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Detection and target strength measurements of uneaten feed pellets with a single beam echosounder

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Abstract

The possibility of detecting uneaten food pellets in aquaculture floating cages using a scientific single beam echosounder is demonstrated. The applied methodology is based in a basic scheme with the ultrasonic beam facing upwards the sea surface from the cage bottom. The target strength of single pellets is measured resulting in a linear relationship between target strength and pellet size. These results are the basis to quantify the uneaten food falling and to develop an automated feeding system based on demand.

Keywords: aquaculture, feeding, pellet, echosounder, target strength

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1. Introduction

There is a great variety of fish farming in marine aquaculture in which feeding is mainly based on commercial pelleted food. Nowadays much of the economic investment of a fish farm is due to feeding costs, which can reach 60 percent of expenditure on salmon farming (Acker et al., 2002). It is not easy to know, during the feeding process, when the individuals in a cage have ingested the optimum amount for their adequate growth. Usually, the moment to stop food supply is determined by observation, so that, when there are not or there are few individuals near the surface, it is considered that these are satiated. This method is inaccurate and it gets more complicated due to the high fish density

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and turbidity in sea cages (Mallekh et al., 2003). Because of this inaccuracy, feed is often provided in excess; near 8 percent of the total feed is lost (García et al., 2011), which carries a high economic waste and adds environmental impact because the extra organic matter that is deposited on the seabed producing a nutrient enrichment (Pearson, 1991).

Therefore, due to economic and environmental reasons, there is an obvious interest in developing methods to supply the optimal amount of food for marine cage farming. Different studies have been carried out with this objective, from calculating the amount of feed needed for a culture by collecting the uneaten pellets (Helland et al., 1996) to a mechanism of self-feeding in which fish regulate the level of feeding by activating (through presses or bites) a trigger of a feed dispenser (Alanärä et al., 2001). Indirect process control mechanisms have been carried out too, such as interactive feedback systems, based on the feed amount adjustment either by means of uneaten pellets detection or evaluation of fish feeding activity. Juell (1991) developed an acoustic method to detect the accumulated uneaten feed and the individual pellets, and (Blyth and Purser, 1993) used infrared sensors to detect pellets (Mallekh et al., 2003). Later image analysis softwares orientated to uneaten pellets detection and quantification were developed (Foster et al., 1995; Ang and Petrell, 1997). Acker et al. (2002) designed a system of detection, quantity and direction monitoring of waste food pellets by a digital scanning sonar, besides capable of predict the sinking trajectory. Also there have been used echosounders in combination with video cameras to determine the position of individuals(Alanärä et al., 2001) and the swimming speed as appetite indicators (García et al., 2011). Mallekh et al. (2003) developed a method to determine the moment of supply stop in the turbot culture by means of passive acoustic, based on the sounds produced by the individuals during the feeding, a decrease in the feeding sounds indicates lack of demand. Therefore the required amount of feed can be fixed for a determined culture, but it can not be extrapolated to other species.

The aim of this work is to investigate the application of the echo integration method initiated by Juell (1991) to estimate the falling pellet abundance, based on the assumption that the total integrated echo intensity returned from randomly distributed targets inside the acoustic beam is proportional to the quantity of those targets and to the echo intensity returned by an average scatterer. As it is commonly applied in fisheries acoustics (Simmonds and Mac Lennan, 2005), the backscattered energy per unit volume Sv is proportional to the scatterer density ρ and to the backscattering cross-section of an average single scatterer σ, and therefore the scatterer density inside the acoustic beam is given by: $\rho = S_v/\sigma$. With the limitations of the available technology (an analogical echosounder), Juell (1991) demonstrated that the integrated echo energy was proportional to the total weight of food batches thrown at the surface inside the beam volume. Also an estimation of the target strength of relatively big size pellets were performed, comparing the integrated energy (over a certain period of time) when a suspended pellet or a calibration sphere were placed in the beam axis. The minimum quantity of falling pellets that could be detected with the electronics and transducers available at that time were between 5 and 10 g. We suggest to improve the acoustical method using the capabilities of modern quantitative echosounders to apply more adequately the linear superposition principle to automate an estimation of falling pellets density in the water column below the caged school. For such a purpose it is necessary the determination of the backscattering cross-section (or its equivalent logarithmic expression, known as target strength, TS) of individual pellets, for all the sizes used in every growing stage of a production cycle; this implies to detect individual pieces with weights below the milligram. This can be the beginning of the development of a method capable of determining, during the feeding process, when individuals in a sea cage have ingested the optimal amount of food for optimum growth by detecting and quantifying uneaten pellets. This would minimize economic and environmental impacts due to oversupply of food. Another key point is the use for this purpose of a quantitative single beam echosounder as a part of a cost-effective system installed permanently in every single floating cage in aquaculture farms. In spite of the relative high number of proposed systems to monitor the feeding process as we mentioned above, the fact is that nowadays no automated system has been implemented in a generalised way in intensive aquaculture, and only visual (human) inspection performed directly or with video cameras is commonly applied. We propose the use of a simple control set up like in Figure 1 with a fixed upward looking ultrasonic transducer to monitor school behaviour and to detect and to quantify uneaten pellet falling. This could be also a part of a more ambitious system to monitor fish biomass (Knudsen et al., 2004) boosting the benefits of the investment in control equipment.

2. Materials and Methods

Five different sizes of cylindrical pellets (1, 2, 4, 6 and 8 mm of diameter equal to their length) of commercial dry-pelleted feed for sea bass were measured sinking from the surface with a single beam echosounder Simrad EK15. The measurements were taken inside a scaled floating cage which had 3 m of diameter and 3.5 m of depth. The cage was almost empty with the exception of the intrusion of tiny harbour fishes. The upward looking transducer of 30.3 degrees of aperture at -3 dB was placed on the net bottom on a support formed by two PVC tubes arranged crosswise, with a resulting distance to the sea surface of 3.3 m. The emission frequency of the echo sounder was 200 kHz, with a ping duration of 64 μs, a repetition rate of 2 pings per second, a bandwidth of 18.76 kHz, and the power set to 90 w. The experiment took place inside Gandia's harbour waters during the same day in the time interval of one and a half hour.

To guarantee the repeatability of the measurement of TS absolute values with the EK15, we used a 13 mm copper calibration sphere moved by a positioning system in a tank to obtain the maximum on-axis value. The difference with the theoretical value for the experimental conditions was introduced as an on-axis gain in the post-processing software used for data analysis. Data processing was carried out using the dedicated software Sonar5-Pro ® and Matlab ®. The first echogram processing was performed with Sonar5-Pro. In this step single echo detection (SED) algorithms based on echo length and amplitude were applied to isolate single targets, and echo traces corresponding to pellets were identified in the so-called "SED echogram"; only those with specific length, continuity and slope were taken into account. Figure 2 shows an example of a recorded amplitude echogram and the resultant echogram after applying single echo detection (SED) algorithms and the selected layer for pellet trace identification. We selected for our analysis a layer of 1 m of vertical dimension, once the far field of the transducer is achieved, corresponding to a distance between 0.3 and 1.3 m. Parallel lines with negative slopes correspond to pellet echo traces. Lines with positive slope are formed by gas bubbles ascension from the sinking pellets or from the bottom. Other traces are attributable to the crossing of the few present fishes.

A single beam echosounder can not offer information about the target angular position inside the beam, so *TS* variations added by the uncompensated transducer's directivity were expected. Two representative variables of echo traces were studied: average *TS* (TS_{av}) and maximum *TS* (TS_{max}) of each trace. In order to investigate the possible relationship between pellet size and *TS*, correlation analyses were performed between the averages of such quantities, $< TS_{av} >$ or $< TS_{max} >$, versus pellet size (given by its size in mm).

3. Results and discussion

The five measured sizes of pelleted food could be acoustically detected by means of a 200 kHz single-beam echo sounder. Acoustical traces from sinking pellets were isolated following the methodology exposed above and quantitatively characterised. The number of analysed traces, *TS* results and standard deviation obtained for each pellet size are summarized in Table 1. In Figure 3 can be seen the results of TS_{av} and TS_{max} frequency distributions for each pellet caliber.

In some cases the number of analysed traces is not high, as it occurs in the case of 2 mm pellets, however they have been considered because the standard deviations are acceptable, all of them under 4 dBs, except for those obtained in 4 mm size, which are not inadequate compared with standard deviations achieved by Acker et al. (2002). The highest standard deviation is obtained in 4 mm pellets, both using TS_{av} and TS_{max}. It is also noteworthy that in every size the standard deviation of the data is higher when using TS_{max}. That was what was expected because the pellets sinking occur almost vertically due to the weakness of the water currents in the measurement's area. Therefore, the pellets that felt closer to the central axis of the beam had greater TS_{max} than pellets that passed through the beam side, due to beam directivity.

Figure 4 shows the obtained linear regression charts for the logarithmic size of pellets as independent variable, and $< TS_{av} >$ or $< TS_{max} >$ as dependent variable. The correlation coefficients, the coefficients of determination, the F value of F-test and de critical F-value can be seen in Table 2. In both cases it exists a positive correlation between size and *TS*, proved statistically, with a similar pendent between close to 12.4 with R^2 next to one, and with $< TS_{max} >$ linear adjustment consistently 4 dB above $< TS_{av} >$. R^2 is higher than 0,9 in both cases. The best adjustment, with a R^2 equal to 0,98, is for $< TS_{av} >$. In this case, there is ae high standard deviation of *TS* results for 4 mm pellets, and if such data are removed, R^2 improves to 0,999 and the resulting line equation is $< TS_{av} >= 12,61\ log\,(Pellet\ size) - 64,7$. The bigger the pellet is, the higher acoustic response is achieved, as it was expected.

It must be taken into account that the results have been obtained under conditions different to those of production, with smaller cage dimensions and an almost 'empty cage' (tiny harbour fishes were present as can be noticed in some typical fish tracks of Figure 2 with TS values between -64 and -55 dB). In production cages there is a high fish density, and the detection of non-eaten pellets should be done in a layer below the dense fish school position, but always close to the transducer that could be placed at the bottom of the cage or below the net, in such a way that the detection layer dimensions and vertical distance to the transducer would be the same like in our experiment. Even though the echograms could include fish traces, but it is possible to differentiate the traces of fish and pellets by means of their characteristic shape and the lower *TS*. For example small cultivated Atlantic salmons and gilt-head sea breams have typical average TS values of -36.8 and -42 dBs (Knudsen et al., 2004; Soliveres, 2015). Moreover, the linear characteristic of tracks from falling objects in an echogram, could be extracted by processing SED echograms as an image, by instance applying Hough transform algorithms, that produce as an output the position and the slope of lines (Mukhopadhyay and Chaudhuri, 2015). The continuity of linear tracks in the SED echogram, and therefore the capability of automated detection, can be improved by using higher pulse repetition rates (than can be as high as 30 Hz for usual production cages depths).

The obtained TS *vs.* pellet size relationship obviously depends on pellet composition and storage conditions (altering by instance its gas or moisture contents). Also, under production conditions, the density, texture and size of the sinking pellets could suffer variations depending on the previous storing state and the dispense procedure (being supplied in dry or wet feed devices), and their TS could be consequently altered from the values presented here. In order to quantify properly the non-eaten pellet density, the corresponding TS for the particular chosen conditions must be established, and a protocol of preservation and delivery must be followed; this protocol should not be more strict than the usual caution taken to preserve the properties of the pelleted food (in closed envelopes and a dry store), and it should guarantee the dispense being done always in the same way (either dry or wet). This would assure the accuracy of the TS *vs.* size relationship that it is going to be used to scale the backscattered energy for density estimations. Preliminary measurements of variations in the TS of dry and wet pellets show a lower value of TS for wet pellets, as expected, with a similar reduction for all pellet sizes (about 5 dB), resulting in a vertical shift of the linear adjustments of Figure 4.

Furthermore, the proposed system can be used in combination with the monitoring of fish school position, considering the interest of fish in feeding in terms of the aggregation of the school near the surface, what can be easily detected in terms of the displacement of the center of gravity of S_v in the water column during the feeding process.

Future steps should be addressed to:

- the implementation of the method in production conditions,
- the evaluation of the method accuracy when scaling S_v measurements to estimate falling pellet's density,
- the development of dedicated automated algorithms based on image analysis,
- the combination of pellet's sinking detection with behavioural monitoring through acoustical school positioning.

4. Conclusions

Single aquaculture pellet's falling can be detected using an upwards-looking single beam echosounder placed in the bottom of a floating cage. We have obtained a linear relation between the logarithm of pellet size in mm and the acoustical target strength. This fact allows the development of a quantitative method for non-eaten pellet estimation, in order to diminish the economical and ecological damages caused by the excess of food supply in marine aquaculture.

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Figure Captions

Figure 1. Schema of the proposed pellet detection system. The transducer can be placed at the net bottom (left) or below the pen (right).

Figure 2. Recorded amplitude echogram (left) and the resultant echogram after applying single echo detection (SED) algorithms (right) and the selected lower layer for pellet's track identification near to transducer (of 1 m height from a distance to 0.3 to 1.3 m).

Figure 3. Average Target Strength (TS_{av}) and Maximum Target Strength (TS_{max}) frequency distributions for each pellet size: 1, 2, 4, 6 and 8 mm respectively, from top to bottom.

Figure 4. Average of Average Target Strength ($< TS_{av} >$) (solid line) and average of Maximum Target Strength ($< TS_{max} >$) (dashed) linear adjustments versus pellet caliber.

Table captions

Table 1. Average target strength (TS_{av}) and maximum target strength (TS_{max}) values obtained for the different pellet sizes (of equal diameter and height in mm) with the corresponding average μ and standard deviation values σ for each distribution.

Table 2. Average of average target strength ($< TS_{av} >$) and average of maximum target strength ($< TS_{max} >$) linear correlation results.

			TS_{av} (dB)		TS_{max} (dB)	
Pellet size (mm)	Traces	Single echo detections	μ	σ	μ	σ
1	31	754	-64.95	1.53	-61.07	1.91
2	13	167	-60.46	1.69	-57.68	2.23
4	21	562	-58.49	4.70	-51.66	6.46
6	44	545	-55.22	3.47	-50.91	4.07
8	17	129	-53.15	1.09	-50.87	1.53

Table 1

	$TS = a\ log\,(Pellet\ size) + b$	
	$< TS_{av} >$ (dB)	$< TS_{max} >$ (dB)
a	12.40	12.37
b	-64.86	-60.83
R^2	0.98	0.94
F	129.63	50.52
Critical F-value	0.0015	0.0057

Table 2

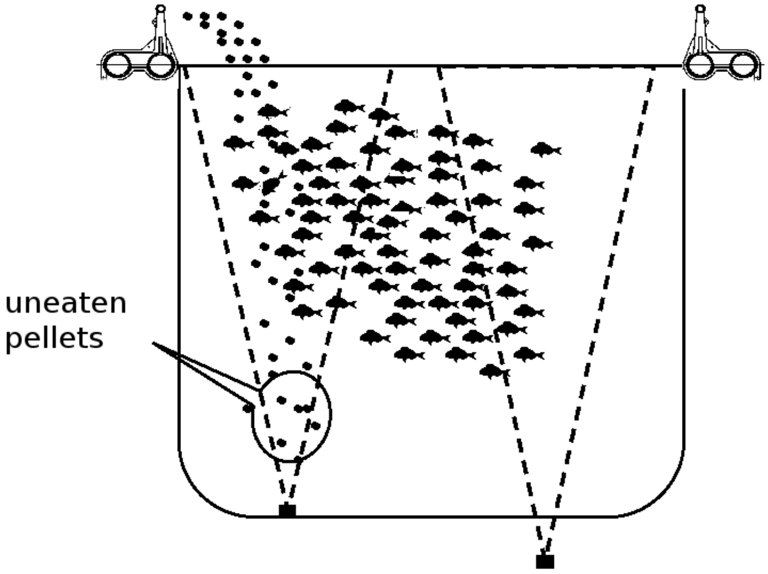

Figure 1.

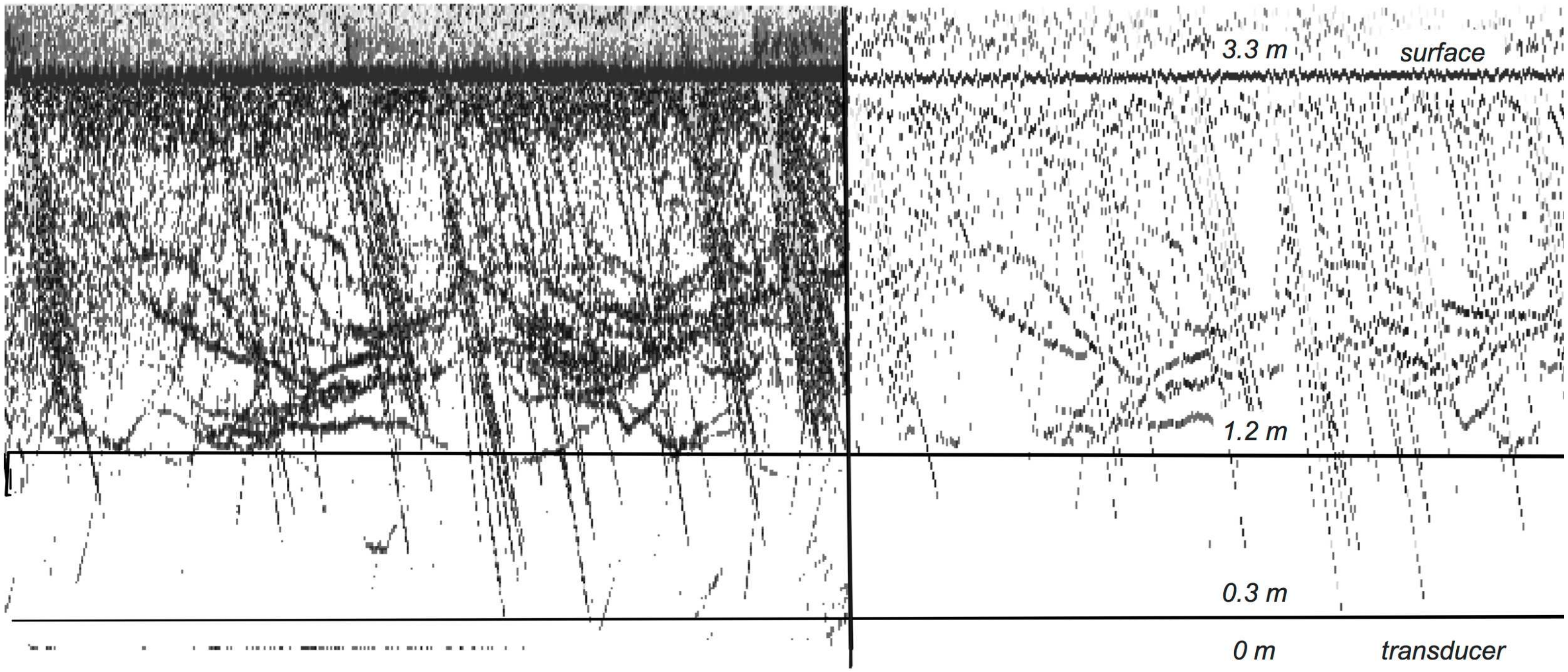

Figure 2.

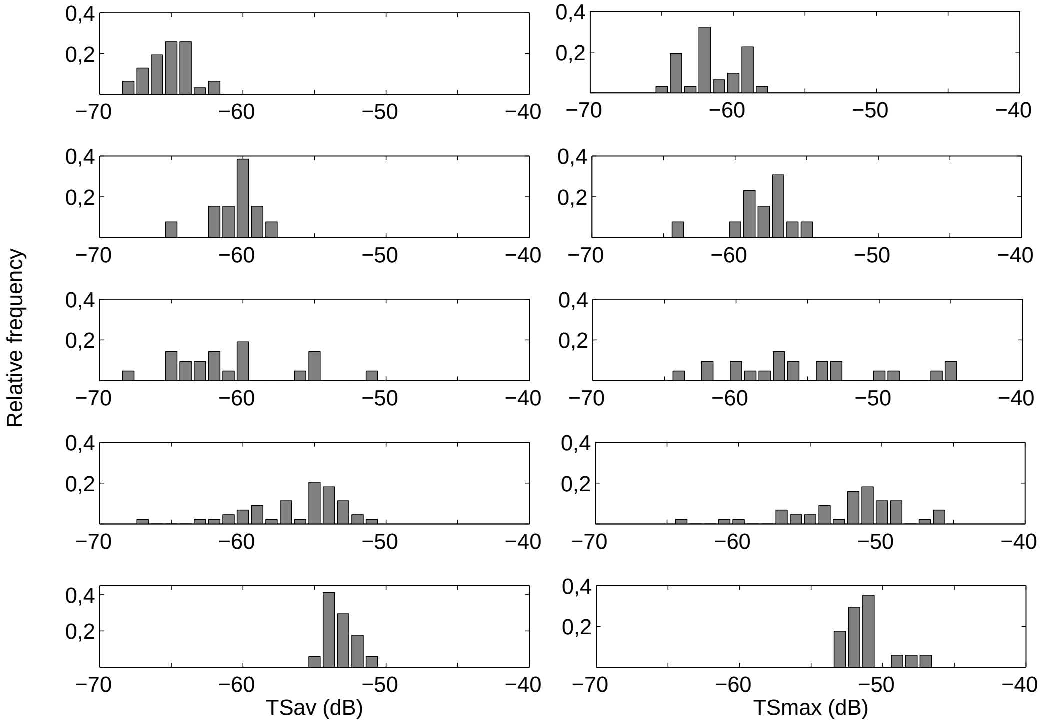

Figure 3.

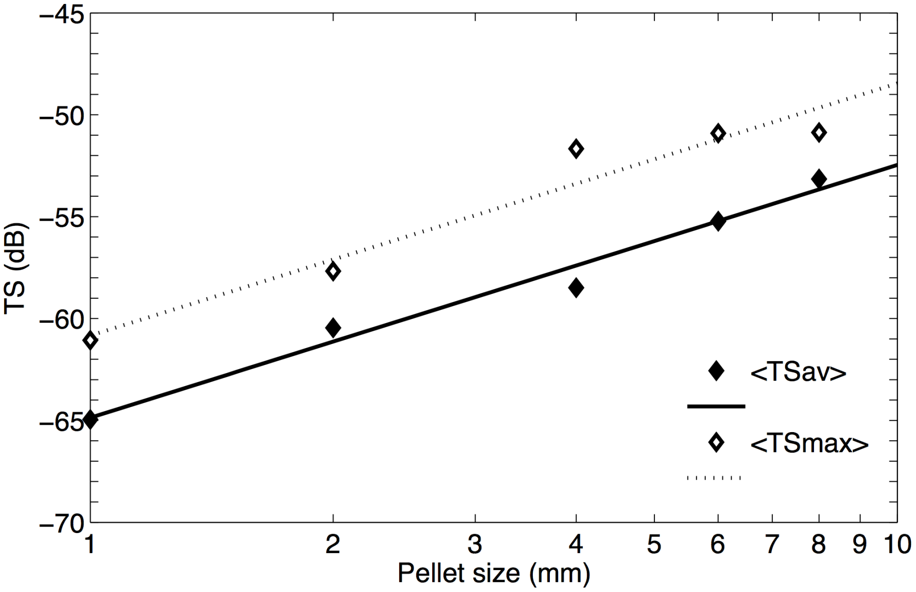

Figure 4.