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# AN EXPERIMENTAL INTERCOMPARISON OF UNDERWATER NOISE EMISSIONS FROM RESEARCH VESSELS

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## ABSTRACT

Oceanographic research vessels are platforms to carry out acoustic surveys to assess pelagic fisheries resources, using scientific echosounders like Simrad EK60. The quantitative use of echosounder's data requires a precise determination of background noise since a good signal to noise ratio (SNR) is determinant to have an accurate estimation of fishery resources.

This paper presents a new systematical analysis of noise test results method. Three different research vessels (R/V) have been analyzed proving that only 18 and 38 kHz frequencies are influenced for vessel's propeller system.

## RESUMEN

Los buques de investigación oceanográfica son plataformas sobre las que se llevan a cabo las campañas de Evaluación Acústica de Recursos Pesqueros, mediante la utilización de ecosondas científicas como la Simrad EK60. Para la utilización cuantitativa de los datos obtenidos es muy importante la determinación de los niveles de ruido de fondo para tener una relación señal-ruido que permita obtener mejores estimaciones de los stocks.

En este trabajo, se presenta un nuevo método de análisis sistemático de los resultados de las pruebas de ruido. Se han analizado tres buques oceanográficos de distintas características y se ha observado que sólo las frecuencias de 18 y 38 kHz se ven afectadas por el sistema propulsor del buque.

## INTRODUCTION

In the last few years underwater acoustic noise characterization is getting increased interest. Noise is defined as unwanted signal present in the medium and, in this particular case, R/V produced and its effects on fish abundance estimation.

Previous studies indicate that noise produced by vessels could modify fish behavior and bias survey estimates of stock abundance. Ona *et al* detected that pelagic species avoid vessels located 200 meters away by vertical or horizontal movements to look for lower noise levels areas [1]. International Council for the Exploration of the Sea (ICES) published in 1995 a report with the noise limits proposals for R/V for both lower frequencies detected by fishes (<1 kHz) and those used by ecosounders (>1 kHz).

Nowadays, R/V have been designed to carry out these low noise specifications, although some studies indicated that they are not needed. For example, De Robertis *et al* studied an inter-vessel comparison between two R/V belonging to the National Oceanic and Atmospheric Administration (NOAA), silent R/V and conventional R/V, to estimate biomass of walleye Pollock (*Theragra chalcogramma*) in the Behring Sea, without significant differences [3], although following studies of same authors found some differences [4-5]. Fernandes *et al* performed an inter-comparison between silent R/V Scotia and an autonomous underwater vehicle (AUV) and found no significant differences in the biomass estimate of herring (*Clupea harengus*) [6]. De Robertis and Handegard [7] in 2012 published a review of fish behavior related with underwater radiated vessel noise.

Sources of underwater noise could be physics, biologic or man-made. In ultrasound frequencies used by echosounders (from 18 kHz to 333 kHz), main noise sources are: ambient, radiated sound associated with wind, rain, etc, thermal, produced for molecular turbulence, electronic, due to transducer's electronics components and echosounder and finally noise produced for the ship, whose main sources are, propulsion system, hydrodynamic and machinery vibrations. Ambient noise decreases with frequency, except thermal noise whose rises with frequency. Ship noise produced is higher at low frequencies (<1 kHz), decreases when frequency increases and rises with ship velocity.

The low frequency noise requirements (<1 kHz) are essential to avoid the effect on the biological species, on the other hand, recorded noise at echosounder transducers, in frequencies bigger than 10 kHz, the purpose of this work, could modify small pelagic species behaviour and, consequently, abundance estimates. Main noise sources in those frequencies are ambient noise, especially thermal noise and propeller's cavitation noise, which is velocity dependant.

In R/V low noise ships, it has been found that cavitation, which occurs in fixed blade propellers, appears in most cases around 9 knots and increasing speeds. As a compromise, common acoustic surveying velocity is around 10-11 knots because lower velocities would increase the cost of acoustical surveys.

Small pelagic species biomass estimate carry out for the Spanish Institute of Oceanography (IEO), is based in the measure of $s_A$ or Nautical Area Scattering Coefficient (NASC), that is the measure of the energy returned from the targets detected in a determinate volume, reduced to two dimension and for a nautical mile, usually with measurements at 38 kHz frequency. Nevertheless, with the aim to identify or quantify other marine species like plankton or specific species, higher frequency information is required, for that reason, the R/V have installed 18,70,120, 200 and in some cases 333 kHz transducers. Nowadays, there is a rising interest for the use of wideband echosounders, like Simrad EK80, that allows for obtaining information in a continuous frequency bandwidth, from 10 to 500 kHz, that makes possible differentiate species for their acoustic dispersion spectrum [9]. Routine vessel velocity for the IEO's acoustics surveys is 10 knots.

This paper presents an experimental intercomparison study of high frequency noise registered at the echosounder in three different R/V and its relationship with the vessel speed and frequency.

## MATERIAL AND METHODS

The experimental intercomparison has been made in three different R/V, usually used in IEO yearly acoustic stock evaluation surveys. The main features of the R/V are described in Table 2. The R/V Ramón Margalef (RF) is slightly smaller than the others, have installed the echosounder's transducers in a retractable keel and have two propeller shafts with one propeller each. Miguel Oliver (MO) and Thalassa (T) have a single propeller shaft with a fixed blade propeller. T is a R/V that belongs to Ifremer (*Institut français de recherché pour l'exploitation de la mer*) and has been described in some works like a very silent R/V [10]. All of them have been designed and constructed according to ICES noise specification [2].

Studied data correspond to acoustics surveys carried out between 2014 and 2017 (Table 1). The MEDIAS survey, was carry out in the Spanish Mediterranean Sea during June and July, PELACUS survey was conducted in the South Galicia and Cantabrian Sea during March and April, RECLUTAS survey was carry out in the Spanish and Portuguese waters off the Gulf of Cadiz during October. The INTERPELACUS 2014 survey was an intercomparison between R/V MO and T that was carry out near to the mouth of Garona River in April.

**Table 1.** Stocks evaluation acoustics surveys with background noise test.

| Survey name | Year | B/O |
|---|---|---|
| PELACUS | 2016-2017 | MO |
| MEDIAS | 2015-2017 | MO |
| RECLUTAS | 2014-2016 | RM |
| INTERPELACUS | 2014 | T/MO |

**Table 2.** Characteristics of R/V studied. All have been designed according to ICES noise specification [2] and all used an electric propulsion system and fixed blade propeller.

| B/O | Length (m) | Beam (m) | Draught (m) | Power (CV) | $V_{max}$ (kn) | Propulsion | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Shafts | Nº blades | $\phi$ (mm) | $V_{max}$ (rpm) |
| MO | 70.0 | 14.4 | 5.5 | 2x1359 | 14.0 | 1 | 5 | 2850 | 178 |
| RM | 46.7 | 10.5 | 4.2 | 2x1223 | 13.0 | 2 | 5 | 2300 | 230 |
| T | 73.7 | 14.9 | 6.1 | 1x2900 | 14.7 | 1 | 6 | - | - |

Three vessels have installed Simrad EK60 echosounder with 18, 38, 70, 120, 200 and 333 kHz transducers (Simrad ES18-11, ES38B, ES70-7C, ES120-7C, ES200-7C, ES333-7C, respectively) although MO does not have 333 kHz transducer and in 2015 was installed 70 kHz transducer.

All the cases studied have been used the same protocol for the background noise test, that consist on with the transducers working in the passive mode, increase the vessel speed from 0 to 10 knots, with 10 minutes constant speed intervals (0, 2, 4, 6, 8 and 10 knots). Depth remained constant during the test. Figure 1 shows an example of evolution of speed versus time. The data were stored in raw in order to realise future analysis.

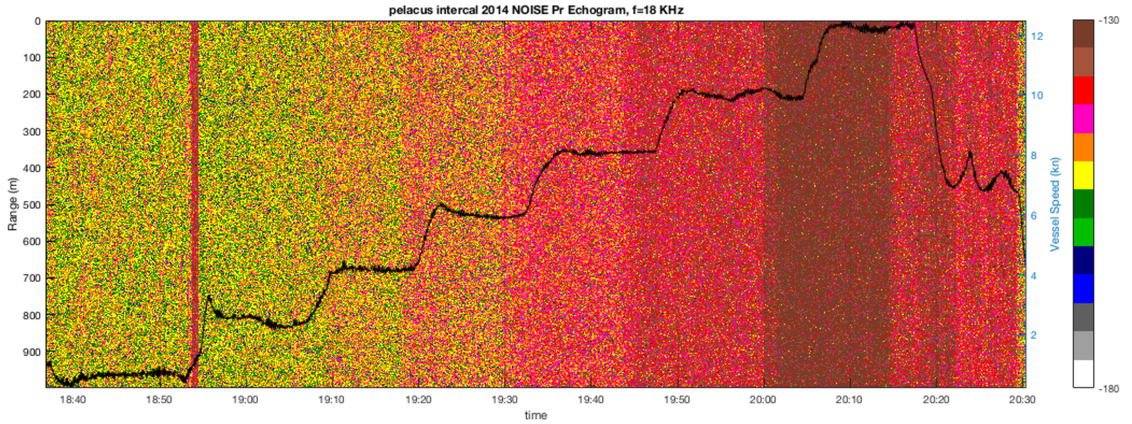


Figure 1. Echogram of the background noise test from INTERPELACUS 2014, carried out with R/V MO. The figure shows power detected by echosounder for ping time intervals (columns) and during test time (horizontal axis). Black line represents instant vessel speed (knots).

Raw data recorded during the test was reading with a custom Matlab script (R2017b, Mathworks) developed for this specific study. With results of backscatter power graphics as Figure 1 were obtained, here can be observed that backscatter power level doesn't change with depth, because the system worked in passive mode. For this reason, it is possible to use all data of depth to obtain a bigger and statistically significant sample of background noise levels
for each velocity of interest or even in time depending.

Figure 1, also show with a superimposed black line which reflects the R/V instant vessel velocity data, this data was used to select a zone of interest for statistical analysis. As an example, in Figure 2, noise power histograms are displayed for different vessels speeds. Figure 2 also shows that experimental data seems to conform an asymmetric unimodal distribution (the data are represented in dB) with a high number of outliers, that must be excluded to obtain average values. That is the reason for the exclusion of 1% extreme values on both sides of histogram (L01 and L99 percentiles) before calculating the average value estimated, using linear values.

The method presented in this work differs than others previously published. Takao and Furosawa [11] recommended the integration of $s_V$ data at depth higher than 200 m in order to avoid errors derived of using small power values obtained by Time Varying Gain (TVG) correction at lower depths. Later the variability of results was reduced by adjust of minimum squares of the R/V speed evolution curve.

In the other hand, Watkins and Brierley [12] use the $s_V$ data calculated with reading echogram software for background noise estimation. The $s_V$ data depend on depth, then they realize the data integration in the TVG correction every 2 m depth, remove the outliers by a threshold use, and used an adjust of minimum squares to fit the TVG curve to 20 log R + 20 $\alpha$R + K, (R: depth, $\alpha$: medium attenuation and K: offset). Our proposed method eliminates the correction requirements by using directly the backscattering power data that usually are not available with commercial software like Echoview. Besides, this method is less sensible to a noise variation, because works with the full range ping power data.

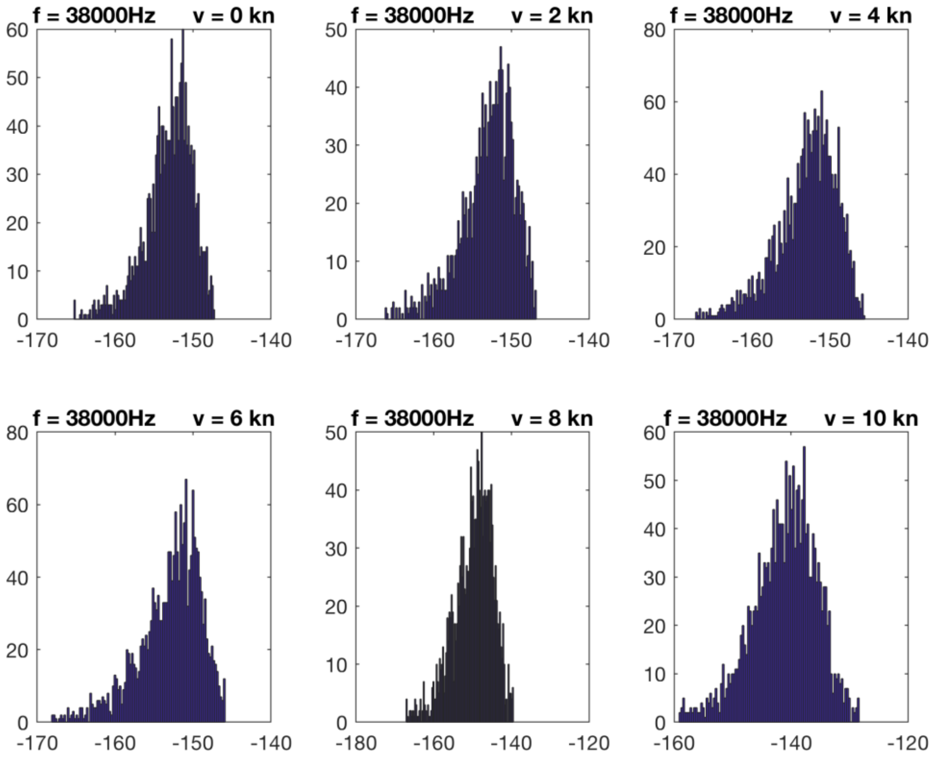


Figure 2. Noise power registered data histogram in the MEDIAS 2017 survey, for 38 kHz frequency, according to the vessel speed (from 0 to 10 knots).

## RESULTS

The results of noise registered by echosounders working in passive mode versus R/V speed of MEDIAS 2015-2017 surveys are showed in Figure 3. The 18 kHz frequency shows higher noise levels than the others and noise power increases with R/V speed from a given value, this indicate that lower frequencies with low vessel speed are mainly influenced by ambient noise, but with high vessel speed, the most important factor is hydrodynamic noise, mainly the propulsion system noise. In 2017 survey, Figure 3c, the power noise increases from 4 knots for 38 and 70 kHz frequencies. High frequencies have a speed-independent behaviour, this could be indicate that the mainly component of noise is vessel external (ambient noise or thermal noise). An example of this behaviour is show in Figure 3d, PELACUS 2017 survey have a fixed noise level in higher frequencies.

The noise levels for the evaluation frequency (38 kHz) and the survey speed (10 knots), are similar in 2015 and 2016 (-139.9 and -139.7 dB, respectively), being slightly major in 2017 MEDIAS survey (-138.6 dB). The PELACUS 2017 survey results are slightly lower (-142.5 dB).

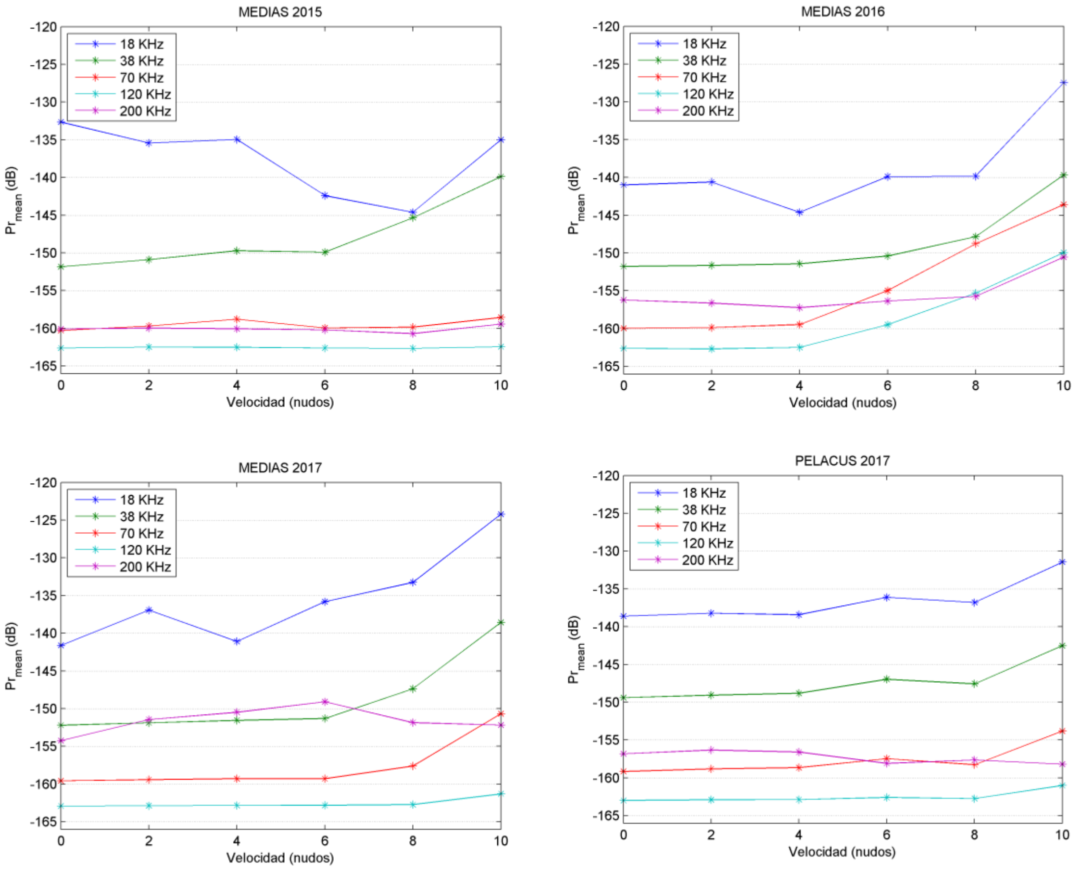


Figure 3. Echosounder Recording Noise levels working in passive mode versus vessel speed for working frequencies (18, 38, 70, 120 and 200 KHz), corresponding to MEDIAS 2015- 2017 surveys and PELACUS 2017 survey.

Figure 4 shows the results for the intercomparison survey INTERPELACUS 2014. Background noise test were carried out simultaneously the same day, at the same time and with a sufficient distance to avoid interferences between the R/V. The results show that noise level registered by 18 kHz frequency rises in both cases with the vessel speed, from -155.1 dB to -140.3 dB (MO) and from -155.9 dB to -149.3 dB (T). MO noise level is similar below 4 knots but significantly major above that speed. The noise level is fixed for 38 kHz frequency (around -150 dB) in entire speed range for MO, while T shows slightly increasing behavior (from -165 dB to -162.9 dB). The rest of frequencies, are not affected by vessel noise (ambient noise), being very similar in the two vessels for 120 kHz (-162 dB) but very different for 200 kHz (around -145 dB in MO and -163 dB in T), that indicates a shielding GPT's cables problem that was detected and later corrected.

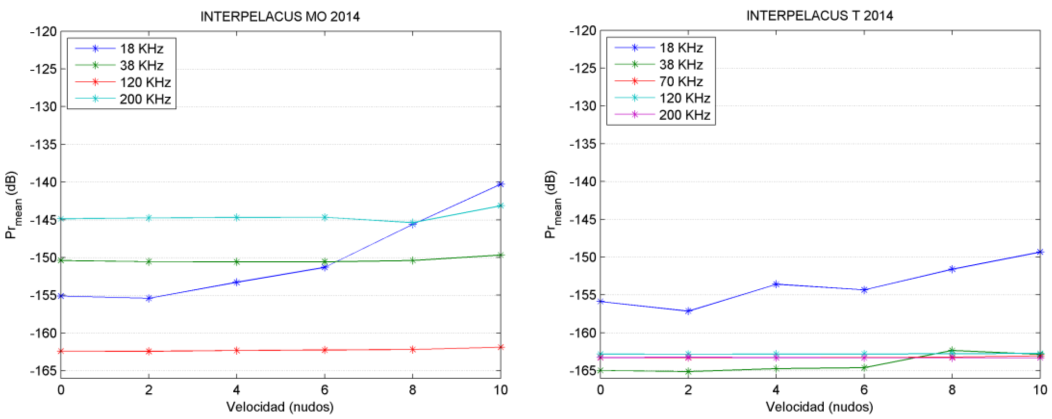


Figure 4. . Echosounder Recording Noise levels working in passive mode versus vessel speed for working frequencies (18, 38, 70, 120 and 200 KHz), corresponding to intercomparison survey INTERPELACUS 2014, R/V Miguel Oliver (left) and R/V Thalassa (right).

Figure 5 shows the results of RECLUTAS 2015 and 2016 surveys carried out abroad R/V RM. The noise levels show a rising trend in 18, 38 and 70 kHz frequencies, nevertheless 200 and 333 kHz frequencies show a stable behaviour over the entire speed range. 120 kHz frequency shows a different behaviour in both years, in 2015 have a fixed behaviour, showing a small variation between -162.6 and -160.2 dB, while in 2016, the results at lower speed are similar (around -160.9 dB) but show a rising behaviour for speeds greater than 6 knots, reaching noise levels of -153.3 dB.

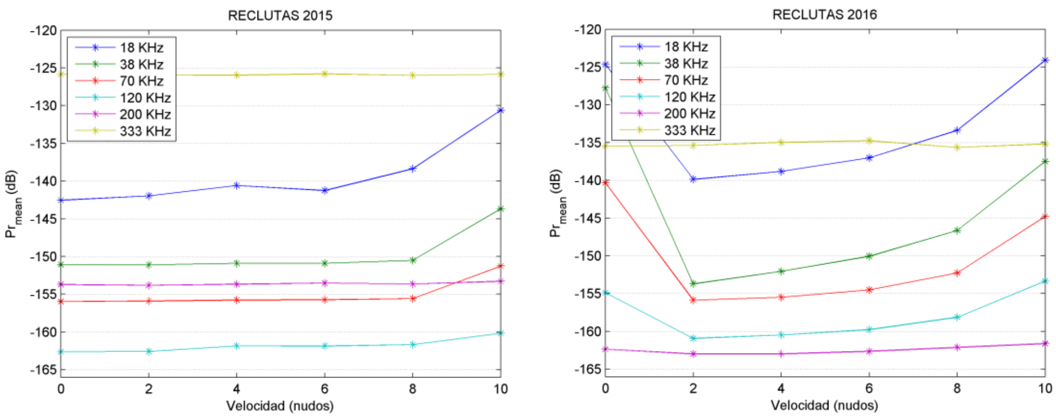


Figure 5. Echosounder Recording Noise levels working in passive mode versus vessel speed for working frequencies (18, 38, 70, 120 and 200 KHz), corresponding to RECUTAS 2015-2017 surveys carried out abroad R/V Ramon Margalef.

Comparing Figure 5 results with Figure 3a and 3b, noted that 10 knots results are slightly higher in 2016 surveys, except 333 kHz frequency that have a higher result in 2015. In all the cases R/V RM shows higher noise levels tan MO.

## CONCLUSIONS

A new systematic analysis methodology from the background noise passive test carried out in stock evaluation surveys has been presented. This methodology facilitates and improves the analysis results because detects and removes the outliers than could modify the results, as well as reduces duration of background noise test.

Results of tree R/V usually used for the IEO surveys have been analyzed, with different characteristics, in different geographical zones and different seasons.
All studies shows than the vessel noise produced, mainly produced for the propulsion system, influenced the low frequencies (18 and 38 kHz), because noise levels increases with the vessel speed, for that reason is advisable to use propellers with low rpm, and big length research vessels, in order to maintain the transducers out of the propeller action zone.

The source of high frequencies noise detected is electronic and is not influenced by action vessel, therefore must be maintained in perfect conditions conductors shielding and GPT's cables must be remained away from others conductors or devices than uses velocity variators in order to minimizes their influence.

## ACKNOWLEDGEMENTS

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