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Testing of new sampling methods and estimation of size structure of sea bass (*Dicentrarchus labrax*) in aquaculture farms using horizontal hydroacoustics

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ABSTRACT

In aquaculture, monitoring fish size and density is fundamental to improve management and profitability of fish farms. The aim of this study is to test whether horizontally aimed 200-kHz transducers are adequate to obtain fish size structure in open-sea cages in order to apply horizontal hydroacoustics as a non-intrusive and innovative technique in sea bass (*Dicentrarchus labrax*) farming. Several sampling strategies have been tested by placing the transducer in two different positions: outside the cage and inside the cage. In addition, two sampling approaches have been implemented: placing the transducer at a fixed position or moving it vertically.

The results show that horizontal hydroacoustics is a useful technique for monitoring size distribution of sea bass in farming cages. The most adequate sampling method consists of using a vertically moving transducer positioned outside the cage, since it exhibits the narrowest size distributions with the lowest variance estimates, which matches the data provided by fish farmers.

1. Introduction

Aquaculture has become a very important field on a global scale. It currently surpasses extractive fishing in terms of tons produced. It is also a growing field where both the production and number of farmed species increase every year (Apromar, 2018). This makes it necessary to improve the production processes to increase efficiency while achieving sustainability (OPP, 2009). In order to accomplish this, different factors must be optimised within farming, not only for improving economic return, but also for minimising potential ecological impacts. Among these factors, feeding strategies should be prioritised along with farming monitoring and its growth (Espinosa et al., 2006).

Sea fish farming in the Mediterranean Sea area is mainly performed on two species: the sea bass (*Dicentrarchus labrax*, Linnaeus 1758) and the gilt-head bream (*Sparus aurata*, Linnaeus 1758), with a production of 81,852 T and 83,186 T in, 2018, respectively. It is mainly performed in open-sea cages (Apromar, 2018). In this kind of facility, monitoring fish size is essential to improve production control (Soliveres et al., 2014). Such information is crucial to feed optimisation and potential cannibalism detection, which is the main cause of mortality during the early farming stages and can be reduced by lowering fish density inside the cages (Hatziathanasiou et al., 2002). Although feeding efficiency has improved in recent years based on diet research of these species (Carbone and Faggio, 2016; Di Marco et al., 2017; Magalhães et al., 2017), production monitoring methodologies are still lacking. Currently, capture-dependent sampling methods are occasionally used. These are both expensive and erroneous. Additionally, they cause a high level of stress to the fish, potentially contributing to an increase in fish mortality (Espinosa et al., 2002; Conti et al., 2006; HSUS, 2008).

Hydroacoustics is one of the most efficient techniques used in fish studies which enables fish detection in a capture-independent way (Simmonds and MacLennan, 2005; Kubečka et al., 2009). It has been used in numerous field studies of fish (Fabi and Sala, 2002; Neilson et al., 2003; Axenrot et al., 2004), as well as to monitor sea bass and gilt-head bream in farming cages (Soliveres et al., 2014; Soliveres, 2015). One of the major concerns when estimating fish abundances in aquaculture using hydroacoustics is the non-linear effects produced when linearity fails at very high fish densities (Simmonds and MacLennan, 2005). The shadow effect can attenuate the acoustic signals, primarily when monitoring dense shoals of fish. The fish nearest to the transducer

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attenuate the acoustic energy in such a way that the more distant fish contribute less to the received signal (Simmonds and MacLennan, 2005; Løland et al., 2007). In addition, multiple scattering is an important feature in high fish densities involved in aquaculture (Simmonds and MacLennan, 2005).

In previous studies, vertical hydroacoustics was applied (placing the acoustic beam perpendicular to the water surface) (Soliveres et al., 2014; Soliveres, 2015). However, this method presents some logistical challenges when applied in real production cages such as the ones in this study. Vertical sampling involves placing the transducer inside the cage, either at the water surface or below the cage, at a considerable depth. When the transduced is located at the surface position, faces logistical issues due to the large solid floating structure located in the middle of the cage to support the net used to protect the fish from bird predation. Second, vertical sampling from the bottom position also involves some major problems. Firstly, professional scuba divers are needed to install the transducer, since the cage depth is usually 10–15 m underwater. This translates into additional time and resources costs. Likewise, because the cage net is usually tied at the bottom (see Material and Methods), it may interfere and bias the recordings. Finally, vertical surveys require continuous recordings for a prolonged amount of time to obtain reliable estimates, due to strong daily differences in the estimated fish density (Soliveres et al., 2014; Soliveres, 2015). Given the above-mentioned difficulties inherent to vertical surveys, horizontal hydroacoustics can be an alternative technique to obtain more accurate fish size estimates in the production cages.

Horizontal hydroacoustics presents important advantages compared to vertical samplings in this case. First, it solves any potential issue caused by the horizontal stratification of fish within the vertical sampling. Further, horizontal surveys can be conducted from either inside the cage, with hardly any interference with the nets, and from outside the cage, which prevents any kind of manipulation of the net or any other structure. In addition, there is no need for scuba divers, which considerably reduces installation costs. A relevant benefit obtained from this technique is the sampling speed. Unlike vertical sampling that implies handling with the protection net construction, or hard installation below cages, the horizontal survey requires less staff, without external support or interfering with the normal operation of the aquaculture facility, and, additionally, this sampling entails a short period of recording time and then requires a single equipment to analyse several cages, which greatly reduces costs.

The main objective of this study was to select the most appropriate sampling technique using horizontal hydroacoustics, in order to develop a sampling and analyse protocol for size structures of fish in cages estimates. This paper describes the methodology used and the results obtained from observations of sea bass in open-sea cages at farming facilities. Various sampling methods have been tested with the aim to provide fish farmers with a functional and efficient tool to monitor the size structure of the fish in their cages.

2. Material and methods

2.1. Experimental design

The experiment was performed at the facilities of the company Seaculture S.A., located in Sines, Portugal. Three cylindrical farming cages were used with sea bass (*Dicentrarchus labrax*) of three different sizes. According to the information provided by the fish farmers after the surveys were conducted, cage 1 contained large, market-size fish (238 mm standard average length after harvest), cage 2 also contained fish of large size (210-250 mm standard average length), and cage 3 contained smaller fish (175-200 mm standard average length). Each cage had a floating circular ring from which the net was suspended, and the net closed at the bottom in a cone shape. Cage 1 was 25 m in diameter and 13 m height, cage 2, 25 m in diameter and 14 m height, and, finally, cage 3, 12 m in diameter and 11 m height.

Acoustic data was obtained using a Simrad EK60 echosounder (Simrad Kongsberg Maritime AS, Horten, Norway) with an ES200-7C circular split-beam transducer operating at 200 kHz with a transmitting power of 150 W. Before the recordings, the hydroacoustic equipment was calibrated using a copper sphere with a diameter of 13.7 mm and a known reference target strength (TS = -45 dB). Water temperature and salinity were added following the calibration protocol of the manufacturer. The mean deviation of TS, backscattered by the calibration copper sphere, was below 0.55 dB. In order to test the potential effect of the net on the acoustic signal, the calibration sphere was placed inside and outside an empty cage and recorded horizontally at different distances. There were no significant differences in the TS recorded in these positions (ANOVA; $p > 0.05$).

The sampling was conducted under favourable weather conditions with a slightly wavy surface in the water and during daylight hours (Balk et al., 2017). The transducer was mounted on a custom structure with two guide ropes placed on its ends, hanging from a boat. This special structure is aimed at maintaining the beam orientation facing horizontally the centre of the cage in a fixed position. The patent on said custom structure is pending. The distance from the transducer to the cage in the outside position remained stable by placing two boats parallel to each other firmly tied to the cage floating structure.

The acoustic signals were recorded placing the transducer horizontally (with the beam axis parallel to the water surface) in two different positions in relation to the cage (Fig. 1). In position 1, the transducer was placed outside the cage, five metres away from the net, hanging from a boat. In position 2, the transducer was placed inside the cage, next to the net and pointing towards its centre.

For each position, data was obtained following two sampling

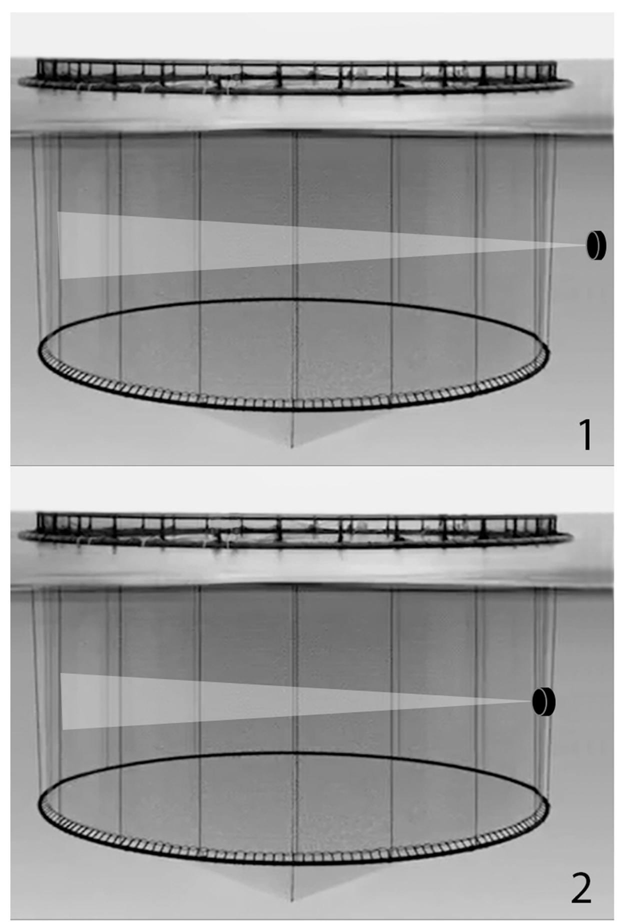

Fig. 1. Position of the transducer in relation to the cage. Position 1: outside the cage. Position 2: inside the cage, next to the net.

methods: either with the transducer placed at a fixed depth or with the transducer moving vertically at a controlled and constant speed through all the depth of the cage. In total, four different sampling plans were analysed combining these two variables.

For the fixed sampling, the transducer took five one-minute recordings, at three different depths: 3 m, 6 m and 9 m. Thus, fifteen one-minute samples were obtained for each cage. Data from all three depths was pooled to represent one sample of the whole column.

For the vertically moving sampling method, the transducer moved from the bottom to the top of the cage and back down to the bottom at a constant speed through the whole cage, thus ensonifying all its depth. Each journey up and down, lasting one minute, was considered a sample. Ten samples were taken for each cage.

2.2. Data processing

Acoustic data were analysed using Sonar5-Pro (CageEye AS, Oslo, Norway). Single echo detections (SED) were stored from echograms since the fish distribution patterns did not allow for isolation of individual fish tracks.

A strict data setting for single echo detection (SED) was selected in order to avoid unwanted echoes coming from noise, multiple targets, etc. The minimum target size was -70 dB. The pulse length selected was 0.128 ms. The minimum and maximum echo-lengths were 0.7 and 1.3, respectively, and the ping rate was 1 ping•s^{-1}. To avoid including echoes from multiple targets placed in the same range, a phase deviation of 0.4 was selected and multiple peak echoes were rejected. Finally, in order for echoes detected in the same ping to be accepted, a separation of 100 mm was necessary between them.

In order to avoid bias in the analysis due to the near-field effect, i.e., the area near the sound source where the wave instability can affect the measurements (Medwin and Clay, 1998; Dawson et al., 2000; Tichy et al., 2003; Rodríguez-Sánchez et al., 2016), the recordings were analysed at a minimum distance of 1.3 m from the transducer. Additionally, erroneous echoes, such as ropes and net folds, recognized as fixed, repetitive and hard sounds in the echogram, located inside the cage were excluded. SEDs were classified in nine categories based on their TS, with intervals of 3 dB. Regarding the angular correction due to the swimming path of the fish, it was assumed that fish swam in a side-aspect orientation, with the incidence angle of the acoustic beam ranging from 70° to 110°. This assumption was made because fish at this kind of facility swim in circles, parallel to the net of the cage, mostly exposing their *side aspect* (Fig. 2). Such behaviour was directly observed from the surface of the cages and from video recordings obtained from cameras installed by the managers into the cages, thus supporting our assumption.

Fish TS depends on morphological parameters such as length, weight, fat content, gonadal development and swim bladder. The latter is responsible for most part of the returned sound (Foote, 1980; Ona, 1990; Hazen and Horne, 2003; Knudsen et al., 2004; Frouzova et al., 2005; Rodríguez-Sánchez et al., 2015). In order to relate the above-mentioned TS categories to the length of the studied fish, we used the TS-length conversion equation developed by Rodríguez-Sánchez et al. (2018) for the horizontal and lateral positions for sea bass (*Dicentrarchus labrax*) (70°-110°), which is $TS = 27.10 logSL - 101.23$ (SL, standard length).

Finally, the fish average size obtained with hydroacoustics was validated with the farmers' estimates.

2.3. Statistical analysis

The Kruskal-Wallis test was used to compare the distribution of SEDs in the different samples of each sampling plan and to detect potential errors in their repeatability.

To obtain an estimate of the presumed shadow effect occurring at high fish densities (Zhao et al., 1993), echoes were analysed in terms of amount (number of echoes/beam volume) and intensity (mean TS), differentiating metre by metre. In all studied cages, it was observed that the number of detected echoes decreased progressively from the beginning to approximately the middle of the cage. In the second half of the cage, the number of detected echoes was too low, which did not correspond with the actual state of the cage (Fig. 3).

Subsequently, a Mann–Whitney *U* test was conducted, dividing the cages in two parts: the first half comprised the distance from the front to the centre of the cage and the second half comprised the distance from the centre to the end of the cage. The heterogeneity in the number and TS values of the echoes obtained from both halves were compared, which allowed for the detection and evaluation of the potential distance effect on the intensity and number of echoes in the recordings.

A permutational multivariate analysis of variance (PERMANOVA) was performed to assess the differences found in TS distribution in each sampling plan, comparing the recordings obtained with the transducer positioned inside and outside the cage and using both the fixed and vertically moving sampling methods. A Bray-Curtis Resemblance matrix was subsequently created for each studied cage using PRIMER 6 & Permanova+. The mixed model PERMANOVA (maximum permutation = 9999) was used to test each data set providing "out-in" or "vertically moving-fixed" as main factors.

An analysis of variance (ANOVA) was conducted to analyse the differences in the mean TS found in each cage. Each pair of cages was compared using the Bonferroni method to analyse their differences. The significance level used for all performed analyses was 95%. To compare TS data dispersion after the PERMANOVA analysis, Levene's test was used to assess the equality of variances.

The Kruskal-Wallis test was used to compare the mean TS obtained for each sampled cage using the plan with vertically moving transducers, outside the cage and the Mann-Whitney *U* test was performed for the pairwise comparison.

All statistical analyses were performed using SPSS Statistics (Version 24.0, IBM Corp., New York, US) and Primer 6 & Permanova+ (Version

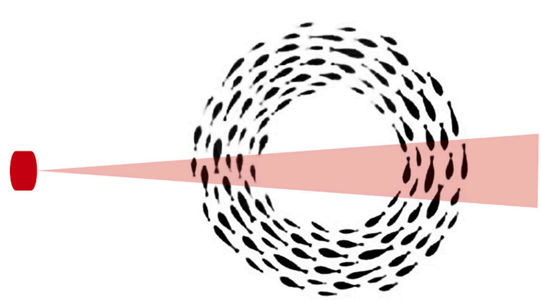

Fig. 2. Representation of the behaviour of fish swimming in circles through the acoustic beam, seen from above.

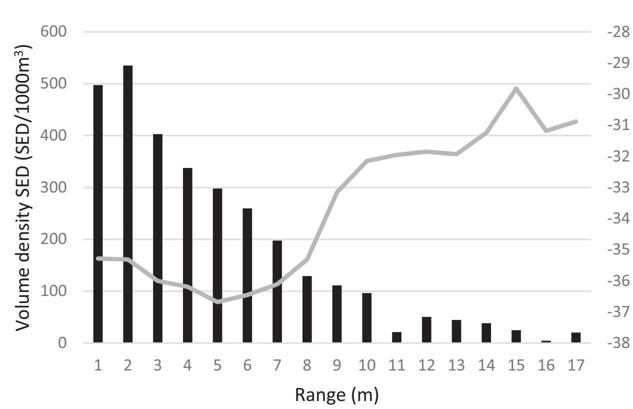

Fig. 3. Representation of Volume density SED (SED/1000m^3) in black bars, and Mean TS (dB) in grey line, vs Range (m) of the inside of an example cage.

6.0, PRIMER-E Ltd., Auckland, New Zealand).

3. Results

The analysis of the SEDs obtained for each sample in each sampling plan showed no significant differences in their distributions (Kruskal-Wallis; $p > 0.05$). Given that all individual samples were comparable with each other, all of them were used for the subsequent analyses. For each sampling plan, the density and mean TS of the echoes obtained in the first half of the cage were compared with those obtained in the second half and it was observed that they presented significant differences (Mann-Whitney U; $p < 0.05$). The SED density in the first half was significantly higher than in the second in all cages (Table 1 and Fig. 3). Likewise, the echoes received in the first half presented a TS significantly lower than those of the second half in all cages (Mann-Whitney U; $p < 0.05$, Table 1 and Fig. 3). These results suggest that the echoes of the first half of the cage had non-linear effects on those of the second half. Thus, only the first halves of the cages were selected in subsequent analyses.

Nv (mean number of fish per sampled volume) values of the first halves of the cages were between 0.05 and 0.23 (Table 2). Those maximum values of 0.23 correspond to 11% probability of accepting multiple targets as single ones (Ona and Barange, 1999). Considering the specific characteristics of the experiment, ensonifying a high-density farming cage, this was considered as desirable multiple targets probability to work with.

Fig. 4 displays the TS frequency distributions for the three studied cages based on the position of the transducer (inside or outside the cage) and each sampling method (fixed or vertically moving sampling). PERMANOVAs revealed significant differences in TS distribution depending on the position of the transducer ($p < 0.05$, Table 3). Moreover, the mean TS obtained for each cage was different regardless of whether the recordings were obtained with the transducer placed outside or inside the cage (ANOVA, $p < 0.05$). The Bonferroni test revealed differences between the mean TS obtained from all pair of cages ($p < 0.05$). Two of the three acoustic samples taken inside the cages presented a broader range of TS (fish size) classes when compared to the samples recorded with the transducer outside the cage (Fig. 4). Similarly, the variance was lower when the sampling was performed from outside the cage (Levene's test $p < 0.05$, Table 2). The results show that the samples obtained with the transducer outside the cage present less dispersion in TS distribution and, therefore, they were selected for the subsequent analyses.

Fig. 5 shows the TS frequency distributions for each studied cage with the transducer placed outside the cage, differentiating whether the sampling was performed in motion or in a fixed way. PERMANOVA showed significant differences in the distribution of size classes between the fixed and vertically moving sampling methods (Table 4). All sampled cages presented differences in the mean TS obtained with the different sampling techniques (ANOVA; $p < 0.05$). The Bonferroni test revealed differences between the mean TS values obtained from all cages ($p < 0.05$). The size distribution showed slight differences regarding the size groups calculated with each sampling technique. The variance of the mean TS in the samples taken in motion was lower than in those obtained with the fixed approach in cage 2 and 3, and very similar in cage 1 (Table 2).

Table 2
Mean target strength (TS), standard deviation (SD) and mean number of fish per sampled volume (Nv) values for fixed or vertically moving and out or in position of the first half of the three cages.

		Fixed			Vertically moving		
Cage	Transducer Position	Mean TS (dB)	SD (dB)	Nv	Mean TS (dB)	SD (dB)	Nv
1	Out	−35.58	2.61	0.13	−37.07	2.91	0.15
	In	−32.44	12.78	0.12	−35.49	2.05	0.06
2	Out	−33.95	4.65	0.17	−35.71	1.01	0.20
	In	−38.51	9.20	0.05	−38.02	3.71	0.05
3	Out	−38.86	3.39	0.23	−40.02	1.02	0.16
	In	−34.20	9.39	0.19	−39.05	2.22	0.23

Table 5 presents the mean TS values and the estimated standard length obtained for each sampled cage with the transducer placed outside the cage and moving vertically. The Kruskal-Wallis test shows significant differences in the mean TS obtained for each cage ($X^2_{2.58} = 30.431$; $p < 0.05$). The pairwise comparison revealed significant differences between the cages (Mann-Whitney U; $p < 0.05$). Cage 1 and 2 contained larger sea bass than cage 3, and the size structure in cages 1 and 3 matched the range provided by the farmers (Table 5). Fish in cage 1 were collected for sale during the weeks following the sampling. Thus, the size data presented in Table 5 represents the actual average length of the fish. The length data from cages 2 and 3 are ranges of fish size estimates provided by the farmers and, therefore, they can include inaccuracies and possible deviations from the actual range.

4. Discussion

Our results show that horizontal hydroacoustics is a useful technique to study fish in farming cages. The sampling method with the transducer outside the cage and moving vertically to cover the whole range of cage depths has proven to be the most adequate to monitor fish at these facilities since it exhibits the narrowest size distributions and variances of size estimates. Besides, the size estimates derived from this approach match the actual size ranges described by the farmers.

An important concern in our analyses is that acoustic data are affected by non-linear effects such as shadow effect and multiple scattering, since echoes are more numerous and of a lower intensity within

Table 1
Mann-Whitney test results for volume density of SED (SED/1000m^3) and TS (dB) comparison between first and second half of the three cages using two different positions of the transducer (position 1: outside the cage; and position 2: inside the cage) and fixed and vertically moving sampling types.

			1st Half		2nd Half		
Cage	Transducer Position	Type	Volume density SED (SED/1000m^3)	TS (dB)	Volume density SED (SED/1000m^3)	TS (dB)	Mann-Whitney U
1	Out	Fixed	190.97	−40	33.47	−34	$p < 0.01$
		V.moving	264.36	−38	40.85	−32	$p < 0.01$
	In	Fixed	151.56	−38	75.78	−33	$p < 0.01$
		V.moving	151.11	−31	41.02	−30	$p < 0.01$
2	Out	Fixed	168.50	−35	43.62	−33	$p < 0.01$
		V.moving	181.01	−36	32.81	−33	$p < 0.01$
	In	Fixed	131.81	−30	61.39	−31	$p < 0.01$
		V.moving	161.77	−38	51.38	−27	$p < 0.01$
3	Out	Fixed	254.99	−40	57.61	−38	$p < 0.01$
		V.moving	318.81	−40	48.06	−37	$p < 0.01$
	In	Fixed	1280.27	−37	230.88	−41	$p < 0.01$
		V.moving	1161.85	−40	350.21	−39	$p < 0.01$

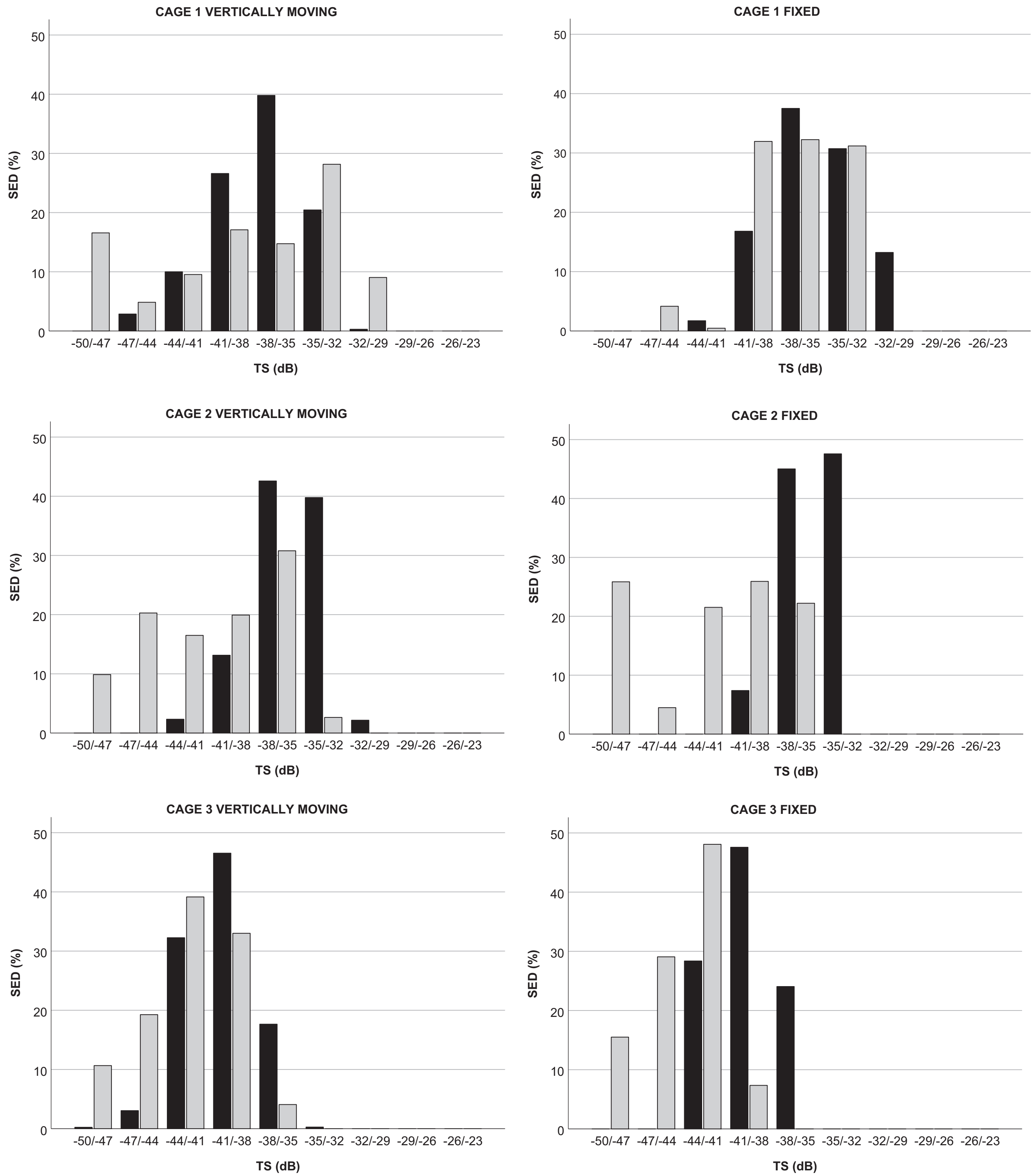

Fig. 4. TS distribution of the SEDs of the three cages analysed depending on the position of the transducer in relation to the cage (inside, in grey; outside, in black) for each sampling plan, differentiating between fixed and vertically moving.

the first half of the cage, whereas fewer echoes with higher intensities are found within the furthest half. A similar attenuation in the acoustic signal caused by the shadow effect produced by the fish shoal was also reported in previous studies where shoals of known densities were analysed (Røttingen, 1976; Furusawa et al., 1984) or in studies conducted in natural environments (Appenzeller and Leggett, 1992).

When comparing the detections obtained in both halves of the cage, our results show that the fish shoal reduces the number of echoes by 74% (average percentage of the three analysed cages). In turn, the average TS of the few echoes returned in the second half of the cage increased by

Table 3
PERMANOVA test performed on single echo detection (SED) distribution in vertically moving recordings for the position of the transducer regarding the cage: inside or outside, for the three cages.

Cage	Factor	df	Sum. Sq.	Mean Sq.	Pseudo-F	*p*	Unique perms
1	Transducer Position	1	2700	2700	5.576	0.019	999
2	Transducer Position	1	3024	3024	13.201	0.001	999
3	Transducer Position	1	1120	1120	4.931	0.009	998

8%. The decrease in the number of SEDs and the increase in TS with range are probably due to the increased uncertainty in the returned phase signal. In high-density aggregations, scattered echoes coming from fish interfere with each other when relayed back to the transducer. This may lead to a scatter signal attenuation, i.e., the loss of some SEDs, as well as to an increase within the signal amplitude, i.e., an increase in TS. Therefore, the analysis of fish size distribution was limited to the first halves of the cages studied. The recordings taken in the second halves were discarded due to the interactions in the acoustic signal.

After comparing samples from inside and outside the production cages, size frequency histograms from inside were more dispersed with more size groups. This higher dispersion may be caused by the bias induced by the near-field effect i.e., because of the proximity of fish to the transducer in the inside position. In spite of having removed enough distance to avoid the near-field effect, the volume of the acoustic beam in the first ensonified metres is low due to its opening angle being 7°. This reduced ensonification space implies that the beam might not encompass the whole fish. Thus, there can be a significant proportion of echoes coming from parts of the fish, resulting in echoes with a TS lower than the actual one (Rodríguez-Sánchez et al., 2016), and the volume density of SED detected can be biased. Conversely, when ensonifying from a distance of five metres outside the cage, the acoustic beam is much larger inside the cage. Therefore, this problem would be greatly reduced since the whole fish can be ensonified, resulting in more representative and unbiased echoes. This can be observed in Table 1, where the presented volume density of SED from inside the cage in cage 3 is much higher than that from the outside. Cage 3 is twice as small as cage 1 and 2, and thereby the ensonified volume is too small, and measurements become unreliable. Furthermore, the fish farming system at this kind of facility involves planting fry from the same cohort in the cages. This means that they grow evenly and, therefore, they should not present large differences in size within the same cage. In light of the above, the sampling approach with the transducer outside the cage was selected as the most adequate one, both because of its higher-quality results and because of its logistical advantages and implications.

The fixed and vertically moving sampling methods showed significant (albeit small) differences both in the distribution of the size histograms and in the average fish size. Samples taken in motion presented a lower dispersion than the fixed ones and the average size obtained in the different cages matched the size ranges provided by the farmers. In case of cage 1, this average length was obtained by measuring the fish directly since the fish in this cage were collected for sale during the weeks following the sampling. The difference between this length and the standard average length obtained by means of hydroacoustics was only 5 mm (Table 5), which can be considered a very reliable value. The standard-length values from cage 2 and 3 were estimations made by the farmers and, therefore, they were less precise. Cage 2 was especially problematic due to several issues which occurred during the farming process. The fish in this cage were collected 18 months after sampling, which hindered the estimation process conducted by the fish farmers. These data does not match the length range obtained by means of hydroacoustics. Cage 3 had recently been sown when the sampling took place. At that moment, farmers had good information about the length of the fish introduced into the cages. This length range matches the one obtained with hydroacoustics.

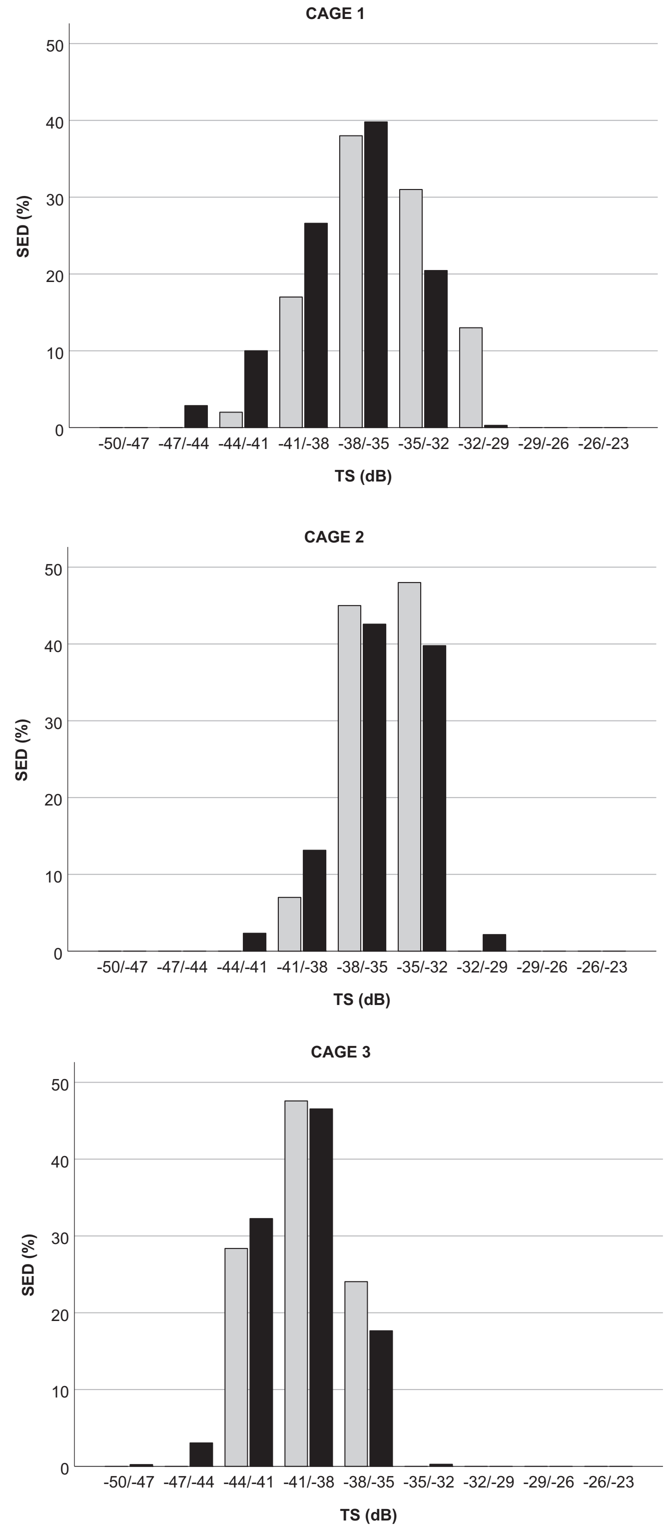

Fig. 5. TS distribution of the SEDs of the three cages analysed with the transducer placed outside the cage, differentiating between fixed (grey) and vertically moving (black).

Moreover, the vertically moving system allows for a whole scanning of the whole depth of the cage, unlike the fixed sampling, where the whole of the cage is estimated based on the data measured at three depths, with the potential deviations that might occur in these

Table 4
PERMANOVA test performed on single echo detection (SED) distribution for the transducer in vertically moving or fixed position, from outside the cage, for the three cages.

Cage	Factor	df	Sum. Sq.	Mean Sq.	Pseudo-F	*p*	Unique perms
1	Transducer V. Moving/Fixed	1	8416	8416	87.958	0.003	424
2	Transducer V. Moving/Fixed	1	2859	2859	26.420	0.001	857
3	Transducer V. Moving/Fixed	1	423	423	18.801	0.009	217

Table 5
Mean target strength (TS) for the vertically moving surveys performed from outside the cage for the three cages, average Standard Length (SL) of the acoustical estimates, average Standard Length (SL) given by fish farmers and corresponding standard deviation (SD).

Cage	Mean TS (dB)	Acoustical average SL (mm)	Fish farmers average SL (mm)	SD (mm)
1	−37.07	233	238	35
2	−35.71	262	210–250	–
3	−40.02	181	175–200	–

calculations. Based on the results obtained in this experiment, the vertically moving system was selected as the most adequate method to conduct the ensonification in production cages.

An additional advantage of placing the transducer outside the cage is that it avoids interactions with the farmed fish, thereby reducing the risks derived from stress. When using vertical hydroacoustic methods, the acquisition of acoustic data is performed within the cage and with the transducer placed in a vertical position (Espinosa et al., 2002; De La Gándara and Espinosa, 2012; Soliveres et al., 2014; Soliveres, 2015). This is a major issue since the effect of the stress on fish has been proven to have negative consequences on their growth and immune system, which increases disease emergence (Pickering and Pottinger, 1989; Caruso et al., 2005; HSUS, 2008; Iwama et al., 2011). In addition, monitoring from outside the cage facilitates the sampling logistics to a great extent since it does not require manipulating the anti-bird nets used in this kind of facility. It also makes it possible to perform the sampling in a faster, easier and more economical way.

We consider that our sampling protocol provides reliable results for sea bass facilities, which has been corroborated with actual size data. This method could also be easily applied to production systems of gilthead bream since they are farmed at similar facilities. It would only be necessary to use the TS-length conversion equation, also suitable for this species (Rodríguez-Sánchez et al., 2018). This monitoring system could improve aspects such as food dose optimization, which constitutes more than 50% of the production costs (Soliveres, 2015). It could also provide relevant information to evaluate the potential effect of cannibalism, which occurs at times during the first farming stages, since the size difference has been proven to be a conducive factor in fry planting that can lead to serious predation issues (Gersanovich, 1983; Giles et al., 1986). For this predation to occur, the predator must be twice as large as the prey (Katavić et al., 1989). Therefore, having a tool that provides information on fish size distribution during the first farming stages can be of great help to fish farmers when assessing losses caused by this problem.

To conclude, our results have enabled us to develop a specific sampling protocol to monitor fish size structures in this type of open-sea aquaculture production system which can be implemented in an easy and quick manner. This study lays the foundation to develop a system that will allow us to know the amount and biomass of the caged farmed fish in the coming years.

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Declaration of Competing Interest

None.

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