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"Incorporation of external factors in marine resource surveys"

Measuring fish school avoidance during acoustic surveys.

by
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Abstract:

Evidence of different avoidance patterns for a pelagic species (*Sardinella aurita*) is given by comparing data on three different stocks in the tropical Atlantic (Venezuela, Senegal and Ivory Coast). The effect of these differences is that no simple correction can be input in abundance estimates by acoustic surveys. We propose to measure in situ and continuously the avoidance characteristics of pelagic fish schools in order to correct the biomass estimates. The fish schools are observed using adapted acoustic devices. We use a high resolution (455 KHz) multi-beam sonar in a vertical plane, and a long range (24 KHz) omnidirectional sonar in the horizontal one. The bias is calculated from the avoidance speed and the average position of the schools at several distances and depths from the vessel. The main patterns of fish avoidance are explored by comparing the data on the same species (*Sardinella aurita*) in three different areas. Results show that avoidance reactions present significant differences between areas and that a single species may present different avoidance strategies (variations of swimming speed and direction).

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Introduction

Fish avoidance is known as a major source of biases and errors in acoustic stock assessment, as well as in most of the fisheries research methods (ICES/FAST, Report, 1998, 1999, 2000). Many works on avoidance reaction have already been done since the first observation with acoustic devices (Olsen *et al.*, 1979; Mitson, 1983). The observation usually documents the vertical reaction (Gerlotto *et al.*, 1992) or the lateral one (Aglen, 1985; Diner *et al.*., 1987; Goncharov *et al.,* 1989; Misund *et al.*, 1991). Nevertheless very few works have been done simultaneously on the two types of reactions, as this requires specific methods. Avoidance occurs in three dimensions and can start at long distance of the vessel (>100m). The avoidance is biasing the abundance estimates based on acoustic surveys, on trawling surveys (Misund et al. 1991), and it affects the results of the vertical distribution (Scalabrin et al., 1993; Gerlotto, 1992) as well as the acoustic density (Olsen *et al.*., 1983, Freon et al. 1993) of pelagic fish schools measured on echograms. The effect of school avoidance is very important on the vertical echo sounder data for two reasons: first it has an effect on the number of schools (lateral avoidance), then on the school structure and shape as well as on the school position in the water column, and the school biomass (shadow effect, tilt angle, etc...). The second reason is that as a vertical echo sounder does not give any information outside the vertical beam, it is impossible to see whether the avoidance has existed or not (no comparison with the actual school density and positions). The way to measure the effect of avoidance on these acoustic data is to deploy simultaneously the two sonars. The general synthesis of the avoidance studies does not give any simple answer to the question "*how much is the abundance estimate affected by fish behaviour*?". This is certainly due to the high plasticity of avoidance behaviour, which depends upon a wide set of factors, such as environmental, biological, hydrological, physical, etc. Therefore it is still impossible to provide the scientific community with a general model allowing to correct the results, and it is unlikely that such a model can be delivered in a next future. Another way to answer this question is to make routine *in situ* measurements of the avoidance level, which would allow to remove the bias for each single data. This requires a method of direct, *in situ* and real time avoidance measurement be achieved. This is the aim of this paper. In order to obtain this kind of information, we have to select proper instruments.

Obviously they are acoustic devices. Many fishing vessels own acoustic devices such as vertical echo sounders and omnidirectional sonars. Fisheries research vessels usually operate the same kind of tools and since recently also multibeam side scan sonars (Gerlotto *et al*, 1999). These devices allow observation of pelagic fish schools in all direction around the vessel, and give information on their shape and dynamics (swimming pattern: Misund, 1991; speed: Bodholdt and Olsen, 1977; morphology and characteristics: Gerlotto *et al.*, 1994).

Material

We use simultaneously three acoustic devices: a low frequency multibeam omnidirectional sonar (LOS), a high frequency multibeam side scanning sonar (MBS) and a scientific echo sounder directed vertically (VES).

Acoustic devices **Setting**	**VES** Echo-sounder *EK 500*	**MBS** *Reson Seabat 6013*	**LOS** *Simrad SR 240*
Ping sector	vertical	Vertical plan	omnidirectionel
Beam angle (Degree) Number of beam	11 (1 beam)	1.5 × 15 (60 beams)	11.25 × 11.5 (32 beams)
Tilt (Degree) from horizontal	90	90	-3° à –15° ; usualy : -5°
Range (Metres)	150	100	200 à 1200
Gain	(depending on survey)	5	9
Frequency (kHz)	120	455	23.75
TVG function	20/40 log R	20 log R	30 log R
Emission: pulse length (ms)	0.6	0.06	3 – 6 (monopulse)
Gain automatic	no	no	no
Reverberation gain control	-	-	Strong position
Ping to ping filter	-	Average 2	Strong position
Video: colour threshold/ gain	- / -	colour / -	5 / 9

Table 1 : setting of the three acoustic devices when operating for current experiment of avoidance study.
LOS low frequencies omnidirectional sonar, MBS multibeam sonar, VES vertical echo sounder.

The LOS

The multi-beam omnidirectional sonar SIMRAD SR240 is installed aboard the R/V Antéa (35m). The settings are presented in the table 1. The tilt angle is defined according to the school depth distribution and the hydrological conditions (Brehmer and Gerlotto, 1999). The maximum range is set at 800 to 1200 meters (depending on the velocity profile in the water column). - The sonar output is a video image which is digitised and processed through a home made software, *Infobancs* (Brehmer et al, 1999). A database is produced, and for each ping a matrix is generated (Brehmer and Gerlotto, 2000). Once the selection and tagging of schools are performed, the echo parameters are recorded. *Infobancs* extracts the following information: picture reference, school code, vessel bearing, sonar range, vessel speed, vessel coordinate, school coordinate, target strength (weak, medium, strong), along wise beam dimensions corrected, school surface, avoidance reaction, dynamics, schools on vessel heading, remarks, reference mark code, angle references (between two reference marks).
We apply a method adapted from Misund (1991), but the settings remain as much as possible controlled by the operator: no automatic control, constant frequency, constant pulse duration, etc. (SIMRAD, 1992). We do not record the vertical sonar information which is not clearly significant at the observation range (Misund, 1991).

vessel speed Knots	NL computed from Sa dB//10e-6 Pa	Test menu PN dB//10e-6 Pa
-1	50.6	-143.8
0	58.1	-137.4
1	57.8	-136.8
2	58.6	-135.7
3	59.8	-134.2
4	59.2	-135.2
5	57.5	-136.8
6	56.3	-137.4
7	55.2	-138.5
8	53.3	-140.5
9	52.6	-141.4
10	55.9	-138.8
11.5	69.1	-124

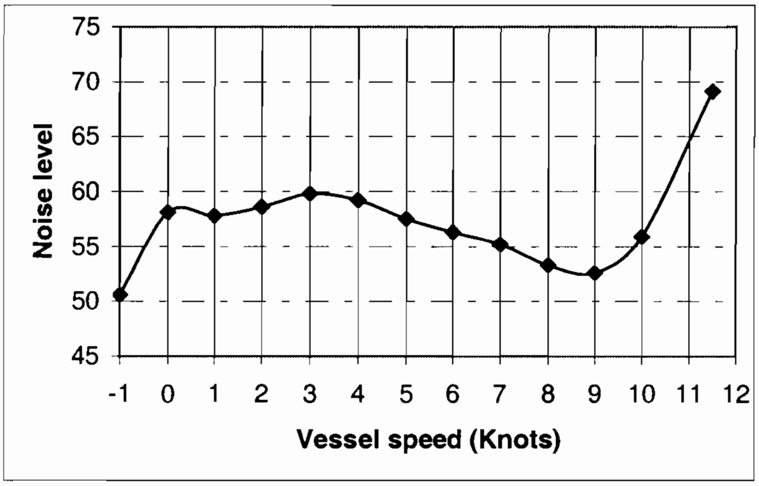


Figure 1: measure of acoustic noise generated by the R/V Antéa according to the vessel speed with a Simrad EK500 echo-sounder (Data March 1999, E. Joss, IRD Brest). On the X axis, -1 mean the clutch is off.

The MBS

It is mounted on the side of the vessel (fig. 2). The sonar we use is a SEABAT 6012 (Reson), covering a total angle of 90° with 60 beams of 1.5° each, and 15° in the perpendicular direction. The settings are presented on table 1. The sonar main plan is vertical, observing from the surface to the vertical beneath the vessel, on the side of the vessel route, which allow it to explore exhaustively that part of the water volume (fig. 2). Two sets of data are provided: video images recorded during the routine survey on videotapes (S-VHS) and digital data (Gerlotto and al., 1994). The last one is processed through a specific software, SBIViewer (Lecornu *et al.*, 1999)

The VES

The vertical echo sounder is a hull-mounted split-beam Simrad EK500 at 120 kHz (table 1), with standard settings.

The vessel speed is adjusted according to the result of the noise measurements (fig. 1). Aboard the R/V *Antea* (IRD), the speed for the survey was set at 7 knots, and varied from 3 to 7 knots depending of the type of experiment. The sonar beams must be calibrated and the correspondence between sonar headings and screen co-ordinates carefully tested (in order to prevent from misinterpretation of avoidance reaction (fig 2)). Our LOS has been calibrated in Venezuela (Mochima bay, March, 1998) with the help of the R/V *H. Gines* (Flasa). We used a drifting buoy with immersed targets on the path of the vessels and we compare the location of the buoy simultaneously on the sonar and the radar, at different angles and speeds.

Method

We define the avoidance as any dynamic reaction (vertical or/and horizontal) that changes the normal swimming speed and pattern of a school in front of a vessel, a gear, a predator or any object. The method consists in measuring the avoidance characteristics on the sonar data and eventually extracting a correction factor to be applied on the VES data. We have performed 8 surveys from 1996 to 1999 using the three acoustic devices in three countries (Senegal, Ivory Coast and Venezuela), aboard the R/V Antéa (421 GRT, 35m). Some additional data presented here come from a previous series of surveys in the Mediterranean. We use the LOS in order to know the swimming pattern and speed of the schools in a horizontal plane for quantifying the lateral avoidance (Brehmer and Gerlotto, 1999). In the same way we use the MBS as Soria and *al.* (1996) in order to complete the omnidirectional data in the knowledge of lateral avoidance, but mainly to observe the vertical avoidance, and the changes in shape and density.

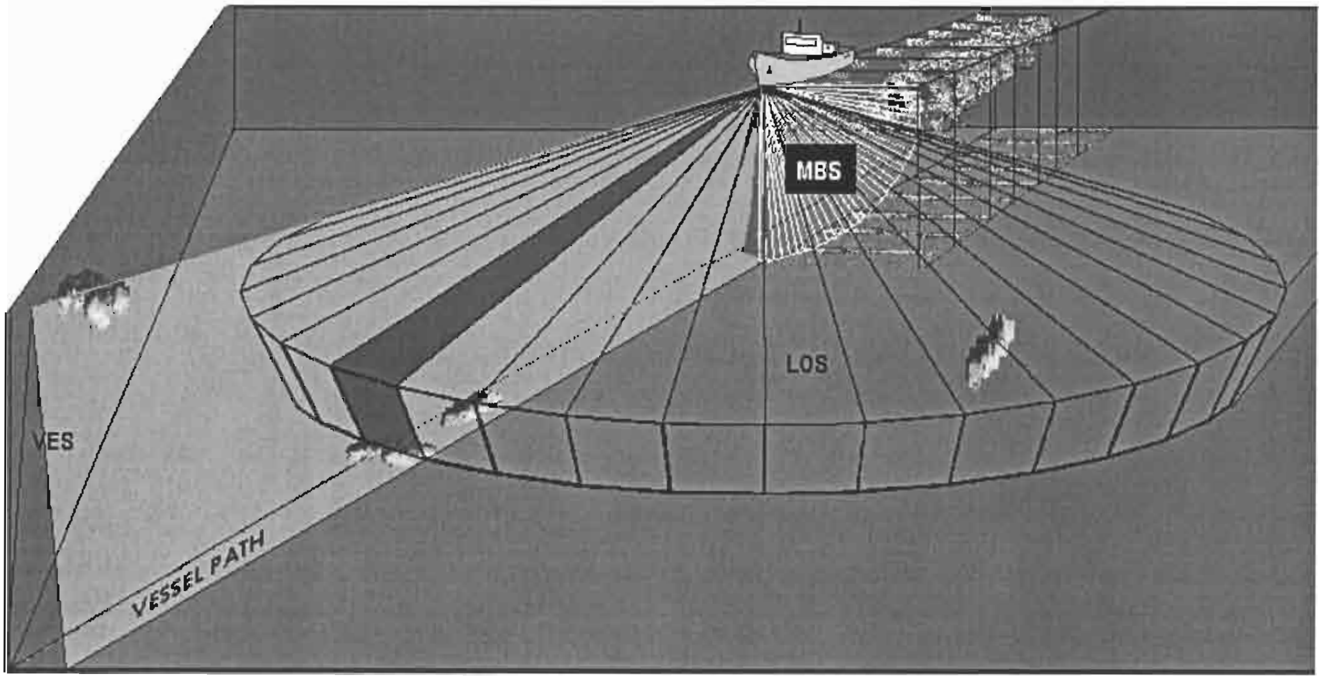


Figure 2: representation of the sampling volume insonified by 3 acoustic devices, in grey the LOS (all around the vessel), in white the MBS (depicting a series of pings) and in red VES (beneath the hull of the vessel). The orange colour symbolize the volume sampled by the VES on the path of the vessel. The LOS have 32 beams of 11.25° on 360°, the MBS *Reson* have 60 beams of 1.5° on 90° and the sounder have one beam of 10°. In red the beam of the LOS adjusted on the path of the boat.

The quantification consists in identifying all the schools recorded of the path of the survey vessel, with the LOS and in controlling whether they are recorded on the VES. The LOS tilt angle must be adjusted according to the local depth and the school position in the water column. Through *Infobancs 2.0* (Brehmer and Gerlotto, 1999) all the schools are identified by an alphanumeric code and analysed (swimming speed and pattern). The MBS documents the vertical bias on the spatial distribution and the school densities (Soria *et al.* 1996 and Gerlotto *et al.* 1999). It can also give a school classification and evaluate the effect of the vessel on school distribution (Soria et al., 1996). The combination of the two methods gives information about the displacement and avoidance behaviour of all the schools previously identified.

When comparing different surveys we can try to identify the main factors influencing the avoidance behaviour. For such a goal, it is necessary to know the "natural" behaviour, i.e. without the effect of a surveying research vessel. This is obtained through the following experiment: the vessel is drifting, motors stopped (during the night the lights are switched off). Several behavioural indexes are measured. The "exploratory speed" is the speed measured from the first to the last recording of a school, using classical Euclidean formulas; the "instantaneous speed" is the distance covered in 30 second periods (Misund 1991). The swimming patterns (drift and diffusion of the school movements in order to determine an oriented or exploratory behaviour) are explored using a numerical sinuosity index integrating both changes of direction and the time lags (Bovet, 1988), in complement of the index of movement proposed by Misund (1991):

$$IM = \frac{M}{\sum_{i=1}^{N} Y_N}$$

M: Horizontal distance between school position 1 and N

Y_x: Movement of school each 30 seconds

This method has not yet be applied to the whole data set, and we present here the result of one survey (Varget 2/98, Western Venezuela) and some preliminary results from other surveys.

Acoustic observations are combined in a single data base with information from the main factors that are likely to influence the avoidance behaviour. The data are analysed using multivariate analysis. The data sets are classified in different categories:

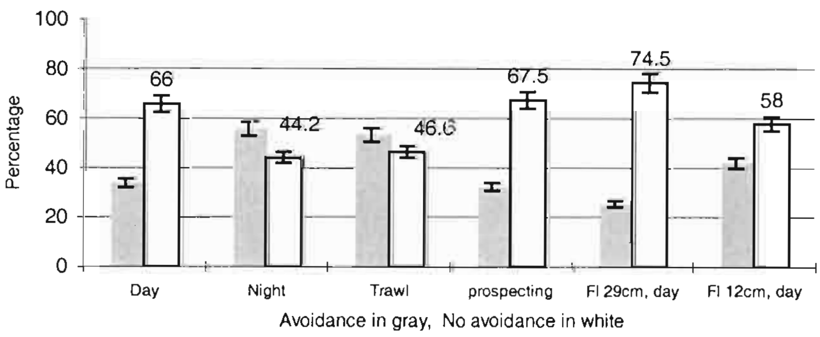
- Period: Day/night (several sub classes by period)
- Experiment Mode: Trawl/prospection/Drift
- Fork length: small/large
- Vessel speed: low/high
- Celerity or Temperature: low/high
- Bathymetry and school depth: shallow/deep
- Cluster Density: low/high, (Compaction level of the cluster; spatial structuring)
- Specific behaviour: spawning [maturity stage]/ migrating/feeding/others...
- Dynamics: swimming speed (Fast/slow) and pattern (polarised/not polarised movement)
- Size of school: small/medium/large

Infobancs provides some special graphic information showing the displacements of the schools and the vessel relatively to reference tags and the swimming speed variation according to the distance to the vessel

Results

1. General pattern of lateral avoidance

The analysis of data collected on *Sardinella aurita* in western Venezuela in February 1998 allows to quantify the lateral avoidance reaction in western Venezuela using Misund's method (Misund, 1991). According to the school type, some important differences can be recorded (fig. 4). The strongest reaction has been observed on juvenile *Sardinella aurita* during the night (69% of the schools avoid the vessel) and the weakest reaction recorded was for adult *Sardinella aurita* during the day (25.5%), both at a same survey speed (6-7 Knots).



***CTD* probe Average value**	***Golf of Cariaco Fl=12cm***	***North Araya Fl=29cm***
Salinity (‰)	36.67	36.59
Temperature (°C)	20.61	22.76
Velocity (m/s)	1525.42	1530.82

Figure 4: percentage of avoidance of the survey vessel (Venezuela 1998) for different configuration, in grey the school avoid the boat, in white the school are detected on the echo sounder. Table of environmental variables for the two areas (gulf of Cariaco and North Araya) and modal fork length class obtained by identification fishing.

We analysed the swimming speed of the schools through a variance analysis (anova, table 2) with one criteria of classification: period (day *vs.* night), mode of recording (drift *vs.* prospecting), and area (juvenile *vs.* adult). The measurements are given in body lengths per second (BL/s) (Blaxter, 1967).

Variable	Va: fork length			Va.: tracking / Drift			Va.: Day / Night			Va. : fork lenght		
ANOVA	**Effect SC**	**F**	**p**	**Effect SC**	**F**	**p**	**Effect SC**	**F**	**p**	**Effect SC**	**F**	**p**
Experiment mode	*Data : tracking*			*Data :tracking+Drift*			*Data : Drift*			*Data : tracking + Drift (day)*		
Exploration speed	20.398	0.30	<0.0000*	0.00	0.00	0.9849	1.088	6.25	0.0141*	5.492	6.25	0.0141*
Instantaneous speed	5.225	52.13	<0.0000*	0.04	0.28	0.59694	0.657	11.76	0.0014*	1.3459	11.76	0.0014*
Length	8514.393	103.0	<0.0000*	1798.76	34.17	<0.000*	1900.504	2.95	0.0935	427.51	2.95	0.0935
Std error	1.445	25.45	0.00003*	0.06	0.70	0.4037	0.282	2.29	0.1384	0.118	2.29	0.1384
Max.	12.208	26.55	0.00002*	1.79	3.16	0.0779	23.603	2.23	0.1436	5.316	2.23	0.1436
Mini.	1.708	36.68	<0.0000*	0.26	4.70	0.0321*	0.348	16.85	0.0002*	0.665	16.85	0.0002*

Table 2: results of ANOVA on the swimming speed variable according to three factors, the fork length, period (day/night) and mode (tracking/drift). * $p < 0.05$ is the significant effect.

We performed a logistic regression with all the data analysed during this survey (183 schools) with three factors identified in previous works as critical for avoidance reaction: area (north Araya and adults *vs.* Gulf of Cariaco and juveniles), period (night *vs.* day) and vessel speed (trawling 3-4 Knots *vs.* prospecting 6-7 Knots). We find that in western Venezuela the avoidance reactions change significantly with the vessel speed (being more important at low speeds) and the size class of the fish (fork length). The juveniles present a stronger avoidance reaction than the adults during the day. The daily variation does not affect the avoidance reaction as much as the two first factors. We must recall that the moon period, which may affect the meaning of the results (Gerlotto, 1993) has not been taken into consideration.

Fitted terms(1)	*Estimation*	*s.e.*	*t(*)*	*T pr.*	
Constant	0.806	0.274	2.94	0.003	Variable : avoidance/ no avoidance
Speed R/V	-1.543	0.385	-4.01	< . 001*	Distribution : binomial
Areas	-2.020	0.584	-3.46	< .001*	Function : logistic
Speed R/V . Areas	2.066	0.828	2.50	0.013*	= log (η / *n*-η)
Period	-0.002	0.410	-0.01	0.995	
Fitted terms (2)					
Constant	0.631	0.247	2.56	0.011	
Speed R/V	-1.199	0.336	-3.56	<0.001*	
Areas	-1.464	0.403	-3.63	<0.001*	*Speed R/V : prospecting or trawling*
Fitted terms (3)					*Areas : Gulf Cariaco Fl=29cm/ North*
Constant	0.174	0.209	0.83	0.405	*Araya Fl =12cm*
Period	-0.835	0.305	-2.74	0.006*	*Period : day/night*

Table 3: results of the logistic regression (S-plus, 97) on 183 schools, obtained for the avoidance variable according to three factors: area (north Araya: adult Fl: 29cm/Golf of Cariaco: juvenile Fl:12cm), period (Night/day) and vessel speed (trawling 3-4Knots/prospecting 5-6 Knots).

The average exploration speed for all the schools is 0.63m/s, with an important variance between schools in a single cluster. By night the dynamics of fish schools is lower than by day. During the night schools can present a low speed (0.5 BL/s, i.e. 0.06m/s), while during the day we measured a maximum speed of 14 BL/s for the two length classes (Fl. 29 and 12 cm). The school swimming speed was analysed by three variance analysis (anova) with one classification criterion: period (day *vs.* night), mode of recording (drift *vs.* prospecting), and area (juvenile *vs.* adults). The results show that the swimming speed depends on the length of the fish expected (fig 4), but is not related to the vessel: only the minimal swimming speed is significantly higher in tracking experiments than during drifting observations. In drift mode, we may observe the same differences in the swimming behaviour between day and night and between the two length classes of *Sardinella aurita*.

2. Effect of the main factors

This short analysis showed that some factors have a major influence. To describe them we will use data from different surveys, where their influence can be extracted from the others.

Effect of depth (school and local):

This effect has been studied in the Mediterranean, where the average depth in the surveyed area in the Catalan sea was 44.13m and 23.83m in the Adriatic sea. The depth of school in the water column depend on several factors: hydrology (temperature, thermocline, chlorophyll,...) and local depth. The distribution of school according to the distance from the vessel as obtained by MBS shows a more important avoidance for the Adriatic schools. In the two first classes of distance to the boat (fig. 5) the schools are more numerous in the Adriatic sea than in Catalan sea.

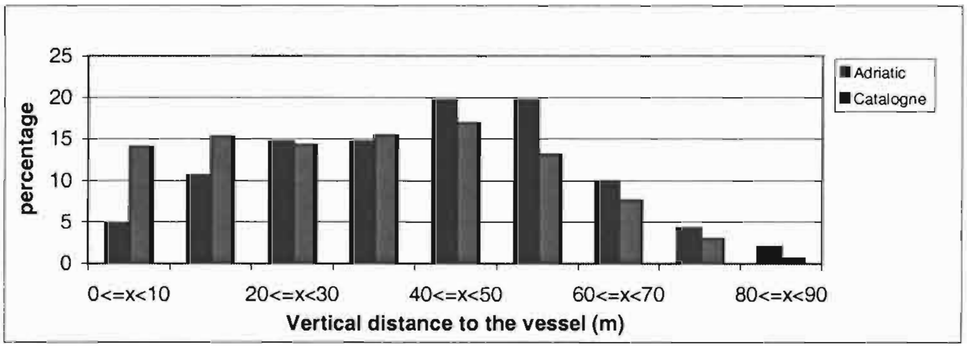


Figure 5: distribution of school according to their vertical distance to the vessel, observed in the Adriatic and in Catalan sea, on 2925 schools of *Sardina pilchardus*.

The depth of schools in the water column depend on its profile (temperature, chlorophyll, etc.) and the local depth; the mean depth for Catalan sea is 44.13m and 23.83m in the Adriatic sea. The distribution of schools according to the distance of the boat, obtained by MBS show a more important avoidance of the Adriatic schools. In the Catalan sea the fish dive deeper than in the Adriatic: when a vessel is passing, the schools are 15 m deeper below the vessel than at 80 metres far from the ship, while this diving is 8 m in the Adriatic (table 4).

School Descriptors	**Boat distance**		**Boat distance**				**p level at 0.05%**	
	0-10m		80-90m		F(dl.1,2)		* significative	
Average by Area	**Cat.**	**Adr.**	**Cat.**	**Adr.**	**Cat.**	**Adr.**	**Cat.**	**Adr.**
Height	5.32	4.46	7.31	5.02	24.71	2.67	0.0000*	0.1032
Width	10.56	9.86	11.95	1006	4.53	0.06	0.0339*	0.8010
Length	9.64	18.23	10.66	16.22	1.45	1.16	0.2295	0.2812
Height/width r2	0.60	0.53	0.73	0.68	5.25	7.74	0.0226*	0.0056*
Depth of gravity centre	43.89	22.78	28.44	14.48	84.97	36.83	0.0000*	0.0000*
Distance sea bed	14.16	6.36	20.07	6.66	7.30	0.12	0.0072*	0.7243

Table 4: Analysis of multiple variance on school descriptor obtained by MBS, for the two opposite classes of distance to the vessel (Maximum and minimum) in Catalan (grey) and Adriatic seas respectively for 1156 and 1769 schools.

Effect of period (night/ day):

We find a horizontal avoidance reaction of 93% during the day and 83% during the night in trawl situation on Senegalese schools. In Venezuela in prospecting mode we have the same trend: 55.8% of 183 school avoid the vessel by night and only 34% by day. In drift mode, the swimming behaviour of the Venezuelan *S. aurita* is lower by night than by day. During the night we measure some school under 0.5 BL/s (0.06m/s) and during the day we find a maximum speed of 14 BL/s for the two classes of size observed (Fl. 29 and 12 cm). The juveniles present a stronger avoidance reaction than the adults during the day. We must recall that the moon period has not been taken into consideration, which may affect the meaning of the results (Gerlotto 1988).

Effect of temperature:

The variation of temperature can change the fish physiology, the celerity, the absorption and propagation of sound. The temperature profile define the beams propagation trough the water column.

The temperature ranges in our surveys are not strong enough to give clear answers to this point. We observe weak differences in temperature between areas in single survey and it is difficult to determine their effect. In Venezuela the temperature in the gulf of Cariaco has an average of 20.6°C and 22.7°C in North Araya. In the case of Adriatic *vs.* Catalan seas, the schools in the warmer water present a slightly stronger avoidance reaction, although it is uneasy to extract significant information.

Effect of boat (noise ⇔ vessel speed):

We find that in western Venezuela the avoidance reaction increases significantly with vessel speed, being stronger at low speed. We recall that the variation of the noise level of the vessel shows (fig.1) a higher noise at low speed (3-4 Knots) than at survey speed (6-7 Knots). The swimming speed behaviour of the schools under the stimuli generated by the vessel noise is not different to the swimming behaviour of the schools recorded under silent vessel situation (drift mode), except for the minimum instantaneous speed (increasing when the stimulus is present). In Senegal (1999) the speed of the schools which avoid the vessel is not very different to the one observed when the vessel stopped.

Swimming speed $m . s^{-1}$ / $Bl. . s^{-1}$	**Avoidance**	**Exploration speed.**	**Instantaneous speed**			
Survey/Fork length, N: number of school	*Day*	*average*	*average*	*Standard deviation*	*Minimum*	*Maximum*
Senegal 1999, FL.= 21cm, N=60	93%(*)	0.8 / 4.77	0.5 / 9.26	1.6 / 6.90	3.4 / 3.10	1.3 / 19.22
Ivory coast 1998, Fl.= 16.5cm, N=79	79%	1.6 / 4.60	2.0 / 6.42	1.1 / 5.92	1.3 / 2.68	2.9 / 15.30
Venezuela 1998, Fl.= 20cm, N=183	34%	0.9 / 9.58	1.3 / 12.22	1.2 / 6.64	0.5 / 7.77	3.0 / 17.52

Table 5:, percentage of avoidance of *Sardinella aurita* schools during the day for the same vessel. The first number is in meters by second and the second is in Body length by second. Preliminary results

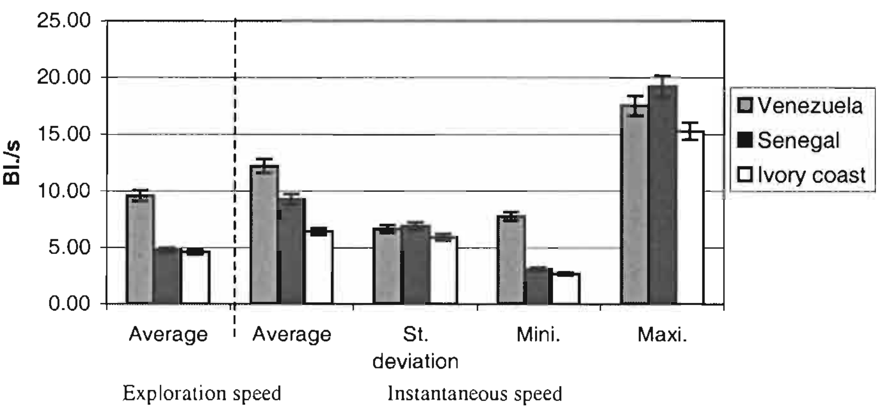


Figure 6: swimming speed in body length by second (Bl/s), for three stocks of *Sardinella aurita* recorded during the day. Error bar ± 5%: measure on sonar picture. Preliminary results

Effect of fishing (trawling).

The most important avoidance reaction recorded in our surveys appears during trawling (3-4 knots) in Senegal (west Africa). We find a horizontal avoidance reaction of 93% during the day and 83% during the night. This reaction changes according to the country, and in Venezuela, this avoidance is 53.4% and 34% respectively in trawl and prospecting situation (fig. 4 and table 5). Here again it is interesting to note that the swimming speed is not significantly different during drifting or trawling situations in Senegal. This seems to indicate that a school is not able to change easily its swimming speed, and uses other strategies for avoiding an unpleasant situation. For the same species of *Sardinella aurita* the avoidance is different among the 3 regions. This is also reflected in the catch (Gerlotto, 1999a.). In Venezuela the avoidance in percentage is weaker than in the 2 others countries. If we compare the swimming speed data, the same opposition appears, the speed being higher in Venezuela than in the others countries.

Effect of fork length

In Venezuela the sardines present a South-North trend in the length distribution (Gerlotto and Gonzales, 1998). This allows us to test the length effect. Juvenile present stronger avoidance reactions than adults during the day (fig. 4). In drift mode the swimming behaviour is different between the day and night for the two cohorts. As expected the larger fish have a higher swimming speed (table 5).

Effect of area

For the same species of *Sardinella aurita* the avoidance is different between the three country (table 5). In Venezuela the avoidance reaction is weaker than in Senegal and Ivory Coast, fish being faster and more polarised in Venezuela. Nevertheless it is still difficult to determine whether this is a real "area effect" or is due to the many other differences between the populations (physiology, demographic structure, hydrology, fishing pressure, etc.).

Discussion

We have showed in this work that there is no simple and linear answer of a fish school to a vessel, and avoidance is a complex phenomenon. Particularly, avoidance is influenced by

- the vessel characteristics : it is clear that the fish will not react the same in front of a silent vessel (Fernandes et al, 2000) and a noisy one.
- The age of the fish .
- The bathymetry and the depth of the school.
- The period of the day/month/year
- The survey pattern (fishing, surveying, at low or high speed).

On the other hand, we have seen that the avoidance reaction may affect several dynamic and spatial characteristics of the school, which have an impact on the acoustic data recorded with a VES:

- the school speed
- the school depth
- the school abundance (lateral avoidance)
- the school morphology
- the fish tilt angle (vertical avoidance)
- spatial distribution the fish.

The measurements of the reactions of a single species in several countries and during several surveys gave a good example of the variability of avoidance reaction depending of numerous factors. We have summarised in the table 6 the most interesting results, expressed in percentage of avoidance .

One interesting point to extract from this table is the important variability of school avoidance under "global vessel effect": from a rather weak avoidance (34%) in Venezuela to a quasi total avoidance effect in Senegal during trawling (93% schools avoiding). This shows clearly that modelling this "global effect" is still impossible.

Table 6 : Examples of the quantitative effect of avoidance under several factors extracted from different acoustics surveys

FACTOR	Effect measured on lateral avoidance	source
GLOBAL VESSEL EFFECT	64% schools avoiding	Adriatic sea (1994 +1995)
	28% schools avoiding	Catalan sea (1994 +1995)
	34% schools avoiding	Venezuela (1998)
	79% schools avoiding	Ivory coast (1998, by Day)
	93% schools avoiding	Senegal (1999, by day, trawling)
BATHYMETRY	61% more avoidance in shallower water	Adriatic *Vs* Catalan sea (1994 + 1995)
AREA (Global)	45% more avoidance in Ivory coast than in Venezuela	Venezuela (1998) Vs Ivory Coast (1998)
PERIOD : Day/night	21.2% more schools avoiding by day	Venezuela (1998)
VESSEL SPEED	20.9% more schools avoiding at low speed	Venezuela (1998)
FISH LENGTH	16.5% more small *Sardinella* schools avoiding (compared to adult schools)	Venezuela (1998)

In the literature, the first (and only) avoidance model published is by Olsen *et al* (1983), concerning the fish density reduction "Δρ" beneath a surveying vessel, according to the vessel's length L (meter), vessel speed v (m/s) and mean depth (m) :

$$\Delta\rho = -\frac{32}{\sqrt{L*v}} * D + 110$$

As expressed by the authors, this model is demonstrative and does not correct the horizontal avoidance which can occur at large scale and which is a major source of under estimation. But it shows clearly that trying to build a more complete one is still an impossible task, as we do not yet know the determinism of each one of the factors.

On the contrary, we have showed that the acoustic techniques at present are able to record most of the avoidance characteristics listed above, and therefore to give an « instantaneous index of avoidance » that can correct the data. It is clear that such a measurement presents several drawbacks: it requires an expansive equipment, the processing methods for the sonars are not yet completely automated, some information are lacking (especially those on the fish tilt angle), the data base becomes huge, etc.

Nevertheless there is an urgent need of information on the biases induced by the avoidance. It has been demonstrated during the FAST working groups that avoidance is the major source of bias in the direct methods of stock assessment, and these methods are becoming the most widely used nowadays.

The method we propose gives information about the following avoidance factors:

- Dynamic lateral avoidance (LOS, use of *Infobancs*, etc.)
- Statistical lateral avoidance at short distances (MBS)
- changes in school morphology (MBS, software *SBIViewer*)
- diving behaviour (MBS)
- changes in the school spatial distribution (MBS and LOS, spatial point process methods)

Practically there is only one factor that is not documented by this addition of two sonars in a survey, which is the fish tilt angle.

Conclusion

In correct sonar condition (e.g.: in a water column without strong variation of the thermocline profile) our method seems effective but still requires some heavy manual processing. The acoustic devices can already provide more precise evaluation of the bias generated by the avoidance reactions.

Technical improvements are already in development: the dimension of the LOS audio beam channel can be reduced, and the range and number of beams (i.e. scanned area) of the MBS will increase. Ideally the best system will be the use of omnidirectional sonar coupled with a 180° MBS. These two sonars, combined with a scientific echo sounder, as suggested by Reid (2000), will permit to obtain:

- Classic acoustic characteristics of schools (using specific software, such as Movies+, Masse et al., 1999)
- School descriptors (Soria et al. 1996)
- Swimming pattern and swimming speed (Gerlotto et al. 1999b)
- Morphology of schools (3D) (Gerlotto et al. 1999c)
- Biomass estimates in sub surface (Misund et al. 2000)

The use the sonar data is indispensable for the schools in sub surface because they cannot be recorded by the echo sounder. Although avoidance reactions of the surface schools seem to appear at very short distances from the vessel (above 20 m, no redistribution of fish schools can be noticed), when they start they are very strong and produce an important reduction of fish density. This is clearly visible in all our data sets, where it always appears an "empty ring" at small distance (10-15 m) all around the vessel. The avoidance reaction can be decomposed in two particular events: at large distance of the boat the noise of the vessel can provoke a progressive avoidance reaction preferentially horizontal (learning?) with no change of swimming speed. Close to the vessel, the combination of visual effect and the high level of noise of the boat generate a spontaneous reaction (increase of the minimum instantaneous speed) of fish schools with an important vertical component.

The side scan sonar is adapted to study the second wave of avoidance (Soria, 96) close to the boat. The schools which react at large distance of the boat can be recorded only with the omnidirectional sonar. Together these devices should help in the studying of the avoidance determinism, and permit indeed to measure, in a continuous *in situ* way, the bias obtained during a classical acoustic survey that it to say estimate the percentage of the density reduction during the echo integration and the bias on schools characteristics measured by echo sounder. At term, when the determinism of the avoidance reaction are clearly identified it should become possible to model this behaviour, for instance by applying neural networks methods (Huse G. and al., 2000) and to test the fish learning hypothesis.

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