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CONCEPT AND PRELIMINARY ANALYSIS ON OMNIDIRECTIONAL SONAR DATA

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The behaviour of pelagic fish school has an impact on the abundance estimate (avoidance reaction) and provides valuable information on the biology and dynamics of a population. Behavioural studies require in situ observation. The omnidirectional sonar system allows tracking a target and samples a large water volume. This tool presents a number of applications. We introduce a specific methodology for sampling, digitising and processing the data through the Infobancs *software that we developed under Windows. We discuss the meaning of the data, their use in fisheries research and their reliability.*

1. INTRODUCTION

Omnidirectional sonars such as *Simrad®* SR240 (or SP270) have a spherical multi-element transducer allowing the sonar beam to be oriented in any direction. Such a tool can be used to insonify the whole water volume around the vessel at long range, to display the fish school distribution and movements in this volume and to track a single school. The transmission, reception and data processing are under *Simrad* hardware and software control (*Simrad*, 1992). We have been using SR240 in acoustic survey for studies and experiments on fish schools since 1996. During this period, we identified a number of problems, and we developed several research projects on behaviour of pelagic fish schools. Sonar data analysis requires software for postprocessing to be written. The paper presents the software *Infobancs 2.1* that is specially designed under Windows to process the omnidirectional data.

2. MATERIAL and METHODS

The multi-beam omnidirectional sonar *Simrad* SR240 is installed aboard the research vessel Antéa (IRD, Abidjan). The total receiving beam angle is 360° with 32 beams of 11.25° each and 12° in the perpendicular direction. The sonar operating frequency is 23.750 kHz. We use different pulse lengths according to the range. The TVG function (Time Varied Gain) is 30 log R, its source level (*SL*) is 217 dB/1µPa and the transmitter output power is 7000 Watt. Other settings are: transmit in mono pulse mode, continuous wave pulse form and full power, with constant frequency of transmitter pulse. Frequency modulation can be used during tracking operations. The tilt angle is defined according to the school depth distribution and the hydrological conditions. The maximum range is set at 800 to 1200 meters (depending on the velocity profile in the water column). The narrowest audio beam channel is selected. The sonar display uses 32 colours with a resolution of 512 * 680 pixels. *Infobancs* applies to the sonar analog output, which consists in *s-video* images reconstructed from 32 beams to produce a real-time observation. The sonar display is recorded on a S-VHS videotape by means of a videocard. In the laboratory, the video sequences are selected and digitised before to being inputted in *Infobancs*. A database is produced and, for each ping, a matrix is generated.

Tilt: -5
Bearing: 255
Speed: 6.1
Time (h:mm:s): 05:06:33
Id_School: Shoal 1
○ Mem ● New ○ Trail
○ Mark1 367.00 347.00
○ Mark2 440.00 406.00
○ Boat 321.00 284.00
○ School 306.00 216.00
○ Along beam dimension 133.76
TS: Yellow
Evitement: Non
Dynamique: Scission, Fusion
Ligne de foi: Sur ligne
Remarks: after yawl 4
C:\data\bc39_6.bmp
Tracking | C:\data\trak_select.txt | Picture 6/11 | Scale: 400m (=1.5319m/pixels) | Celerity: 1544.1 (m/s) | Range resolution: 3.09 (m)

Fig. 1. Infobancs 2.1 windows of data capture after a selection of sonar pictures.

The first step of any spatial analysis is to set geographical reference marks. Two are needed simultaneously on the sonar display in order to apply Euclidean calculation for the projection in orthogonal references. The second step before any analysis is to correct the size of the schools (Misund O.A., 1990):

$$LW_c = LW_a - \left(\frac{c.\tau}{2}\right) \tag{1}$$

τ : pulse duration (ms); must be inputted in Infobancs through the menu "survey parameter"
c : celerity of sound; Infobancs calculates it according to local temperature, depth and salinity
LW: along wise beam dimension; LW_a for apparent, LW_c for corrected

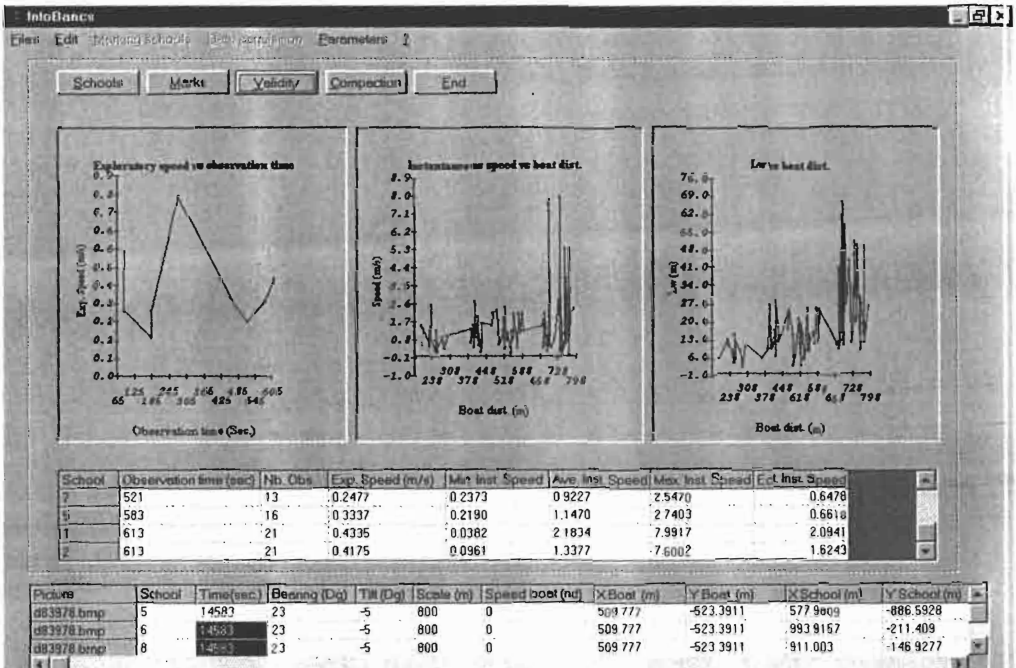
The school surface is calculated automatically during the data acquisition in *Infobancs 2.1*, assuming that schools are spherical. The school depth is obtained considering the beam tilt angle (θ) and the distance to the boat. Unnecessary pictures are discarded using the "selection of pictures" function that permits the classification of the selected pictures in an "*Infobancsworks*" file. The recognition and following of a single school requires a specific procedure: with the menu "marking of school" an alphanumeric mark is positioned with the cursor close to each echo in order to follow the evolution of the school. Once the selection and marking are performed, the echo parameters are recorded. There exist two modes of data capture : *Tracking* or *Drift*. A worksheet in ASCII format is created and constitutes the basis of all analysis made by *Infobancs*. It is exportable towards other applications via the clipboard. It consists of 23 columns: picture reference, school code, vessel bearing, sonar range, vessel speed, vessel coordinate (X_{boat}; Y_{boat}), school coordinate (X_{school}; Y_{school}), target strength (weak, medium, strong), along wise beam dimension corrected by formulas (1), school surface, avoidance reaction (no data: 0, yes: 1, no: 2), dynamic (stable: 0, fusion: 1, scission: 2), school on vessel heading (not recorded: 0, yes: 1, no: 2), remark, reference mark code, angle reference (between two reference marks).

3. RESULTS

The acoustic validity of the data is scrutinised using the "validity" menu of the software. We presented the results on worksheets and graphics (fig. 2) obtain in February 1998 in west Venezuela on Sardinella aurita. Two modes of analysis are available. *By school*: the analysis is performed on a single school, or by *reference mark*: the analysis associates all the schools present in the same sequence (a sequence is a duration where the same reference marks are used). *Infobancs 2.1* provides several types of results that characterise the fish school behaviour: dynamic (swimming pattern) and spatial structuring (abundance, 2D spatial point process), also on the size of school fish. The analysis offers different graphic exit possibilities, as well as a worksheet where one recovers all parameters seizures. After the first processing, the instantaneous speeds of school between each observation with its elementary statistics, the speed of exploration for every school and the distance of the school to the boat are determined. In the *school* mode analysis, you have to choose the code of a school to see three graphics on the swimming behaviour. The first shows the target displacement in the reference marks, the boat is fixed in the origin of the reference marks. The second, called *relative position,* shows the displacement of the boat and the school within the reference marks. The last shows the instantaneous speed of the school in function of the distance of the school to the vessel. In *reference mark* mode analysis, you can see the global displacement of all the schools in the same area (same reference marks). *Drifts*, boat stopped, permit to observe the natural dynamic behaviour of the schools (Gerlotto F. and *al.*, 1998) their variation of the abundance and the change of spatial structuring of clusters of fish schools. In *drift* mode one can use *Compaction* menu to obtain the number of observations on sonar, an average density of the cluster, its moment of inertia and the density of schools by tore (Brehmer P., 1997). All these results are shown in a specific worksheet. The moment of inertia gives us a global characteristic on the state of compaction "I_c" of the cluster. This I_c indication can therefore be considered as a complementary descriptor of the spatial structuring of pelagic fish schools. It permits us to have a notion by default of the degrees of "compaction" of a cluster. Due to proportionality, we will calculate the frequencies of density by classes of distances to the R/V, in number of schools by unit of surface (Km^2), and by tore, noted N/m^2/t. The principle is to calculate the surface of the rings having for radius boundary-marks of intervals of the « n » chosen classes.

Density by Tore = $N/\ Tore_n$ (2)
N: number of schools;
$\prod R_n^2$: surface of radius equals to sonar range
$Tore_n = \prod R_n^2 - \prod R_{n-1}^2$ (where, R_n radius $\in \left]0; Range\right]$ with steps of 100m)

From these calculations, one may construct histograms of distribution of the school density by Km² and by tore. At the time of the interpretation of these results, some torus can be denser than others because of the depth of schools and not due to an acoustic bias. The global displacement of all the schools observed on one same reference mark is obtained by vectorial addition. One defines every unit vector from the exploration speeds of every school. Then, one adds all the vectors observed in the same reference mark by calculating its components to obtain their resultant vector (Hafsteinsson M.T. and *al.*, 1995). The results are displayed in a graph where all vectors originate from the origin of a new reference mark, as well as the resultant of the whole of these vectors. The position of the north is recovered by the mediator of the bearing, which was previously captured in the worksheet of data.



School	Observation time (sec)	Nb. Obs	Exp. Speed (m/s)	Min Inst. Speed	Ave. Inst. Speed	Max Inst. Speed	Ect. Inst. Speed
7	521	13	0.2477	0.2373	0.9227	2.5470	0.6478
5	583	16	0.3337	0.2190	1.1470	2.7403	0.6618
11	613	21	0.4335	0.0382	2.1834	7.9917	2.0941
2	613	21	0.4175	0.0961	1.3377	7.6002	1.6243

Picture	School	Time(sec)	Bearing (Dg)	Tilt (Dg)	Scale (m)	Speed boat (nd)	X Boat (m)	Y Boat (m)	X School (m)	Y School (m)
d83978.bmp	5	14583	23	-5	800	0	509 777	-523.3911	577 9809	-886.5928
d83978.bmp	6	14583	23	-5	800	0	509 777	-523.3911	993 9157	-211.409
d83978.bmp	8	14583	23	-5	800	0	509 777	-523 3911	911.003	-146 9277

Dolt | C:\data\trak_select.txt | Picture 6/11 | Scale: 400m (=1.5319m/pixels) | Celerity: 1544.1 (m/s) | Range resolution: 3.09 (m)

Fig. 2. graphics of Infobancs 2.1 menu acoustic validity (data: Sardinella aurita, west Venezuela February 1998), behind its dynamics and data worksheet. The results show the limit of data validity here: 658m to the boat for the (LW) along beam dimension and the validity of instantaneous speed observed.

When you have a complete worksheet data, you must look at three specific graphics to control the dependability of your data. It is important to know if the school exploratory speed is dependent of the ping number (observation time), or if the instantaneous speed is linked to the distance of the vessel (fig. 2). The interpretation of the graphics needs some attention, be careful do not confuse biologic and acoustic hypothesis when you do the statistical analysis of the school's swimming speed behaviour. This graphic (fig. 2) gives the correction that will apply to each kind of sonar. The beam width and the celerity profile usually define the useful data limit, in agreement with local behavioural hypotheses. The third graph represents the evolution of the dimension "along wise" (*Lw*), according to the distance to the boat. It permits to control the validity of the TVG function to the selected range. Graphically it is simple to note the distance apart from the mean, generally in the torus superior or lower of detection. In own example in west Venezuela the limit is 658m (fig. 2). One can use the density by tore to know the efficient range of the sonar, but one must use this result with care. Before an interpretation, do not confuse the behaviour of schools fish (dynamic and spatial structuring) with an acoustic hypothesis.

4. DISCUSION – CONCLUSION

It is clear that this type of sonar is not in its conception similar to a «scientific» one, it needs a direct access to acoustic data to be a scientific acoustic device and a diminution of the audio beam channel for increase the data validity. However, it permits an observation *in situ* of pelagic environments, allowing observations on long distances and on large zones (several Km^2), which permit behaviour studies on many schools all around the vessel. It is very useful for the observations of relative movements of vessel and schools (Diner N., Masse J., 87). These details confer the sonar 's possibility to offer a precise and complete study of the behaviour of pelagic fish school stocks at different moments of their life cycle. Omnidirectional data permits several topics of study in fisheries research as the behaviour of pelagic schools in natural condition (fusion ~ separation, avoidance reaction, diel variation...), or under constraint (of a ship prospecting, fishing devices,...). The omnidirectional sonar is particularly adapted to study the dynamics behaviour of schools (Swimming speed, migration and global displacement,...). The spatial structuring of the large cluster of schools can be treated via the *Spatial point processes 2D* (Petitgas P., 1996) with the *Infobancs* data. The understanding of the school behaviour facing the ship permits to avoid serious mistakes of echogram interpretations and permit a finer analysis of the Target Strength. We can discriminate schools that avoid the trawl, but not the basis of the sounder and *vice versa* during a trawl identification in order to harvest fish *TS* (McLennan D.N. and *al.*, 1992); on the same way this kind of sonar data can help in the interpretation of some special echotrace on echogram (McLennan D.N. and *al.*, 1992) by comparative method of the echo parameters on acoustic devices. One can use omnidirectional data as an information complementary to a lateral sonar (to know the swimming speed of the school). The analysis of data harvested during an acoustic survey permits to correct the indication of biomass obtained by echointegration (Fréon P. and *al.*, 1993), while quantifying the global horizontal avoidance of schools (Misund O.A., 1993). It is possible to use omnidirectional data in order to do an abundance estimation (Smith P.E., 1970) or a sonar mapping of schools distribution. This type of data offers a supplementary and complementary information to fishery surveys in general and acoustics in particular. The limitation of its use it due to the necessity of an experienced sonar operator (Diner N., 1995). Different operations of the behaviour studies of pelagic fish schools (Masse J., 1985-86; Goncharov S.M. and *al.*, 1989; Misund O.A., 1990; Hafsteinsson M.T. and *al*, 1995) have been successfully led with omnidirectional sonar. Developing new methods for the behavioural study of fish, which yields the most important sources of bias in fishery acoustics (Fréon P. and *al.*, 1999), is an important step in acquiring a new knowledge of fish behavioural effects on fisheries surveys.

5. ACKNOWLEDGEMENTS

Special thanks to T. Lafont own devoted “great visual” programmer. O.A. Misund (University of Bergen, Norway) for their help during the elaboration of *Infobancs 2.1*.

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Data acquisition
Tilt: -5
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Speed: 6 1
Time (h:mm:s): 05:06 33
Id_School: Shoal 1
Positions (pixels)
● New
○ Mark1 367 00 347 00
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○ Boat 321 00 284 00
○ School 306 00 216 00
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TS: Yellow
Evitement: Non
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Ligne de foi: Sur ligne
Remarks: after trawl 4

C:\data\bc39_6.bmp

Tracking | C:\data\trak_select.txt | Picture 6/11 | Scale: 400m (=1 5319m/pixels) | Celerity: 1544 1 (m/s) | Range resolution 3 09 (m)

Fig.1: Infobancs 2.1 windows of data capture after a selection of sonar pictures.

The first step of any spatial analysis is to set geographical reference marks. Two are needed simultaneously on the sonar display in order to apply *Euclidean* calculation for the projection in orthogonal references. The second step before any analysis is to correct the size of the schools (Misund O.A., 1990) :

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3. RESULTS

The acoustic validity of the data is scrutinised using the "validity" menu of the software. We presented the results on worksheets and graphics (fig. 2) obtain in feburary 1998 in west Venezuela on Sardinella aurita. Two modes of analysis are available. *By school*: the analysis is performed on a single school, or by *reference mark*: the analysis associates all the schools present in the same sequence (a sequence is a duration where the same reference marks are used). *Infobancs 2.1* provides several types of results that characterize the fish school behaviour: dynamic (swimming pattern) and spatial structuring (abundance, 2D spatial point process), also on the size of school fish. The analysis offers different graphic exit possibilities, as well as a worksheet where one recovers all parameters seizures. After the first processing the instantaneous speeds of school between each observation with its elementary statistics, the speed of exploration for every school and the distance of the school to the boat are determined. In the *school* mode analysis you have to choose the code of a school to see three graphics on the swimming behaviour. The first shows the target displacement in the reference marks, the boat is fixed in the origin of the reference marks. The second, called *relative position,* shows the displacement of the boat and the school within the reference marks. The last shows the instantaneous speed of the school in function of the distance of the school to the vessel. In *reference mark* mode analysis, you can see the global displacement of all the schools in a same area (same reference marks). *Drifts*, boat stopped, permit to observe the natural dynamic behaviour of the schools (Gerlotto F. and *al.*, 1998) their variation of the abundance and the change of spatial structuring of clusters of fish schools. In *drift* mode one can use *Compaction* menu to obtain the number of observations on sonar, an average density of the cluster, its moment of inertia and the density of schools by tore (Brehmer P., 1997). All these results are shown in a specific worksheet. The moment of inertia gives us a global characteristic on the state of compaction «I_c» of the cluster. This I_c indication can therefore be considered as a complementary descriptor of the spatial structuring of pelagic fish schools. It permits us to have a notion by default of the degrees of « compaction » of a cluster. Due to proportionality, we will calculate the frequencies of density by classes of distances to the R/V, in number of schools by unit of surface (Km²), and by tore, noted N/m²/t. The principle is to calculate the surface of the rings having for radius boundary-marks of intervals of the « n » chosen classes.

$$\text{Density by Tore} = N \,/\, Tore_n \qquad (2)$$

N: number of schools;

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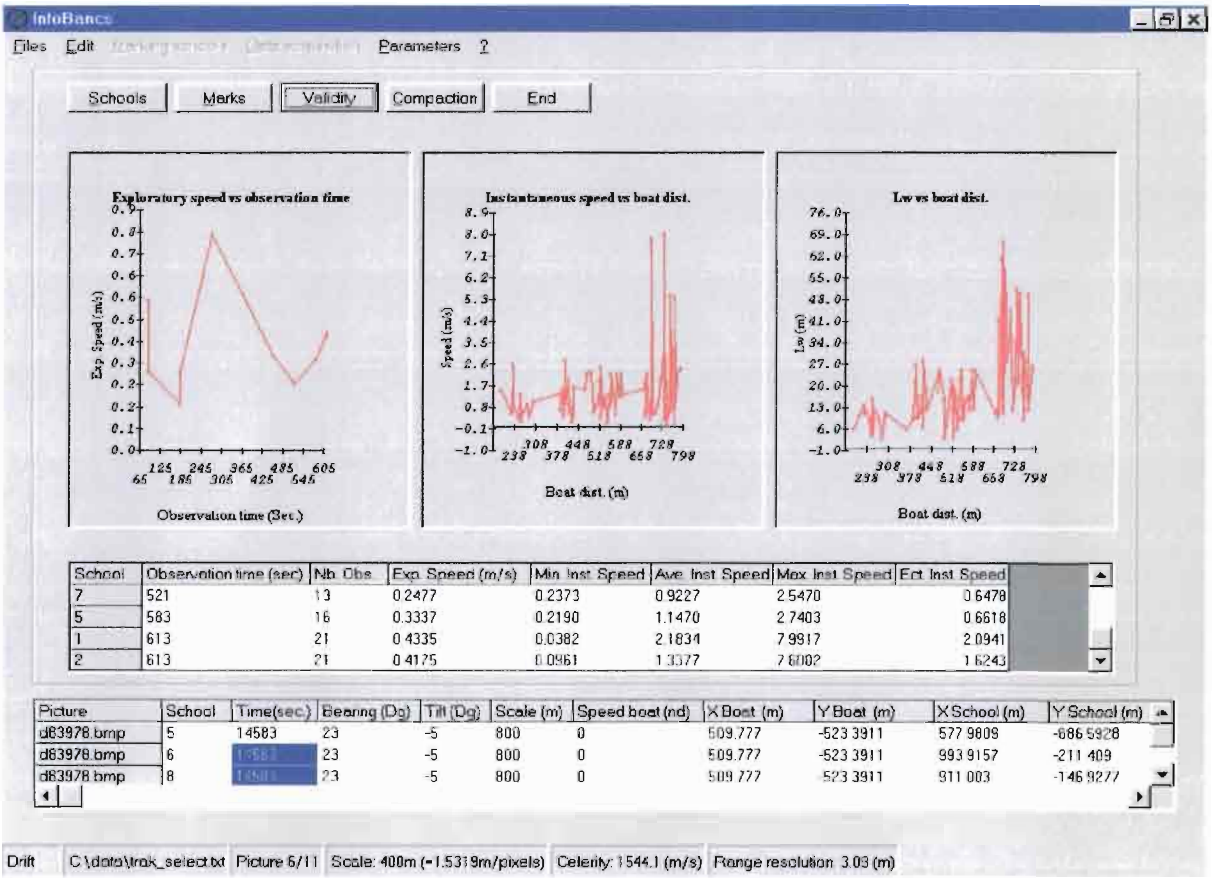

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When you have a complete worksheet data, you must look at three specific graphics to control the dependability of your data. It is important to know if the school exploratory speed is dependent of the ping number (observation time), or if the instantaneous speed is linked to the distance of the vessel (fig.:2). The interpretation of the graphics needs some attention, be careful do not confuse biologic and acoustic hypothesis when you do the statistical analysis of the school's swimming speed behaviour. This graphic (fig. 2) gives the correction that will apply to each kind of sonar. The beam width and the celerity profil usually define the useful data limit, in agreement with local behavioural hypotheses. The third graph represents the evolution of the dimension "along wise" (*Lw*), according to the distance to the boat. It permits to control the validity of the TVG function to the selected range. Graphically it is simple to note the distance apart from the mean, generally in the torus superior or lower of detection. In own example in west Venezuela the limit is 658m (fig.:2). One can use the density by tore to know the efficient range of the sonar, but one must use this result with care. Before an interpretation, do not confuse the behaviour of schools fish (dynamic and spatial structuring) with an acoustic hypothesis.

4. DISCUSION – CONCLUSION

It is clear that this type of sonar is not in its conception similar to a «scientific» one, it needs a direct access to acoustic data to be a scientific acoustic device and a diminution of the audio beam channel for increase the data validity. However, it permits an observation ***in situ*** of pelagic environments, allowing observations on long distances and on large zones (several Km^2), which permit behaviour studies on many schools all around the vessel. It is very useful for the observations of relative movements of vessel and schools (Diner N., Masse J., 87). These details confer the sonar 's possibility to offer a precise and complete study of the behaviour of pelagic fish school stocks at different moments of their life cycle. Omnidirectional data permits several topics of study in fisheries research as the behaviour of pelagic schools in natural condition (fusion ~ separation, avoidance reaction, diel variation...), or under constraint (of a ship prospecting, fishing devices,...). The omnidirectional sonar is particularly adapted to study the dynamics behaviour of schools (Swimming speed, migration and global displacement,...). The spatial structuring of the large cluster of schools can be treated via the *Spatial point processes 2D* (Petitgas P., 1996) with the *Infobancs* data. The understanding of the school behaviour facing the ship permits to avoid serious mistakes of echogram interpretations and permit a finer analysis of the Target Strength. We can discriminate schools that avoid the trawl, but not the basis of the sounder and *vice versa* during a trawl identification in order to harvest fish *TS* (McLennan D.N. and *al.*, 1992); on the same way this kind of sonar data can help in the interpretation of some special echotrace on echogram (McLennan D.N. and *al.*, 1992) by comparative method of the echo parameters on acoustic devices. One can use omnidirectional data as an information complementary to a lateral sonar (to know the swimming speed of the school). The analysis of data harvested during an acoustic survey permits to correct the indication of biomass obtained by echointegration (Fréon P. and *al.*, 1993), while quantifying the global horizontal avoidance of schools (Misund O.A., 1993). It is possible to use omnidirectional data in order to do an abundance estimation (Simth P.E., 1970) or a sonar mapping of schools distribution. This type of data offers a supplementary and complementary information to fishery surveys in general and acoustics in particular. The limitation of its use it due to the necessity of an experienced sonar operator (Diner N., 1995). Different operations of the behaviour studies of pelagic fish schools (Masse J., 1985-86; Goncharov S.M. and *al.*, 1989; Misund O.A., 1990; Hafsteinsson M.T. and *al*, 1995) have been successfully led with omnidirectional sonar. Developing new methods for the behavioural study of fish, which yields the most important sources of bias in fishery acoustics (Fréon P. and *al.*, 1999), is an important step in acquiring a new knowledge of fish behavioural effects on fisheries surveys.

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