Quantification of acoustic target shadowing for biomass estimation in aquaculture net-pens

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Michalis Asderis
Hellenic Centre for Marine Research

Nikos Papandroulakis
Hellenic Centre for Marine Research

Walter Caharija
Lloyd's Register, Consulting - Energy

Kevin Frank
SINTEF

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Espen Eilertsen
SINTEF Ocean AS
Trondheim, Norway
Espen.Eilertsen@sintef.no

Walter Caharija
SINTEF Ocean AS
Trondheim, Norway
Walter.Caharija@sintef.no

Zacharias Kapelonis
Hellenic Centre for Marine Research
IMBRIW, Crete, Greece
zkapelonis@hcmr.gr

Michalis Asderis
Hellenic Centre for Marine Research
IMBBC, Crete, Greece
m.asderis@gmail.com

Kevin Frank
SINTEF Ocean AS
Trondheim, Norway
kevin.frank.private@outlook.com

Christian Schellewald
SINTEF Ocean AS
Trondheim, Norway
Christian.Schellewald@sintef.no

Nikos Papandroulakis
Hellenic Centre for Marine Research
IMBBC, Crete, Greece
npap@hcmr.gr

***Abstract*—In this paper we present our initial findings from investigating the dampening of acoustic signals through dense fish layers, referred to as shadowing. These findings are based on measurements which were performed in the Mediterranean Sea and off the Norwegian coast using gilthead seabream and Atlantic salmon respectively. The paper also presents the experimental setup for data acquisition. The results from the initial data analysis show that the shadowing effect is measurable and indicate that it can be compensated for. Future work will include the creation of a compensation strategy for this effect.**

***Index Terms*—Aquaculture, Echo-sounder measurements, biomass estimation, underwater acoustics**

I. Introduction

In the aquaculture industry biomass estimation is a crucial part of the fish production process and aims at measuring the growth rate and the final production as accurately as possible. Any commercial aquaculture operation must keep track of the number of fish within the net-pen, their growth rate and the overall fish health and welfare. Biomass estimation can uncover fish health issues, as a reduced growth rate can be a symptom of reduced welfare [1]. If the biomass within a net-pen should drop this might also indicate that individuals are escaping from the net-pen. In terms of national rules and regulations it is also necessary for fish farmers to document that they are not exceeding the maximum limit of individuals permitted within one net-pen, which is $25kg/m^3$ for salmon [2]. For gilthead seabream this varies between $5-20kg/m^3$ and $10-20kg/m^3$ depending on fish weight and size [3]. However, the aquaculture industry has a unique challenge in keeping track of the farmed animals due to the large number of fish within a single net-pen. Another issue is the fact that the net-pen volume is largely inaccessible to humans, making the active observation of fish much harder [4]. Despite these challenges, manual approaches for biomass estimation and fish welfare assessment are widely used. These involve physically weighing a given number of individuals and inferring an average weight and welfare evaluation [1] for the entire population, along with a visual inspection of each individual.

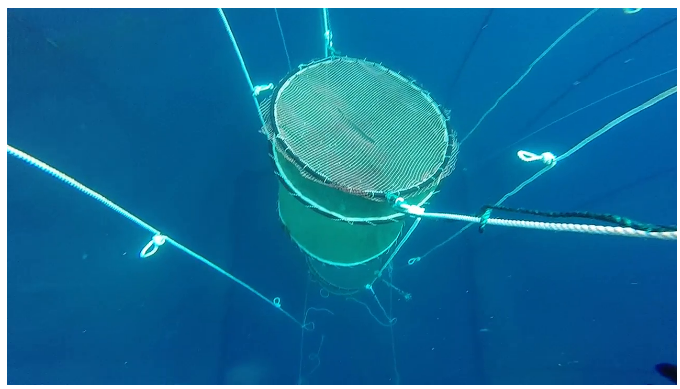

Fig. 1. Image of the fish-cage setup in Greece taken by a diver. The echo-sounder measures from under the cages towards the water-surface through two layers of fish.

Cameras can be used to help this process by increasing the sample while eliminating the need for handling the fish. However, due to turbidity the line of sight can be greatly reduced underwater. Additionally, one principle problem is that a camera system can not observe fish beyond the first few

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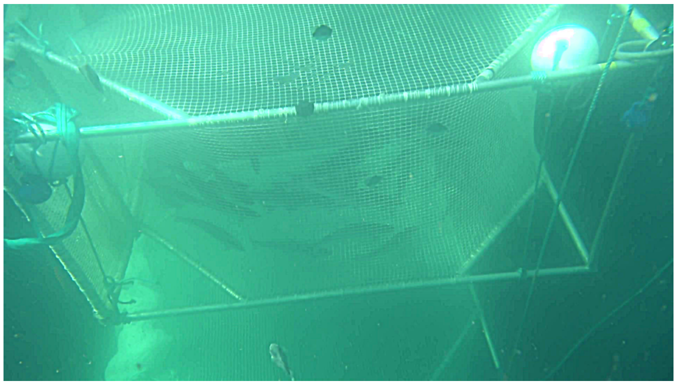

Fig. 2. Image from a ROV filming the underwater setup in Norway. Two separated fish cages containing salmon are mounted on top of each other. The echo-sounder measures from under the cages towards the water-surface through two layers of fish.

occluding layers of fish. The visible field of view that still allows for a good image resolution is also a limiting factor, as the observable volume in salmon net-pen is small compared to the large volume of the whole net-pen. Nevertheless, camera systems represent a significant improvement compared to manual methods and subjective observations. Yet, there is another tool which is often employed for biomass estimation, namely echo-sounders.

Echo-sounders are instruments which use acoustic energy in order to obtain information regarding a target or target-area. In oceanography echo-sounders are used to map the sea floor. In the fishing industry they are used to identify, and estimate the abundance of fish. In the Aquaculture industry they are used to estimate the biomass and monitor fish behaviour and distribution within a net-pen [5]–[7]. Echo-sounders function by emitting a pulse of acoustic energy, referred to as a *ping*, and listening for the signal return. The return amplitude indicates how reflective the target region is, and hence, its density, as the relationship between the two are assumed to be linear. The distance from the echo-sounder transducer face and the target can also be calculated and is referred to as the *range*. In order to maintain linearity between the received signal and target size echo-sounder systems employ compensation functions in order to compensate for signal loss due to range. The absorption function compensates for signal loss due to acoustic absorption, while the TVG (time varied gain) function [8] is meant to compensate for the range dependant signal loss due to geometrical spreading.

Echo-sounders have great potential as a tool for biomass estimation since they do not require handling of the fish and can, unlike cameras, capture data from a volume of the net-pen beyond the first visible layer. Even though there are many positive aspects to echo-sounders, accurate biomass estimation is yet very challenging due to the uniqueness of the application. In fishery echo-sounders are used to monitor fish from a distance. However, due to the limited size of the net-pen the echo-sounder will be closer to the target in an aquaculture application. Additionally, traditional echo-sounder biomass estimation techniques do not consider signal loss between dense layers of fish. Due to this effect, which we refer to as the shadowing effect, the relationship between the target strength and its size can no longer be assumed to be linear. Shadowing is therefore a source for systematic error in biomass estimation using echo-sounders in aquaculture. The shadowing effect is also described in [8], where the authors suggest it may be the main cause of non-linearity within fishery acoustics. Additional study into this topic is therefore necessary in order to enable the development of alternative tools and methods for accurate biomass estimation in aquaculture net-pens using echo-sounders.

This paper documents the application of echo-sounder technology for biomass estimation purposes in sea-based aquaculture. We have quantified the effect of dense fish layers on echo-sounder measurements focusing on signal loss. The loss in acoustic signal and its quantification is fundamental to properly estimate biomass via echo-sounder technology in the aquaculture context. The data required for the quantification of shadowing were gathered from two separate trials. One executed in Norway with Atlantic salmon (*Salmo salar*), and the other one executed in Greece with gilthead seabream (*Sparus aurata*). The data from the trials represented a ground-truth for shadowing quantification with respect to fish layers of known biomass. Images from the actual trials are depicted in Figure 1 and Figure 2.

The results indicate that it is possible to measure and quantify shadowing for both Atlantic salmon and gilthead seabream. And adds to the results from previous work on the topic, such as [9]–[11], for a future, more accurate, biomass estimation systems using echo-sounders.

The paper starts with an introduction followed by an brief explanation of terminology. Section III covers the experimental setup for the field trials conducted in both Norway and Greece. In Section IV the analysis of the data will be described and Section V presents the initial results from the analysis of the data yielded by these trials. Finally, Section VI will discuss the results and planed future work. Note that the results can only be compared relatively between cases within each separate trial, and should not be compared between species and trial location.

II. Glossary

The definitions and variable names listed in this section are gathered from [5].

- S_v = Volume back-scattering strength (logarithmic (dB))
- s_v = volume back-scattering coefficient (linear domain)
- TS = Target strength
- P_{er} = Received power
- s_a = Area back-scattering coefficient (ABC)
- δ_{bs} = Back-scattering cross section
- TVG = Time varied gain
- R = *Range*, the distance between the echo-sounder face and a given target.

III. Materials and methods

We note that the experimental setup is similar to that outlined in [10] but differs in so far that our setup includes multiple layers of fish and utilizes a layer of fish itself as a target for the final analysis. This will give a more clear indication of how the shadowing effect acts upon a second layer of fish rather then a clear target with a known back-scattering strength.

A. Ethical statement

The experimental setup for the Norwegian trial was planed in coordination with the Norwegian food and safety authorities in order to secure fish welfare during the field trials. The planed field trials were deemed to not place any increased stress on the individuals and was therefore exempt from research animal applications in accordance with Norwegian law.

The experiments with the gilthead seabream were perform at the pilot sea cage farm of HCMR at Souda Bay, Chania, Crete, Greece. The farm is certified as an aquaculture facility from the national veterinary authority (code GR94FISH0001) and standard rearing methodologies are applied. As the field trials were implemented applying standard practices, not causing any increased stress on the individuals, they were therefore exempt from experimental animal use in accordance with the Greek law.

B. Norwegian trials: Materials

For the Norwegian trials a Simrad ES70-7CD echo-sounder was used for data acquisition along with the EK80 system. A metal plate was used as the reference target during data acquisition. The cages for the Norwegian trials were constructed using an aluminium frame which measured $3m \times 3m \times 1.5m$. The cages were covered in standard netting forming an octagonal cage inside the aluminum frame, approximating a circular cage with $3m$ diameter.

In order to minimize the necessary handling of the caged fish population the cage was designed so that the net volume could be increased for the population to stay within the cage over night, thus minimizing the handling of fish. This was done by adding a gate leading to an extra net which can be extended to increase the volume of the cage.

C. Norwegian trials: Method

The field trials were conducted using two octagonal cages filled with Atlantic Salmon. The cages were suspended in vertical alignment above the Simrad split beam echo-sounder which was mounted on a gimbal and oriented upwards. Between the topmost cage and the surface a reference target was placed. The cages were placed at depths of 2 and 5 meters. The echo-sounder was located at 12 meters depth and the reference was located at approximately 1 meter depth. Information on the cage population can be found in Tables I. Figure 3 shows a sketch of the trial setup.

The equipment was placed inside a commercial net-pen also containing a population of Atlantic salmon. Three different biomass densities were used during the experiments, high (H), medium (M) and low (L) densities, see Tables I. Cage 1 was kept at a high biomass density while cage 2 started with a high density and was adjusted to medium and low density over the course of the experiment. The configurations measured in the trial are shown in Table II. Between each change in biomass density the salmon would rest overnight in order to recover from handling and be able to refill their swim-bladders.

TABLE I
Population information in both cages for the Norwegian trials. H, M and L refers to the biomass densities in the cages which were High, Medium and Low, respectively

	Species	Avg weight	H	M	L
Cage 1	Atlantic Salmon	$1.92kg$	$253.4kg$	–	–
Cage 2	Atlantic Salmon	1.88 kg	$292.6kg$	$204.2kg$	$95.9kg$

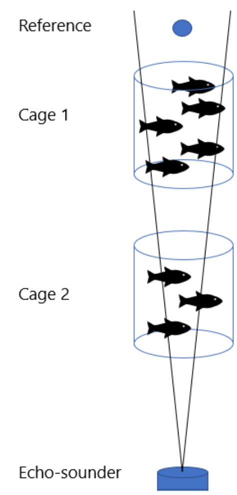

Fig. 3. Sketch of experimental setup from Field trials.

TABLE II
Table showing a subset of configurations from the Norwegian and Greek trials, which this paper is based on. Depth is in meters and under configuration the letter specifies the density (high, medium and low) while the number specifies the cage, H1 and H2 are not exactly equal.

Depth	Configurations			
2m	H1	H1	H1	H1
5m		H2	M2	L2

D. Greece trials: Materials

The echo-sounder used in the Greek trials was a Simrad *ES120-7C* along with the EK80 system. A calibration sphere of known signal intensity was used as a reference. The cages used in this trial were cylindrical cages with a plastic frame measuring at $1.2m \times 1.1m$ ($diameter \times hight$).

E. Greece trials: Method

The trials in Greece utilized a similar overall cage setup as the Norwegian trials, as shown in Figure 3. In this setup the echo-sounder was placed underneath the net-pen. The net-pen was empty during the trial except for the fish within the cages.

TABLE III
POPULATION INFORMATION IN BOTH CAGES FOR THE GREEK TRIALS. H, M AND L REFERS TO THE BIOMASS DENSITIES IN THE CAGES WHICH WERE HIGH, MEDIUM AND LOW, RESPECTIVELY

	Species	**Avg weight**	**H**	**M**	**L**
Cage 1	Gilthead seabream	$383.6g$	$25.0kg$	–	–
Cage 2	Gilthead seabream	$383.6g$	$25.0kg$	$17.2kg$	$9.9kg$

IV. DATA ANALYSIS

The data analysis was performed using a combination of Python [12], ESP3 [13] and the EK80 [14] software. Python was used in order to process the data, ESP3 was mainly used for visual inspection of the echo-gram and the EK80 software was used for data acquisition and storage. In order to access the raw data using python it was necessary to convert the .raw file into a netCDF format. First the ranges encompassing the interior of both cages was identified as $[8.60m, 9.55m]$ for the topmost cage and $[6.60m, 7, 55m]$ for the bottom cage. These ranges were used for the analysis of both the Greek and Norwegian data, as the range holds true for both cases. Second, the received raw back-scattering values were extracted from the data set, which in turn were used to calculate the received power value P_{er}. P_{er} can be seen as the s_v value without any compensation for absorption or the range dependence. As the cages, and therefor the "targets", were located at the same range in all configurations the range compensation for all signals in the cages would be the same when comparing the signal received from the topmost cage. This means that if no shadowing effect is present the cages should, despite not including range compensation, have an equal accumulated average signal intensity.

By integrating the P_{er} value over the range for each cage we get a value that represents the biomass of that cage within one ping. This value was then averaged over time in order to get a stable value for comparison, this value is from now referred to as the *biomass number*. Finally the matplotlib library for python was used in order to plot the results and present them in this paper. For the initial analysis the hypothesis was that if there indeed exists a shadowing effect then the biomass number from the cage 1 will be weaker as the biomass increases in cage 2.

A. Norwegian data

During the measurements of the Norwegian data salmon was occasionally swimming in the volume between the echo-sounder and the lower cage, disturbing the measurements. Though efforts have been made to filter away such data points this likely still increases the noise seen within the data set.

B. Greek data

In the Greek data set some of the data seemed to suffer from disturbances where all signals within the echo-gram seemingly disappears. This disturbance will be referred to as *ghost pings*. In order to cope with this effect the relevant data sets were filtered by using the cage frame as a reference. The idea here was that if the cage frame signal strength falls below a certain threshold, then the data point would be discarded. As the cage frame is constantly within the echo-sounder beam, and is a clear target, there is no reason that it should disappear.

V. RESULTS

The results presented do not take into account differences in regards to species behaviour or environmental effects. We would also like to note that different cages, transducer and reference target was used in each trial. Due to this the results from the Norwegian and the Greek trials should be looked at as data from two separate trials and not be compared directly between trials.

A. Norway

For the Norwegian data Figure 4 and 5 Shows that there is a clear difference in the received signal strength when varying the biomass in the lower cage. The figures shows the biomass number (in dB) for the top cage with varying shadowing biomass. However, observe the signal from the topmost cage (Cage 1) when the shadowing biomass (which is present in Cage 2) is at a low density. If we assume that a shadowing effect is present the signal from the topmost cage should not be stronger than what we are receiving from the cage by itself, without any shadowing biomass. The reason for this is currently unclear, however, looking at Figure 5, we can see that the signal from the lower, shadowing biomass itself is initially far more intense then the signals from the same cage with medium and high biomass density. Even though it does degrade in intensity over time, it does not have the time to stabilize. The received signal from both cages in this configuration seems extremely unstable.

Figures 6 and 7 show the same information in a box-plot format. Here the P_{er} average over time is plotted against the biomass density in the lower cage. This includes the median for the data set and quartiles. It is interesting to note that the Signal received from the lower cage in Figure 7 with medium and high biomass density are very close, the medium density being the most stable of the two.

From the Figure 6 it is possible to quantify the average signal loss through a biomass by comparing the zero shadowing biomass case to the other two, excluding the configuration with low biomass density. Assuming that cage 1 without a shadowing biomass present lies around $-27dB$, there is a loss of approximately $-0.5dB$ when the medium shadowing biomass density is introduced, and a loss of $-2dB$ when a high shadowing biomass density is introduced.

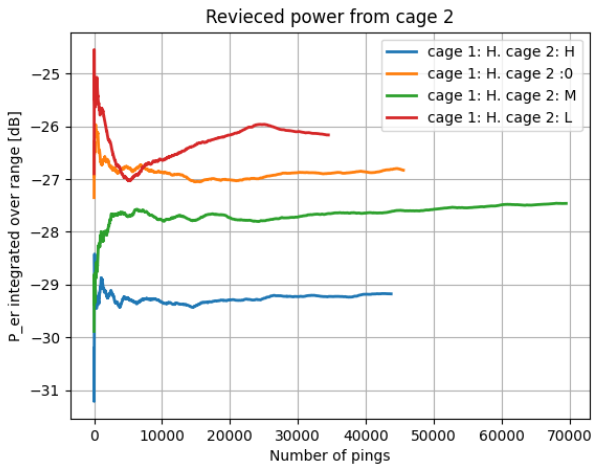

Fig. 4. Biomass number over pings from the Norwegian data. Cage 1 is the topmost cage. This cage is the contains the same biomass for all configurations, while cage 2 biomass is varied.

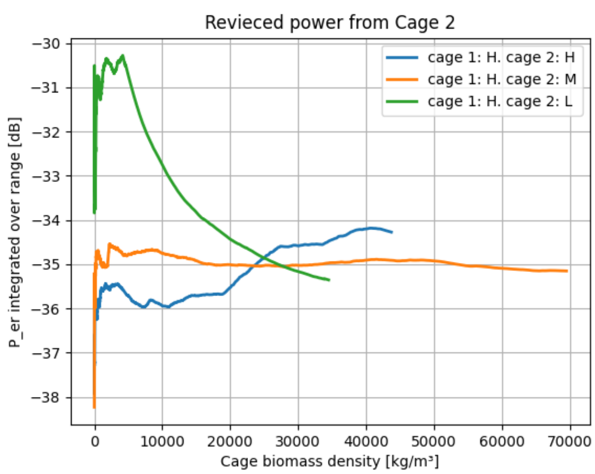

Fig. 5. Biomass number over pings from the Norwegian data. this plot shows the signal from the bottom cage over various biomass densities

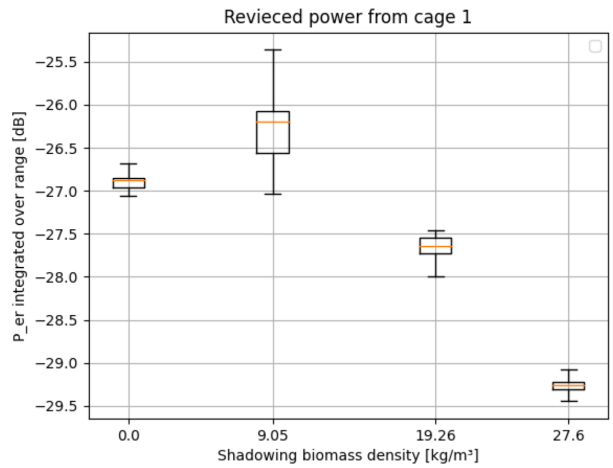

Fig. 6. Average received power from cage 1 (topmost cage). Cage biomass density referees to the shadowing biomass i.e cage 2

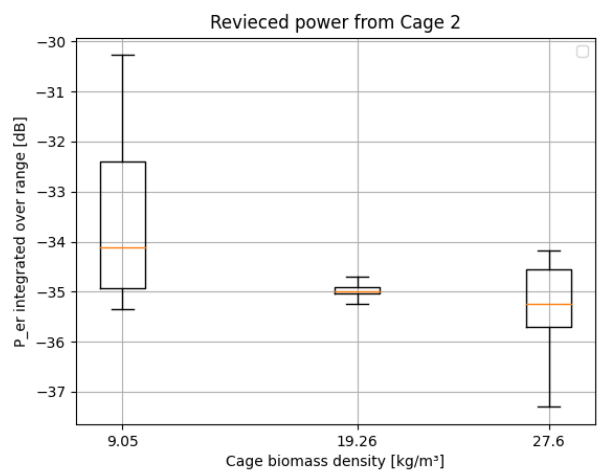

Fig. 7. Average received power form cage 2 (bottom cage). Cage biomass density referees to the shadowing biomass i.e cage 2

B. Greece

The data from the trials in Greece show similar results. Figure 8 and 9 shows that, while the cage alone gives the strongest signal, the configuration with medium shadowing biomass gives of the weakest signal. while the configuration with the low shadowing biomass density gives the second strongest. While reviewing the echo-grams it was noted that the case with medium shadowing biomass density had the largest occurrence of *ghost pings*. Though efforts to filter out these pings were made, it is possible that the filtering algorithm was not strict enough and this is why we are seeing artificially low intensity in the received signal. This is also reflected in Figure 9, where the cage with medium biomass density seemingly continuous to drop, while the cage with low biomass density stabilises at a higher intensity.

The box-plots shown in Figure 10 and 11 also reflect the same information. As with the Norwegian data, assuming that cage 1, without any shadowing biomass present, lies around $-34dB$, there is a loss of approximately $-3dB$ when the high shadowing biomass density is introduced, and a loss of $-2dB$ when a low shadowing biomass density is introduced

VI. Discussion/Conclusion

Though the Norwegian results show that there is a shadowing effect occurring which is not being compensated for, there are some issues here. The fact that we do not know what effects results in the unexpected intensity in the configuration with a low shadowing biomass density raises some questions. The reference target was also not ideally chosen. We had tested the use of a smaller calibration sphere as a reference target during pre-trials, however found that this target was impossible to locate when even a small biomass was introduced. Due

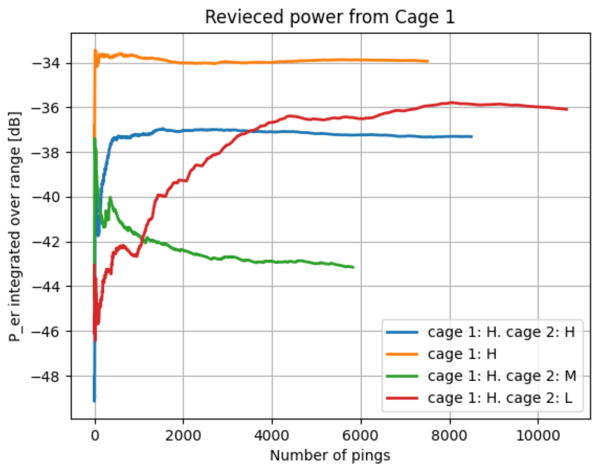

Fig. 8. Biomass number over pings from the Greek data. Cage 1 is the topmost cage. This cage is the contains the same biomass for all configurations, while cage 2 biomass is varied.

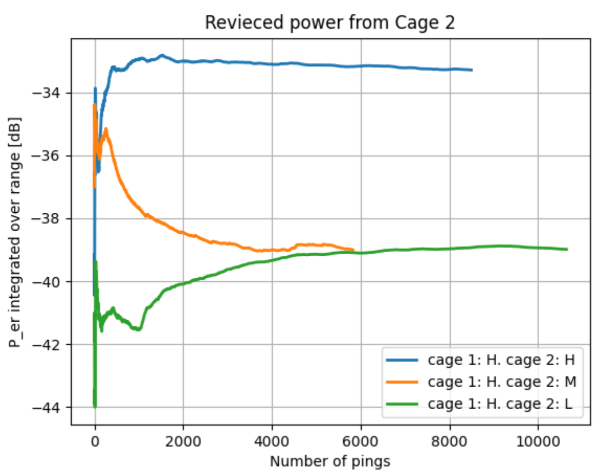

Fig. 9. Biomass number over pings from the Greek data. this plot shows the signal from the bottom cage over various biomass

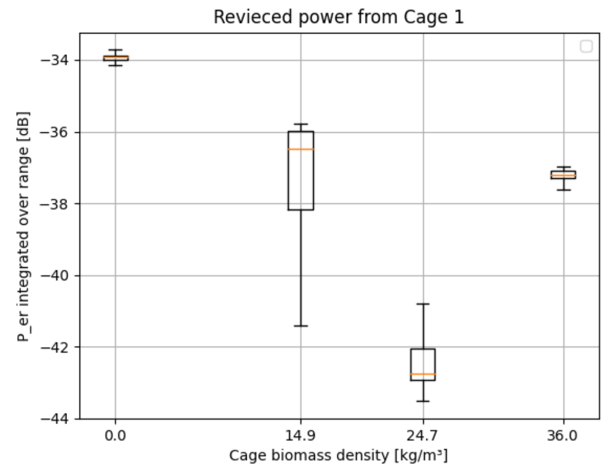

Fig. 10. Average received power from cage 1 (topmost cage). Cage biomass density referees to the shadowing biomass i.e cage 2

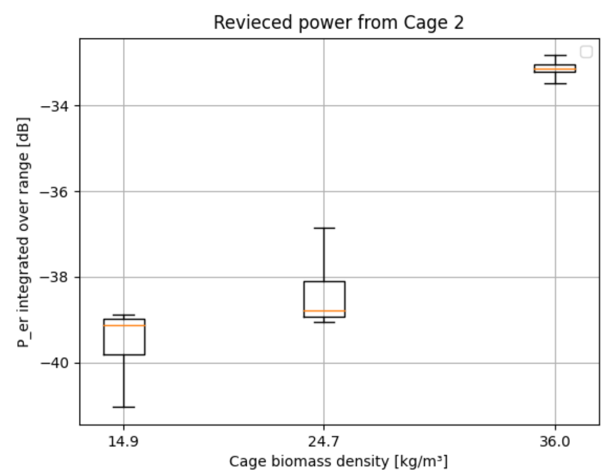

Fig. 11. Average received power from cage 2 (bottom cage). Cage biomass density referees to the shadowing biomass i.e cage 2

to this a metal plate was chosen to take its place, however upon reviewing the data we saw that the plate did not yield a stable enough signal to be used for a comparison of signal loss between two layers with varying biomass configurations.

The Greek results, while showing that the shadowing effect is also present with gilthead seabream, has the issue with ghost pings. The fact that the configuration with medium shadowing biomass seems to have the lowest signal strength is likely due to the ghost ping issue corrupting the data, this, however, needs to be confirmed. The team that executed the trials in Greece also learned the same lesson as the Norwegian team regarding the calibration sphere during the main trail. The experience gained from both these trials will be used in order to improve the next set of experiments which are planned to take place in Greece during the summer of 2021.

Outside this the results indicate that the shadowing effect is both present and quantifiable, the results also highlight a need for a compensation function for shadowing between dense fish layers will be necessary in order to accurately estimate the fish within a net-pen. This could for instance be done using a function of range and the estimated density of the previous layers in order to compensate in an iterative fashion throughout the water column. The results also highlight how difficult acoustic data analysis can be at times and the need for more development of data analysis methods and tools.

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REFERENCES

[1] C. Noble, S. Gismervik, M. Iversen, J. Kolarevic, J. Nilsson, L. Stien, and J. Turnbull, *Welfare Indicators for farmed Atlantic Salmon: tools for assessing fish welfare*. Nofima, 11 2018.

[2] A. Skonhoft, "National aquaculture legislation overview norway," May 2007. [Online]. Available: $http : //www.fao.org/fishery/legalframework/nalo_norway/en$

[3] "Animal welfare aspects of husbandry systems for farmed european seabass and gilthead seabream - scientific opinion of the panel," *EFSA Journal*, vol. 6, 11 2008.

[4] M. Føre, K. Frank, T. Norton, E. Svendsen, J. A. Alfredsen, T. Dempster, H. Eguiraun, W. Watson, A. Stahl, L. M. Sunde, C. Schellewald, K. R. Skøien, M. O. Alver, and D. Berckmans, "Precision fish farming: A new framework to improve production in aquaculture," *Biosystems Engineering*, vol. 173, pp. 176–193, 2017. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S1537511017304488

[5] D. N. MacLennan, P. G. Fernandes, and J. Dalen, "A consistent approach to definitions and symbols in fisheries acoustics," *ICES Journal of Marine Science*, vol. 59, no. 2, pp. 365–369, 2002.

[6] S. Vatnehol, H. Peña, and E. Ona, "Estimating the volumes of fish schools from observations with multi-beam sonars," *ICES Journal of Marine Science*, vol. 74, pp. 813–821, 03 2017.

[7] D. Li, Y. Hao, and Y. Duan, "Nonintrusive methods for biomass estimation in aquaculture with emphasis on fish: a review," *Reviews in Aquaculture*, vol. 12, no. 3, pp. 1390–1411, 2020.

[8] J. Simmonds and D. N. MacLennan, *Fisheries acoustics: theory and practice*. John Wiley & Sons, 2008.

[9] H. Kim, D. Kang, S. Cho, and M. Kim, "Effect of densely fish school on the acoustic propagation," in *EFFECT OF DENSELY FISH SCHOOL ON THE ACOUSTIC PROPAGATION*, 11 2018.

[10] D. N. MacLennan, F. Armstrong, and E. J. Simmonds, "Further observations on the attenuation of sound by aggregations of fish," *Institute Of Acoustics: Proceedings*, vol. 12, no. 1, pp. 99–106, 1990.

[11] E. Ona and K. Utne, "Acoustic extinction in dense herring layers, measured from a bottom-mounted transducer," Norwegian Institute of Marine Research, Tech. Rep., 10 2006.

[12] P. software Foundation, "Python v.3.9.5." [Online]. Available: $https : //www.python.org/doc/$

[13] NIWA, "Esp3 v.1.10.0." [Online]. Available: $https : //sourceforge.net/projects/esp3/$

[14] Kongsberg, "Simrad ek80." [Online]. Available: $https : //www.kongsberg.com/maritime/products/ocean - science/fishery - research/es_scientific/ek80$