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Comparative observation of school lateral avoidance using multibeam sonar

By

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ABSTRACT

Pelagic fish schools were observed on the side of a vessel using a multibeam sonar deployed perpendicularly to the vessel path in the vertical plan. The observations were done during several surveys in different countries (Senegal, Ivory Coast, Mexico, Venezuela, Spain and Italy). The results show two different avoidance patterns: a general one, where fish schools clearly avoid the vessel following the "double wave of avoidance", and a less clear pattern, where avoidance is weak and limited to the nearest schools. Two hypothesis are proposed to explain this difference, related to shallow water effect: a biological one, where fish change its avoidance behaviour in shallow waters, and a more likely acoustic one, where the difference represents a bias due to background noise and signal-to-noise ratio.

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INTRODUCTION

A large number of works on fish school avoidance published during the last decades (see Fréon and Misund, 1999) have demonstrated that such behaviour was related to many parameters and might present some high variability. The last FAST meetings were in part focused on this problem (see the FAST WG Reports for 1998, 1999, 2000). Avoidance can take a wide number of characteristics: vertical, horizontal, change in fish tilt angle, in school morphology and depth, in concentration shapes, in fish speed, etc. (Fernandes et al, 2000; Olsen et al, 1982; Soria et al, 1996; Diner and Massé, 1987; Gerlotto, 1993; Gerlotto and Fréon, 1993, among others). We may cite the general conclusion that arose from the last ICES FTFB-FAST Joint Session in Haarlem*: fish avoids a survey vessel (G. Arnold) in a large part in relation to the noise radiated by the vessel (P. Fernandes: R/V Scotia which is very silent has a weak effect on avoidance; C. Wilson: the same fish avoids differently according to the type of vessel that is approaching a buoy). The spatial fish behaviour and avoidance follows a pattern that can be described when a series of data is available (R. Vabö: movements of NS herring in time and depth is described from a series of surveys), but present a rather high variability (F. Gerlotto: the same stimuli give different results on the same species in different areas).*

Our team has defined one of these patterns which appeared during some surveys in the Mediterranean Sea (EC FAIR TECHO Project, 1993-1997). The observations were done using a multibeam sonar oriented in a vertical plan perpendicular to the vessel direction, observing all the schools from the vertical line below the vessel up to 100 metres on the side. The idea of a "double wave of avoidance" was proposed (Soria et al, 1996), which was the following:

- Assumptions: fish school are randomly distributed at some distance from the vessel ; all the schools present an avoidance reaction normal to the source of noise; schools tend to actively reach the less noisy area;

- due to the noise radiation of the vessel, as described by Urick (1982), where the hull produces a "silent cone" ahead, fish schools inside this cone are trapped and tend to concentrate on the vessel path (Gerlotto and Fréon, 1988. Misund, 1990). The other schools are able to avoid laterally.

- When the vessel arrives closer, the trapped fish schools become able to avoid laterally also, either because they are deep enough to be outside the noise area or because they can see the vessel, and most of them are avoiding; the few schools remaining for any reason are those which are observed on the echo sounder echogram (fig. 1).

These observation were suffering some potential biases.

The first one was that the multibeam sonar was set on a 40 log R function, and thus schools close to the vessel could be too attenuated to be observed on the screen, while the farthest ones were clearly visible. This potential bias had to be considered.

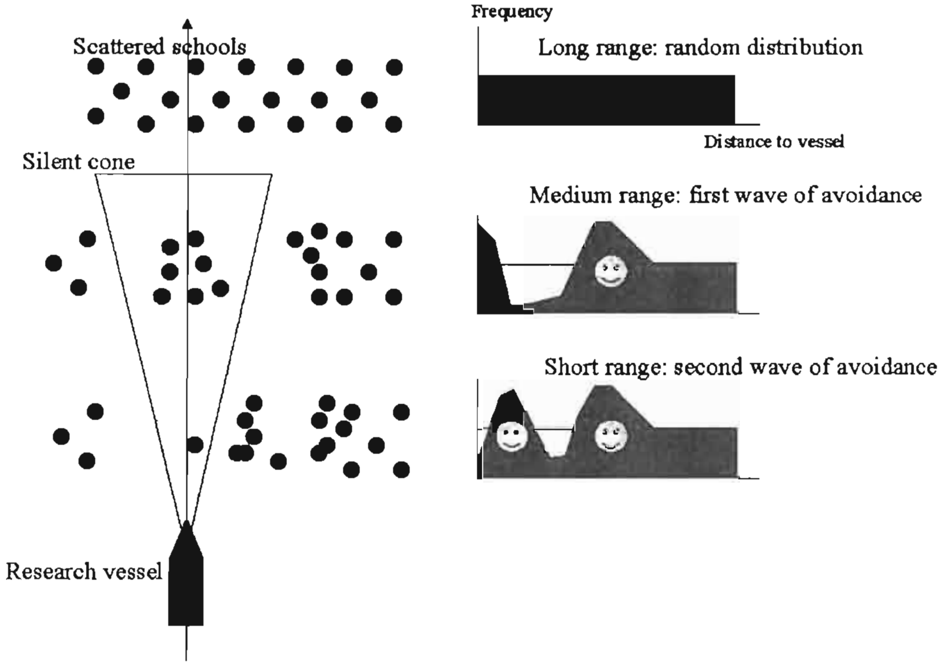

Figure 1. Scheme of the "double wave of avoidance" pattern
(redrawn from Soria et al, 1996)

The second one is that there is a strong noise due to the bottom, at any distance equal or above the depth. Therefore some effect can be present in the school numbering at the depth distance (fig. 2). At larger distance, the signal-to-noise ratio makes observation quite difficult, and schools at more than 80 metres are hard to discriminate from the noise. It was decided not to take into account the observation at more than 80 m.

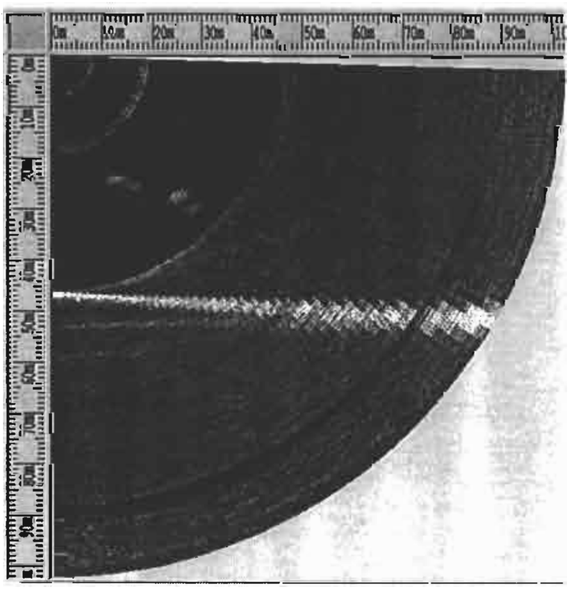

Figure 2. Example of multibeam image. Depth: 45 m, range 100 m.
Note the background noise beginning at distances longer than the depth, and becoming stronger at 80-90 m.

Finally it was important to check whether this avoidance model was a particular case only observed in the Mediterranean and/or during these cruises or if it is a more general pattern.

In order to evaluate these points, the same experiments were done in several areas, specifically in Senegal, Ivory Coast, Venezuela and the Pacific Coast of Mexico. The results are presented in this paper.

MATERIAL AND METHODS

The use of multibeam sonar allows to evaluate the horizontal avoidance, when it is used as shown on figure 3. This has been done in all the IRD surveys, measuring the distance to the vessel of each school.

The null hypothesis being that there is a constant number of schools at any distance to the vessel. The way to test this hypothesis is to compare the actual number of schools at each distance from the vessel to the expected one. This has been done for the different areas. In each case some adjustment has been necessary, which are described below. We present in the document detailed results for the Mediterranean and global information for the other areas: Venezuela, Senegal, Ivory Coast and South-West coast of Mexico (Bahia Magdalena).

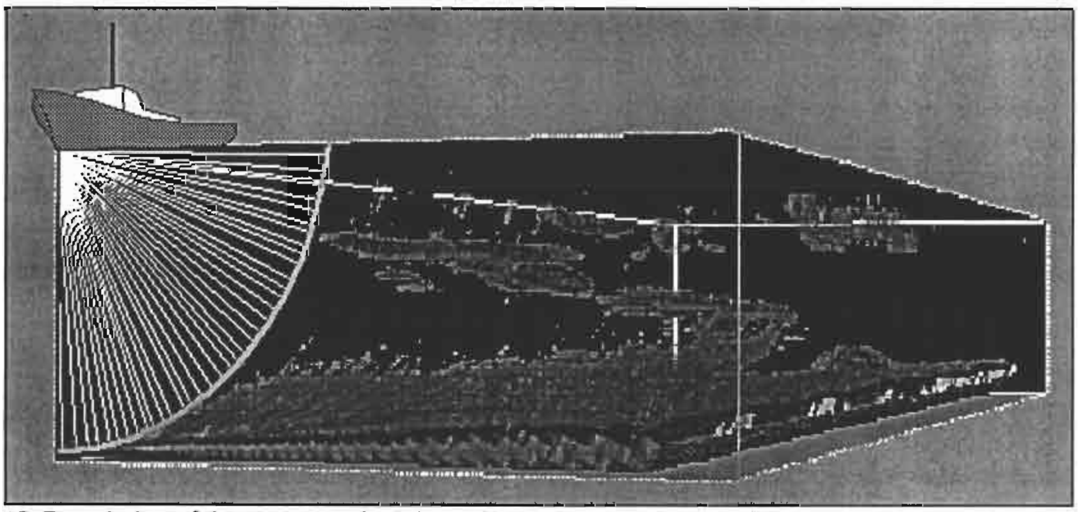

Figure 3. Description of the survey methodology. Schools are observed and exhaustively located and numbered on the side of the vessel route

Mediterranean: the Catalan Sea.

The data come from a former EC FAIR Project. The surveys were performed aboard the Spanish R/V Garcia del Cid, 45 m long research vessel. We gathered in the analysis the data from 2 surveys, each one being repeated twice (i.e. 4 overall coverage of the Catalan Sea, from Barcelona to Valencia), as no visible difference appeared between the school distributions. At this time the Seabat was not yet operating the 20 log R hardware function. Hence there is a risk of bias in the data: being measured with a 40 log R function, the schools echoes recorded at short distance from the transducer are more attenuated than the echoes of schools far from the vessel. This leads to a series of biases in most of the school descriptors, and especially the school density and the overall shape. As far as school location and number is concerned, the way the measurements was done was supposed to limit the risk: the schools were recorded on SVHS video, and they were observed and measured by eye on the video tape images. All the schools, and even the smallest ones were taken into consideration, at least up to 80 m distance to the vessel. Therefore although their overall dimension at short distances is obviously underestimated, the potential bias on the distance to the vessel and the number of schools should be weak.

Mediterranean: the Adriatic Sea.

Here too the data come from the TECHO Project in 1994 and 1995 and were collected using the same vessel. Two surveys were performed in the North-West of the Italian Adriatic. In this case we chose to show separately the two surveys, as their results are slightly different one to the other. The SeaBat was operating with the 40 log R function. The processing and analysis methods were identical to those for the Catalan Sea. As in the Catalan Sea, the pelagic species are sardine (*Sardina pilchardus*), horse mackerel (*Trachurus trachurus*), mackerel (*Scomber japonicus*), sprat (*Sprattus sprattus*), anchovy (*Engraulis sp*) and Spanish sardine (*Sardinella aurita*)

Senegal

The data come from a IRD Project (VARGET), on the "Petite Côte" (from Dakar to Gambia). The results presented in this paper come from a survey performed in March, 1997. The data were collected using the 20 log R function on the SeaBat. The vessel was the French R/V Antea, 35 m long catamaran. The same methods for recording and processing data were applied. Pelagic fish were mostly the Spanish sardines (*Sardinella aurita* and *S. maderensis*), horse mackerel (*Decapterus rhonchus, Trachurus trecae, D. punctatus, Selar crumenophtalmus*), Anchovy (*Engraulis enchrasicholus*), mackerel (*Scomber japonicus*).

Ivory Coast

The data come from the same project VARGET, using the same vessel (R/V Antea). The survey which is presented here was performed in August, 1997, using the 20 log R hardware function for the first time. The same pelagic species as in Senegal were observed, at different proportions (anchovies being the most abundant species, while sardines were dominant in Senegal). Apart the 20 log R function, the processing and analysis was identical as the one applied on Senegalese data.

Venezuela

Coming from the same project VARGET and the same Vessel, the data from Venezuela were recorded in 1999, with the 20 log R function. The processing was distinct from the former one, as we could use the software SBI Viewer (ENSTB, 1998) for measuring the distances and dimensions of the schools. Fish were principally the Spanish sardine (*S. aurita*), horse mackerels (*Trachurus lathami, Decapterus punctatus, Selar crumenophtalmus*) and a wide set of anchovies species (around 15 spp, although the total anchovy biomass was not dominant).

Mexico

The survey belongs to a research project developed by the ICMyL, UNAM[4], was performed aboard the UNAM R/V Puma (55 m fisheries research trawler, Mexico) in Bahia Magdalena, on the southwest coast of Baja California Peninsula.

The part of the survey which was operating the sonar represented a repeated transect from the open sea to the inner part of the bay. During this survey, 514 schools were recorded and measured. During this survey, as in the case of Venezuela, the schools were not measured on a video image recorded on video tape, but directly on the SBI Viewer software screen, which allowed more precise measurements.

RESULTS

. The table 1 gives the number of schools measured in each one of the areas.

Table 1. Number of schools measured on the sonar in different areas.

Area	Number of schools	Observations
Adriatic Sea	2434	R/V Garcia del Cid, 1993-1996
Catalan Sea	1268	R/V Garcia del Cid, 1993-1996
Venezuela	648	R/V Antea 1999
Senegal	841	R/V Antea 1997
Ivory Coast	624	R/V Antea, 1997
Mexico	546	R/V Puma, 2000

Catalan Sea. The results are described on the figure 4. The results show a strong avoidance reaction of the schools, principally in the 20 metres from the vessel: the school number is much lower than the expected number. On the contrary, one may note a higher number of schools compared to the null hypothesis at distances higher than 40 metres (Soria et al., 1996).

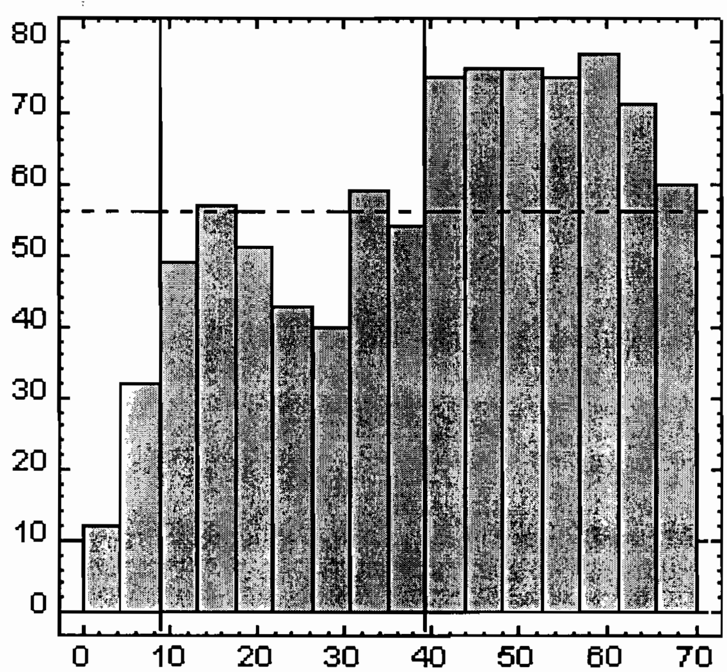

Figure 4. Distances of fish schools to the research vessel, Survey Catalan Sea (from Soria et al, 1996)

[4] ICMyL : instituto de Ciencias del Mar y Limnologia. UNAM : Universidad Nacional Autonoma de Mexico

Adriatic Sea.

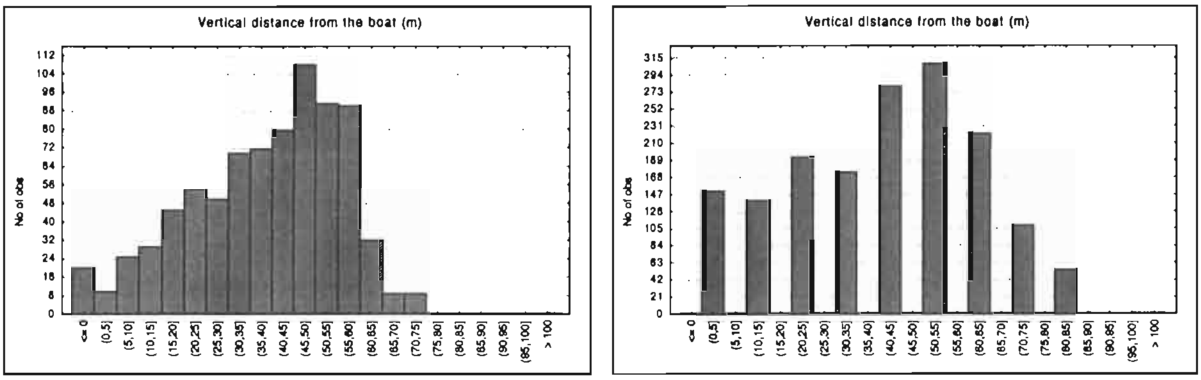

Figure 5. Number of schools at different distances to the vessel for two Adriatic surveys.

In the Adriatic (fig. 5), we can see that as in the Catalan Sea there is a strong decrease of school numbers at distances longer than 70 m. Therefore we do not consider these classes. This shows that the Adriatic presents a rather similar pattern as the Catalan sea: important avoidance at short distances (from 0 to 20 m). Nevertheless one may note a clear difference between the two surveys: avoidance seemed much stronger during the first one than during the second one, although both present the two peaks observed in the Catalan Sea.

Senegal. The data show similar avoidance pattern as in the Mediterranean surveys. 814 schools were measured. It can be noted that the decreasing of school number begins at shorter distances than in the Mediterranean (around 65-70 m).

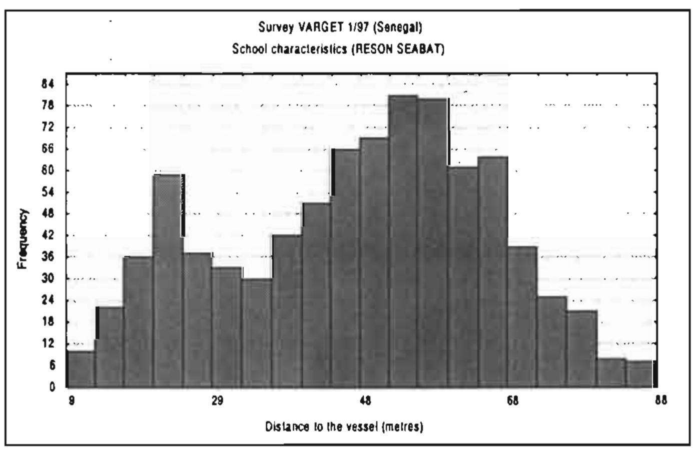

Figure 6. Senegal, survey Varget 1/97, 814 schools observed

Ivory coast.

We present the results of the survey made in 1997 (fig. 7). They show rather few difference with the other surveys: there is also a strong avoidance reaction, and the histogram shows the two peaks that were assumed by Soria et al (1996) as due to the "double wave of agitation". During this survey, 624 schools were measured.

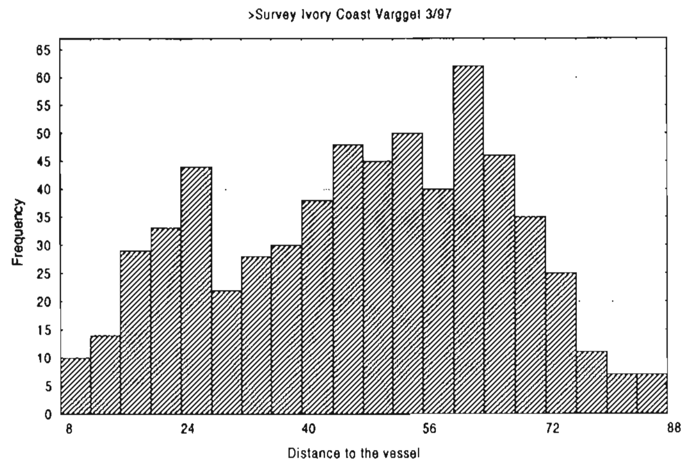

Figure 7. Ivory Coast. Survey Varget 3/97, 624 schools observed

Comparing Ivory Coast with Senegal is interesting for two reasons: first the communities are rather similar, the pelagics being formed by the same species. Therefore the avoidance reaction can be compared, especially when induced by the same vessel (R/V Antea) as was the case. Second, the Seabat was equipped with the standard system (40 logR) in Senegal, and with the upgraded system (20 logR) in Ivory Coast. The rather similar avoidance pattern (the differences are quantitative and not qualitative) shows that the risk of bias that was suspected in the Mediterranean surveys is rather weak.

Venezuela.

The data in this survey (VARGET 2/99) present a global pattern similar to those of the Mediterranean surveys, with two differences: first the avoidance seems much weaker and located to a small area around the vessel (first –and only- peak at less than 20 m from the vessel); second, the decrease of number of schools with the distance begins much closer to the vessel (30 m). The histogram of number of schools at different distances from the vessel is given on figure 8. The avoidance exists, but it is difficult to draw a null hypothesis. We may assume that the average number of schools per class should be a number between the maximum one (106 schools) and the beginning of the slope (class 20-30: 104). Another question is the reason of this decrease at distances above 30 m. This should be linked to the survey design: most of the survey has been done in shallow waters (fig. 9), and the farther part of the sonar images are extremely noisy, which hides part of the schools. In the recent surveys, we only considered the schools that were collected with the upgraded version of the SeaBat sonar, i.e. using 20 log R and digital output. The Venezuelan data come from the survey VARGET 2/99.

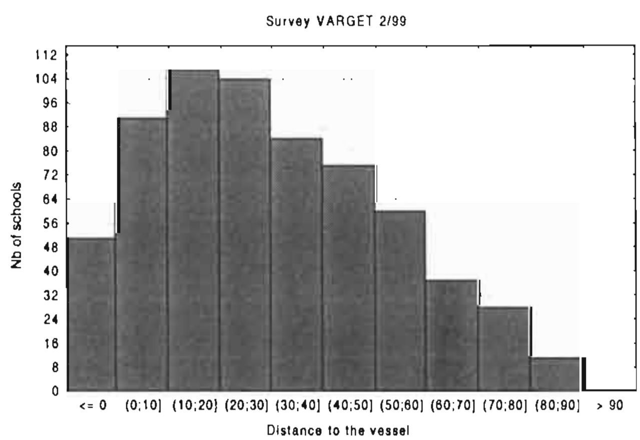

Figure 8. Distances of fish schools to the research vessel,
survey VARGET 2/99

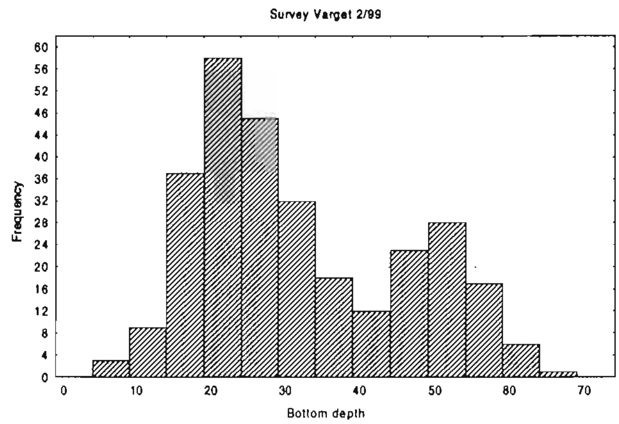

Figure 9. Distribution of the schools according to bottom depth

Mexico.

The survey was performed for rather different purposes than the others, and in particular it is worth noting that the transects did not cover a large area: it is a set of repeated transects crossing the main entrandce of Bahia Magdalena. Thus the sampling is representing the same schools (behaviour should be more homogeneous than in other areas). During this survey, 514 schools were recorded and measured. During this survey, as in the case of Venezuela, the schools were measured directly on the SBI Viewer software screen (figure 10).

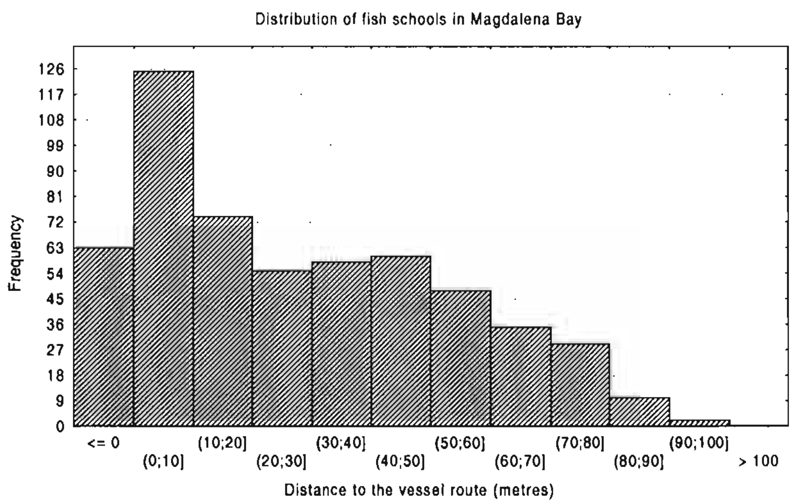

Figure 10. School distribution in Magdalena Bay, Mexico

The histogram is rather similar to the Venezuelan one, with this difference that two peaks are visible. It is noteworthy that the depth in this survey was also similar to the Venezuelan one.

Synthesis of the results.

The synthesis of the observation on lateral avoidance in all the IRD surveys using the SeaBat sonar is presented in the table 2.

Table 2. Synthesis of the observation on lateral avoidance in all the IRD surveys using the SeaBat sonar. Distances are given in metres. Unclear values are in parenthesis

Country	First peak	Low density between peaks	Second peak
Catalan	18	30	45
Adriatic 1	(20)	33	45
Adriatic 2	20	28	45
Senegal	20	(33)	50
Ivory Coast	24	30	45
Venezuela	12	-	-
Mexico	10	(25)	(40)

DISCUSSION

Role of the biases.

It seems that the data which were obtained during the first surveys were not biased by the 40 log R function, as the comparison between Senegal and Ivory Coast present a good similarity (figure 11). A Rank test (Spearman) on the frequencies gives a correlation coefficient of $r = 0.9172$, which is highly significant: distributions are similar. Moreover one could expect that due to the difference un gain, although the peaks are identical, a trend would be observed, the proportion of schools close to the vessel being inferior in Senegal than in Ivory Coast. The drawing of the differences in number of schools for each distance to the vessel shows that there is no trend in the data (figure 12).

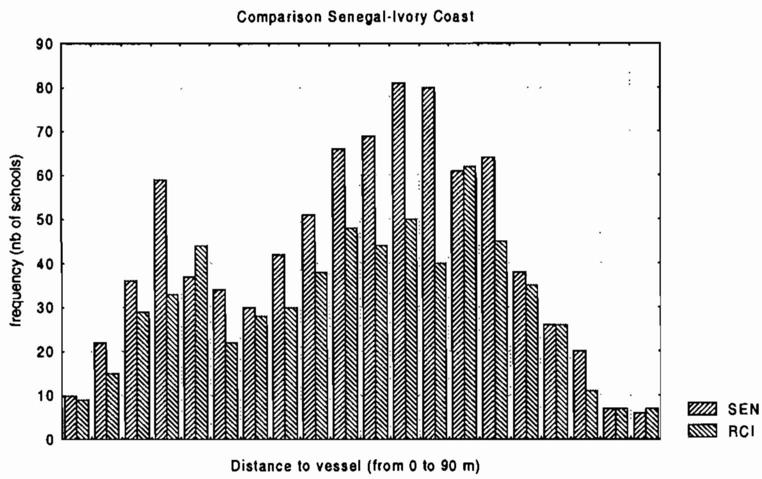

Figure 11. Comparison in the school frequencies in Senegal and Ivory Coast

The other important point is to compare the values of table 2.

- Peak of the first wave. It presents two characteristics: first it is not always observed (specially, it is completely absent in the Venezuelan data and very weak in the Mexican ones); second, when it is present, it is very well located between 45 and 50 m.
- Peak of the second wave. This one is present in all the data. But it does not present the same regularity as the first one: two groups of surveys can be defined: one formed by Mediterranean and African surveys, present a peak at a rather constant

distance, between 18 and 24 m. The second group, Mexico and Venezuela, present this peak at a very short range from the vessel, i.e. 10 m.

- Inter-wave distance: this series of low densities of schools between the two peaks are also very stable, between 28 and 33 m. Obviously it is not apparent in Mexico and Venezuela, due to the lack of the first peak.

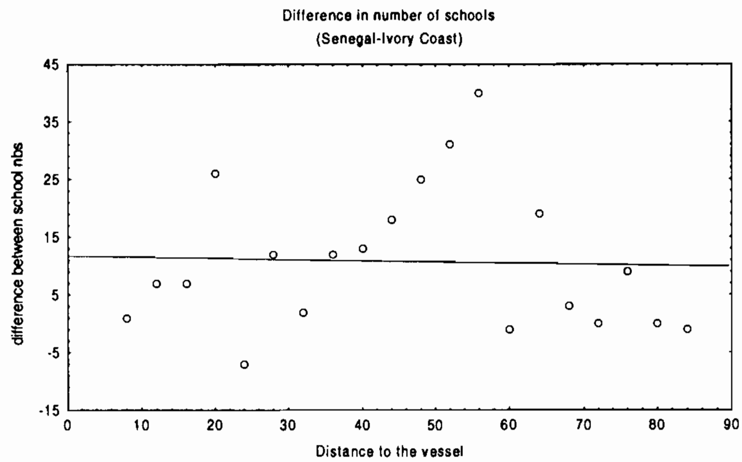

Figure 12. Values of the difference in abundance of schools between Senegal and Ivory Coast for each distance to the vessel

These observations indicate that the pattern defined by Soria et al (1996) seems robust, and that the most important potential biases were not affecting the results presented in 1996. Nevertheless there is a rather important difference between the two groups that have been noted. We were suggesting that one reason for this difference could be the mean depth of the surveyed areas, which is shallower in Venezuela and Mexico than in the African and Catalan Seas (Adriatic being an intermediary depth).

We did not make precise evaluation of the impact of the depth, but such characteristics could have two implication:

- it could have a behavioural effect: we may consider that avoidance reactions change when the school is in shallow or deep waters. Some observations in very shallow waters (Gerlotto et al, 1998) seem to indicate that a school has not a strong avoidance behaviour in shallow waters and avoidance is limited to a few metres. This hypothesis should be documented.
- It could also have an acoustical effect: we have shown that there is a strong "noise ring" produced by the vertical bottom echo (fig. 2). This is usually the strongest background noise that can be observed in the 2D sonar image. The area at longer distance than the depth are also polluted by this background noise. In these conditions, this noise could affect the capability to observe and count the schools at this "depth distance". We can give here a description of the background noise level in a sonar image (figure 13a): the data presented are the density values (in volts, coded on a 256 grey level scale) of each pixel in a rectangle selected inside the sonar image at 20 m depth (figure 13b). If this strong noise ring affects the lecture of the school echoes, then it could be responsible in part of the "inter-wave" low school numbers. The way to evaluate this risk would be to measure precisely the mean depth of the survey area and test whether this distance is similar or not to the inter-wave distance. Although we have not yet done this measurement, we may assume that this is unlikely, as most of the schools present a longer diameter than the ring cross section. Nevertheless it should be checked.

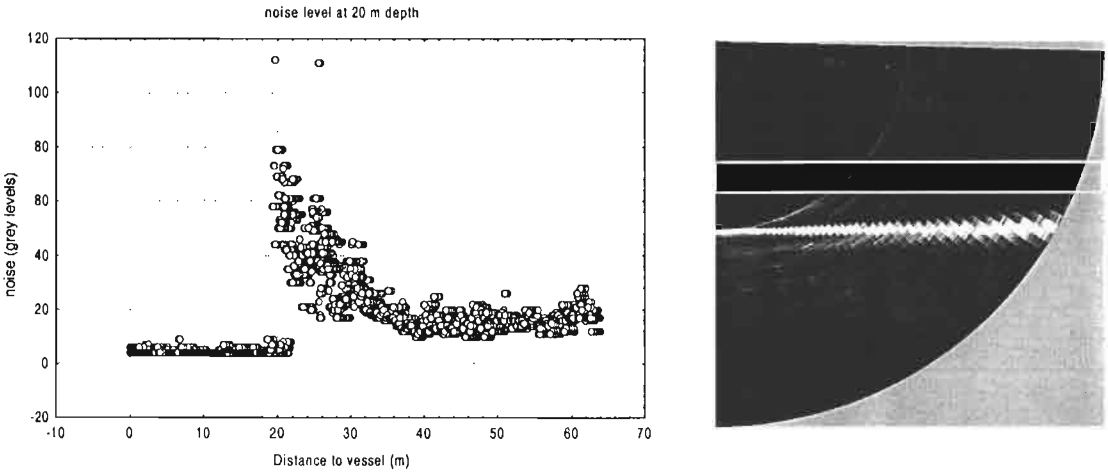

Figure 13. Values of background noise in a sonar image. 13a (left): values of echo energy (in volts) coded in a 256 grey level scale, for all the pixels included in the yellow rectangle in the sonar image (13b, right). In this example the bottom depth is 30 m.

Conclusion

These series of observations are supporting the "double wave of avoidance" theory presented by Soria et al. We may at least conclude that fish behaviour may follow some constant patterns in their horizontal avoidance, as was suggested by Vadö (2000) for vertical avoidance.

Nevertheless the differences among the reaction strengths show that avoidance is not a simple process and is subject to strong changes according to numerous parameters which are not easy to measure permanently. The comparison of several survey data in different areas shows for instance that the bathymetry is likely an important factor: the shallowest the area and the strongest the horizontal avoidance. The vessel noise is also important, and different vessels, or even the same vessel in different situations (e.g. surveying and trawling) may produce very different avoidance reactions. Fish learning (habituation to fishing) is likely another source of variability, which could also explain the difference in the distance of the second wave between overexploited areas (Senegal, Mediterranean, Ivory Coast) and underexploited stocks (Venezuela and Mexico).

Finally these remarks lead to two main conclusions:

- avoidance is a coherent behavioural process which follows some patterns;
- avoidance depends upon a number of parameters, which reinforces our suggestion to record permanently this parameters during an acoustic survey, by the use of multibeam sonar.

Gerlotto François, Soria Marc, Brehmer Patrice. (2001).

Comparative observation of school lateral avoidance using multibeam sonar.

In : Working group (joint session) on fisheries acoustics science and technology and fishing technology and fish behavior : C. Evaluation of effects of fish avoidance during surveys. Copenhague : CIEM, 12 p. multigr.

Fisheries Acoustics Science and Technology and Fishing Technology and Fish Behavior : C : Evaluation of Effects of Fish Avoidance during Surveys : ICES FAST WG Joint Session, Seattle (USA), 2001/04/24-27.