EFFECT OF *IN SITU* RADIATED NOISE OF THE PLATFORM USED ON SHALLOW WATER AREA ON ECHO SOUNDER DATA IN FISHERIES-ACOUSTICS

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The shallow water area of the coastal fringes is important to take into consideration in fish stock assessment because a great part of the stock, especially for the small pelagic fish is distributed in this area (20). In shallow water research vessels are prohibited to navigation (usually <20m) and usually only small boats can be used. One of the main source error in acoustics fish sampling is due to the avoidance reaction generated by the three dimensional noise diagram emitted by the boat. In this paper we highlighted the importance of wind direction and strength in the noise diagram emitted by the boat under in situ condition. A comparison of the noise level of two boats (a Research Vessel and a Speedboat equipped of similar echo sounder) has been made before simultaneous records of echo sounder data: the speedboat is more silent as revealed by in situ hydrophone measurement and near the ICES recommendations. The observation of shoal echo sounder descriptors shows an avoidance reaction as expected more important for the noisier boat: there the schools avoid more the research vessel. The avoidance reaction is characterised by a deeper position of the fish school barycentre, in the water column, detected by the research vessel and a shoal minimum depth higher than for the speedboat. The effect of noise diagram difference is clear on the same shoal descriptors, the difference appears for the vertical position of the barycentre and minimum altitude.

INTRODUCTION

The assessment of many fish stocks is now to be done on the result of echo integration methods (23). The major bias of such data is the fish school avoidance (14, 26), the fish is not recorded on sounder beam due to a horizontal (2, 26) and downward (18, 32) swimming reaction of escape in front of a research vessel (31). This reaction has been studied by many authors (2). The main factors of such a reaction is due to the noise emitted by the boat as it was reviewed and recommended by ICES (27); $SPL=135-1.66\log f_{Hz}$ between 1 Hz and 1 kHz and $SPL=130-22\log f_{kHz}$ between 1 kHz and 100 kHz (see annex). Under this level of noise generated by the boat, the fish schools do not avoid survey vessels (8) and then follows the recommendation of ICES for fisheries research (27). Underwater noise of research vessels as it has been presented in the literature (17, 25, 32) is clearly the main factor of such a reaction. Coetzee et al., (5) made experiments with small boats and two echo sounders as the experimentation described in this paper (3) and observed fish school variations of their descriptors. We want to formalize the noise variation between the two platforms measuring by compatible methods the noise level emitted by two platforms: a "fisheries research vessel" and a shallow draught boat. In this study we have made a comparative analysis of the two echo sounder data, Target Strength (TS) (23) and mainly the shoal descriptors (7) which constitute the essential part of the "converted biomass energy" studied across national evaluation of small pelagic fish in the French Mediterranean Sea.

The noise level sensibility of the small pelagic fish (in this case mostly Clupeid and Engraulidae), targeted by the echo integration process, is situated between 30 and 500 Hz and more recent studies show a sensibility over 4 kHz. The effect of visual stimulus generated by the arrival of the boat has not been formally studied. Although it seems evident, it is difficult to formalize, because of a lack of *in situ* useful data and as a lot of highly variable biological processes. This effect should highly vary under the effect of: species, physical environment (temperature, salinity, etc.), local conditions (turbidity, weather), etc, which can produce misleading in statistical analyses. Anyway the results remain the same, the complex avoidance reaction of echo sounder target (fish and shoal) on shallow water area. The noise level of the used platform is now easy to measure (motor, propeller, hull) (6, 27), *in situ* variation of the environment, as the wind direction, which makes that the choppy sea can be suspected to produce a higher noise according to the shape and structure of the boat hull.

1. MATERIAL

The data have been recorded during one national annual surveys of Ifremer *Pelmed 2002*. The main species are small pelagic fish, anchovies and sardines. We used acoustics methods, the classical "echo integration" process (11, 23) from a *Simrad EK 500* echo sounder (table 1). In order to estimate the importance of the littoral area, in shallow water (30-5 meters), a small boat equipped of a portable echo sounder *Simrad EY 500* (table 1) has been used for insonifying the area not covered by the research vessel and the common transects between (30-10 meters) (19). The both split beam echo sounder (9) had been calibrated before the surveys (10). The two boats (table 1) have aluminium hulls, the research vessel *"L'Europe"* is a Catamaran useful for open sea and the *"Chlamys"* a speedboat with shallow draught has a flat hull convenient for lagoon investigations ; their characteristics are summarized in the table 1.

Table 1: Settings of the two echo sounder and the main characteristics of the two boats.

Sounder	Simrad EK500	Simrad EY500
Acronym/ boat	VES 1(L'Europe)	VES 2(Chlamys)
Surveys	2002	2002
Frequency (kHz)	38	70
Beams	Split	Split
Beam shape (°)	6.8 * 6.6	11**11
TVG	20 and 40 log R	20 and 40 log R
Ping rate	auto	auto
Pulse duration (ms)	0.3	0.3
Range (m)	auto	auto
Beam position	vertical	vertical
Sound celerity ($m.s^{-1}$)	1540	1540
Boat	R/V L'Europe	Chlamys
Gross t.	264	1.5
Length (m)	29.6	10
Width (m)	10.6	3
Aft draught (m)	3.5	0.5
Power (kw)	2*345	2*86
Motor type	diesel	petrol
Hydraulic block	yes	no
Elect. power	yes	no
Acoustic devices	yes	yes
Hull colour	blue/white	blue/Aluminium

Special experiments (Ifremer, 9-10 October 2002, Sète, France) have been lead to estimate the noise "Ns" (dB uPa/Hz 1 meters) emitted by the small boats in order to obtain compatible data with the experiments already lead on the *R/V L'Europe* (4) and to evaluate the effect of the atmospheric condition on the Ns values. The radiated noise emitted by the Chlamys has been recorded by a hydrophone (*ITC 8095*) at an immersion depth of 2.5 meters along the port (local depth dock: 7 meters). The boat has made repeated straight transects at different constant speeds (motor rpm (row per minutes) and directions relatively to the wind (Sector East between 20 to 30 Knots with rainfall). The data have been recorded on DAT (listen station: preamplifier *EGG*, speaker) and processed by classical spectral analysis (*HP 3562A*) between 10 Hz to 20 kHz (1). The acoustic ambient noises (33) of the experiment area had been previously measured, which gives, by adding the propagation loss the threshold of our Ns measurements generated by the Chlamys.

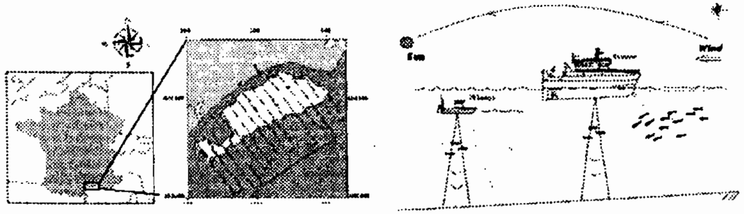

Figure 1: Map of the transects covered by the two boat during two days (29 July and 1st August), area of common transect in white. The two boats used as *in situ* platform to record simultaneously the fish echo sounder data. The noise level emitted by the boat and its shadow, as stimulus on the fish behaviour, influence the sampling.

2. METHOD

The sampling data on shoal structure (7) or "sounder fish school detection", have been chosen by the overlay of the two boats transects (figure 1). All the *R/V L'Europe* data recorded outside the simultaneous transects with the Chlamys, which sampled specially the shallow water, have been removed from the analysis. Exceptionally, the captain of the *R/V L'Europe* continued the transect over the depth of 20 meters in order to join the Chlamys one. The two boats have assumed the leader boat position alternatively for each successive transect. The data selected, TS (24) by night and shoal descriptors (312) by day, delivered by scientific echo sounder have been recorded between a depths of 30 to 10 meters on a transect of 39 miles.

The Target Strength (TS) of individual fish are analysed trough *Movies+* software (7) for the EK500 data and on EP500 software for the EY500 Simrad sounder data. Characteristic discriminations of individual targets are: minimum and maximum returned pulse width 0.6 to 1.8 fold the transmitted pulse duration, maximum gain compensation 6 dB, maximum phase deviation 3 phase steps (21). Noise thresholds were set at -60 dB for target strength (TS) in 40 log R time-varied-gains, and -55 dB for volume scattering strength in 20 log R data.

The echo integration processes by shoal have been processed under *Movies+* algorithm (7). *Movies+* provides the morphometric shoal descriptors in meters according to elementary rectangular sample of dimension defined by the distance travelled since the previous shot and from the previous sample (7). So "L" is the length of shoal, "H" the height of shoal, "P_{min}" the minimum depth, "A_{min}" the minimum altitude (bottom distance), "Prof" the local depth, "Peri" the perimeter of the shoal, and "A" the area of the shoal (m^2). The parameters used which define the shoal specification are : $2.10^{-6} < Energy\ (\sigma_{sg}/m^2) < 100.10^{6}$; $1 < height\ (m) < 500$; $1 < length\ (m) < 1000$, $2 < area\ (m^2) < 500$, and $-55 < density\ (dB) < 0$ (offset: 5 meters). We prefer discriminating all the shoals even if they are really small, their presence informs on the presence of a fish school (maybe taller). The very small groups, defined by valid Corrected Sv values (7) and area corrected inferior at 10 m^2, are removed from the second comparative analysis of echo sounder descriptors delivered by the two boats.

3. RESULTS

Comparative spectral analysis of in situ *noise of the two echo sounder platforms*

At a constant speed there is a variation of the noise level, mainly at high frequency (10 kHz), according to the position of the boat in front of the wind direction (here: East). The Ns values are superior (between 1 to 19 Ns units i.e. dB ref micro Pascal) when the boat sails in the East direction in front of the wind than in the West direction, except for one measure at 100 Hz and 6 Knots (table 2).

Table 2: NS variation for the Chlamys, at constant boat speed (Knot) between the East and West transects (NS East –NS West).

Chlamys Speed	100 Hz	1 kHz	10 kHz
6 Knots	-5	3	19
8 Knots	1	8	14

The local ambient noise(s) (figure 2) makes a blind zone on the noise level measurement presented in our results. Hopefully the ambient noise is lower than the research vessel *L'Europe* noise, and there is no problem to show that the *Chlamys* is quieter than the

R/V L'Europe. Around 50 Hz for the *Chlamys*-East (figure 2); there is a peak of noise, which can be due to the hydrophone generator (preamplifier DC supply).

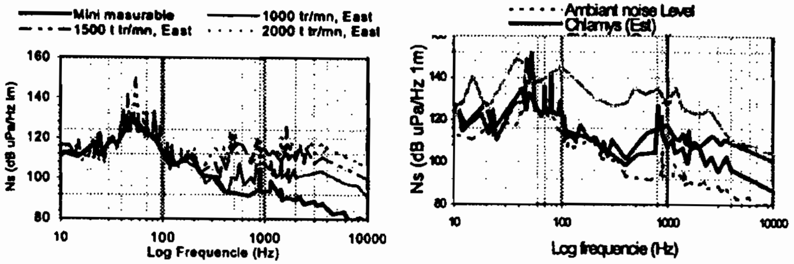

Figure 2: Noise in dB uPa/Hz 1meters from 10 Hz to 10 kHz (logarithmic scale), generated by the Chlamys according to the bearing relatively to the wind direction (East blow). And the second spectral analysis compares the noise of the two boats at 8 knots and the ambient noise of the experiment area.

Individual target strength of fish

The TS distribution recorded by the two boats indicates a strong schooling behaviour during the day and scattered structure during the night as expected by the diel variation of Freon et al. (13). During the day, the great part of the pelagic fish is aggregated in school detected by sounder beam. During the night there are numerous individual Target Strengths of fish, scattered across the water column. The results show that the TS distribution (figure 3) recorded by the two boats is significantly similar (Smirnov test, $p<0.001$). The area was divided in three parts (the first one near the shore, the last one, in the deeper zone) and there are no significantly difference (Smirnov test, $p<0.001$) (30) between the TS distribution in the three areas.

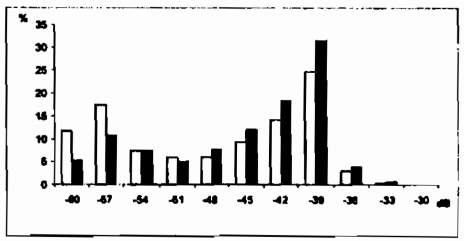

Figure 3: example of TS distributions from the EY500, 70 kHz (white) and EK500, 38 kHz (black), from the same area.

Acoustics discrimination of shoal sounder detections: position, shape and energy

On 327 schools selected there are 15 schools detected by sounder which give corrected dimensions equal to 0 and no values can be given for the "Sv" corrected. There are 153 schools, including 15 very small ones, detected for the *l'Europe;* 159 schools for the *Chlamys*. We made variance tests of the boat noise effect on the normal distribution of shoal depth; the non-normal variables were translated to logarithmic scale (table 3). Two series of processes have been lead: on the total schools (312) and on the 125 bigger ones (see § method). The corrected areas of the schools (as the non log) have no significant difference the

same for the perimeter and minimum altitude of the shoal values, which seem similar for both echo sounder data. The schools detected by the *Chlamys* have a significant ($p<0.001$) higher depth of their barycentre; their minimum depth ("Pmin") is higher than the *R/V L'Europe* one.

Table 3: ANOVA, Univariated Tests of Significance for echo sounder shoal descriptors, (without the 15 too small school: n=312), effect marked (*) at $p<0.001$. *Italics* descriptors selected school (removed Area corrected >10m²: n=123).

	SS	Degr. of	MS	F	p
Log P_{min}	0.5497	1	0.5497	16.16	*0.000073
Log A_{min}	0.0002	1	0.000197	0.000212	0.988383
$Prof_{bary}$	354.00	1	354.00	11.797	*0.000678
Log $area_{cor}$	0.1003	1	0.1003	0.2938	0.588217
Log $peri_{cor}$	0.1567	1	0.1567	1.277	0.259440
Log P_{min}	0.7300	1	0.7300	24.845	*0.000002
Log A_{min}	0.2272	1	0.227232	0.241949	0.623678
$Prof_{bary}$	370.33	1	370.33	17.377	*0.000057
Log $area_{cor}$	0.4361	1	0.4361	3.036	0.083927
Log $peri_{cor}$	0.0422	1	0.0422	0.631	0.428520

The corrected areas "area cor" of the school have no significant differences but they are superior for the Chlamys on the average. The perimeter and minimum altitude of the shoal values are similar ($p<0.05$) for both echo sounder data. The schools detected by the Chlamys have always a significant ($p<0.0001$) higher depth of their barycentre.

4. DISCUSSION

The discussion will deal with the *in situ* measurement of the noise experiment of *Chlamys* speedboat, and then we propose to show by preliminary results (additional data are in processes 2001 surveys and shoal energy descriptors at several frequencies) how and why echo sounder data can be influenced by the platform used to insonify the fish.

The spatio-temporal variability of fish does not occur here due to our sampling methods: the simultaneous record of the two boats transects (same position and same time) with alternative boat leader positions.

In situ measurement of the platform noise level

The *Chlamys* speedboat *in situ* measurement seems to place it near the recommendation of ICES (27) on underwater noise of fisheries research vessel. The radiated noise measurement on the research vessel *L'Europe* has been made during sunny weather and no wind on the hydrophone field of "*Lanvéoch*" (4), our measure allows comparing it to the *in situ* Chlamys one. The radiated noise of the R/V *L'Europe* is lower at 8 knots by 4 knots as expected (diesel propulsion and variable pitch propeller). The spectral analysis leads on the *Chlamys*, revels a radiated noise lower than the noise generated by the research vessel *L'Europe*. In lower frequencies (<100 Hz) the *Chlamys* noise, at several frequencies, cannot be discriminated from the ambient noise, but its noise level remains under the *L'Europe* one. Then as expected the noise increases with the *Chlamys* speed, particularly (figure 3) at high frequencies (10 kHz) where we can find variations around 40 dB (a factor 100); less at intermediate medium frequencies. Some noise peaks sometime appear mainly at low frequencies (e.g. in Hz [25, 42, 83, 95]) but also at medium frequencies (e.g. in Hz [900]). We did not find any effect between the noise peak and the *Chlamys* speed.

The *in situ* measurement with strong East blowing winds allows a comparison between east and west transects under an important ambient noise level (shallow water 7 meters and rainfall). The effect of the choppy sea (although the dock experiment decrease the sea noise state at 30 Knots) on the flat aluminium hull of the *Chlamys*, seems to produce additional noise mainly in the high frequencies (10 kHz); at 1 kHz the difference with the *L'Europe* decreases to 20dB (factor 10). The ambient noise level is sometimes (when rainfall or wind increases) higher than the *Chlamys* boat under 300 Hz.

We set up a future experiment during sunny day (no wind) which will permit to have a more detailed spectral analysis (lower ambient noise) but also new value without choppy sea surface. Ideally the three-dimensional vessel noise directivity diagram as described by (16, 25, 31) should be produced. For instance it is necessary to use heavy logistic procedures particularly for vessel measurement.

Effect on fish target of the platform radiated noise

Our experiments which have been done on the same shoals and small pelagic fish species (*Sardina pilchardus, Engraulis encrasicholus*) with the two different platforms (figure 1) show different results on echo integration by shoal.

As expected the results show a decrease of the number of fish schools (153 *L'Europe*/159 *Chlamys*; for 123 large shoals (>10m²) 60 *L'Europe*/63 *Chlamys*) on the *L'Europe* echogram in front of the Chlamys one. The shoal position descriptors show significant different behaviours according to the platform. The schools avoid the *l'Europe* more vertically (18; 14) because the shoal barycentre ($\Delta \overline{Prof}$ =-1.68 meters) and their minimal depth is deeper ($\Delta \overline{P}$ =-1.84 meters) than for the *Chlamys* shoals. Effects on large schools (>10m²) remain the same but a trend of higher area of *L'Europe* shoal seems to appear, which needs more data to be validated. Although there is no significant variation of "A_{min}", the schools detected with the higher altitude have been detected to the Chlamys. The positions of the *L'Europe* shoals indicate a downward avoidance reaction more important than aboard the Chlamys one.

In situ target strength studies analyses are needed as Gauthier et al. (15), and complementary data on shoals (same experiments lead in 2001) allow validating our observations. The combined effects of individual fish downward components in front of the vertical sounder beam and global shoal (and individual fish) avoidance of the sounder beam (3) also influence the relative biomass estimates per surveys. The detections of fish in the sounder beam indicate their presence if they have not avoided the vessel. But the reverberated signal can decrease by a change in the individual fish position inside the group (15, 18) as shoal dimensions. A "density draining" (28) can also occur. Shoal positions in the water column inform on vertical reaction, which reflect an avoidance reactions of the platform.

The vessel size effect must include boat noise (27) but also the visual effect of the boat (or/and is shadow) by day and full moon (Ratio boat/individual fish of 15 cm: 233 for the *L'Europe* and 46 for the Chlamys). By night there no fish school to improve avoidance reaction and no visual stimuli: we record numerous TS on individual than by day we have detected no significant individual fish target strength. On both signal detections by one or several fish of the shoal is transmitted as a frightened signal to the others member of the fish school which produces characteristic collective escape movements as described by several authors (12, 18, 25) has presented the effect, during fishing action, of a change of the three

dimensional noise boat diagram of directivity on fish behaviour (figure 4). Gerlotto (18), shows the effect of light on echo sounder data by night that reveals the influence of visual stimulus, as Soria (29) who combined visual (net) and acoustic stimuli in water tank experiment. Direct observations as described in the literature show the visual effect of the predator attacks on fish schools (avoidance reaction, splitting, fountain effect etc…). All these facts show the influence of acoustic but also visual effect on fish behaviour.

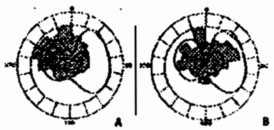

Figure 4: Three dimensional fishing boat noise directivity diagram according Misund (1987); A and B characterised the three-dimensional radiated noise change during fishing operation.

5. CONCLUSION

In situ measurements of radiated noise can vary in an interval of (20 dB) according to the wind direction. The ambient noise during bad weather condition (wind, rainfall) can cover the sound perception of fish below 300 Hz at low boat speed, without any consideration to an increase of this threshold with the bottom and surface sound reverberation effect (22) on radiated noise at long range on shallow water area. The speed boat Chlamys (Ifremer-Sète) equipped by portable acoustics devices follow the recommendation of ICES for leads fisheries surveys (which constitute a serious alternative to onerous quite devices) and so have to be recommended for assessment propose by echo integration methods particularly in very shallow water area.

In shallow water and during daytime (sunny weather) the effect of boat noise on fish school avoidance appears to be as expected a downward vertical shoal position (*L'Europe* shoal descriptors show a "downward reaction" more important than the Chlamys one) but we don't find any change in shoal area and perimeter. It appears as usual that there is no significant individual fish detection (at a distance inferior at ct/2) on daily echo sounder records on the both boats which constitute a typical response of aggregative fish species to alarm signal. The visual effect of boat and/or its shadow can constitute the major stimulus of alarm signal in fish avoidance in shallow water and so have to be taken into consideration in shallow water area as the variation of ambient noise level with the *in situ* condition.

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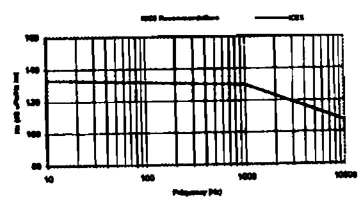
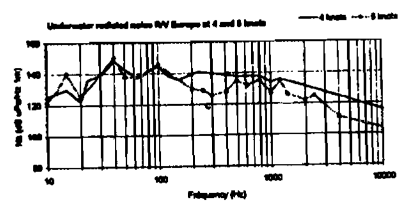
ANNEX





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Effects of in situ radiated noise of the platform used on shallow water area on echo sounder data in fisheries acoustics

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