ACTA ACUSTICA UNITED WITH ACUSTICA
Vol. 88 (2002) 730–733

In Situ Inter-Standardization of Acoustics Data: An Integrated Database for Fish School Behaviour Studies

P. Brehmer[a], F. Gerlotto[b], A. Rouault[c]
[a]: IRD, Centre de Recherche Halieutique Méditerranéenne et Tropicale, BP 171, 34203, Sète, France. brehmer@ird.fr
[b]: IRD c/o, IFOP, Huito, 374, Valparaiso, 5a Region, Chili. fgerlotto@ifop.cl
[c]: UBO/IUEM, Université de Bretagne Occidentale, Plouzané, Brest, France. arouault@ifremer.fr

Summary
This paper presents a method that permits to inter standardize three sources of acoustic data delivered by several different acoustic devices in order to monitor the behaviour of pelagic fish schools. An omnidirectional multi-beam sonar (32 beams/23.75 kHz), a lateral multi-beam scanning sonar (60 beams/455 kHz) onboard a research vessel and a portable echo sounder (129 kHz) onboard a small craft are used. The method is presented in two parts. The first deals with the multi-beam acoustic sonar (lateral and omnidirectional) and the second with the portable echo sounder and the omnidirectional sonar. The same schools using the portable echo sounder and the omnidirectional sonar are recorded. The same experiment with the lateral sonar and the omnidirectional one is done. The echo characteristics of the omnidirectional sonar data are compared with the two other sources of acoustic data. The preliminary "behavioural database" of fish schools is obtained by gathering the information from the three complementary devices. For each school the depth, size, two and three dimension morphology, acoustic characteristics and the swimming behaviour characteristics (swimming speed and pattern) are measured. The potential output of such database for fisheries research is discussed through preliminary results.

PACS no. 43.80.Jz

1. Introduction

The development of direct observation of fish resources by acoustic methods leads the scientist to use different acoustic devices such as vertical echosounder (VES), lateral multi-beam sonar (MBS) and long-range omnidirectional sonar (LOS). Each device is complementary for the study of fish schools: the VES gives a precise acoustic information, the MBS provides with the morphology in three dimensions and the LOS with the displacement according to the transducer location. The acoustic calibration procedure is already well documented for the echosounder [1]; it has been described recently for a MBS [2] and is under construction for a LOS [3]. However this does not fulfil the need for standardisation of the data coming from the different acoustic devices. This must be done on the biological data, i.e. the fish schools. This standardisation is obtained through a series of *in situ* observations of the same target (a school) using the different acoustic devices. Each acoustic instrument presents a set of characteristics. The LOS range is long (low frequency) which implies a low accuracy due to its long pulse duration (8ms at a range of 800m) and its large beam width (11.5° around the −3 dB point). The displacement of the school inside the beams induces a great variability in the LOS school size values. The VES presents a rather small range (limited by the bottom depth) and a good accuracy (signal analysis) in the vertical direction due to the vertical beam. Its precision in the horizontal plan is low. The MBS presents a very precise definition (high frequency, short pulse duration) in the vertical plan. Its range is limited (high frequency) and its definition in the horizontal plan is similar to that of the VES. The paper presents the results of a series of simultaneous observations and measurements on a series of schools in the Atlantic Ocean.

Received 15 May 2002,
accepted 30 June 2002.

2. Material and methods

The data have been collected during an IRD project (Varget: 1996-1999) in cooperation with two laboratories: the *Centre de Recherches Océanographiques de Dakar-Thiaroye (CRODT)* in Senegal and the *Fundacion La Salle (FLASA)* in Venezuela, aboard the 35 m long IRD catamaran Antéa. The acoustic devices used are presented in Table I.

The LOS is mounted aboard the research vessel and the VES on a small craft. The data from each instrument are

Table I. Main characteristics of the acoustic devices: "MBS" multi-beam sonar, *Reson Seabat 6012* [4], "LOS" long range omnidirectional, sonar *Simrad SR240* [5] and "VES" vertical echosounder, *Biosonics DT5000* [6].

	Reson Seabat 6012 (MBS)	*Simrad SR240* (LOS)	*Biosonics DT5000* (VES)
Pulse duration (ms)	0.06	8	0.6
Range (m)	100	800	150
Frequencies (kHz)	455	23.75	129
Number of beams	60	32	1 (split)
Beam width (degree)	1.5*17	12*11.5	11
TVG	20 log R	30 log R	20 log R
Plan of observation	Lateral 90° starboard	Omni. 360	Vertical
Software for data process	Sbiviewer 5.01	Infobancs 2.0	Visual analyser 4.02

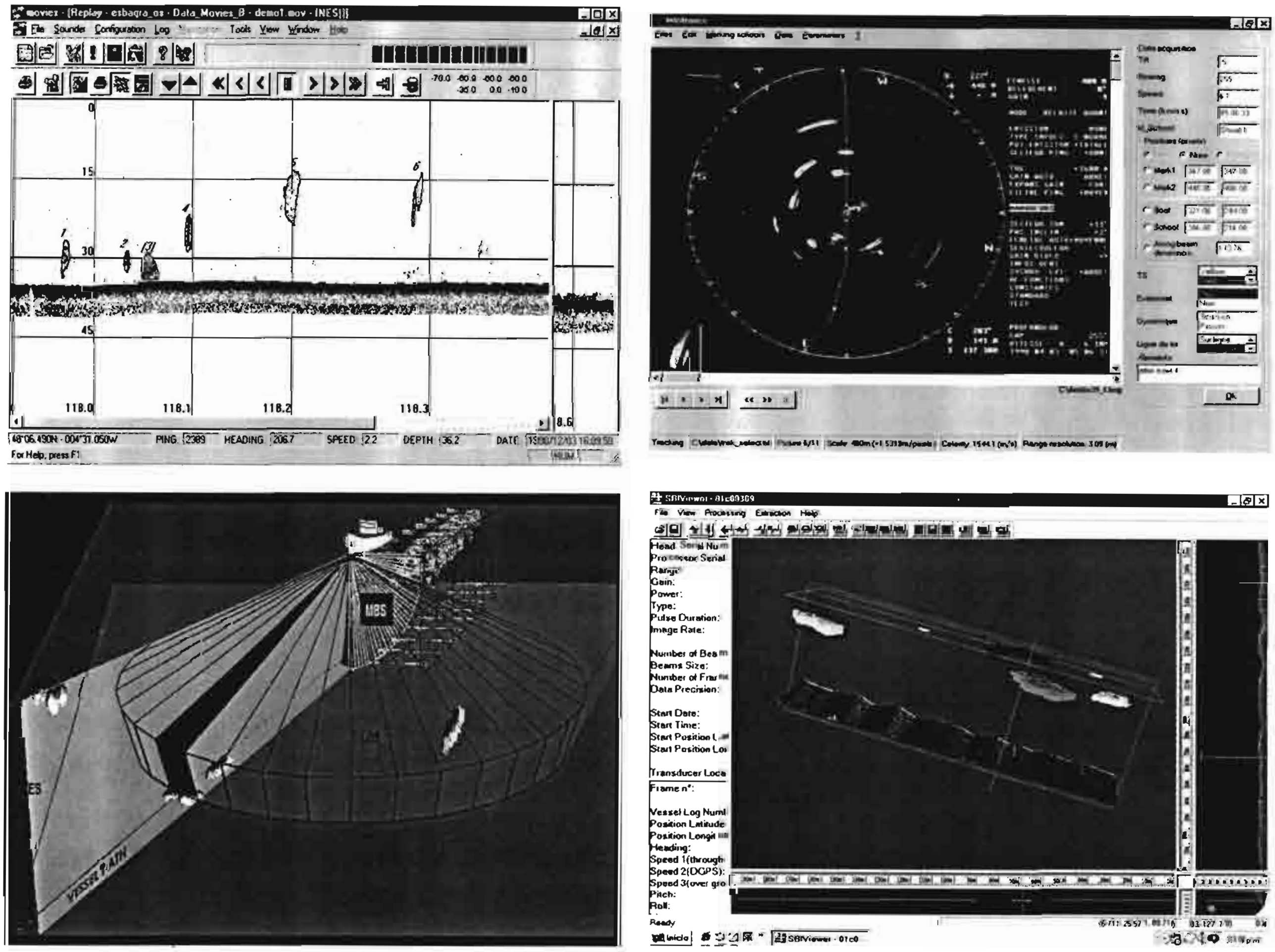

Figure 1. Software and sampling volume of each acoustic device. From the upper left to the lower right: echosounder analysis with movies+ [7]; LOS picture under *Infobancs 2.0* [8], in the centre the boat (diameter: 800 m) on starboard a school detected on the MBS (range 100 m); on the right lower the picture of the three dimensional morphology of some school analyses by *Sbiviewer 5.01* [2].

processed using specific software. In total, 211 couples of data were recorded, i.e. 160 for the LOS-MBS couple and 51 for the LOS-VES one. For obvious reasons it is very difficult to observe the same school simultaneously on the three devices, but in any situation a school is observed by the LOS, which can be used as reference. The LOS gives two kinds of shape information: the along beam dimension $LW = LW_s - c\tau/2$ and the across beam dimension $CW = CW_s - 2R_n \tan(B/2)$, this last one being dependent on the transducer distance R and the beam width B; the measure s is observed on the LOS screen and corrected by a scale factor [9]. c is the sound celerity in water (m/s) and τ (ms) the pulse duration. LOS versus MBS: the two sonars (MBS and LOS) are mounted aboard the research vessel, the MBS is on starboard with a range of 100 m. All the schools, which pass in the lateral sonar range, are digitised [2] by a specific interface unit, which records data that allow to reconstruct the school in three dimensions

(Figure 1) and to extract its elementary descriptors (length, width and height etc.). The schools are easily identifiable on the LOS recordings and their descriptors are extracted with *Infobancs 2.0* [8] (Figure 1). For the second part of this work we use a LOS and a portable VES. The vertical echosounder is installed aboard a little craft and directed towards the fish school, which is detected on the LOS display, the vessel adrift. The dinghy is equipped with a radar reflector and its successive positions are recorded. The VES is equipped with a GPS in order to reconstruct its road. The operator aboard the main vessel directs the dinghy towards the school. In theory this methodology permits to obtain the school's swimming speed characteristics and its VES descriptors [10]. This is not always possible for different technical reasons, and it is very difficult to identify accurately the school observed on the LOS as one school observed on the echogram. On the other hand, we can rather easily obtain a set of data belonging to a same small population of schools (cluster).

3. Results

We present the results of the two methods by comparison of the basic fish school descriptors on each sample, then the fish school database and some preliminary analyses made possible by this database.

LOS/MBS operation. The first task is to test the impact of the visual extraction of the parameters. This was done for the MBS by comparing the results obtained on a single database by 3 series of measurements: 2 visual extractions (E1, E2) and an automatic extraction using *SBIViewer 5.01* (E3). A Principal Component Analysis was calculated on these data. It shows that the lengths (E1 to E3) are similar, but the width and the height are not. On the other hand the width and the height obtained by manual operators are homogenous and different from the software results. Once this test performed, we compared the fish schools descriptors obtained with the MBS (data extraction by *Sbiviewer 5.01*) and the LOS (data extraction by *Infobancs 2.0*), on a sample of 102 fish schools. The results (Figure 2) show that the length (MBS dimension along the boat) is the largest measure with the highest variation (mean: 34.6 m; σ: standard deviation 25.33). The width of the school (mean: 15.2 m; $\sigma = 10.1$) is higher than its height (mean: 9.6 m; $\sigma = 6.7$) on the MBS data. For the same sample the morphological LOS descriptors give an mean of 12.4 m and 18.6 m respectively for the LW_{mean} and the LW_{maxi}. These two descriptors have approximately the same standard deviation (6.3 and 6.7) as the height obtained by the MBS.

The descriptors extracted by *Sbiviewer 5.01* and *Infobancs 2.0* are tested by sample comparison of independent variables ($n = 108$). Then a second data series is made with a new version of *Infobancs* (version 3.0), which takes into account the CW dimension of new schools (n=58); the results for the LW variable are similar. The MBS width corresponds to the LW_{mean} but the length ($p < 0.05$) and the height do not have any relation with the LOS descriptors (LW and CW). As expected the CW dimension do not correspond directly to a morphological fish school feature (this dimension depends on the beam width at a certain distance to the boat).

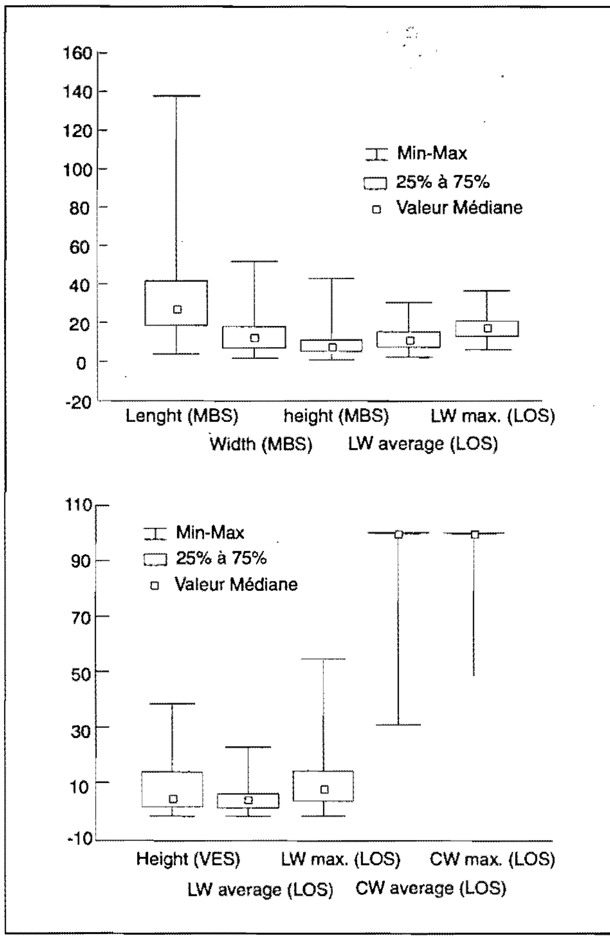

Figure 2. Box plot "1" in meters (median value, minimum, maximum and second and third quartile), of each morphological descriptor obtained on the same school ($n = 102$) for the MBS and the LOS detection. On lower Box plot "2", of each morphological descriptor obtain on the same cluster ($n = 51$) for the VES and the LOS detection.

LOS/VES operation. The data obtained from three operations led during the same surveys in eastern Venezuela with the same devices (boat etc.) have been grouped. The fish school (n=51) have been observed at an average distance of 265 m from the boat (maximum: 455 m/minimum: 62 m), and their Sv_{mean} equals −60.9 dB. The vertical dimension (height) of the school presents an mean of 10.7 m ($\sigma = 9.4$) this is the only dimension used for the VES descriptors. As there was no log aboard the dinghy, it was impossible to evaluate accurately its speed, which prevented from calculating the schools length. For the same sample the mean of LOS descriptors are respectively $CW_{\text{mean}} =$ 91.3 m, $CW_{\text{maxi}} = 93.9$ m, $LW_{\text{maxi}} = 12.6$ m and LW_{mean} = 6.8 m (Figure 2). We processed a non-parametric test for independent samples (sign test), which showed a good correspondence of the LW LOS measure with the height observation of the VES ($p < 0.05$); better for the maximum value of LW than for its mean.

Table II. Preliminary behavioural fish school database on the basis of MBS [2], VES [10] and LOS [8] detection, it give a worksheet of 45 parameters or descriptors of fish schools.

Descriptors	VES	MBS	LOS
Acoustics	7	4	1
Bathymetric	4	6	1
Morphological	6	9	2
Swimming speed	0	0	5

Fish school database. It permits to describe the school morphology in two and three dimensions and the school swimming behaviour (for a total of 45 parameters: Table II). The VES gives the most accurate school descriptors (Rv, number of sample, statistics on the amplitude of the sample etc.). The MBS gives a precise description of the school in three dimensions. The LOS data provides with the swimming pattern of the school. Some descriptors are redundant between the VES and the MBS such as the height or the vertical position of the school but have an interest in behavioural study. Some ancillary data can be added (temperature, salinity etc.) and other parameters which can be post-processed on the bases of the acoustic observation (VES, MBS and LOS) as their spatial structure and catchability.

In order to show the interest of this database, we calculated some tests on the swimming behaviour of school (LOS descriptor) according to the MBS and VES observation presented in the first part of this work. The "exploration speed" of a school seems to be linked to its mean acoustic density and its local mean width ($p < 0.05$). The "instantaneous speed" is correlated with the distribution characteristics of the acoustic density (skewness and kurtosis) but not with the morphometric descriptors. The height (MBS and LOS) and the length do not present any link with the swimming speed. The small pelagic fish schools seem to be unaffected by the presence of a boat adrift: the behaviour is not in relation with the distance from boat to school as shown by a Kruskal-Wallis variance analysis, only a weak effect ($p = 0.0567$) of the VES height can be suspected, although it is not confirmed by the LOS observation.

4. Discussion

The preliminary results obtained by our database show that such a combination of data could bring new perspectives in school behaviour studies. For instance, we observed that the school swimming speed increases with the density of the fish school. Another example is the analysis of school avoidance and its effect on abundance estimate. During the MBS/LOS operation we had the opportunity to observe one same single school with the three devices. We could note that the VES detected only a part of the school; such "partial avoidance" could not be measured without the MBS or LOS. Figure 1 shows the pictures obtained by the three devices; on this figure, a school observed with the LOS on starboard is detected only in part by the echosounder. This phenomenon can correspond to the density dilution [11] and we already observed it on synchronous detections by MBS/LOS and VES. It must be pointed out that all the parameters collected in the database have not the same values and meanings. From the small set of data we studied, we can extract a series of remarks. Surprisingly, the LW dimension corresponds to the height of the school: this is confirmed by the MBS and VES data. The choice of the mean or maximal value for the LW dimension can be dependent on the swimming speed of the school. For the operation 1 (LOS/MBS) the height fits better to the mean and for the operation 2 (LOS/VES) to its maximal value (better than for the LW_{mean}). For the two operations the height is similar (9.57 m and 10.7). We can formulate the assumption that the best value depends on the record mode: boat in movement (operation MBS/LOS) or adrift (operation VES/LOS). But more work and data are needed in order to conclude on that point. Some other data are potentially interesting, such as the "LOS Target strength" (in relative units). We also can make some assumptions on the school shape and calculate its surface with CW and LW dimension [12] on the basis of the MBS observation. The Operation VES/LOS can be repeated with an adequate GPS in order to recognise each fish school specifically on the two devices. Evidently the data recorded by the VES (e.g. *Simrad EK500*) of the research vessel during an acoustics survey can be input, although the effect of fish school avoidance can bias the result [13]. The avoidance of the fish schools is the major problem in fisheries acoustics. The fish school, which are detected by the echo sounder of the survey vessel, are morphologically and energetically different from the others detected by an analogous device on a small embarkation [13]. The best way is to calibrate all the devices on a same target but the choice of a satisfactory "reference target" still needs additional research, and with respect to the historical data this kind of calibration cannot be applied *a posteriori*. Finally, although it is not the main objective of this paper, some biological and behavioural results can be discussed. The dimension along the boat is always the largest dimension in the MBS descriptors: it seems to be an effect of boat avoidance. This is in agreement with other results from different authors, e.g. the observations from Coetzee *et al.* [13] using two VES, the former on a research vessel and the latter on a little craft, on a same transect. Nevertheless their hypothesis of an increase of swimming speed is not confirmed by our data. From this observation we can postulate a change in school morphology at very close range of the vessel, only in the horizontal plane as observed by Coetzee *et al.* [13]. This assumption can be tested through the exhaustive processing of the complete database. The distance to the boat (adrift) does not seem to affect the swimming speed of the school; therefore we can assume that the presence of boat adrift may not affect the dynamic behaviour of a fish school. This observations if confirmed would allow one to study the schools in their natural environment without the influence of low frequencies usually generated by a research vessel in cruise. Some other types of research on school behaviour can be performed using the fish school database presented here but would require special experiments such as VES/LOS recordings, or buoy observations [14, 15] which permit to have information on fish school at different distances of the vessel, i.e. suffering different degrees of vessel influence. The vessel induces an avoidance reaction of a category of fish school, which will not be recorded on the VES and so bias the sample in the area with multispecific aggregative species.

5. Conclusion

The variables of the MBS and the VES are calibrated using specific methods. The LOS which is a fisheries device can be standardized using the two others devices. The accuracy of the *LW* LOS descriptors allows using it for categorizing the fish school. A preliminary fish school database can be built with the three devices for a better knowledge of the fish school behaviour and morphology at meso scale. The avoidance reaction can be studied more deeply by the use of such database. It can help the fishery managers to improve their models and concepts with actual exhaustive field observations in the case of trawl sampling or acoustics surveys. The preliminary database can also be helpful for the acoustic identification of species, which represents one of the main research topics in fisheries acoustics. The next step is the development of our software (*Sbiviewer* and *Infobancs*) toward the automation of picture and/or signal analysis of multibeam sonar data. The progress in archiving sonar data leads us to record sonar data continuously during acoustic fisheries surveys for producing a real time *in situ* fish school observation at meso scale.

References

[1] K. G. Foote: Fish target strength for use in echo integrator surveys. J. Acoust. Soc. Am. **82** (1987) 981–987.

[2] F. Gerlotto, C. Hammitouch, E. J. Simmonds, S. Georgakrakos, P. Fernandes: Analyse et visualisation tri-dimensionelle des images sonar. Final report,. Fair CT 96 1717, 2001, 1–228.

[3] P. Brehmer, F. Gerlotto: Method for a standardization of omnidirectional sonar in fisheries: calibration and sampling data. 3rdEAA International Symposium on Hydroacoustics, Jurata, 2001, 27–30.

[4] S. M. Jacobsen: Seabat 6012 data acquisition system Sbirecorder, user manual version 1.12. Reson, Denmark, 1999, 1–30.

[5] Anonymous: Operator manual simrad sr 240 sonar. p2291e software version 5.0x.mar. Horten, Kronsberg, 1992, 0.1–3.10.

[6] Biosonics: Dt series, hardware & software biosonics inc., manual v 4.09. Biosonics, Seattle, 1997.

[7] L. Berger, C. Durand, C. Marchalot: Movies+ user manual version 3.3. Ifremer, Brest, 2001, 1–74.

[8] P. Brehmer, F. Gerlotto: Concept and preliminary analysis on omnidirectional sonar data. Proceedings of the 5th European Conference on Underwater Acoustics, Lyon, 2000, 1427–1432.

[9] O. A. Misund: Swimming behaviour of schools related to fish capture and acoustic abundance estimation. University of Bergen, Bergen, 1991, 1–132.

[10] C. Scalabrin: Identification acoustique des espèces pélagiques à partir d'attributs discriminants des bancs de poissons mono spécifiques. UBO, Brest, 1997, 1–223.

[11] E. Ona, R. Korneliussen: Herring vessel avoidance; diving or density draining. Proceedings of the 5th European Conference on Underwater Acoustics, Lyon, 2000, 1515–1520.

[12] O. A. Misund, A. Aglen, E. Fronaes: Mapping the shape, size, and density of fish schools by echo integration and a high-resolution sonar. ICES J. mar. Sci. **52** (1995) 11–20.

[13] J. Coetzee, O. A. Misund, D. Boyer: Survey vessel avoidance reaction of Sardinella off Angola. ICES-CM-2000/K:10, Bruges, 2000.

[14] K. Olsen, J. Angell, A. Lovik: Quantitative estimations of the influence of fish behaviour on acoustic estimates of fish abundance. FAO Fish Report **300** (1983) 139–149.

[15] C. D. Wilson: Buoy measurement of underwater radiated vessel noise to explain variation in possible fish avoidance reactions. ICES/ Fast W.G. session C, Seattle, 2001.