***Rolf J Korneliussen.** Ecosystem management in 4 dimensions. Proceedings of the 34th Scandinavian Symposium on Physical Acoustics, Geilo 30 January – 2 February, 2011.*

Ecosystem management in 4 dimensions

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Abstract

Management of marine resources is supported by extensive use of acoustic data. Ecosystem management requires simultaneous observations of marine organisms and their interactions. The use of quantitative sonar combined with vertical oriented echo sounders is essential: the multi-frequency echosounder data is used to remotely identify acoustic scattering categories and the spatial distribution of these below the ship, while the quantitative essentially single-frequency Simrad MS70 sonar is able to measure the water volume around the ship in time and space (4D). For practical reasons, the large volumes of data that are collected during 24 hours should be scrutinized within 2 hours in front of the computer. Methods used to visualise and process the acoustic data are discussed together with the basic philosophy to make the system work in practical use.

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Introduction

Acoustic methods have been used widely in fisheries acoustics (**Nakken and Ulltang, 1983; Simmonds and MacLennan, 2005**). Echo integration of echosounder data, supported by biological sampling, is a commonly used method used for abundance estimation (**MacLennan, 1990**). Acoustic methods may be used to survey large areas during short time, which makes estimation of fish stock abundance based on acoustic data cost-effective compared to other methods. The process of scrutinizing acoustic data is generally done by analyzing and correcting echograms in digital form using a dedicated post-processing system. The goal is to achieve optimal quality of the stock assessments given the available resources. This means that the acoustic data has to be analyzed fast enough so that there is still enough time to perform the other work needed to calculate fish stock abundance to optimal quality.

Traditionally, acoustic investigations of stocks have been done at times of the year when the investigated species is found in the water column not too close to the surface (i.e. in the surface blind-zone) and not too close to the bottom (i.e. in the bottom dead-zone). In recent years, it has been an increasing desire to move from management of single stocks to manage complete ecosystems. Although this is currently a too challenging task to achieve completely, an obvious necessary acoustic requirement is to measure the complete water-column around the ship as illustrated in **Figure 1**. Generally, some species of the ecosystem may be ideally distributed for acoustic measurements by means of vertically oriented echosounders while others species are not. The Simrad MS70 echosounder is designed to quantitatively measure in one single ping common sizes of fish-schools from close to the sea surface and downwards in the pelagic region, i.e. in the blind-zone of vertically oriented echosounders. The term quantitative refer to the ability to calibrate the SONAR so that it gives quantitative measures.

The acoustic abundance, i.e. Nautical Area scattering Coefficient (NASC), s_A, or volume scattering coefficient, s_v, (**MacLennan *et al.*, 2002, Simmonds and MacLennan, 2005**) for each species is estimated by scrutinizing visual images of the acoustic returns as illustrated in **Figure 2**. The numeric density, ρ, of the measured objects is determined by dividing the acoustic abundance, e.g. s_A, by the mean backscattering cross-section, σ, of a single object: $\rho = s_A/\sigma$, where σ depends on species, specimen size and species behaviour, where behaviour includes mean tilt-angle, tilt-angle distribution. This is commonly known as the echo-integration equation, and converts acoustic measures to biological. For vertical oriented sound-beams, the relation between the logarithmic equivalent of σ, i.e. target strength TS, and specimen sizes is known for many species, while TS is only known for a few species while ensonified with horizontally oriented beams (**Pedersen *et al.*, 2008**). TS relations for horizontally oriented beams are not the topic for this paper.

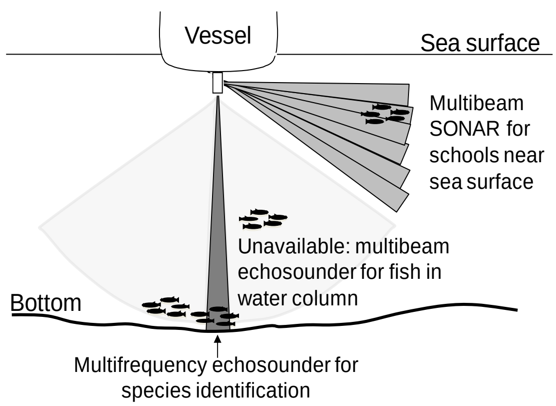

***Figure 1.** The acoustic needs for investigating species of marine ecosystems. Necessary, but not sufficient for ecosystem investigations.*

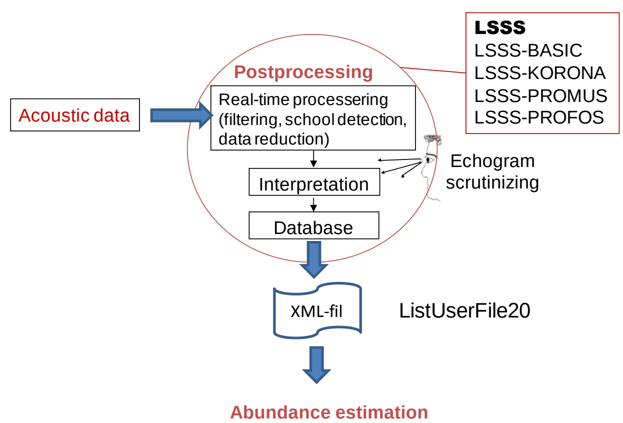

***Figure 2.** Principle for the interpretation of acoustic data.*

A system to process acoustic data with a true graphical interface was firstly introduced by the Bergen Echo Integrator in 1988 (**Foote et al., 1991; Korneliussen, 2003**). In this paper it will be presented how large amounts of acoustic data can be scrutinized within relatively short time in front of the computer. This requires efficient algorithms for detection of potential schools, and an efficient user-interface to manually process those school-candidates further. The results are stored into a database for further processing, e.g. calculation of stock size.

Operating procedures

At the beginning of a cruise, the log processes are started, and the data are stored to files. The log processes do not require active interference by the operator. The post-processing system LSSS (Large Scale Survey System) is set up to identify where each type of data is stored, and each data type is visualised in one or several dedicated graphical windows. Further, a survey database is set up where the acoustic categories to be scrutinized are defined, and the storage grid of the acoustic data is specified. The acoustic data are of special interest here. The acoustic data are firstly pre-processed to remove noise, detect bottom, detect schools and identify acoustic categories. Then, the multi-frequency echosounder data are processed through the Echogram Window and the multi-beam sonar data are processed through the 3D/4D-Ping Window, the Phantom-echogram Window and the Ping-slice Window. These windows are shown in **Figure 3**.

Figure 3(a) and **(b)** are pelagic echograms based on the data from the multi-frequency echosounder. **Figure 3(a)** use artificial colours to visualise different acoustic categories, where red is "herring" and orange is "mackerel". In this case, both these acoustic categories are in fact the biological species herring (*Clupea harengus*), but when herring release the content of the swimbladder it acoustically looks like mackerel. **Figure (b)** shows 38 kHz data, where the strongest backscatter are shown in dark red, and the weakest in light blue as shown in colour-scale in **Figure 3(bC)**. **Figure 3(bD)** shows a single multi-beam ping in the 3D-Ping Window. Each ping has 3 spatial dimensions and consists of 500 beams (25 horizontal x 20 vertical). When time is added, this becomes a 3D movie, i.e. 4D (space and time).

From suggested acoustic categories (**Figure 3(a)**) and experience, including knowledge of sea area and season, the operator has concluded that the bulk of the fish concentrations in the central zone is homogeneous with respect to fish species. This is reflected in the irregular closed lines surrounding the schools of herring in the pelagic windows (**Figure 3(a)** and **(b)**). The operator also use the relative frequency response shown in **Figure (3dC)** (**Korneliussen and Ona, 2002, 2003**) and the strength of the scatter, s_A, shown in the (echosounder) Interpretation Window to identify species. The Interpretation Window is the tool used by the operator to insert the result of the data interpretation, i.e. which acoustic category (species) the operator have concluded that the acoustic returns originates from. The Promus Interpretation Window shown in **Figure 3(dB)** used to scrutinize sonar data is similar to the echosounder Interpretation Window. The Threshold response Window (**Figure 3(dC)**) is used to ensure that backscatter at none of the frequencies (here 18, 38, 70, 120, 200 and 333 kHz) is limited by noise, i.e. that the relative frequency response is valid to be used in species identification. Supportive information from trawl and CTD (Conductivity Temperature Depth) are also used during the scrutinizing process.

Figure 3(dA) shows the cruise track in the Map Window as a dark blue line, and the multi-beam sonar as a lighter blue line (area). The green "blobs" in the map are school candidates detected by the pre-processor, but alternative technique by using phantom echograms (**Figure 3(c)**) to localize schools have proved to be a more efficient method, especially for schools very close to the surface. The phantom echograms (**Patel and Ona, 2009**) are vertical echograms similar to the pelagic echograms in **Figure 3(a)** and **(b)**, but are generated from multi-beam sonar data. The Phantom Window is used to jump directly to the schools to be scrutinized. At this stage, the pre-processor has already removed ambient noise, but the operator may still decide to remove additional bad data, or to use the original data not corrected for noise. The operator instructs LSSS how to estimate the school extent from the acoustic data. The default settings, i.e. those used during last grow-operation are usually sufficient. A seed-point is selected in the Slice Window (**Figure 3(cD)**) together with minimum and maximum depths, minimum and maximum acoustic strengths and other information. Then typically 10 pings prior to the current and 10 pings after are used to grow the school to estimate its extent, so that its volume, surface, and acoustic abundance can be calculated. The grown school may be visualised in the 3D-Ping Window (**Figure 3(bD)**), but here only the acoustic data are shown. Further, the operator may decide to manually remove parts of the grown school, or to reject the grown school completely. Further, acoustic categories (species) are allocated to the acoustic returns limited by the extent of the grown schools.

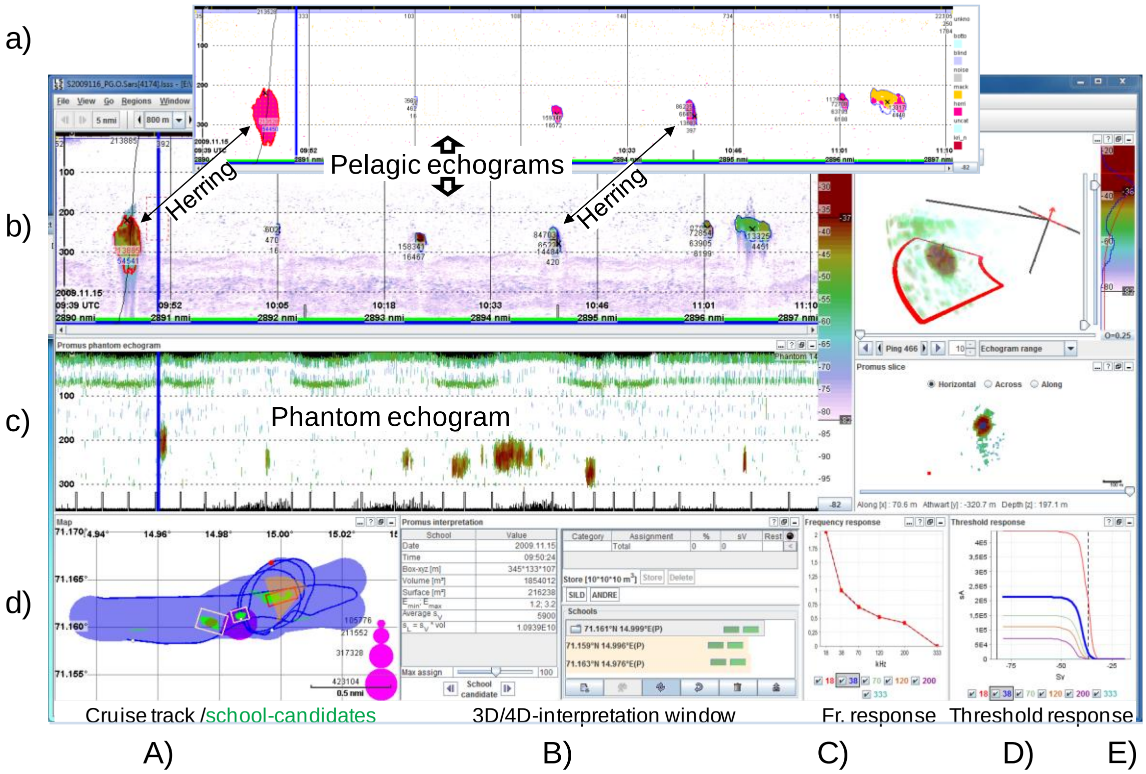

Figure 3. Common windows of the graphical user interface used to scrutinize acoustic data.

Finally, when both the echosounder data and the sonar data are scrutinized, the result is stored to a database. The database is encapsulated by Hibernate, so that any of the database-engines HSQLDB, JavaDB, Ingres, MySQL, PostgreSQL, or Firebird may be used. The database model is shown in Figure 4. For abundance estimation, it is especially the database tables Scatter and ScatterData (for echosounder data) and Scatter3D and ScatterData3D (for sonar data) that is important. In those tables the acoustic data are stored as NASC, s_A, for echosounder data and Nautical Volume Scattering Coefficient, $s_V=4\pi 1852^2 s_v$. The method used to estimate abundance from the acoustic data in Scatter and ScatterData, and Scatter3D and ScatterData3D removes the need for gridding the data, which could introduce uncertainties regarding abundance estimations. On the other hand, those database tables are not suited for storing morphological and bathymetrical information of single schools, such as volume, school surface, length, width, height, depth below surface, etc. Therefore, morphological information is stored in specially designed school-object database tables indicated in **Figure 4**.

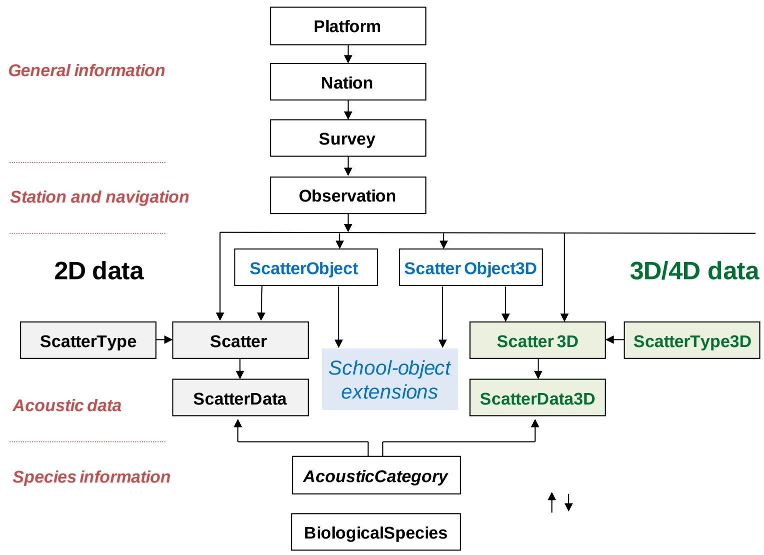

Figure 4. *Database for storing data in both 2 and 3 dimensions.*

Field trials and Discussion

The LSSS system expanded with the PROMUS module (Processing System for Advanced Multi-beam SONAR) has been tested on several surveys. These surveys involve surveys with the main purpose of testing the sonar Simrad MS70, and abundance estimation surveys where the target species were close to the bottom (sandeel surveys in the banks of the North-Sea), method development surveys where the schools are distributed in the water column (**Figure 3**) and abundance estimation surveys where the majority of the schools are located close to the surface. Each of the early surveys revealed weaknesses of the sonar MS70, that was eventually corrected, and then the following surveys revealed weaknesses regarding the post-processing system PROMUS. The final of these surveys in May 2011, dealt with schools located close to the surface. The sonar MS70 is designed for the purpose of estimating abundance of schools close to the surface, i.e. in the echosounder blind-zone, so that survey was in many ways the most important.

The most recent problems solved were the identification of schools very close to the sea-surface in presence of heavy reverberation, i.e. reflection from the surface of the uppermost fans (1 fan = 20 beams in same angle to the surface). A modification of the Phantom Window solved this problem by letting the operator remove the uppermost fans, and then by selecting the maximum scatter at one depth. Another problem was the time consumption for storing 3D data to the database, which could in practice hinder the PROMUS module to be used on operational surveys. This was solved by only reading high-resolution acoustic data in those regions where schools were detected and scrutinized, and deducing no species scrutinized on the rest. The time to store to the database for a selected dataset was the reduced from 60 seconds to 3 seconds.

In conclusion, the PROMUS module of the LSSS is now ready for operational use on oceanic surveys.

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