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ON THE USE OF BROADBAND SIGNALS FOR THE ACOUSTICAL CHARACTERISATION OF THE GILT-HEAD SEA BREAM

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ABSTRACT
The biomass control through acoustical techniques is a desired but not immediately achievable tool in marine aquaculture cages. The strong attenuation of the acoustical beam in a very dense school and the varying behaviour of the fishes inside the cages reveal it as a very complex problem. In order to cover the total lack of studies of the acoustical properties of Mediterranean species like the gilt-head sea bream (Sparus auratus, Linnaeus 1758), we have considered the use of broadband signals to measure the total target strength (TTS) and acoustical absorption following the method introduced by de Rosny and Roux [J. Acoust. Soc. Am. 109 (6), June 2001]. We show the compared results between signals and different analysis criteria in order be confident on the frequencial signatures depending on the fish size.

INTRODUCTION
Marine aquaculture is a strong industry and a certain reality in the Mediterranean Sea. In 2005 the production reached the 84,017 tones of European sea bass (Dicentrarchus labrax) and 93,355 tones of the gilt head sea bream (Sparus aurata), produced mainly in Greece, Turkey, Italy and Spain [1]. The estimation of fish growth and biomass are essential in aquaculture in order to prepare the production plan of the fish farms and to organize and to carry out several management operations, such as classification and distribution of fish, discharge of new lots, harvesting schedule and also for calculating the daily feeding rates. In spite of the sufficient technology to fulfil the production needs, it is necessary to optimize different production factors, not only to improve its economical profitability but also to minimize the possible ecological impacts. Among these factors we must emphasize the feeding strategy, the growing and population monitoring. The daily feeding is estimated in terms of the present biomass and it is a function of different factors like the average size of the fishes, the season, the water temperature, etc. Therefore, size (mass) and fish number estimation reveal as crucial needs for the adequate management of the production. The traditional method to control the population has been the periodic manual sampling, by fishing a certain number of specimens, but it results to be costly in terms of animal stress and workforce costs
Different non-invasive techniques have been assayed to estimate both fish number and size distribution: video monitoring and digital image processing, electromagnetic pass-through frames, acoustical echo sounders, etc. The effectiveness of every method is limited by different factors and one of the most conditioning facts is the necessity of monitoring a large number of cages almost continuously what impulses the achievement of a permanent, and therefore affordable system, suitable to stand long periods of time in a hard environment. We consider that the acoustical techniques provide such capabilities. Nevertheless still much work must be done to achieve all these objectives. The technology of scientific or commercial echosounders has been oriented mostly to pelagic surveys, and both the equipment and common algorithms can not be applied immediately to the aquaculture farms control. In the following sections we will expose the first approaches to the acoustical characterisation of the gilt-head sea bream in a reverberated sound field in a tank, following the method introduced by de Rosny and Roux [2] that permits to obtain the total target strength (TTS).

METHODOLOGY

The method suggested in [2] has been validated for the measurement of the TTS of moving calibrated spheres in [3], and applied in [4] to monitor density, behaviour and growth rate of sardines and anchovies in a tank. It is based in the emission of a number of chirp pulses and the recording of the corresponding reverberated time series in one or more positions. If we emit in a tank *m* pulses, we obtain the recorded series $h_{i,j}(t)$ with $i=1,2,\ldots,m$ and $j=1,2,\ldots,n,$ where *n*, is the number of hydrophone positions. For a given position j, the echoes variations when considering $h_{i,j}(t)$ with different time pulses *i*= $1, 2,\ldots,m,$ are due only to the fish movements, taking into account that the echoes from walls remain constant. Moreover, single fish contributions to $h_{i,j}(t)$ will be uncorrelated between pulses if its displacement is greater than the acoustical wavelength, and the tank contributions will be virtually identical. For each receptor j=$1,2,\ldots,n,$ the coherent $S_{C,j}(t)$ and incoherent $S_{I,j}(t)$ intensities are defined for the i=$1,2,\ldots,m$ sequence of recorded time series $h_{i,j}(t)$ (or alternatively, introducing as $h_{i,j}(t)$ the calculated impulse response of the tank, obtained from the deconvolution of the emitted signal for every recorded time series what provides an important reduction of experimental noise [4]):

$$S_{C,j}(t) = \frac{1}{m-1}\sum_{i=1}^{m-1} h_{i,j}(t)\, h_{i+1,j}(t), \qquad S_{I,j}(t) = \frac{1}{m}\sum_{i=1}^{m-1} h_{i,j}^{2}(t) \tag{1}$$

The decay of $R(t)$ is a function of the total scattering cross-section σ_T of all the N fish swimming:

$$R(t) = \left\langle \frac{S_{C,j}}{S_{I,j}} \right\rangle \approx \exp\left(-\frac{N\,\sigma_T\, c}{V} t \right) \tag{2}$$

where < > means the average of the *n* recording positions and the TTS can be obtained from the known relationship

$$TTS = 10\log\frac{\sigma_T}{4\pi}, \tag{3}$$

EXPERIMENTAL SETUP

We have used a National Instruments portable PXI-1031DC with NI PXI-ExpressCard8360 connected through a USB to a laptop, and including an 100MS/s arbitrary function generator NI PXI-5412, and a NI PXI-5102, 2 channel, 20 Ms/s digitizer card, both synchronized through the same built-in clock reference. The bus connection between the PXI and the laptop permits to acquire long time series and to process the data through the Labview ® programming environment. The emitted broadband signals are amplified through a ENI 240L RF amplifier. The system permits to control the emission and two simultaneous recordings using three identical omni directional reference hydrophone Reson TC3440 that are placed in three different geometrical configurations, thus giving *n=6* recording positions for *m=100* pulses and recorded reverberated time series.
The input signals are logarithmic sine-sweeps of 1ms of duration, with a bandwidth of 5 kHz covering from 30 to 310 kHz. Alternatively, and in order to reduce the amount of recorded data and the measuring time we have made some assays with broadband signal of only 3 ms of

duration that covers the same total spectrum, a Time Stretched Pulse (TSP) [5], with the inconvenient of emitting less acoustical power per frequency unit which reduces the signal to noise ratio.

During the measurements it is necessary to stop the oxygen and water circulating systems in order to avoid the presence of bubbles which would increase the total cross-section and the noise sources.

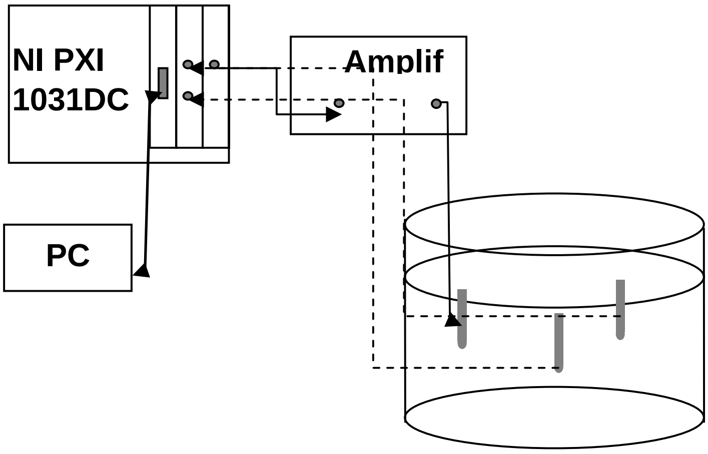

Fig.1: Experimental setup diagram: three identical TC3440 Reson hydrophones are used, one as the emitter and two receiving positions.

Table 1 shows the distribution of fish sizes and number in the five identical quasi-cylindrical tanks measured, with dimensions of 1.5 m of diameter and 0.9 of height; the fishes were sampled manually before every acoustical measurement.

Tank	*Fish number, N*	**Average weight (g)**	**Typical deviation (g)**	*Water temp. (°C)*	*Water height, centre (m)*	*Water height, side (m)*
A	14	173.7	9.3	18.9	63.5	52.5
B	21	148.3	9.2	19.5	62	51
C	71	99.8	12.6	19.6	62	51
D	50	82.5	7.5	21.6	62	51
E	37	21.5	3.6	21.5	62	51

Table 1: Description of tank occupation.

RESULTS

The processing of the important amount of data implies to establish different important criteria to obtain the desired total scattering cross-section from the logarithmic decay of equation (2). We have adopted the option of calculating the impulse response for every time series and limited the duration of the considered decay to the time that maintains a horizontal slope with the empty tank (null scattering cross-section). Figure 2 shows the results for both the σ_T and the TTS from 30 to 310 kHz in 5 kHz steps of the measurements with sine sweeps. It is remarkable the consistency of the results with the increase of size between tanks, and that the expected increase of scattering cross-section with frequency is more important when the size is bigger. The curves of TTS show a clear change of tendency, and the inflexion point shifts to lower frequencies with increasing size.

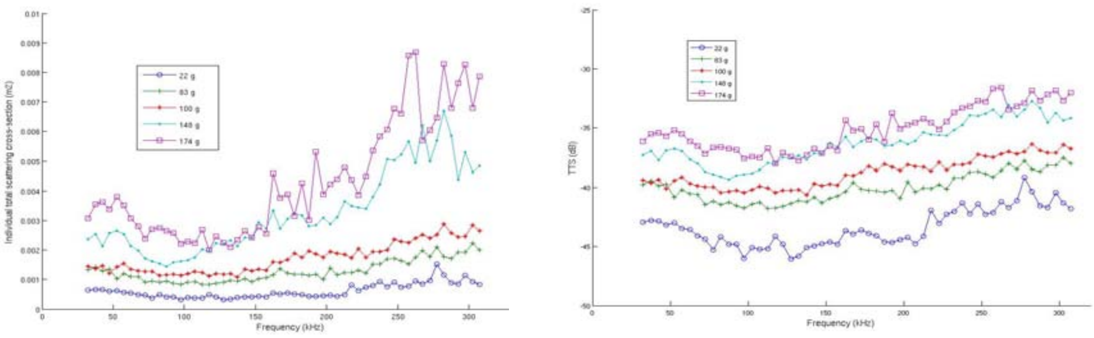

Fig.2: Total scattering cross-section (left) and TTS (right) vs frequency in 5kHz bands for increasing fish weigths, tanks E to A.

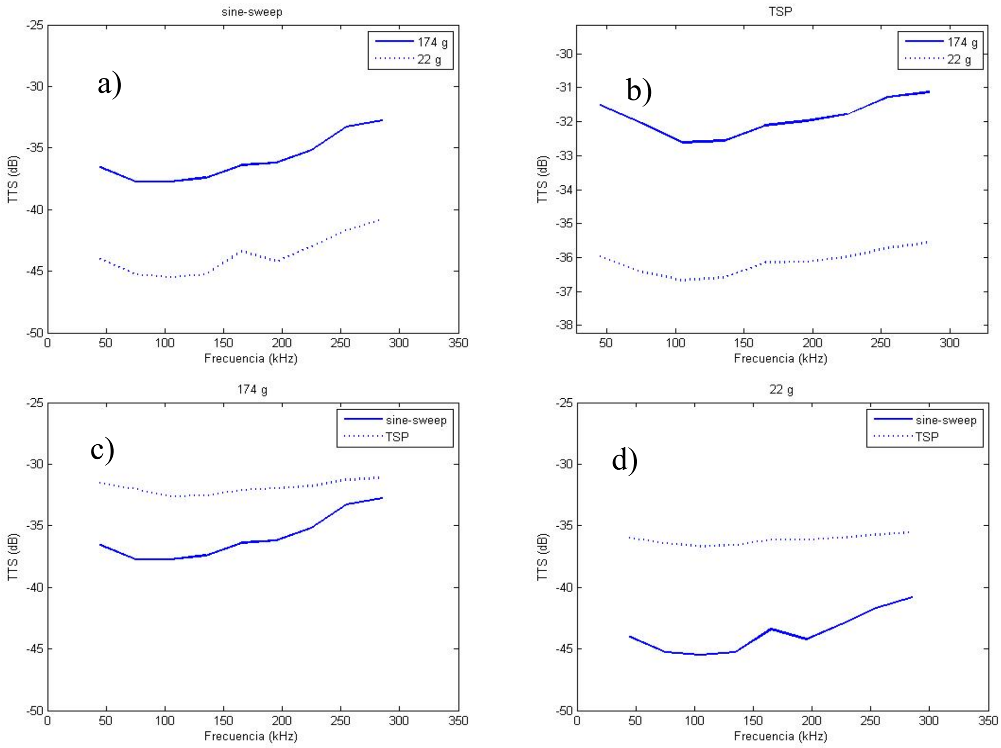

Fig.3: Comparison of the TTS results by using sine-sweeps or TSP as input signals: a) TTS obtained with sine-sweep for tank A (174 g, 23 cm) and E (22 g, 12 cm). b) TTS obtained with TSP for tanks A (174 g, 23 cm) and E (22 g, 12 cm)c) TTS obtained with sine-sweeps and TSP for tank A (174 g, 23 cm)d) TTS obtained with sine-sweeps and TSP for tank E (22 g, 12 cm)

In Figure 3 we have depicted compared results with different input signals: the sine sweeps with increasing central frequency and the TSP. For the sake of simplicity we have applied a moving average to the curves in order to visualize the major differences and tendencies. Both signals provide consistent results with respect to the animal size but with quantitative differences between them. These differences tend to be smaller at the higher frequencies, where the sensitivity of the hydrophones as emitters is bigger. Since the emitted acoustical power per band is much lower in the case of the TSP, and the signal to noise ratio is much better for the sine sweep case, we must be much more confident about its present results.

CONCLUSIONS

We have studied for the first time the acoustical properties of the gilt-head sea bream measuring in a reverberating tank the total scattering cross-section and the equivalent total target strength of the fishes as a function of frequency and animal size.

It would be interesting to remark the sensible differences observed for the σ_T results when different emitter and recording positions and different frequencies are considered (see Fig. 4). The dispersion of the σ_T values was higher for higher frequencies and for fish with greater weight and size. More concretely, for big fishes and frequencies greater than 150 KHz we obtain values of σ_T very dispersed. So the computation of σ_T seems to be less sensible to the position of the transducers and the frequency values for small size fish than for big size fish. Nevertheless, the behaviour of the average line seems quite reasonable for great and small fish.

The frequency dependence of the curves provides some clues for the future broad-band or multi-frequency measurement of the fish size. We have introduced the simplified use of special broad-band signals like the TSP which reveals as an economical tool, but also needs of the use of reference transducers with higher operating power input.

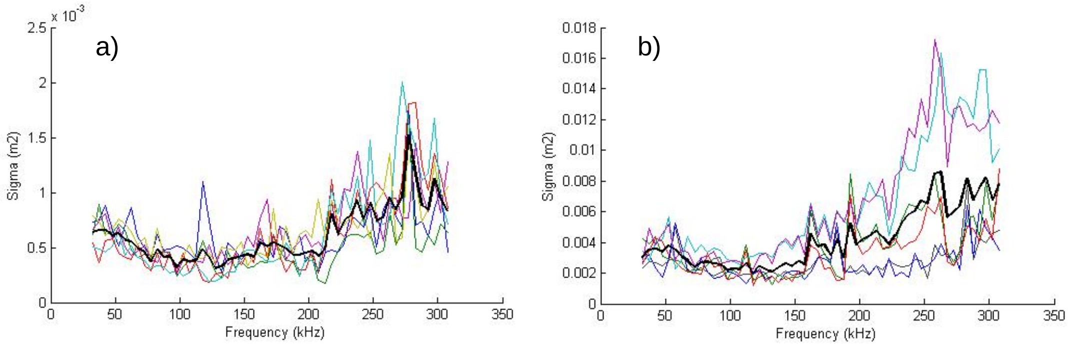

Fig.4: σ_T results for six different positions of the transducers by using sine-sweeps as input signals. The solid heavy line represents the average of the six σ_T values a) σ_T results for tank E (22 g, 12 cm) b) σ_T results for tank A (174 g, 23 cm)

ACKNOWLEDGEMENTS

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