ICES/CIEM
6th International Symposium on Acoustics
in Fisheries and Aquatic Ecology,
Montpellier, 10-14 June, 2002.

A comparative evaluation of school lateral avoidance to survey vessel in different tropical areas.

by

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Abstract

The patterns of fish school avoidance to survey of fishing vessels as described in the literature are often contradictory, and depending on several conditions, such as the noise of the vessel, the species, the environment, etc. In order to evaluate the consistency of the avoidance pattern defined as the « double wave of avoidance », we recorded the avoidance characteristics of 6942 schools of tropical Clupeids in the eastern and western Atlantic, the Mediterranean and the Baja California, using a multibeam vertical scanning sonar. The comparative results show a generally good consistency, and the double wave of avoidance pattern has been confirmed in most of the areas. In some of the regions observed, this pattern suffered some changes, and the biases in the method of observation or due to external factors, such as bathymetric conditions or background noise, were considered..

keywords: school avoidance, horizontal avoidance, multibeam sonar.

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, on http://www.ices.dk web site). 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; Wilson, 2000; Vaboe, 2000; among others). A few sets of general observation can be listed:

- fish school avoidance has been documented very early in the history of acoustic research, and we may cite the works of Olsen (1979), Diner and Massé (1987), Goncharov (1983), Neproshin (1972), etc. These observations were done on horizontal avoidance as observed by sonar. Avoidance could appear at large distances, and according to the characteristics of the vessel, a fish school may even split in several sub-units when the vessel is approaching.

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- the fish avoidance amplitude is strongly dependent on the vessel noise. This was modelled by Olsen et al (1982) on individuals, and described on schools by Gerlotto and Fréon (1989) and Misund (1991) through the observation of schools avoiding a fishing vessel. It was confirmed later by the very different strengths in avoidance reaction of Clupeids world-wide (Brehmer et al, 2000), and by comparative experiments performed by Fernandes et al (2000) using an autonomous underwater vehicle in parallel with the R/V Scotia.
- Works using drifting or fixed floating buoy equipped with a small echo sounder were initiated by Olsen et al (1982), and several works following the same protocol have been done since this time (Gerlotto and Fréon, 1992; Wilson, 2000; Vaboe, 2000, for example). They also demonstrated that the avoidance reaction was highly variable and although depending in a large part on the vessel noise and illumination (Levenez et al, 1988), some environmental effect could be suspected, especially noise habituation and fishing pressure.
- some patterns could be observed in the fish avoidance reaction, in both the vertical (Vaboe, 2000) and horizontal plans (Soria et al, 1996), but the variability of the fish reaction is quite important, depending on environmental conditions.

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).

This model was supported by a large set of observation on fish schools recorded using a multibeam sonar in the Mediterranean. But these observations were limited and suffering some potential biases.

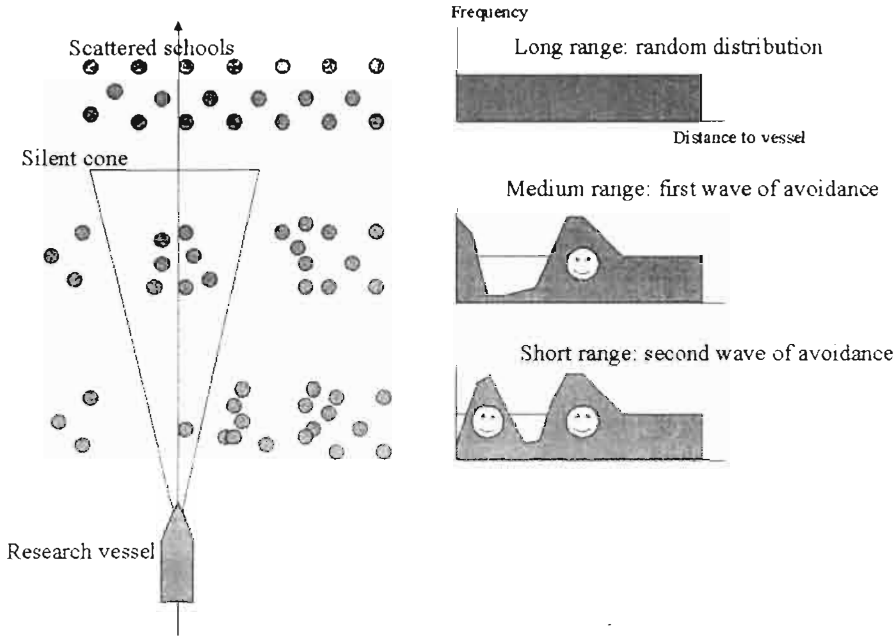

Figure 1. Scheme of the "double wave of avoidance" pattern
(redrawn from Soria et al, 1996)

The first one was that during these surveys, 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.

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. Then the meaning of observations at more than 80 m is doubtful.

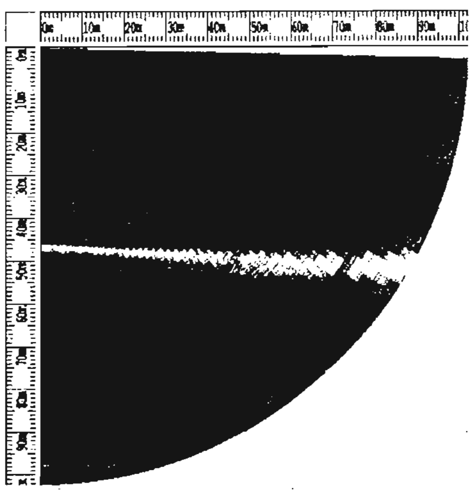

Figure 2. Example of multibeam image. Depth: 45 m, range 100 m. Note the background noise beginning at distances longer than the depth, and becoming stronger at 80-90 m.

Once these biases documented, the following step is to evaluate the principal natural characteristics that may influence the school avoidance.

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 evaluating the horizontal avoidance, when it is used as shown on figure 3. This has been done in all our surveys, measuring the distance of each school to the vessel. 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 most of the cases some adjustments have been necessary, which are described below. We present in the document detailed results for the Mediterranean, Venezuela, Senegal, Ivory Coast and South-West coast of Mexico (Bahia Magdalena).

The sonar we used is a RESON SeaBat 6012, with 60 1.5°beams forming an overall beam of 90°, and 15° in the perpendicular direction. The data were recorded in two ways: during the first surveys the data were recorded on a SVHS video tape and processed by eye on the video screen. After 1997 the data were also recorded in a digital mode once this function be installed on the sonar, and the data were processed through a specifically designed software, SBI Viewer, which reconstructs each school in 3D and gives the main morphometric parameters and the density distribution inside the school. In this paper we only studied the main morphometric and geographic parameters: length, width and height of the school; distance to the vessel, altitude and depth of the school. The data studied were colledted during the day, at a distance from 0 to 100 m from the vessel, this last one performing a regular route in parallel transects over the studied area, at a fixed speed (depending on the vessels, from 6 to 8 knots).

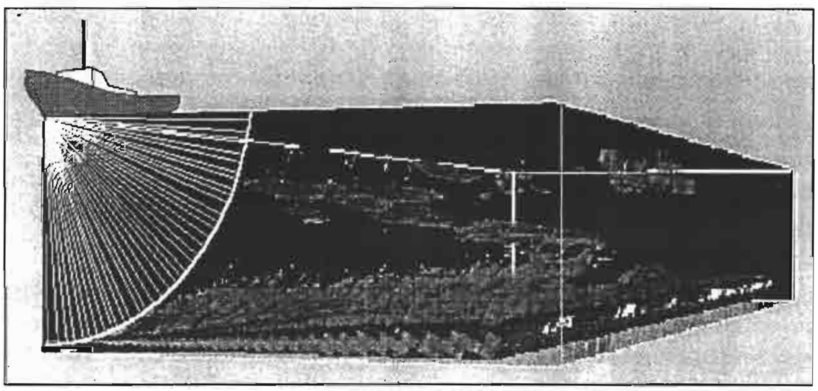

Figure 3. Description of the survey methodology. Schools are observed and exhaustively located and numbered on the side of the vessel route

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 3 surveys, each one being repeated twice (i.e. 6 overall coverags 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 measurement 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. 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*). We must say that the results presented here differ consistently to the results presented on the same data base by Soria et al (1996). This is due to the fact that in order to be able to compare the data from all the regions, we had to simplify the correction and selection factors that were applied. Soria et al's data are certainly more precise and realistic than the one we present for the Mediterranean (Catalan and Adriatic seas), but even though the choice of the schools is less selective, the main pattern appears clearly.

Senegal

The data come from an 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 40 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 to 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*), and in a marginal proportions, 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[5]; it 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. 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	773	R/V Garcia del Cid, 1993-1996
Catalan Sea	2726	R/V Garcia del Cid, 1993-1996
Venezuela	1111	R/V Antea 1999
Senegal	1104	R/V Antea 1997
Ivory Coast	752	R/V Antea, 1997
Mexico	514	R/V Puma, 2000

(*) (not all the parameters were measured on all the schools: in some cases the only available parameter was the distance to the vessel, in others we measured only morphometric parameters, and in most of the cases all the data were recorded.

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). As we said for the Adriatic, the global histogram looks slightly different from the one presented by Soria et al (1996), looks this is due to the choice made to take into consideration al the schools (including those fond at more than 70 m), and to differences in the correction factor applied.

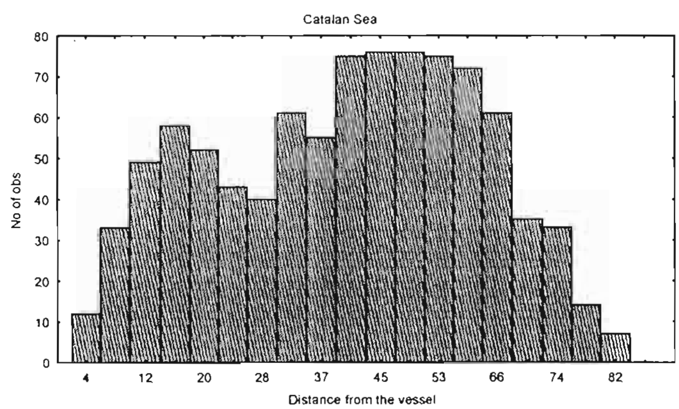

Figure 4. Distances of fish schools to the research vessel, Survey Catalan Sea (from Soria et al, 1996)

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

Adriatic Sea.

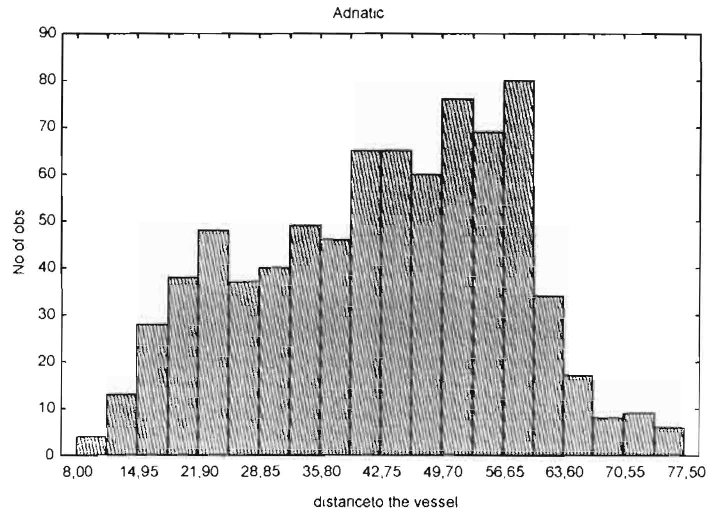

Figure 5. Number of schools at different distances to the vessel for two Adriatic surveys.

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. 1104 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), and that the two peaks seem more individualised.

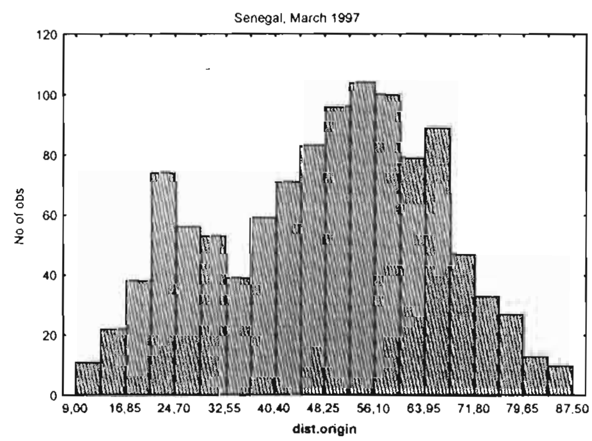

Figure 6. Senegal, survey Varget 1/97, 814 schools observed

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 due to the “double wave of agitation”. During this survey, 624 schools were measured.

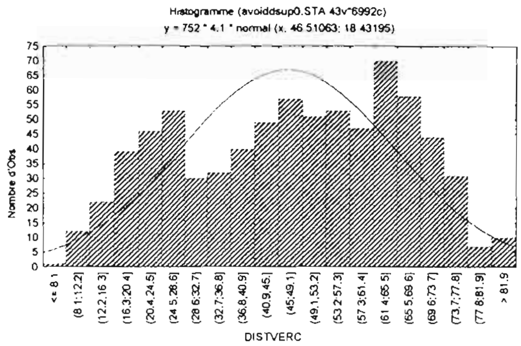

Figure 7. Ivory Coast. Survey Varget 3/97, 624 schools observed

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, and quite comparable to the Senegalese and Ivorian ones. The histogram of number of schools at different distances from the vessel is given on figure 8. In this recent survey, 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.

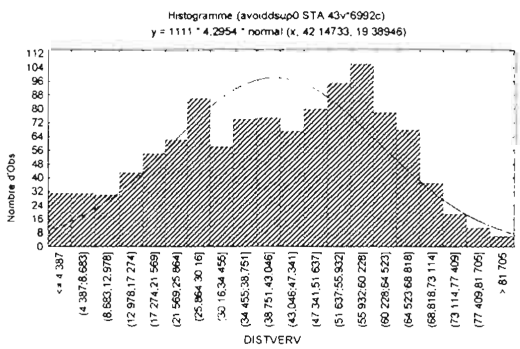

Figure 8. Distances of fish schools to the research vessel, survey VARGET 2/99

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 entrance 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. As in the case of Venezuela, the schools were measured directly on the SBI Viewer software screen (figure 10).

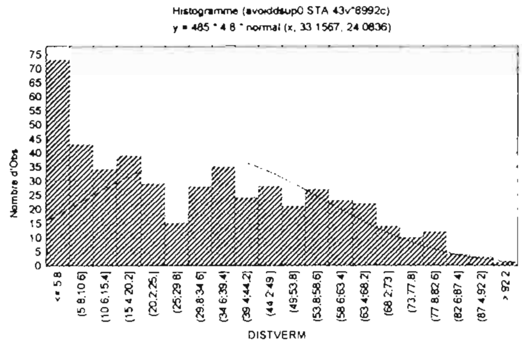

Figure 9. School distribution in Magdalena Bay, Mexico

The histogram is rather different from most of the other ones, especially at short distances. The high peak below the vessel is probably due to the fact that all the schools were taken into consideration, and even the "cut" schools, i.e. those that are visible in part below the vessel. In these conditions, if the schools are not avoiding, due to edge effects, there is an apparent increase of the schools at the vertical of the vessel: the schools which are mostly present on the other side of the vessel, but with a small part in the observed area are counted as being entirely present inside the observed area, which may duplicates the apparent number of schools. It is not clear whether the decrease of school abundance at 25 m corresponds to the limit between the first and second waves, as the modes are not well defined.

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)

Main school characteristics

Besides the distance to the vessel, we made some measurements on the main morphometric features of the schools according to their origin (figure 10). From these figures and table we can extract the following observations :

- there is a visible difference in the mean distances to the vessel between the Mexican schools and the others. Schools in Mexico were found closer to the vessel.
- similarly, the Catalan schools are encountered much deeper than the other schools;

- the schools from the Mediterranean are significantly smaller than in other areas. We must point out a potential bias in the calculation of the length in the Atlantic data, where no detailed recording of the vessel speed could be done. Therefore the length, which is calculated using the ping rate and the vessel speed, is subject to some bias. It seems preferable not to compare these data with those of the Mediterranean and Mexico, but they can be compared inside the Atlantic group, as the vessel was the same and the bias potentially constant. Under these conditions, the ivorian schools look far longer than in Venezuela and Senegal.
- the tropical observations were made in platforms presenting the same average depth, while the evaluation is quite different in the Adriatic (very shallow waters)

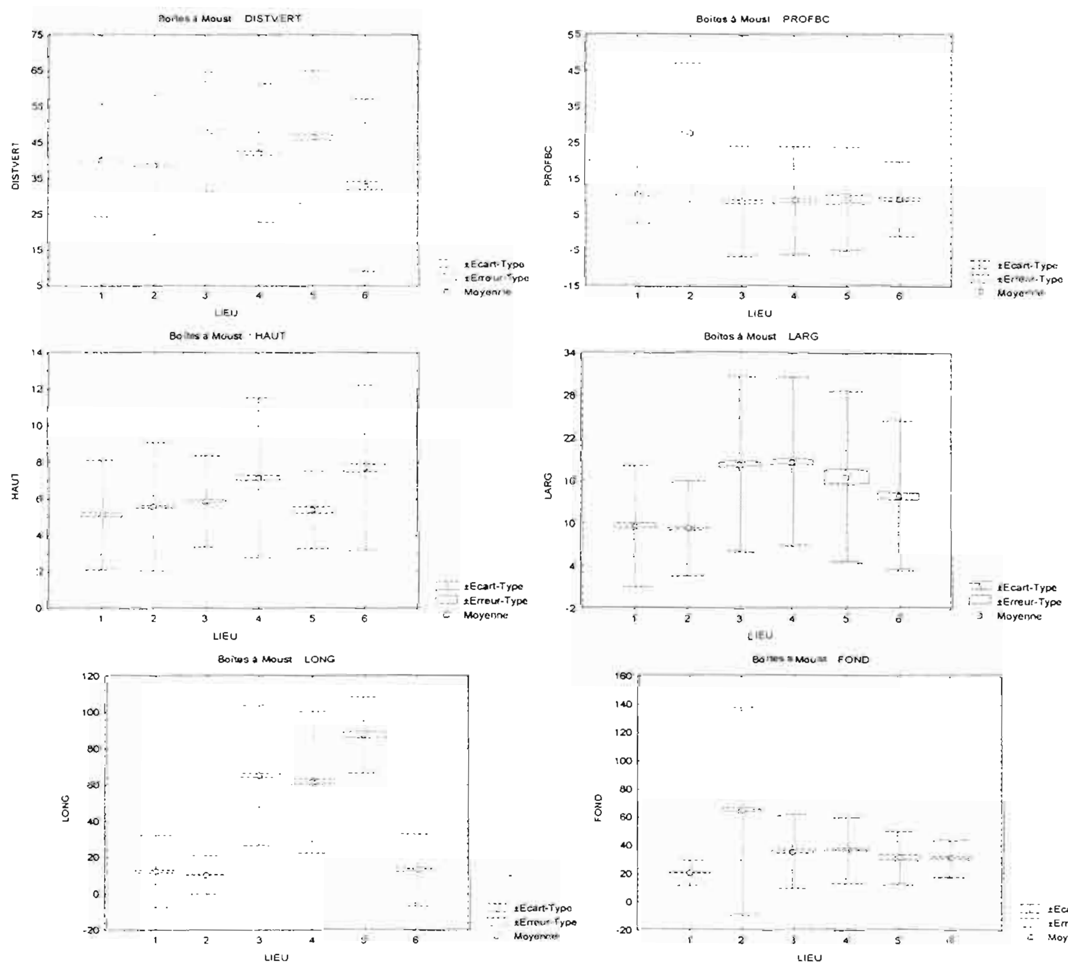

Figure 10. Description of the main characteristics of the schools for each region (in each figure, from left to right : 1 Adriatic, 2 Catalan, 3 Senegal, 4 Venezuela, 5 Ivory Coast, 6 Mexico ; top left: mean distance to the vessel; top right: mean depth of the school; mid left: height of the school; mid right: width; down left: length; down right: bottom depth. Statistics: mean value, standard error, (erreur type).

and Catalogne (very deep waters). The observation of median values, which is less influenced by outliers, shows also that the catalan schools are deeper than the others.

- we cannot see any significant relationship between the school height and the bottom depth.

It was interesting to evaluate the effect of the distance to the vessel on the school shape, which could be in part due to a vessel effect and changes in shape due to avoidance. The figure 11 presents the main features.

- both length and width obey a particular pattern where the dimension is small close to the vessel, increases until around 20-30 m from it, then remains stable up to 60 m and decreases again.
- the height and the depth of the school follow a common pattern, where the school is the smallest and deepest close to the vessel then regularly increases its height and becomes closer to the surface.

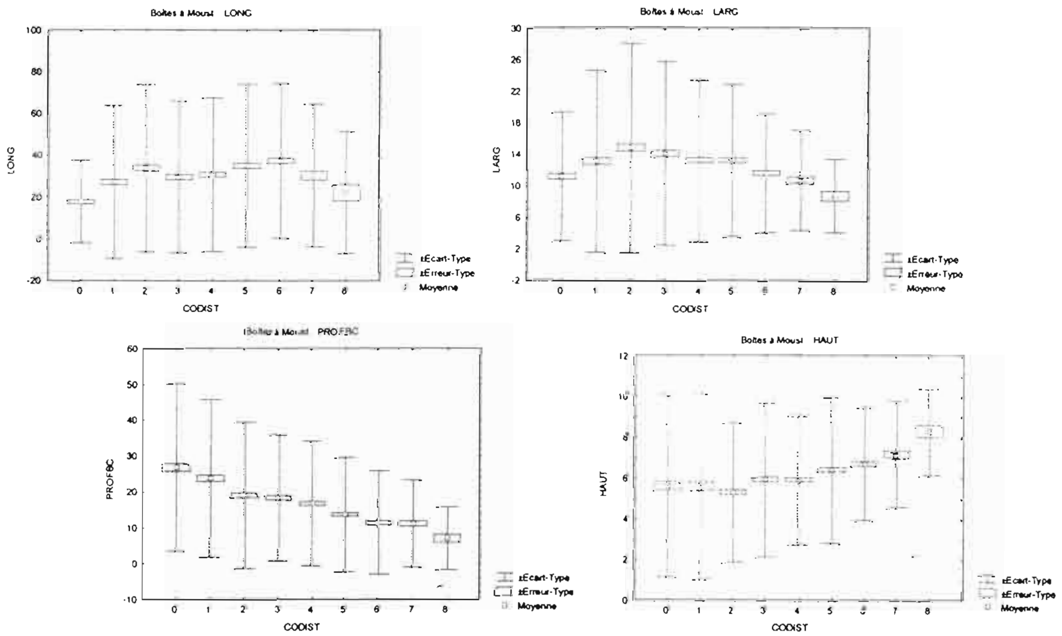

Figure 11. general characteristics of the schools (all regions gathered) according to the distance to the vessel (0 : 0 to 10 m; 1: 10 to2à m, etc.): top left:length; top right: width; down left: depth of the school; down right: height of the school.

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. 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 in 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).

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 Mexican data); 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. It is not apparent in Mexico and Venezuela, due to the lack of the first peak.
- Relationships between school depth and height and the distance to the vessel, as described above.

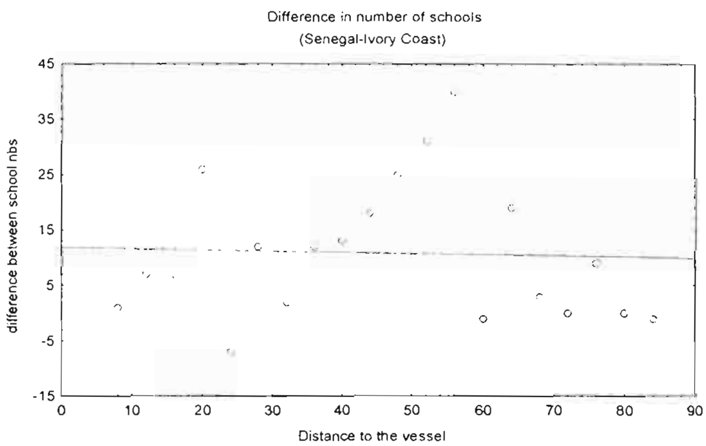

Figure 12. Values of the difference in abundance of schools between Senegal and Ivory Coast for each distance to the vessel

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. We may add another feature in Soria's avoidance model, which is that the avoidance is also reflected in the height of the schools and their depth: close to the vessel the school is deeper; this indicates that it dives vertically, and its height is smaller: there is a compression effect during the diving behaviour. This was already noted by Gerlotto et al (1992) when comparing the height of the schools at different depths. Therefore the avoidance is a 3D reaction, mostly horizontal with a relatively limited vertical effect. Nevertheless there is a rather important difference between the two groups that have been noted. We suggest 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 bottom 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 horizontal 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 is also polluted by this background noise. In these conditions, this noise could affect the capability to observe and count the schools at and farther than 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.

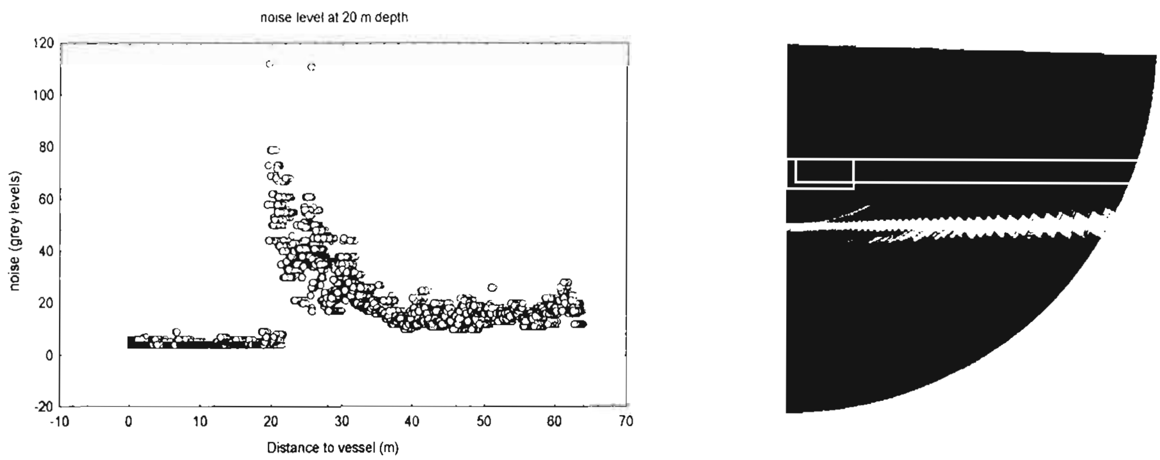

Figure 13. Values of background noise in a sonar image. 13a (left): values of echo energy (in volts) coded in a 256 grey level scale, for all the pixels included in the yellow rectangle in the sonar image (13b, right). In this example the bottom depth is 30 m.

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. Volpatti (1999) listed the most important factors affecting the avoidance, which are the species, the bottom depth, the fish age (length), the temperature of the water, the period of the day, the physiological condition of the fish. Obviously not all these parameters were studied in this paper and more work should be done in order to model the avoidance; But some conclusion can be drawn from our results. Particularly our data allow considering the effect of the species, which is likely to have a very important impact. This can be suspected in our data: the group Senegal-Venezuela-Ivory Coast, where a single species, *Sardinella aurita*, is largely dominant, presents similar features, slightly different from the other regions (Mediterranean, with *Sardina pilchardus* and Mexico with *Sardinops sagax*). The comparison of several survey data in different areas shows also that the bathymetry is likely an important factor: the shallowest the area and the strongest the horizontal avoidance compared to the vertical avoidance. Apart these results, our data are not in contradiction with other considerations. The vessel noise is known to be the most important factor, 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 stocks (Senegal, Mediterranean, Ivory Coast) and underexploited stocks (Venezuela and Mexico).

Finally these remarks lead to two main conclusions/recommendations:

- avoidance is definitely a coherent behavioural process which follows some patterns, among which the "double wave of avoidance" is generally observed;

- Avoidance depends upon a number of parameters, which reinforces our suggestion to record permanently this parameter during an acoustic survey, by the use of multibeam sonar.

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