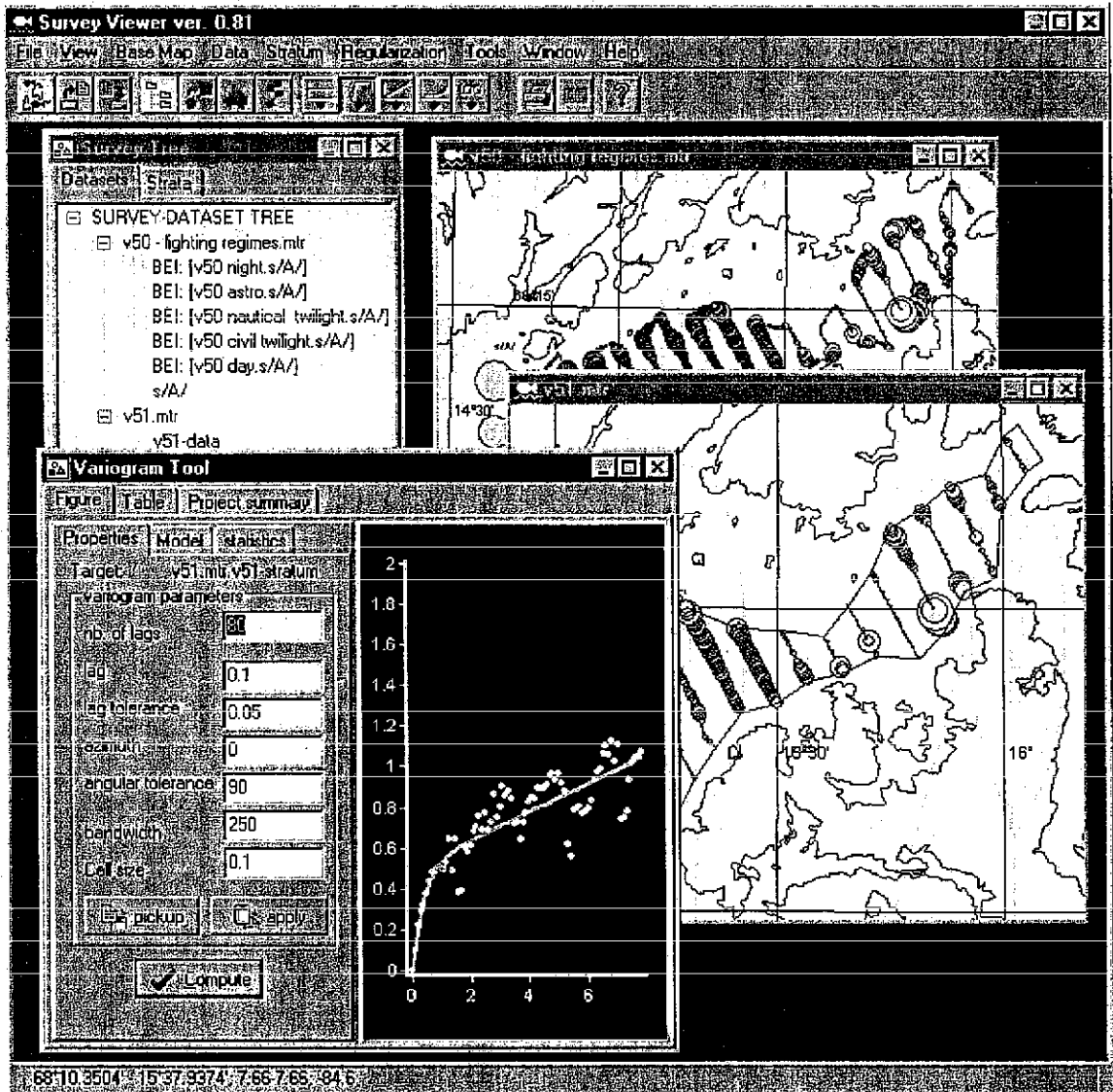
Fig 1. An SV application. Visible are three types of windows: Survey Hierarchy
Tree is in the top left; two Survey Windows are to the right; Variogram Tool Window
is to the bottom left. Seen in the Survey Hierarchy Tree is a fragment of the Dataset
hierarchy for the two visible Survey Windows (*v51.mtr* and *v50-ligthing
regimes.mtr*). The Variogram Tool window displays an experimental variogram for
the Stratum denoted as *v51-stratum*, which is contained in the Survey Window named
v51.mtr.

3.2 Basic operations

Figure 2 shows the implementation of data processing in the SV in terms a data flow
diagram (DFD). DFDs are useful to describe how data flow through the system and
how processes and algorithms transform the data. (Schroeder et al., 1996). The major
components of a DFD are data sources, data stores, and processes. Data sources are
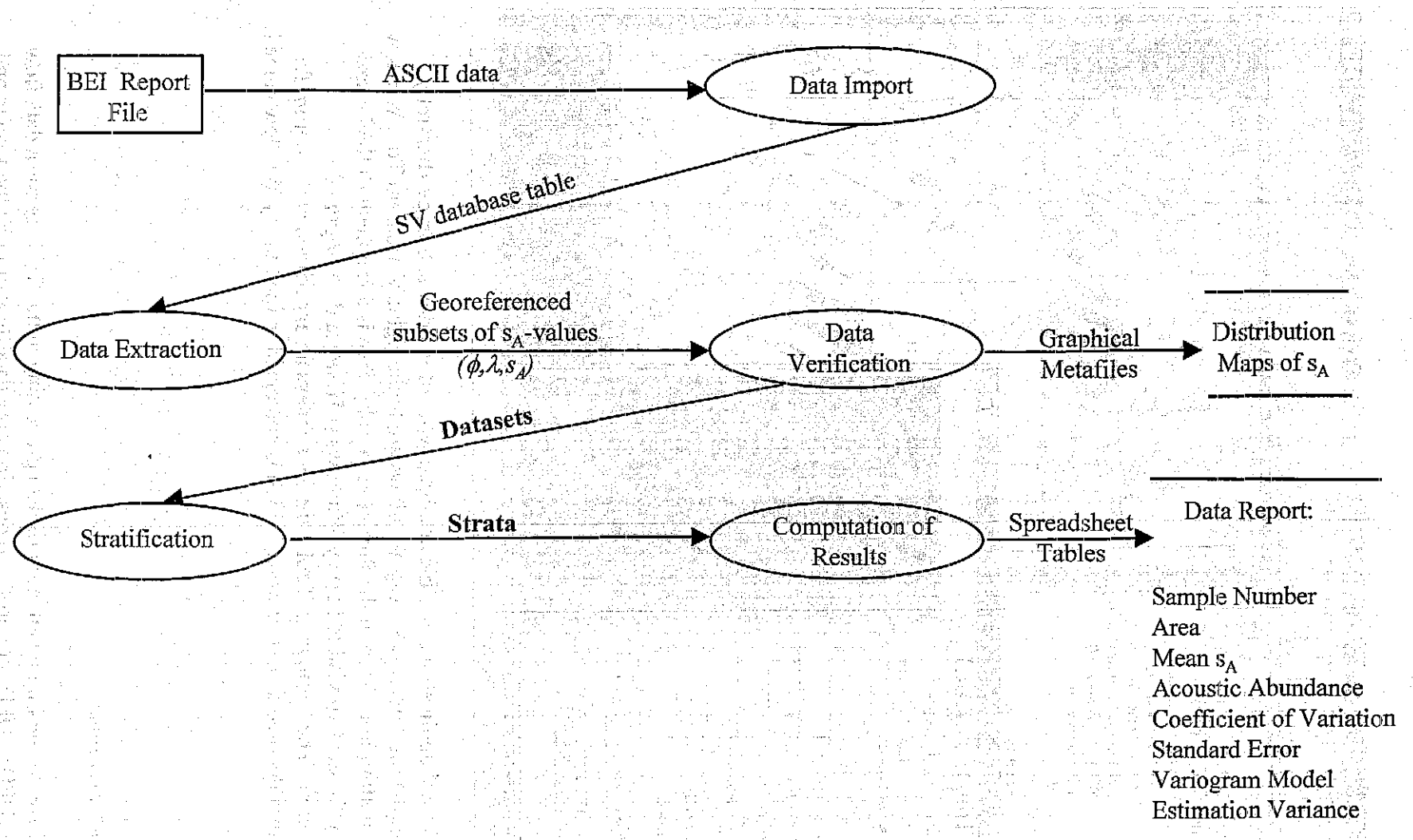represented by rectangles. Ellipses show processes. Data stores are shown within

Fig.2 The data flow diagram of the SV application

two horizontal lines. Arrows points to the direction of data transfer. Descriptions on top of the arrows indicate status of data at a given stage of analysis.

In Figure 2, the input to the SV system is represented by BEI report files. Those data are transferred to a local database, attached to SV. While importing the data, the system performs computation of acoustic density according to the methodology outlined in the beginning of Section 1.3. Importing data by ASCII files and using them from local database, rather than connecting directly to the BEI database, was chosen for performance and security reasons.

The processing initiates with *Data Extraction* (Figure 2). The data are selected from the local SV database, and than are reduced to the flat data sets comprising a single parameter referenced by geographical coordinates (e.g. s_A-value, or sailed distance). Those reduced data sets are downloaded to the Survey Window. The Survey Window provides tools for presentation of the georeferenced data, for doing statistical and geostatistical analysis on the downloaded content, and for storing status of visualization and the analysis into a single file. The basic modes of presenting data are those of scaled circles (Figure 6 and 7) and the along-track histograms (Figure 4). These are applied by the user during *Data Verification* in order to scrutinize the data, and to identify eventual errors.

Having verification completed, the data in the Survey Window are stratified (a process denoted as *Stratification* in Figure 2). In accordance with the methodology introduced in Section 2, stratification is required before any other operation on the data, including the export and analysis. Delineation of strata is accomplished visually by drawing polygonal boundaries on top of the Survey Window map. Currently, the SV implements simple polygon structures with no topological links between adjacent strata, (Burrough, 1989).

Next process described in Figure 2 is *Computation of Results*. It involves computations of abundance, statistics and geostatistical parameters, according to the description given in Section 2.1. Some of those computations, namely, acoustic abundance and standard statistics are maintained in the SV system - each time when a new delineation of a stratum is completed, these parameters are recomputed from the enclosed data. The geostatistical computations, on the other hand, are invoked explicitly by the user, because those (e.g. variogram modeling) are user-interactive routines.

At the final stage of the processing the SV system generates results, both in graphical and tabular forms. The graphical output consists of distribution maps of s_A-values, provided in the metafile format – the scalable image format that on Windows may be pasted to another applications or printed out with high accuracy of detail. The tabular output contains numerical results from statistical analysis, and those are provided in a spreadsheet form (through Microsoft Excel).
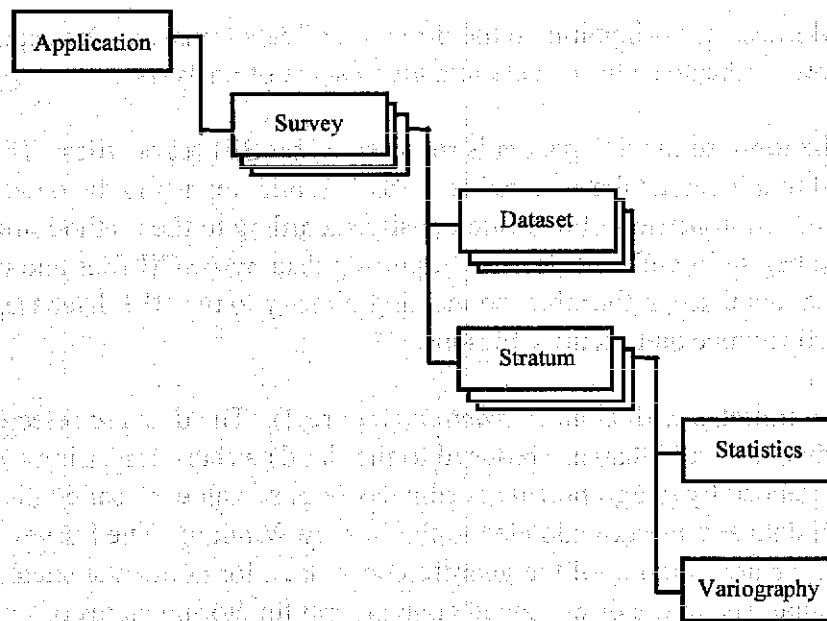
Fig. 3. Object hierarchy of the SV system. The overlapping rectangles denote collections.

3.3 Programming the SV – an object model

Objects are high level, abstract components of the software system with crisply defined behaviors and properties (Booch, 1994). A useful objects, from a perspective of a user of a software system, are those that are modeled on concepts and semantics of his domain knowledge. The SV system is object-based; it has object hierarchy modeled on the terminology pertaining to research surveys. The SV hierarchy of objects is depicted in Figure 3. Note that names of objects are identical to those of the user interface components described in Section 3.1. On top of this hierarchy, there is the *Application* object; it contains collection of *Surveys*; each survey contains *Datasets* and *Strata*. Two additional objects, not clearly resembled in the user interface, are *Statistics* and *Variography*. Those are for retrieving results of analyses. The SV object hierarchy is programmable from other Windows applications that support OLE Automation (Brockschmidt, 1995). These include, among others, the Microsoft Office programs (Word, Excel, PowerPoint, and Access).

The SV system, in addition to its object model, exposes through OLE Automation a number of algorithms, used internally, but useful to other applications - not necessary related to processing of acoustic data. Examples of these are: routines for computation of variogram (Deutsch and Journel, 1992), point-in-polygon selection algorithm (O'Rurke 1994), or cartographic transformations (Snyder, 1987).

4. EXPERIENCES IN USING THE SV SYSTEM

This section demonstrates the use of the SV system in the processing of survey data. The processing requires these three phases:

- quality-control by means of visualization of the allocated data,
- selection of spatially representative data subsets from those data by means of ad hoc queries, and through visual selection,
- stratification followed by the analysis.

4.1 Quality control of the scrutinized data.

Echo interpretation on the BEI is carried out continuously through the whole period of acoustic survey. Reports with scrutinized results are released on daily basis. Those reports are being immediately transferred to the SV database. Once in that database, the data are visualized. Figure 4 demonstrates the two basic modes of visualization: transects of s_A-values along a ship's survey track (Figure 4a), and pin maps of depth-cumulated s_A-values (Figure 4b). While the received data are generally of high quality, occasionally, there are fragments requiring intervention. Three specific types of problems have been encountered: (1) missing sections of survey tracks, (2) the bottom echo in the scrutinized record, and (3) recordings when echo sounder settings were incorrectly adjusted (e.g. echo sounder operating in a passive mode). Case (1) is immediately visible on the pin map (Figure 4b); while cases (2) and (3) are more apparent on vertical transects (Figure 4a). In doubtful cases, these two visualizations are compared with the pertaining echograms (Figure 5). The encountered problems are reported back to the BEI operator, who makes the respective corrections in the database, and than resubmits the corrected data report for use in the SV. In addition to the above-mentioned errors, there are rare cases of wrong geographical locations of the data, caused by malfunction of a GPS device. These are easily to distinguish in the pin maps, due to the offsets from the otherwise continuous trace of a vessel. Correcting of those errors depends on the configuration of the data: if erroneous positions protrude from the otherwise straight track segment, than these are fixed using linear interpolation between the first and last location, correctly aligned with the straight segment; if the geometry along the track is complicated, than the ship's turning points must be determined from the navigator's chart prior to such interpolation.

4.2 Data selection

The are three reasons why the extraction of data pertaining to the acoustic coverages from the survey database is, in the case of the Norwegian spring spawning surveys, a very involving task.

Sequential character of the collected data The surveyed distance exceeds 2000 n.mi. in a confined fjord region. There are multiple coverages of the same fiords, and there is a number of ancillary measurements, not being a part of the acoustic coverage. Despite of this, acoustic data are continuously recorded during period of the whole survey. The total number of the recorded s_A-values typically exceeds 20000 samples. Only one-third to a half of that number pertains to systematic acoustic coverages and is useful to the abundance estimation.
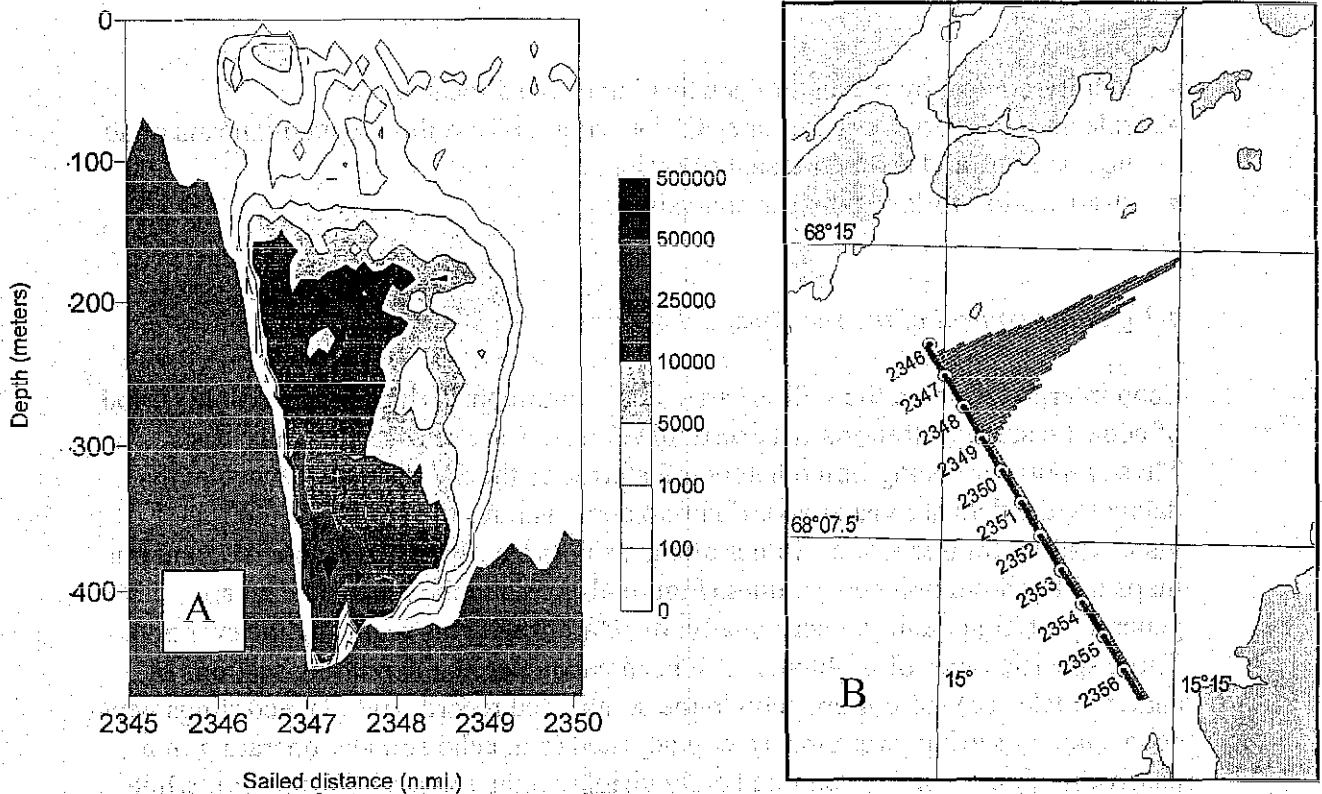
Fig. 4 Visualizations for comparing the content of the BEI database with source echograms: left - a vertical section of s_A-values for ten-meters thick layers; right - a bar chart of s_A-values along the track of a surveying vessel. Both views shown in this figure include the same data as those seen on the echogram from Figure 3. The data are from a transect in Vestfjorden during December 1997, when herring concentrated along the northern boundary of the fiord.
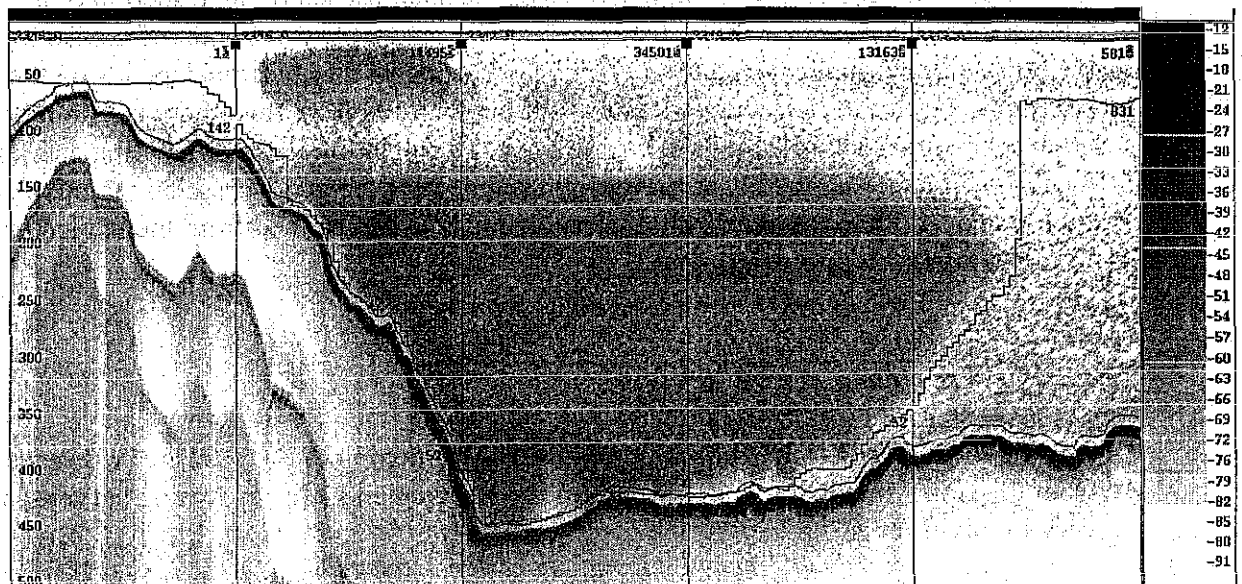

Fig. 5 Five-nautical mile fragment of the scrutinized echogram, as it appears on the computer screen of the BEI postprocessor. Visible are the lines delimiting the allocated scatterers: the pelagic layer, classified as herring, extends from the top horizontal line down to the upper of the two lines drawn by the system operator; the bottom layer extends from the lower of the two lines down to the echo trace of the bottom. The counter of the distance sailed by the surveying vessel is given below the echogram.

Diversions from systematic design While every precaution is made to survey a fjord in a single continuous effort, in practice, there occur diversions from an assumed track of the acoustic survey. Diversions are caused, among others, by the vessel's maneuvers during auxiliary measurements (e.g. trawling), sudden weather changes, or the vessel's maintenance. While, under these circumstances, the ship temporarily leaves the survey track, the acoustic recording and echo interpretation continues. After some time the vessel resumes acoustic survey, but than the quality of the spatial information in the recorded data is contaminated with traces of the preceding maneuvers.

Removal of endpieces in the case of parallel transects The boundaries of survey area, for the concerned surveys, are primarily determined by coastlines. For parallel transects and such geometry, the recommended procedure is to remove the inter-transect data (Anon. 1991).

For a smaller survey effort, identification and extraction of the spatially representative data may be a trivial task, to be accomplished with ad hoc data operations. However, for the Norwegian spring spawning surveys, due to the size of the database, the manual extraction is a major undertaking. The visualization and data selection tools built-in the SV system make the data selection easier. The process of data selection using the SV tools is demonstrated in Figure 6; the right-hand images demonstrate user interface elements for doing data selections; those in the left demonstrate results from the selections by means of pin maps seen in the Survey Window. Data selection is accomplished in three steps. The first two, depicted in Figure 6A and 6B, are pursued with SQL queries, while the third, depicted in Figure 6C, through a visual selection. The process of data selection is incremental. Figure 6A depicts a situation of an initial data selection, where the search range in the SQL query is roughly defined, and hence the resulting visualization returns too many data. The paths of the ship's approach and return from the acoustic coverage bias the data useful to spatial analysis. Therefore, in Figure 6B the extraneous tracks are removed by means of an updated query, based on visual inspection of the pin map from Figure 6A. This method of elimination, however, is not effective in the case if there is a lot of redundant data to remove - as it is in the case of endpieces of the transects.
The better method for removal of endpieces is through delineation of a polygon, such that it includes transects but excludes the endpieces. This is demonstrated in Figure 6C. The user carries out delineation by drawing a polygon with the mouse. Once he completes delineation, the SV resembles the change by adding a new item to the strata hierarchy list, (Figure 6C, left). Selecting this item, with right-click of the mouse, brings the user to the commands pertaining to the new polygon. By performing the data exclusion command, he removes the data outside of the polygon. After that, he switches the visualized variable from the sailed distance, seen on the pin maps in Figure 6, to s_A-values, depicted in Figure 7. The data content in the Survey Window becomes now ready for doing stratification and the analysis (Figure 7A). The whole process of data selection in the SV takes, typically, less than 5 minutes, except for a complicated geometry of those surveyed grids that have large number of the diversions from survey track.
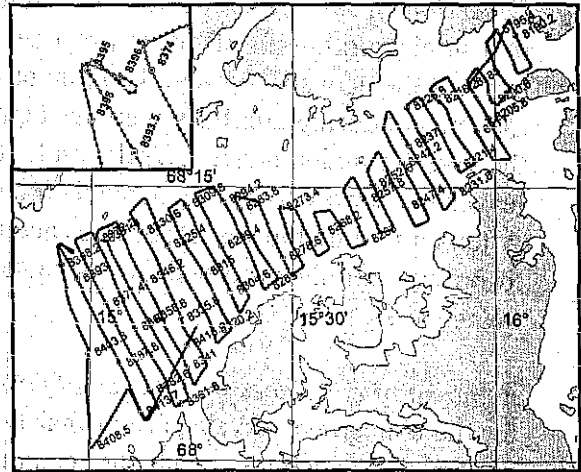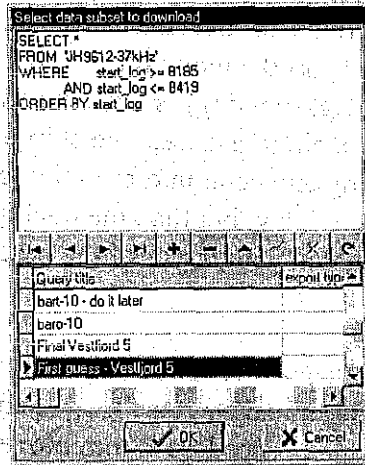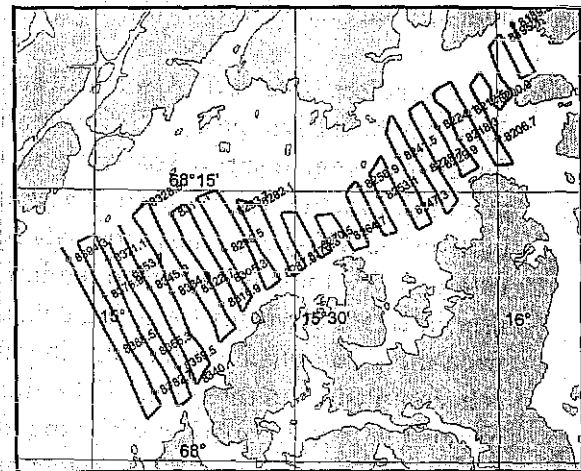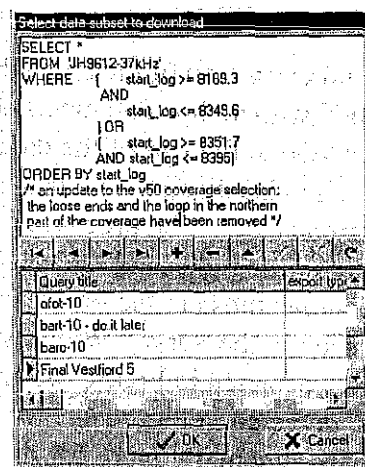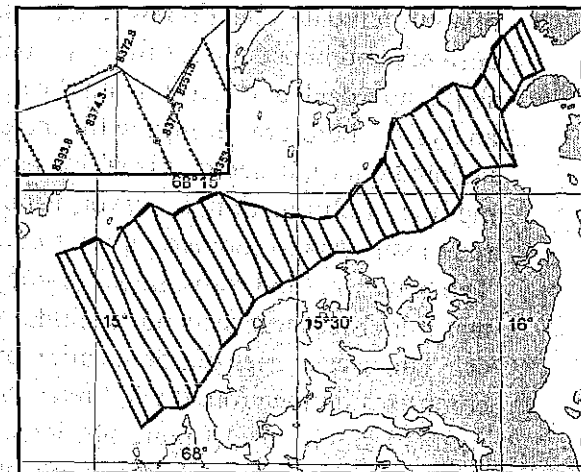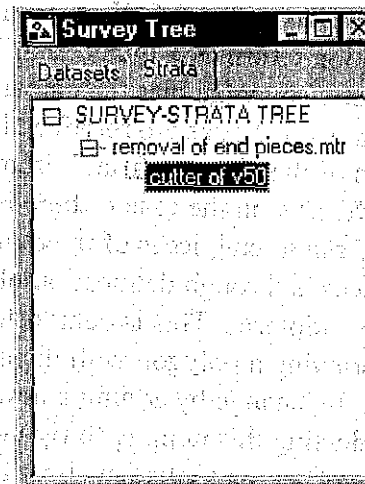
Fig. 6 Selection of survey data for analysis in the SV system. Figures on the left depict user interface elements for doing data selection, figures on the right are the corresponding visualizations, seen in the Survey Window. The inserts in (A) and (C) are the enlarged fragments of the northwest corners of their respective polygons. The methodology pertaining to these figures is described in Section 4.2.

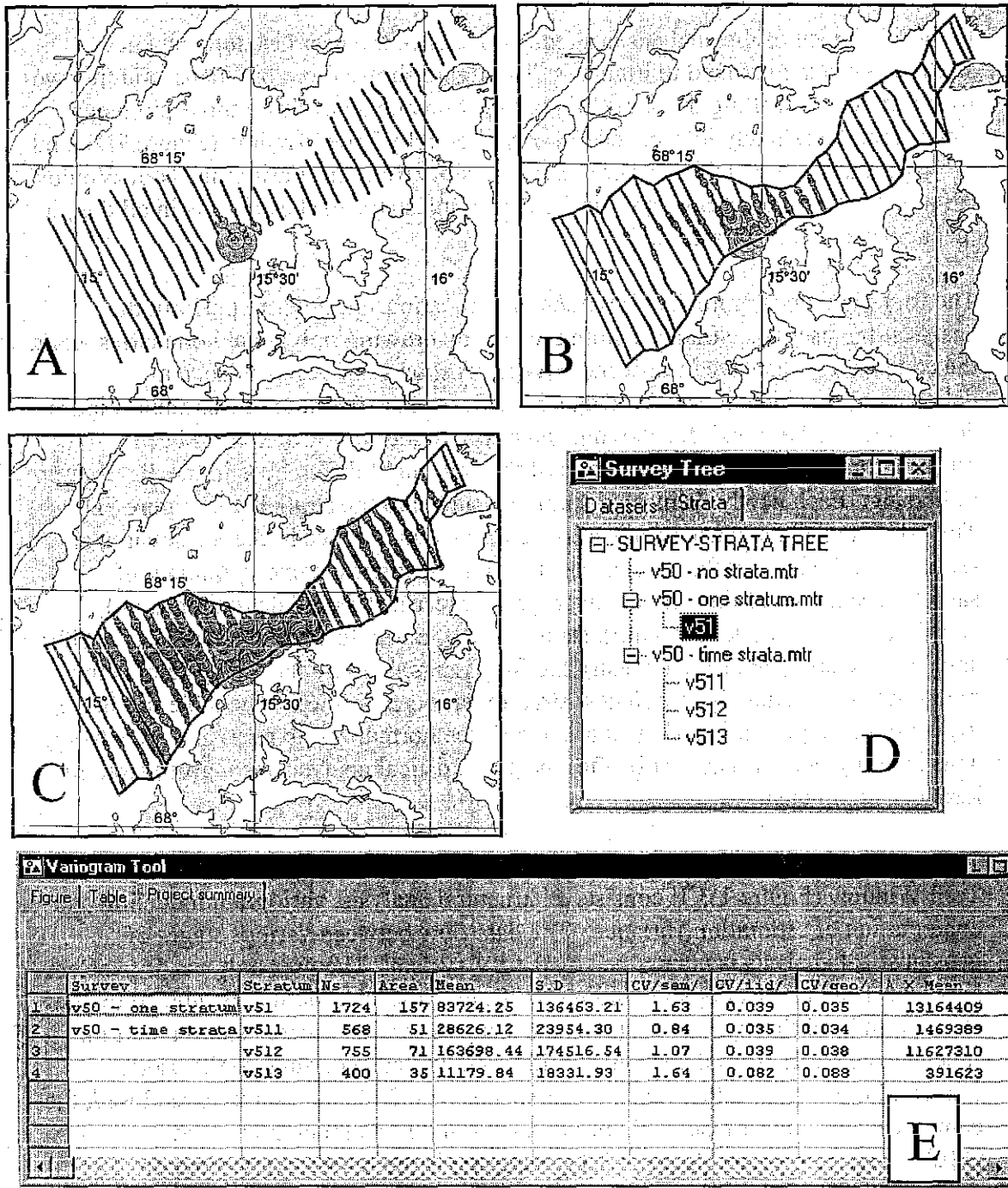|	Survey	Stratum	Ns	Area	Mean	S.D	CV/sem	CV/lid	CV/geo	X Mean
1	v50 - one stratum	v51	1724	157	83724.25	136463.21	1.63	0.039	0.035	13164409
2	v50 - time strata	v511	568	51	28626.12	23954.30	0.84	0.035	0.034	1469389
3		v512	755	71	163698.44	174516.54	1.07	0.039	0.038	11627310
4		v513	400	35	11179.84	18331.93	1.64	0.082	0.088	391623

Fig. 7 Examples of stratification and the results of the analysis in the SV. Panel A depicts the data after spatial selection. Those are stratified in two ways: in a single stratum (Panel B), or in the three strata revealing day-and-night differences. Panel D describes hierarchy of the strata, as seen in the Survey Hierarchy Window; Panel E shows statistics pertaining to those strata. The maps show the same distribution of s_A-values in three proportional representations, where circles radii are proportional to: squares (Panel A), linearly (Panel B) and square roots (Panel C) of the s_A-values.

4.3 Stratification and the analysis

In the SV, much of the analysis is already done once the user has defined a new stratum. This is illustrated in Figure 7. The figure shows three pin maps, and the two windows for controlling the status of stratification and analysis on those pin maps. Those are: the (already introduced) Survey Hierarchy Tree Window (Figure 7D), and a "Project Summary" table (Figure 7E), accessible from the Variogram Tool Window (Figure 1). The Project Summary is for displaying status of the analysis in all the pin maps opened in an SV session.

The first pin map (Figure 7A) is without stratification. In order to perform the analysis, the user first stratifies those the data by drawing polygonal boundaries along the edges of the displayed transects. Figure 7B shows one result of such a delineation, in which all surveyed data have been classified into one stratum. Figure 7C depicts another result for the same data, where the survey area have been separated into three strata on the basis of the day- night differences in the distribution of herring. Each newly delineated stratum is added to the strata list in Figure 7D. The estimates of abundance and statistics, for all strata active in the SV session, are reflected in the Project Summary. Most of those statistics, namely, number of samples (Ns), area of the stratum, average s_A (Mean), standard deviation (S.D.), coefficient of variation (CV/sam/), standard error normalized to average s_A (CV/iid/), and acoustic abundance (A x Mean), are fully maintained by the SV system, being recomputed immediately after a new stratum has been defined. The table in Figure 7E depicts also geostatistical estimation variance normalized to average s_A (CV/geo/). This quantity becomes available after the geostatistical analysis for a given stratum has been completed.

The geostatistical analysis is performed from the "Figure" page in the Variogram Tool Window (Figure 1). It consists of structural analysis, variogram modeling and computation of estimation variance. The data flow between various stages of geostatistical analysis is maintained by the SV system. The user only needs to select a stratum from the list depicted in Figure 7D, and after that he will be guided by the Variogram Tool through the stages of the analysis for the selected stratum. At the first step, an experimental variogram will be computed according to the user's settings. For a low-end Pentium PC (100 MHz), and 2000 data samples enclosed, the computation is almost instant, thanks to an optimal implementation of the GSLIB-based algorithm (Section 3.1). Next step is the interactive variogram modeling followed by computation of geostatistical estimation variance. The algorithm for estimation variance implements Equation (5, Section 3.1) by discretizing the area of the selected stratum, and than by doing a numerical integration over the discretized domain. The order of this computation is $N(N+1)/2$, where N denotes number of samples enclosed in the stratum. Assuming the following configuration: a low-end Pentium PC; 2000 data samples; area of the stratum of 150 squared nautical miles, and discretization size of 0.2 nautical mile, this computation should take about 1 minute.

There are two areas of the Norwegian spring spawning herring survey methodology that are not directly supported in the SV system: computation of fish abundance and

cumulative estimates. Those simple computations, however, can be easily implemented in the general software using the object model provided by the SV (see Section 3.3). For instance, in order to the compute, in Excel, cumulative abundance in a fjord using the strata enclosed in the Survey named "v50-time strata" (Figure 7E) one needs to write the following code snipped:

```
Set Survey = sv.Surveys("v50 - time strata.mtr")
Sum = 0
For Each stratum in Survey.Strata
   Sum = Sum + stratum.Statistics.Abundance
Next
ActiveSheet.Cells(1,1) = Sum ' send it to Excel
```

In the current, onboard-based, applications of the SV, the Excel-based scripting is mainly used to produce cruise reports, but also to generate isoline maps, based on kriging of multiple strata, using the variograms that have been derived during the geostatistical analysis in the SV (Figure 8).

5. CONCLUDING REMARKS

The software presented in this report delivers a simple, yet effective interface for onboard preparation of the high-resolution acoustic data, and for their basic analysis including computation of abundance and the measures of uncertainty of the estimate by means of geostatistics. The processing begins with capturing the output from the echo interpretation system (BEI), and is carried out in the four steps: data selection, verification, stratification and analysis - all these steps are integrated in a single visual environment. Such integration significantly reduces times of the analysis, otherwise spend on the computer-related data manipulations. A simple, intuitive object model - that of Survey-Dataset-Stratum hierarchy - implemented both in the visual tools and in the programming interface, delivers a consistent way for users to navigate through various functions of the system. The ability to use the visually selected data and the analytical results by means of programming, opens almost indefinite possibilities of extensions to the built-in functionality of this software.

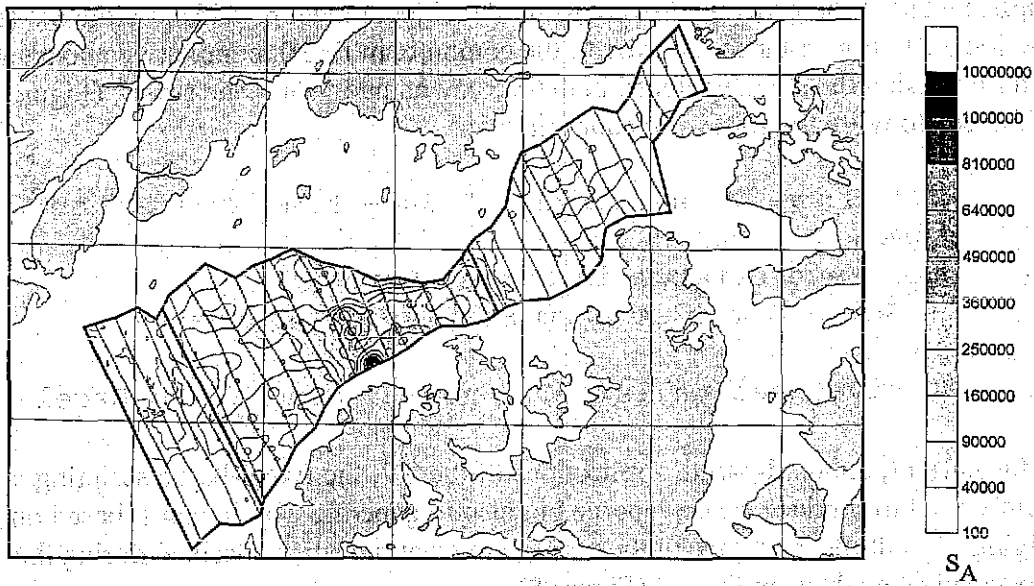| | 10000000 |
	1000000
	810000
	640000
	490000
	360000
	250000
	160000
	90000
	40000
	100

S_A

Fig. 8. A routine visualization of the fish distribution generated by an OLE
Automation compatible presentation software (SURFER for Windows), using the data
retrieved from the Survey Window by means of the SV programmable objects.

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