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In situ inter-standardization of acoustics data: an integrated data base for fish school behaviour studies

P. Brehmer[a], A. Rouault[b], and F. Gerlotto[c]

[1] *IRD/HEA, Centre de recherche halieutique méditerranéenne et tropicale, BP 171, 34203, Sète, France, brehmer@ird.fr*
[2] *UBO/IUEM Université de Bretagne Occidentale, Plouzané, Brest, France, arouault@ifremer.fr*
[3] *IRD c/o. IFOP, Huito, 374, Valparaiso, 5a Region, Chili, tel : +32 25 57 41, fgerlotto@ifop.cl*

Summary

We present a method that permits to inter standardize three sources of acoustic data delivered by several different acoustics devices in order to monitor the behaviour of pelagic fish schools. We use 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. 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. We record the same schools using the portable echo sounder and the omnidirectional sonar; then we do the same experiment with the lateral sonar and the omnidirectional one. 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 we measure the depth, size, two and three dimension morphology, acoustic characteristics and the swimming behaviour characteristics (swimming speed and pattern). The potential output of such database for fisheries research is discussed through preliminary results.

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 give a precise acoustic information, the MBS provides with the morphology in three dimensions and the LOS the displacement according to the transducer location. Apart the acoustic calibration procedure, which is well documented for the echosounder (Foote, 1987); has been described recently for a MBS (Gerlotto et al., 1999) and is under construction for a LOS (Brehmer and Gerlotto, 2001), there is a 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 instruments presents a set of characteristics. The LOS presents a long range (low frequency) and low accuracy due to its long pulse duration (8ms at a range of 800m) and its large beam width (11.5°around the -3dB point). The variation of the school position inside the beams, mobile target, induce a great variability of the LOS school size. 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 observations and measurements on a series of schools in the tropical Atlantic Ocean.

2. Material

The data have been collected during an IRD program (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 (fig. 1). The data from each instrument are processed using specific software.

Table I: characteristics of the acoustic devices: "MBS" multi-beam sonar, *Reson Seabat 6012*, "LOS" long range omnidirectional, sonar *Simrad SR240* (Simrad, 1992) and "VES" vertical echosounder, *Biosonics DT5000* (Biosonics, 1997).

Specification	**Reson 6012 (MBS)**	***Simrad* SR240 (LOS)**	***Biosonics* DT5000 (VES)**
Ping rate (ms)	0.06	8	0.6
Range (meter)	100	800	-
Frequencies (kHz)	455	23.75	129
Number of beams	60	32	1 (split)
Beam width (degree)	1.5*17	12*11.5±0.5	11
Plan of observation	Lateral 90° starboard	Omni. 360°	Vertical
Software for data process	Sbiviewer 5.01	Infobancs 2.0	Visual analyser 4.02

In total, 211 couples of data were recorded, i.e. 160 for the LOS-MBS couple and 51 for the LOS-VES one.

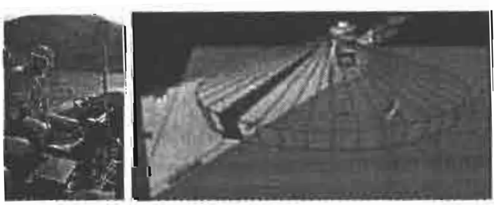

Figure 1: sampling volume of each device, in pink the VES, in grey the LOS and in white the MBS. On the left photo the dinghy where the VES was mounted

3. Methods

For obvious reasons is very difficult to observe simultaneously on the three devices the same school, but in any situation a school is observed by the LOS, which can be used as reference. The LOS give two kind 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 (Misund, 1991). "c" is the celerity of the sound in water (m/s) and τ (ms) the pulse length. LOS versus MBS:

The two sonar (MBS and LOS) are mounted aboard the research vessel, the MBS is on starboard with a range of 100m. All the school, which pass in the lateral sonar range, are digitized (Gerlotto et al., 1999) by a specific interface unit, which record data allowing to reconstruct the school in three dimensions (fig. 2) and to extract its elementary descriptors (length, width and height etc...). The schools are easily identifiable on the LOS recordings (fig. 2) and their descriptors are extracted with *Infobancs 2.0* (Brehmer & Gerlotto, 2000).

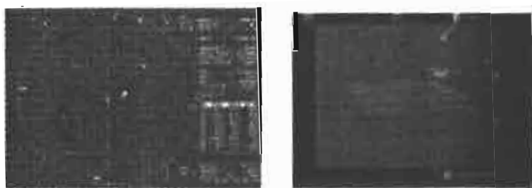

Figure 2: LOS picture in the centre the boat (diameter: 800m) on starboard a school detected on the MBS (range 100m); on the right the picture of the three dimensional morphology of the same school.

oLOS versus VES:

The vertical echosounder is installed aboard a little craft and directed on the fish school, detected on the LOS display, the vessel adrift. The dinghy is equipped with a radar reflector and followed by an operator. The VES is equipped of a GPS in order to rebuilt its road (fig. 3). It is directed towards the school by the operator aboard the main vessel.

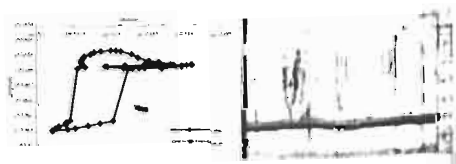

Figure 3: road of the dinghy around the LOS referred to the research vessel. On the right echogram obtained by the VES.

In theory this methodology permits to obtain on a single school its swimming speed characteristics and its VES descriptors (Scalabrin, 1997). This is not always possible for different reasons, and it is very difficult to identify accurately the school observed on the LOS as one school observed on the echogram (fig. 3). On the other hand, we can rather easily obtain a set of data belonging to a same small population of schools (cluster).

4. 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 analysis made possible by this data base.

o LOS/MBS operation.

The first task is to test the effect of the visual extraction of the parameters. This was done for the MBS by comparing the results obtained on a single data base by 3 series of measurements: 2 visual extractions (1 and 2) and an automatic extraction using *SBIViewer 5.01*. A Principal Component Analysis was calculated on these data. It shows that the lengths (1 to 3) are similar, but the width and the height are not (fig. 4). 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 (fig. 5) show the length (MBS dimension along the boat) be the largest measure with the highest variation (average: 34.6m/σ: standard deviation 25.33).

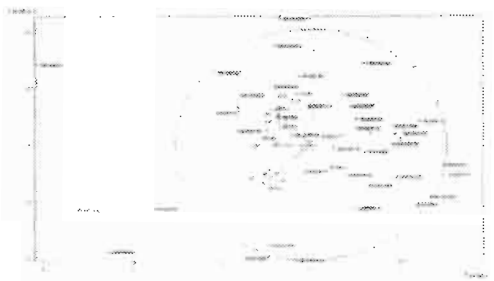

Figure 4: PCA made on MBS data (see text). The most homogeneous measure have been obtained by the software *Sbiviewer 5.01*

The width of the school (average: 15.2m/σ = 10.1) is higher than its height (average: 9.6m/σ = 6.7) on the MBS data. For the same sample the morphological LOS descriptors give an average of 12.4m and 18.6m respectively for the $LW_{average}$ and the LW_{maxi}. These two descriptors have approximately the same standard deviation (6.3 and 6.7) than the height obtained by the MBS.

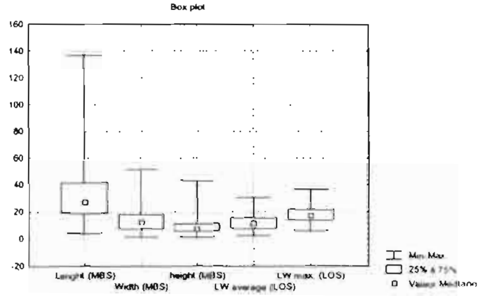

Figure 5: Box plot in meters (median value, minimum maximum and second and third quartile) for each morphological descriptor obtained on the same school (n=102) for the MBS and the LOS detection.

Table II and II': sample comparison of basic morphological descriptors (MBS/LOS). The MBS width seems to correspond to the $LW_{average}$. The "Sign test" gives the same results.

MBS/LOS (version 2)	n	Percent	Z	p-level
Length & $LW_{average}$	102	16.67	6.63	0.000
Length & $LW_{maxi.}$	102	27.45	4.46	0.000
Width & $LW_{average}$	102	41.18	1.68	0.092
Width & $LW_{maxi.}$	102	70.59	4.06	0.000
Height & $LW_{average}$	102	68.63	3.66	0.000
Height & $LW_{maxi.}$	102	87.25	7.43	0.000

MBS/LOS (version 3)	n	Percent	Z	p-level
Length & $LW_{average}$	58	36.207	1.97	0.049
Length & $LW_{maxi.}$	58	24.138	3.81	0.000
Length & $CW_{average}$	58	70.690	3.02	0.003
Length & $CW_{maxi.}$	58	70.690	3.02	0.003
Width & $LW_{maxi.}$	58	75.862	3.81	0.000
Width & $LW_{average}$	58	53.448	0.39	0.694
Width & $CW_{average}$	58	93.103	6.43	0.00(
Width & $CW_{maxi.}$	58	93.103	6.43	0.00(
Height & $LW_{average}$	58	93.103	6.43	0.00(
Height & LW_{maxi}	58	77.586	4.07	0.00(
Height & $CW_{average}$	58	98.276	7.22	0.00(
Height & $CW_{maxi.}$	58	98.276	7.22	0.00(

We tested the descriptors extracted by *Sbiviewe* *5.01* and *Infobancs 2.0* (Table II and II': sampl comparison of independent variables). The Table I is made with a new version of *Infobancs* (version 3 which takes into account the CW dimension of new schools; the result for the LW variable are similar. The MBS width corresponds to the $LW_{average}$ but the length and the height do not have relation with the LOS descriptors (LW and CW). As expected the CW dimension do not correspond directly to a morphological fish school feature.

o LOS/VES operation.

The data obtained from three operations lead 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 265m form the boat (maxi.: 455m/mini.: 62m), and their $Sv_{average}$ equals -60.9 dB. The vertical dimension (height) of the school presents an average of 10.7m (sd = 9.4) This is the only dimension used for the VES descriptors (the dinghy ,having no speedometer, it was impossible to evaluate accurately its speed, which prevented to calculate the school length). For the same sample the LOS descriptors are 91.3m, 93.9m, 12.6m and 6.8m respectively for the average of $CW_{maxi.}$, $CW_{average}$, $LW_{maxi.}$ and $LW_{average}$ (fig. 6). We processed a non parametric test for independent sample which show a good correspondence of the LW LOS measure with the height observation of the VES; better for the maximum value of LW than for its average (respectively p=0.57 and p= 0.40) (table: III).

o The fish school database.

The fish school database (table: IV) permits to know the school morphology in two and three dimensions and the school swimming behaviour. The VES give 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.

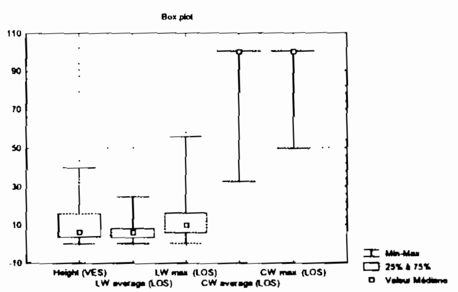

Figure 6: Box plot (in meters) for each morphological descriptor obtain on the same cluster for the VES and the LOS on 51 fish school.

Table III: comparison of the school descriptors obtains on three samples (cluster of fish school). The height of the school observed at the sounder corresponds to the LW_{maxi}.

VES/LOS; Test Sign	Nb.	v < V	Z	Level-p
$Height_{sounder}/LW_{average}$	51	43.14	0.840	0.401
$Height_{sounder}/LW_{maxi}$	51	54.90	0.560	0.575
$Height_{sounder}/CW_{average}$	51	100.00	7.001	0.000
$Height_{sounder}/CW_{maxi.}$	51	100.00	7.001	0.000

Some descriptors are redundant between the VES and the MBS like 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 others parameters which can be post-processed on the basis of the acoustic observation (VES, MBS and LOS) as their spatial structure and catchability.

Table IV: preliminary behavioural fish school data base on the basis of MBS (Gerlotto et al., 1999), VES (Scalabrin, 1997) and LOS (Brehmer et al., 2000) detection, give a worksheet of 46 parameters on fish schools.

VES	MBS	LOS
7 Acoustics descriptors 4 bathymetric 6 morphological parameters	4 Acoustics descriptors 6 bathymetric 9 morphological parameters	3 Acoustics descriptors 5 Swimming speed 2 Horizontal position (x;y;t) school and boat

In order to show the interest of this database, we made 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.

Table V: correlation between the swimming behaviour, instantaneous and exploration speed, of 102 fish schools (LOS records) and the MBS descriptors.

Correlations significant mark * at p < .05000		
n=102	Instantaneous	Exploration
Length (MBS)	-0.048	0.082
Width (MBS)	0.071	0.230*
Height (MBS)	-0.034	0.138
LW average	-0.058	-0.109
LW maxi.	-0.061	-0.111
Acoustics density (MBS)		
Mean	0.189	0.205*
Skeweness	-0.250*	-0.075
Kurtosis	-0.258*	-0.092

The "exploration speed" of a school seems to be linked to its mean acoustic density and its local average width (Table V).

Table VI: Non-parametric variance analysis on VES and LOS descriptors of 52 schools according to the distance of the boat (or transductor).

ANOVA Kruskal-	Wallis. // Var: D_{boat}
Speed explo.	H(8, N= 51) = 7.20 p = .5148
Speed Instant	H(8, N= 51) = 9.65 p = .2899
Seize (VES)	H(8, N= 51) = 15.13 p =.0567
Sv	H(8, N= 51) = 13.46 p =.0969
Depth	H(8, N= 51) = 12.76 p =.1203
LW average	H(8, N= 51) = 9.85 p = .2750
LW maxi.	H(8, N= 51) = 10.51 p =.2309
CW average	H(8, N= 51) = 6.58 p = .5818
CW maxi.	H(8, N= 51) = 6.27 p = .6161

The "instantaneous speed" is correlated with the distribution characteristics (skewness and kurtosis) of the acoustic density. The height (MBS and LOS) and the length do not present any link with the swimming speed. The small pelagic fish school seems to be unperturbed by the presence of a boat adrift: the behaviour is not in relation with the distance boat/school (Table VI), a weak effect of the VES height can be suspected, although it is not confirmed by the LOS observation.

5. Discussion

The preliminary biological results obtained by our data base show that such a combination of data can bring new perspectives in school behaviour studies. For instance, we observed that the school swimming speed increase 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 observed 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. This phenomenon can correspond to the density dilution (Ona et al., 2000) and we already observed it on synchronous detection by MBS and VES.

It must be noted that all the parameters collected in the database have not the same value and meanings. From the small set of data we studied, we can extract a series of remarks.

Surprisingly, the LW dimension corresponds the height of the school: this is confirmed by t MBS and VES data. The choice of the average maximal value for the LW dimension can dependent on the swimming speed of the scho For the operation 1 the height fit to the average a for the operation 2 to its maximal value (better th for the $LW_{average}$). For the two operations the hei is similar (9.57m and 10.7). We can formulate t assumption that the best value depends on t record mode: boat in movement (operati MBS/LOS) or adrift (operation VES/LOS). I more work and data are needed in order to conclu on that point. Some other data are potentia interesting, such as the "LOS Target strength" relative units). We also can make so assumptions on the school shape and calculate surface with CW and LW dimension (Misund et . 1995) on the basis of the MBS observation. T Operation VES/LOS can be repeated with adequate GPS in order to recognise each fish sch specifically on the two devices. Evidently the d recorded by the VES (e.g. Simrad Ek500) of research vessel during an acoustics survey can input, although the effect of fish school avoida can bias the result (Coetzee et al., 2000). T avoidance of the fish schools is the major probl in fisheries acoustics. The fish school, which detected by the echo sounder of the survey ves are different (morphologically and energetical than the others detected by an analogous device a small embarkation (Coetzee et al., 2000). The b way is to calibrate all the devices on a same tar but the choice of a satisfactory "reference targ still needs additional research , and with respec the historical data this kind of calibration cannot applied *a posteriori*.

Finally, although it is not the main objective this paper, some biological and behavioural res can be discussed. The dimension along the boa always the largest dimension in the M descriptors: it seem to be an effect of b avoidance. This is in agreement with other res from different authors, e.g. the observation fr Coetzee et al. (2000) using two VES, one o research vessel and the second on a little craft, same cluster. Nevertheless their hypothesis of increase of swimming speed is not confirmed our data. From this observation we can postula change in school morphology at very close rang the vessel, only in the horizontal plane as obser by Coetzee (2000). This assumption can be tes with the process of complete fish school data b The distance to the boat (adrift) don't affect swimming speed of the school, so we can make the assumption that the presence of boat adrift does not affect the fish school behaviour. This interesting conclusion would allow one to study the schools in their natural environment without the influence of low frequencies generated usually 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 observation (Olsen et al. 1983; Wilson, 2001) 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.

6. Conclusion

The variables of the MBS and the VES are calibrated by 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 to use 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 such database. It can help the fisheries managers to improve their models and concepts with actual exhaustive field observation in the case of trawl sampling or acoustics surveys. The preliminary database can also be helpful for the identification of species, which represent the main target of the fishing industry.

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