CageEye Report — Haverøy

Fish Abundance Analysis for "The Well"

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We present results measured with the CageEye equipment at the Haverøy site of Marine Harvest Norway AS, investigated by the Institute of Marine Research, Bergen. Two sets of transducers, with 50 kHz and 200 kHz each, were installed upward-looking in the same cage. One pair was directed onto a freshwater pool with an interlayer used for independent lice treatment. The measurements investigate the difference in fish abundance inside and outside of the pool, with and without the use of surface lights. We find that the fish abundance is reduced to (31 ± 4) % inside the pool on average. The installation of lights significantly deteriorates the tendency of the fish to populate the pool from (33 ± 4) % to (29 ± 3) %.

Lice infestation is a remarkable issue in the production of Atlantic salmon, giving rise to the exploration of techniques to reduce the risk and related effects on the fish. We present fish abundance measurements carried out with the CageEye echosounder system accompanying a study of a freshwater pool called "The Well". It is assumed that fish populating the pool can reduce their lice infestation caused by the sea lice's intolerance of fresh water.

The setup used two sets of transducers, with a frequency of 50 kHz and 200 kHz each. The 50 kHz has a larger view angle and therefore covers a larger volume, while the 200 kHz features a higher spatial resolution. The transducer were installed upward-looking in the same cage, with one pair being directed onto the shielded pool, and the other onto a standard region. We assign the channel ideas to their respective meaning here for reference:

- `4113-002C/1`: 50 kHz inside the pool,
- `4113-002C/1-200`: 200 kHz inside the pool,
- `4113-002C/2`: 50 kHz outside the pool,
- `4113-002C/2-200`: 200 kHz outside the pool.

In the following, we give a brief theoretical background to explain the presented physical quantities. We show the results in form of echograms in an overview of the whole study, and single-day high resolution versions and additional derived quantities. We close with a statistical view on the results and conclude that the measurements demonstrate the negative effect of the pool on fish abundance.

1. THEORETICAL BACKGROUND

The purpose of the measurements performed with the CageEye system is to determine the depth distribution of fish contained in a production cage. Using the current equipment the volume which is covered by the beam is smaller than the actual cage volume. The measured fraction depends on the beam pattern $b(\theta, \varphi)$ of the utilized transducers, which themselves differ depending on the operational frequency.

From the actual measurements, we derive the reverberation level RL as the basis for deriving fish density and biomass-related quantities, by normalizing the raw measured voltages to hardware specific parameters. We deal with so-called volume reverberation, for which we assume that the fish school is perfectly equally distributed in each individual pulse volume.

The *volume back-scattering strength* Sv is used to describe the returned signal. It is connected to the reverberation level via

$$\mathrm{Sv} = \mathrm{RL} - \mathrm{SL} + 2\mathrm{TL} - 10 \log_{10} V_p, \tag{1}$$

where V_p is the pulse volume, SL the source level describing the intensity of the sound source, and $2\mathrm{TL} = 20 \log_{10} r + ar$ the transmission loss. Here, r in m is the range from the echosounder, and a in dB m^{-1} the absorption coefficient. Note that all quantities which are not explicitly defined differently are in decibel (dB) units in the following. For the pulse volume we assume that the beam pattern has an "ideal shape", with unity intensity in a sphere segment described by the equivalent beam angle Ψ in steradian (sr), and zero elsewhere. It is given by

$$V_p = \frac{c\tau}{2} \Psi r^2, \tag{2}$$

where $c = c(d, T, S)$ in m s^{-1} is the speed of sound in seawater, and τ in s is the pulse length. Accordingly, for an accurate pulse volume calculation the depth and water characteristics have to be known as well.

Note that the depth is not constant, as the echosounder is moved by currents, and the water surface itself is deformed by waves. Accordingly, depth is a function of time, $d = d(t)$, so that each quantity that depends on d has a time dependency as well. The calculation of Sv is therefore itself depending on a proper surface detection, which is the process of determining the range of the water surface from the transducer.

In the following, we present $\mathrm{sv} = 10^{\mathrm{Sv}/10}$ as a quantity to estimate fish abundance. Since sv is proportional to fish density, we can identify ratios between different sv measurements as ratios of fish density.

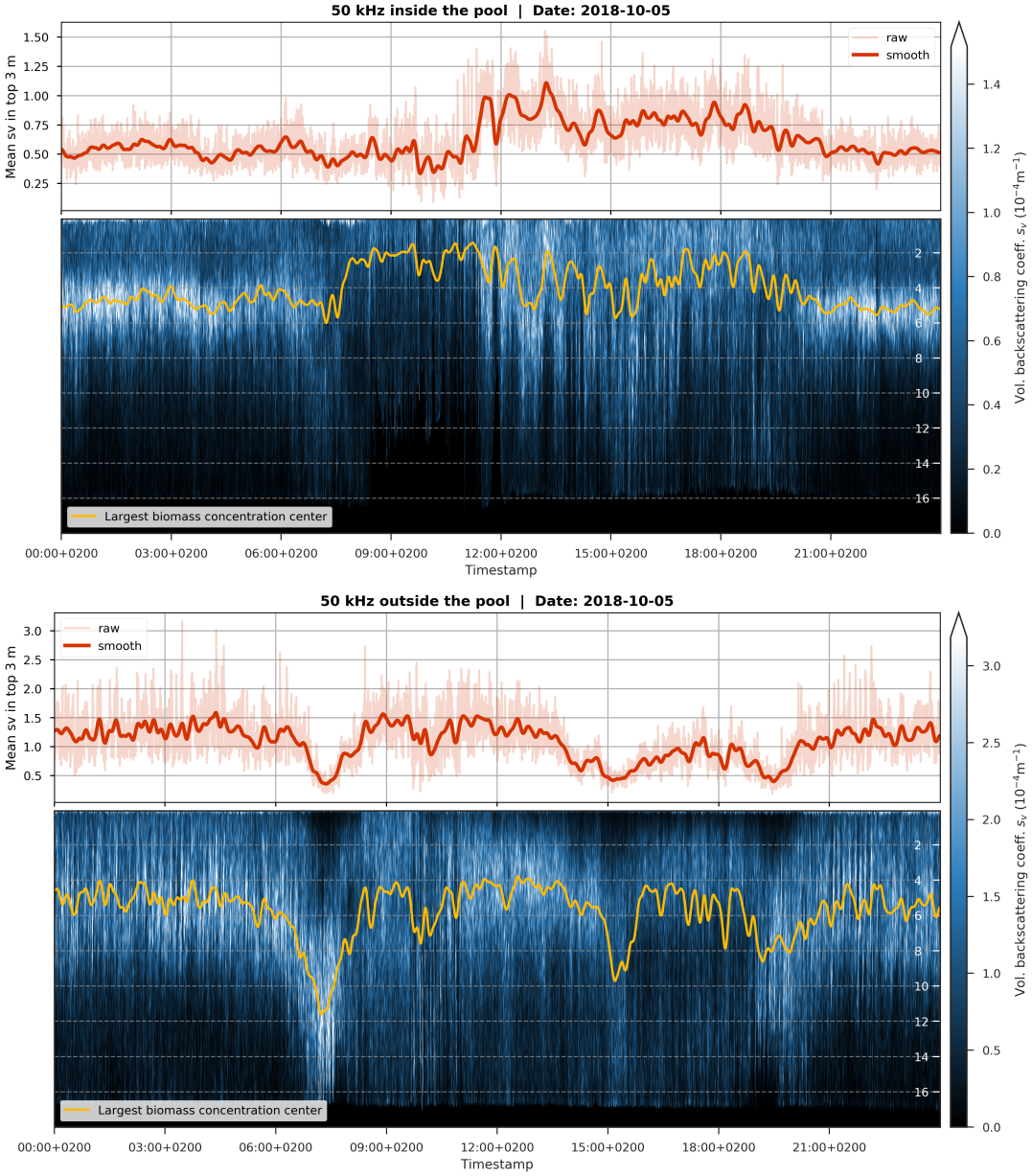

FIG. 1: Comparison of a daily dataset inside and outside of the pool. Shown are two identical panels for the data of the same time range inside (top) and outside (bottom) of the pool. Each panel shows the actual sv-echogram at the bottom, with the largest biomass concentration center marked in yellow. Above the echogram, the average volume backscattering strength in the top 3 m depth is shown as raw (light red) and smoothed (solid red) data. Note the different color scales which indicate the lower fish abundance inside the pool.

2. RESULTS

The data for the complete trial period has been

- normalized to hardware specific parameters (yielding reverberation level RL),
- analyzed with our surface detection algorithm to generate depth information,
- converted to volume backscattering coefficient sv by applying the sonar equation.

Figure 1 shows a comparison of a daily dataset inside and outside of the pool. That is, it shows two identical panels for the data of the same time range inside (top) and outside (bottom) of the pool. Each panel shows the actual sv-echogram at the bottom, with the largest biomass concentration center marked in yellow. The latter gives a visual guide of how the biomass shifts in the cage over time. Above each echogram, the average volume backscattering strength in the top 3 m depth is shown as raw (light red) and smoothed (solid red) data — emphasizing the ac-

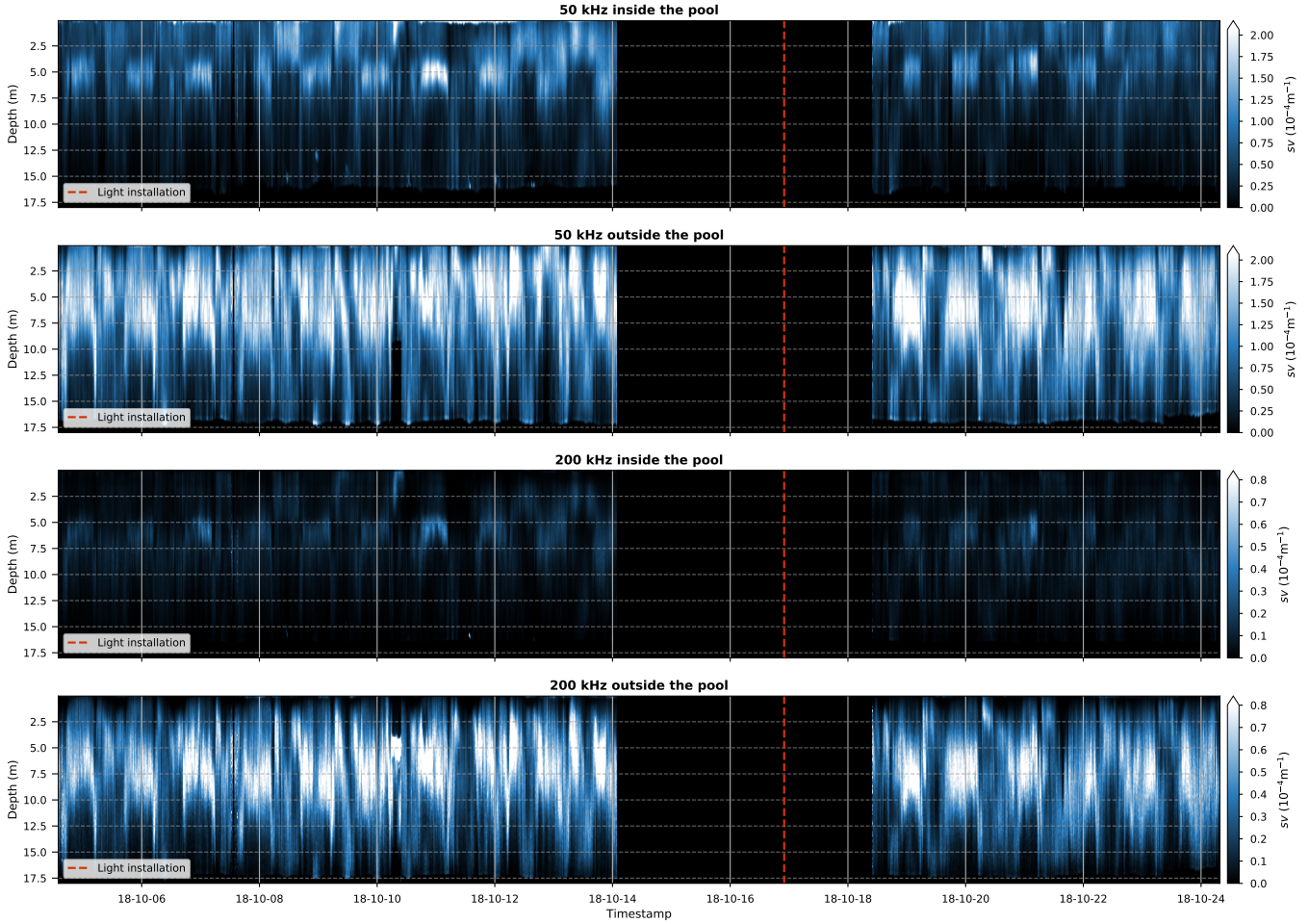

FIG. 2: Overview echogram plot of the complete trial. Shown are 20 minute average sv echograms for each of the involved channels. Channels with same frequency share a color scaling for easy absolute comparison. The red dashed line marks the day at which lights were installed.

tivity of the fish in the vicinity of the water surface. The underlying high resolution graphs are provided as supplementary material of this study for all channels and days of the trial. Note that the color scale of each echogram is scaled for optimal visibility using the 99th percentile of the actual data. Therefore, the compare the datasets quantitatively, care must be taken in observing the given value range of the colorbar.

To facilitate the comparison of the absolute fish abundance values given by the back scattering coefficients, we provide the data of the complete trial period using 20 minute averages in fig. 2. For each pair of identical frequency a common color scaling was applied. The overall brightness of the echograms gives a clear picture of the ratio between the fish abundances inside and outside the cage. The right dashed line moreover marks the day at which lights were installed, which are often used affect the fish in the desired way.

To statistically evaluate the effect of the pool on fish abundance, we calculated 12 hour averages of the raw data to assess the time evolution of the fish abundance ratio. We averaged over the 50 kHz and 200 kHz frequencies in this case, to raise the statistical significance. By dividing the results inside by the results outside the pool, we calculate pool ratio.

Note that for all the calculations we used a depth threshold of 0.5 m to reduce effects of improper surface detection to a minimum. Since it is not clear which depth range is relevant for the assessment of the effects, we performed the calculations for 4 different depth ranges, each starting from 0.5 meters, and going down to 6 m, 10 m, 14 m, and 18 m respectively. The results are shown in fig. 3.

The following table shows the statistical distribution of the ratios determined in that way.

We can see that the mean values are distributed about one third, and the actual average shows that there are (31 ± 4) % of the fish inside the pool on average. We can further subdivide the time range into the ranges before and after the light installation, showing that the ratio further deteriorates from (33 ± 4) % to (29 ± 3) %.

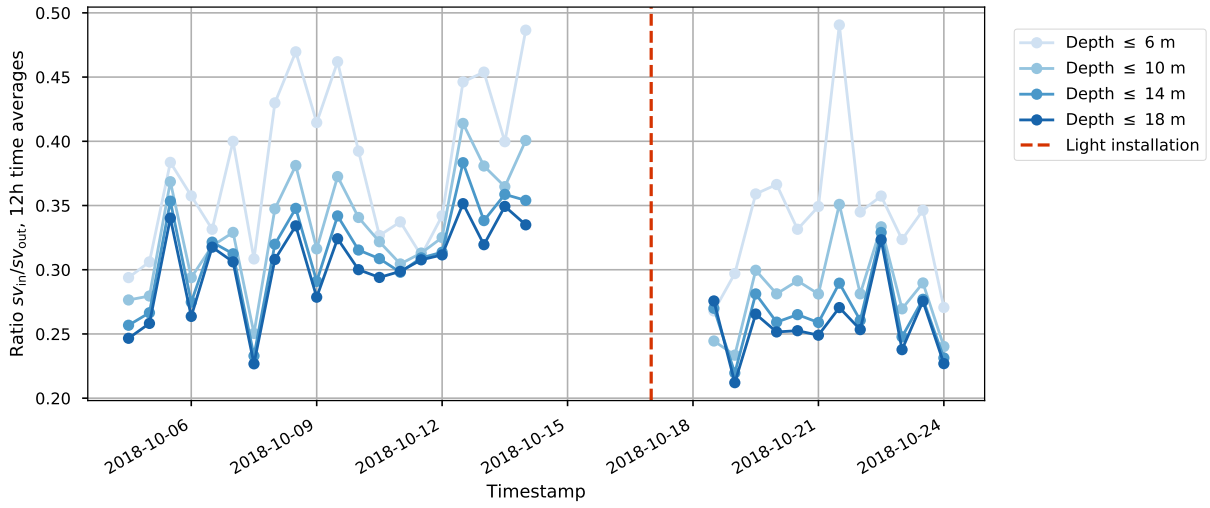

FIG. 3: Time evolution of ratio between fish inside and outside the pool. The ratios between fish inside and outside the pool were calculated from 12 hour averaged sv values, and averaged over the two available frequencies. The differently colored lines show results for different considered depth ranges. The red dashed line marks the day at which lights were installed.

	≤ 6 m	≤ 10 m	≤ 14 m	≤ 18 m
mean	0.367	0.315	0.296	0.286
std	0.062	0.047	0.041	0.038
min	0.267	0.233	0.219	0.212
25%	0.325	0.281	0.263	0.253
50%	0.353	0.314	0.294	0.286
75%	0.403	0.348	0.323	0.318
max	0.490	0.413	0.383	0.351

TABLE I: Statistical distribution of the 12 hour average sv based ratios in different depth ranges.

3. CONCLUSIONS

We conclude that fish are not actively populating a freshwater pool introduced as a subset of the volume of a production cage in the same amount as for regions outside of it. The pool seems to be a perceivable barrier. This result is shown consistently over the entire trial period. The installation of surface lights has another deteriorating effect on the population of the pool, although this result may not be completely statistically significant.

Another aspect of fig. 3 — although not statistically validated — is the increase in population of the pool over time before the installation of the lights. A longer trial period would have been needed to verify this trend. But it may indicate that fish can get used to the pool, and just avoid it in the beginning as they may conceive it as a debris.

Therefore, it needs to be investigated if the observed fraction of fish populating the pool is sufficient to reduce lice infestation by reasonable amounts. This has to be observed in combination with potential negative effects of the pool on e.g. feeding behavior.

4. ADDITIONAL FILES

As a supplement to this document and the source images contained, we provide the actual data behind fig. 2 in form of CSV files. We moreover provide the daily plots for which examples are shown in fig. 1 for all channels and all days of the trial.