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Data report of the EPPO'2019 experiment: acoustic detection of fish behavior

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Foreword and Acknowledgment

About one year ago we were approached by Miguel Theriaga from Viveiros da Espargueira, with a practical question related to determining fish behavior during feeding in an aquaculture environment. Whether underwater acoustics could be used to answer that question was our working hypothesis. This was the motivation for the experiment that was carried out in March 2019, at the EPPO, described in this report. The collaboration and support of Hugo Ferreira and Pedro Pousão-Ferreira from EPPO, was fundamental for carrying out the experiment and is greatly appreciated.

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Abstract

This document describes the data acquired during fish feeding periods at an aquaculture pond at the “Estação Piloto de Piscicultura de Olhão” (EPPO), in the period March 4 - 8, 2019. The primary goal of this experiment was to understand whether fish sound during feeding is audible and automatic detectable with the aim of determining the eventual decrease of fish interest during the feeding interval. The data shows a clear acoustic signature during fish feeding periods. That signature is characterized by a steep noise power increase of about 30 dB re 1μPa^2 in a band of 1 - 5 kHz, with extensions, at smaller power levels, down to 200 Hz and up to 15 kHz. As expected aerial acoustic noise has a low level interference with the noise generated underwater by food drops and fish agitation. Wheter this noise spectra, or part of it, can be associated with fish behavior remains an open question, for further detailed analysis.

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Chapter 1

Introduction

Fish farming became a business area that requires higly specialized competences in fish feeding, water quality and fish health care. The required knowledge should cover a variety of fish species, which behavior and sensitivity vary with a number of abiotic parameters, among which water temperature and lighting. Fish feeding is very resource demanding and, if in excess, may contribute to the deterioration of the water quality. Therefore it is of paramount importance to adapt the quantity of food to the requirements of the fish population, which vary throughout the year and with the fish growing curve. This calls for some real time backfeed information on fish apettite to control the food distributor. There have been attempts to obtain that backfeed information through a variety of sensors, namely through underwater or above water video cameras as well as other means, but results were not always conclusive. Whether that information may be obtained through listening to fish feeding noise is an open question.

In order to obtain a suitable set of data to test the acoustic detection hypothesis, an experiment was setup to listen to the acoustic noise generated during fish feeding cycles in a aquaculture tank at the "Estação Piloto de Piscicultura de Olhão" (EPPO), in March 2019. It is clear that fish attraction for food may vary throughout the day and from one day to the other according to temperature and lighting conditions, so these variables were carefully recorded. Moreover, together with fish noise, there are other noise interferences that may be received in the acoustic sensors, namley that of the feeder noise itself and that of food drops in the water.

The experiment was carried out from March 4 to 8, 2019. The recorded signals show a clear increase of acoustic power during feeding periods. This noise increase is concentrated in the band below 6 kHz with a peak at approximately 2.5 kHz, but extending further up and down in frequency.

This report is organized as follows: chapter 2 describes the fish feeding experiment setup, materials and methods used; chapter 3 reports the preliminary data analysis, and chapter 4 draws some conclusions and potential clues for further work.

Chapter 2

Fish feeding acoustic experiment

2.1 Environmental conditions

2.1.1 The aquaculture tank

The experiment took place in the Estação Piloto de Piscicultura de Olhão (EPPO), IPMA, from March 4 to 8, 2019. An external ground tank with a variety of species was selected for installing the acoustic recording station. The tank is shown in the aerial view of Fig. 2.1, marked in red. The tank is approximately 60×40 m and 1.60 m deep. Water from the Ria Formosa is continuously circulated through the tank. The tank has an water oxigenation air-pump that was stopped during fish feeding periods. The tank was covered with a net to avoid fish catching by birds. There was a mixture of fish species in the tank

Figure 2.1: *EPPO aerial view with selected tank for experiment (red square).*

including sea-bream, and a few Atlantic croaker (corvine), all between 15 and 25 cm long. The density of fish was relatively low. In some occasions it took a few minutes for the water to get agitated after the feeder was turned on.

2.1.2 Weather

According to the meteorological measurements at the close by airport of Faro the weather during the week of March 4 - 8, 2019 followed a pretty constant pattern with min - max temperatures of 10 and 18 °C during night and day respectively. There was no precipitation recorded, although we did notice some very light rain on the afternoon of Wednesday 6 March, at the EPPO location. Wind was variable reaching up to 20 -25 km/h during the day and calmer during the night period. The exception was March 6, where wind speed during the day reached a peak of 45 km/h. Other more local meteorological information may be available from the EPPO station.

2.1.3 Experimental setup

The recording station was composed of a floating panel attached by a long line across the tank at about 10 m in front of the mechanical food feeder. A picture of the floating panel is shown in Fig. 2.2(a) and the view of the tank from the feeder is shown in (b)

(a) (b)

Figure 2.2: *picture of the floating panel with the acoustic recording station (a) and view of the aquaculture tank from the feeder location and with the covering net.*

Feeding periods were set for 30 min in the morning from 10:00 to 10:30 UTC and 30 min in the afternoon from 16:00 to 16:30 UTC. The timing of the feeder was not very precise and not synchronized with the recorder so, the recorder was setup for a recording duration of 75 min in the morning and in the afternoon to be sure to cover the feeding interval and also to record some environmental noise only periods for reference. Noise sources included the feeder itself which noise input into the water is unknown and the drops of the fish food in the water.

2.2 Materials and methods

The recording station is composed of four hydrophones attached in a 2 m long horizontal array placed approximately parallel to the feeder tank side (see picture in Fig. 2.2(a)) so that the feeder is in the broadside beam of the four hydrophone array. The hydrophones' depth was approximately 20 cm.

The acoustic recorder is a digital hydrophone model TP1-4 from Marsensing Lda. The hydrophones are from SensorTech model SQ26 with an approximately flat band from 1 up to 25000 Hz, with a sensitivity of -193 dB re 1V/μPa. The chain gain can be changed remotely via a programable gain array (PGA) which value is monitored through a `csv` file throughout the experiment as shown in Fig. 2.3. Strangely enough the recorded PGA gain is changing over time while it was not changed during the course of the experiment. This is particularly clear on the morning period of March 6 and on the afternoon of March 8, where the file shows an extensive inexistent period of recording at low gain. A constant PGA gain of 16 was used to calibrate the data. The sampling frequency is 52734 Hz

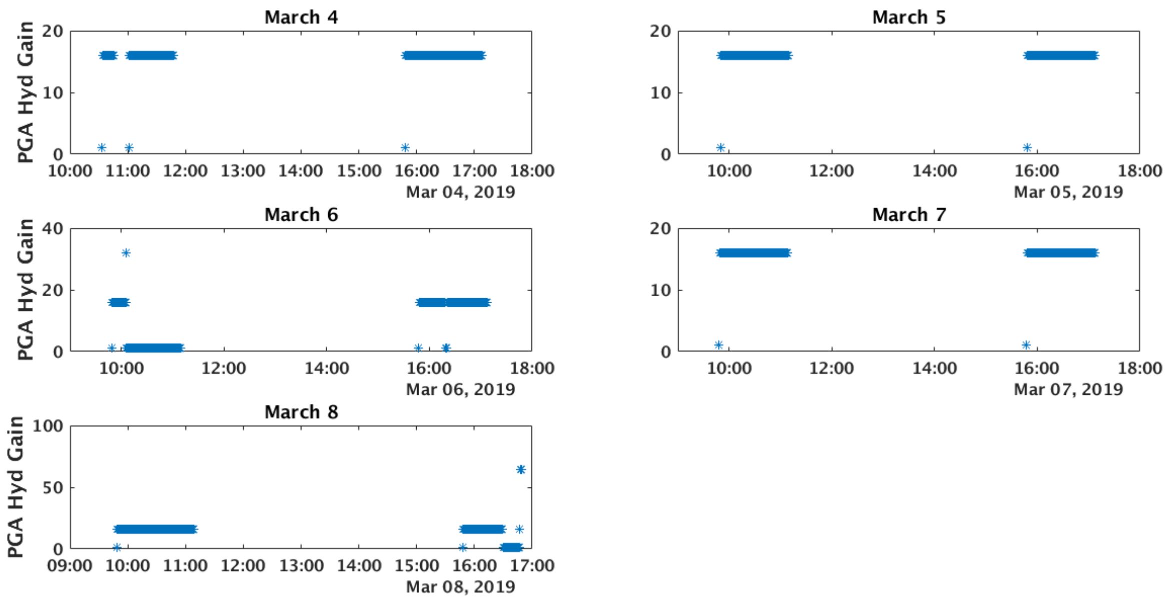

Figure 2.3: *programable gain array over the experiment duration.*

and the quantification is made with a 24 bit Sigma-Delta ADC. The acquired data was transmitted via an ethernet cable to a remote embedded computer located near the feeder where the data was archived on an SD card. The data being acquired and saved on the SD card could be monitored directly on a browser through a wifi connection available from the embedded computer. This embedded computer was powered directly from the mains so it could last for a week long experiment.

In order to capture the morning and afternoon feeding periods a power supply timer was set for the embedded computer so it would boot before each feeding period and shutdown after it, for a total interval of approximately 1h15, twice a day.

Power spectrum estimation was performed with the Welch method, i.e., using a Hanning window over the entire block size, a block overlap of 50% and an averaging over a variable time interval, specified for each case. The block size was N =4096 data samples, which sets a frequency resolution $\Delta f = 12.8\,\text{Hz}$. So, calibrated values of the power spectrum estimate is obtained at periodic frequencies given by $n\Delta f$, for $n = 0, N/2 - 1$.

Finally, a common way to deal with noise variability is by performing statistics, in which case percentiles are used to represent noise power time variability. This consists in computing the data-time histogram and the respective empirical cumulative distribution function. Inverting that distribution function allows to determine the SPL for a given percentile p. Repeating this for the whole spectrum distribution gives an SPL curve that represents the level below which the signal remains p % of the time.

Chapter 3

Preliminary results and discussion

A first glimpse of the acquired data may be obtained by looking at hydrophone 4 as shown in Fig. 3.1 from plots (a) to (e), acquired from days March 4 to 8, respectively. This figure was obtained by estimating the sample power spectrum on the first 10 s of each 2 min long data file, so it does not represents the whole data set. Clearly on March 4, the recording intervals and the feeder were misadjusted. That was corrected from March 5 on. As mentioned above on March 6, the system gain was reduced in part of the morning

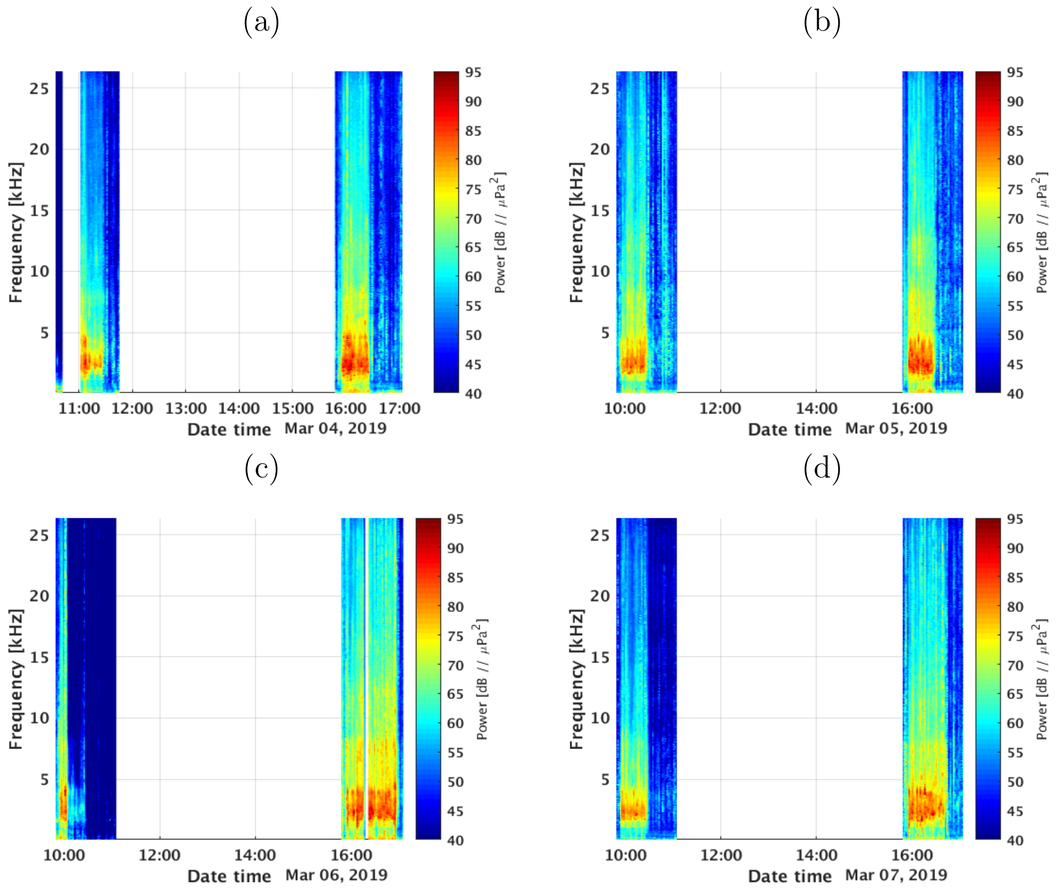

Figure 3.1: *power Welch spectrogram as received on hydrophone 4, for days March 4 to March 7, 2019 from (a) to (d), respectively.*

(e)

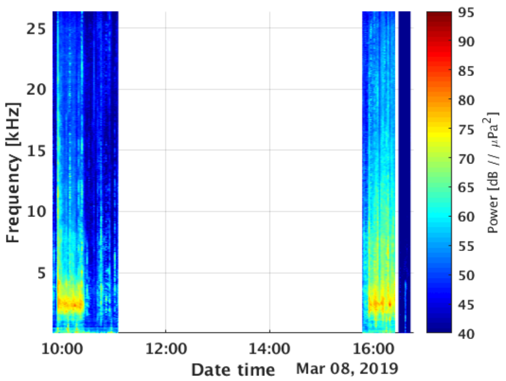

Figure 3.1 (cont.): *power Welch spectrogram as received on hydrophone 4, for March 8, 2019, (e).*

recording and in the afternoon the feeder working interval was much longer than usual (with a recording interruption in the middle). Recorded levels on March 8, were below the mean values recorded on the previous days. There were recording interruptions on the morning of March 4 and on the afternoon of March 6 and 8. These interruptions are of unknown origin.

Concentrating on the frequency band below 6 kHz, Figures 3.2 to 3.5 show the detail of the morning and afternoon recordings for all 5 days and for the four hydrophones, respectively.

SPL between hydrophones is mostly coincident, although there are generic level differences: channel 1 seems to be that with the highest level, followed by channel 4, then 2 and finally channel 3, that appears to have the lowest signal power level.

Whether those differences are real (due to in water sound levels) or apparent, due to differences in acquisition channel gains, is not clear

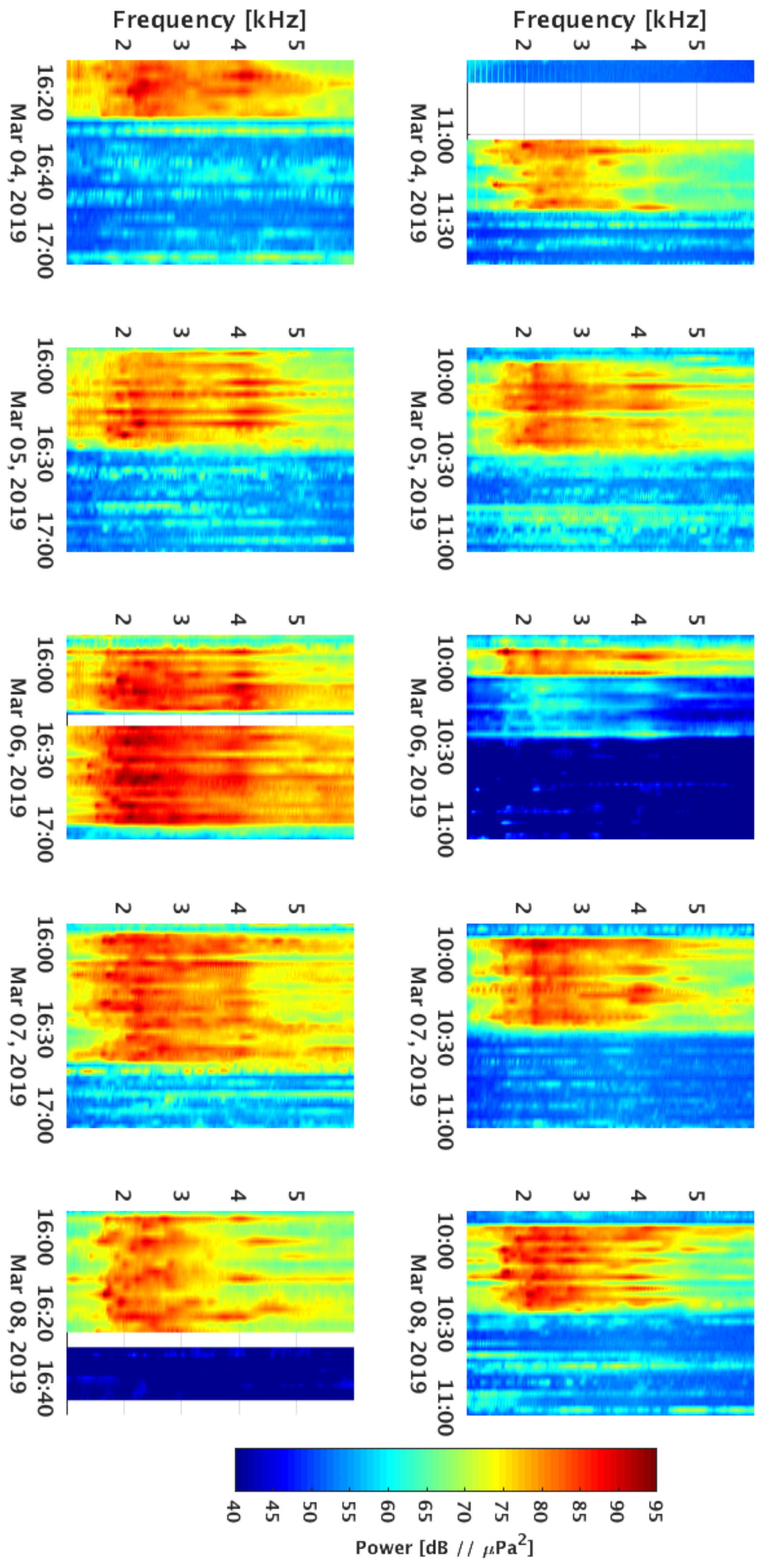

Figure 3.2: *power Welch spectrogram in the 6kHz band for channel 1, over all days and recording periods.*

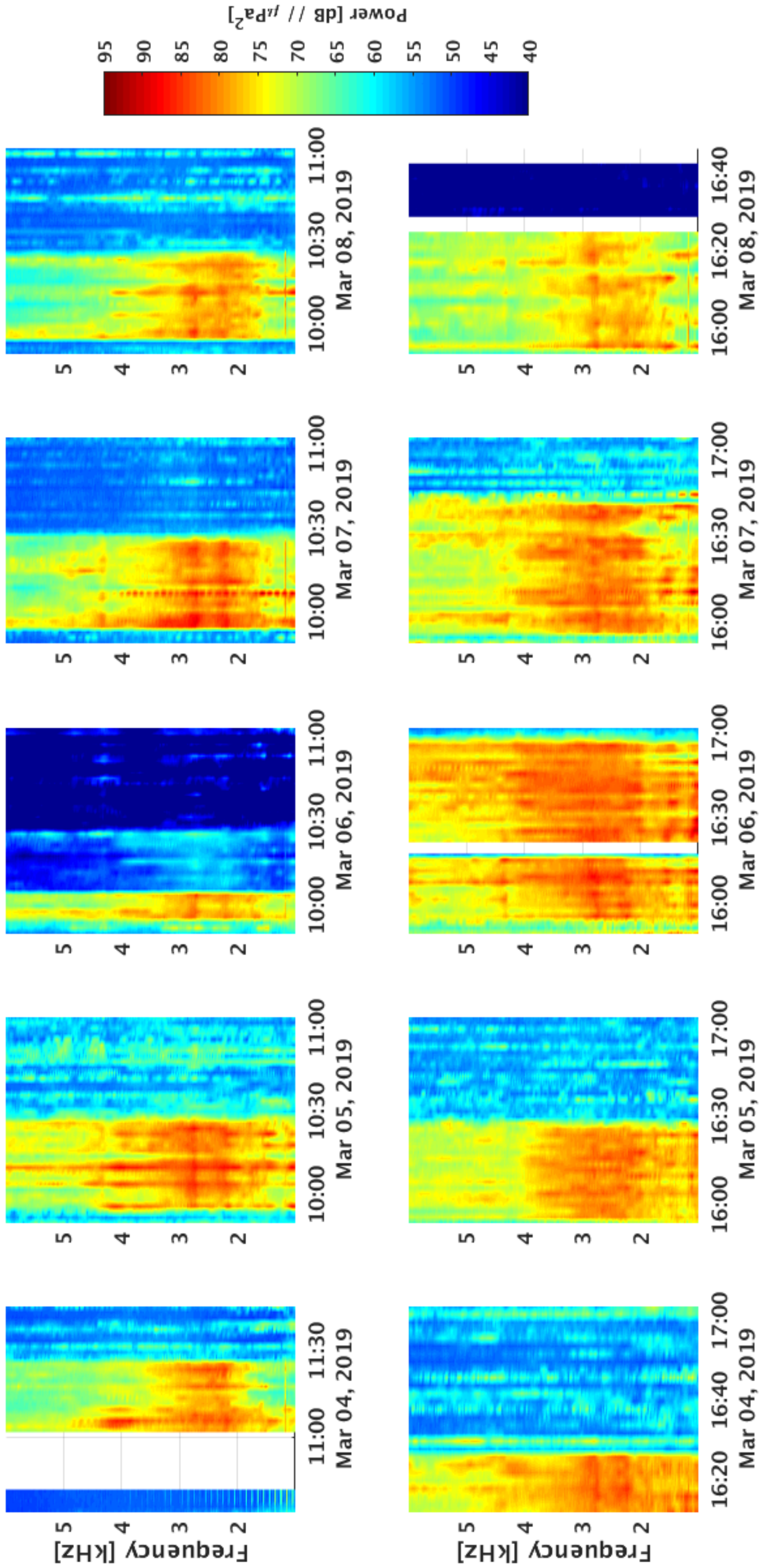

Figure 3.3: *power Welch spectrogram in the 6 kHz band for channel 2, over all days and recording periods.*

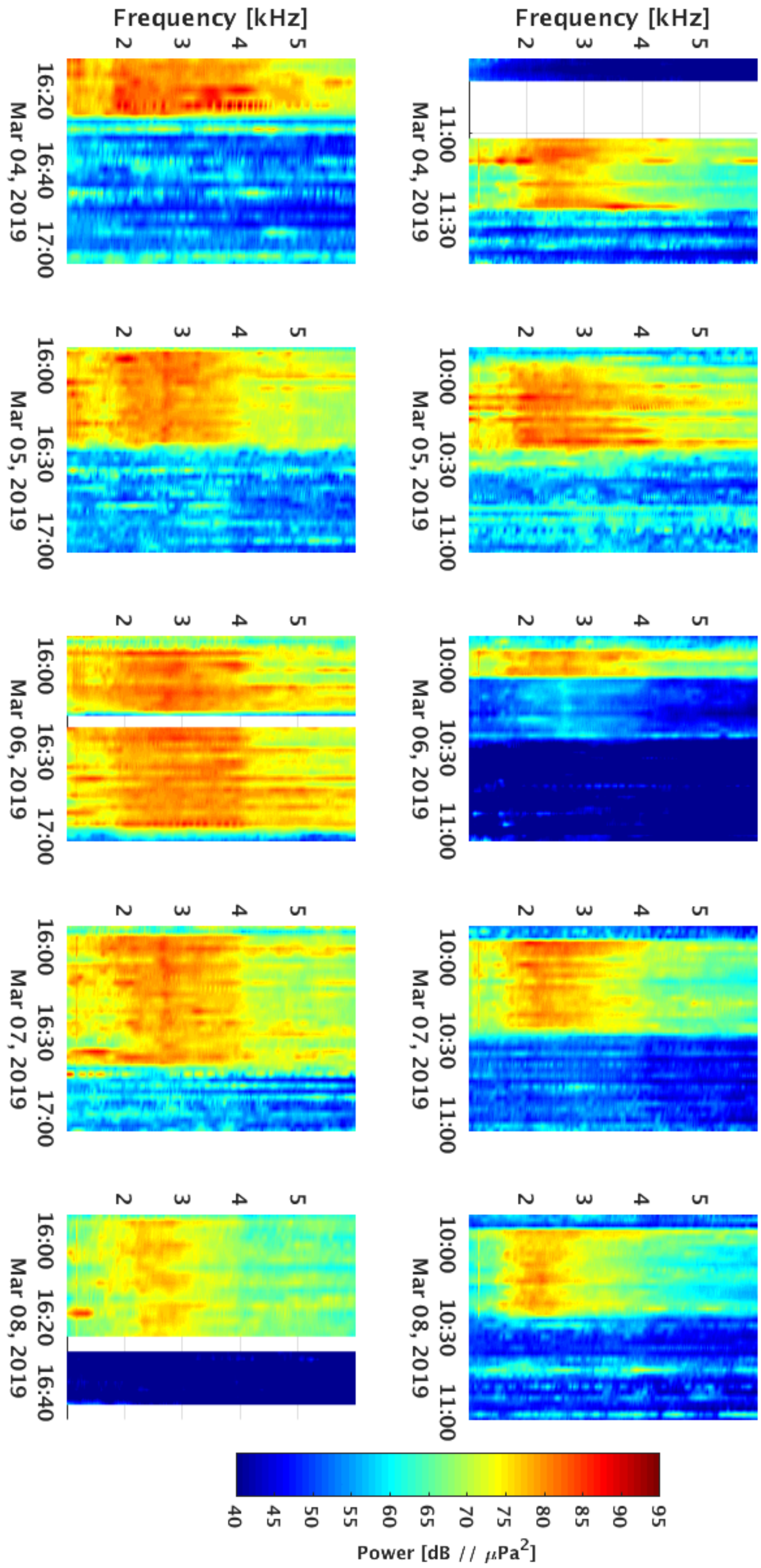

Figure 3.4: *power Welch spectrogram in the 6kHz band for channel 3, over all days and recording periods.*

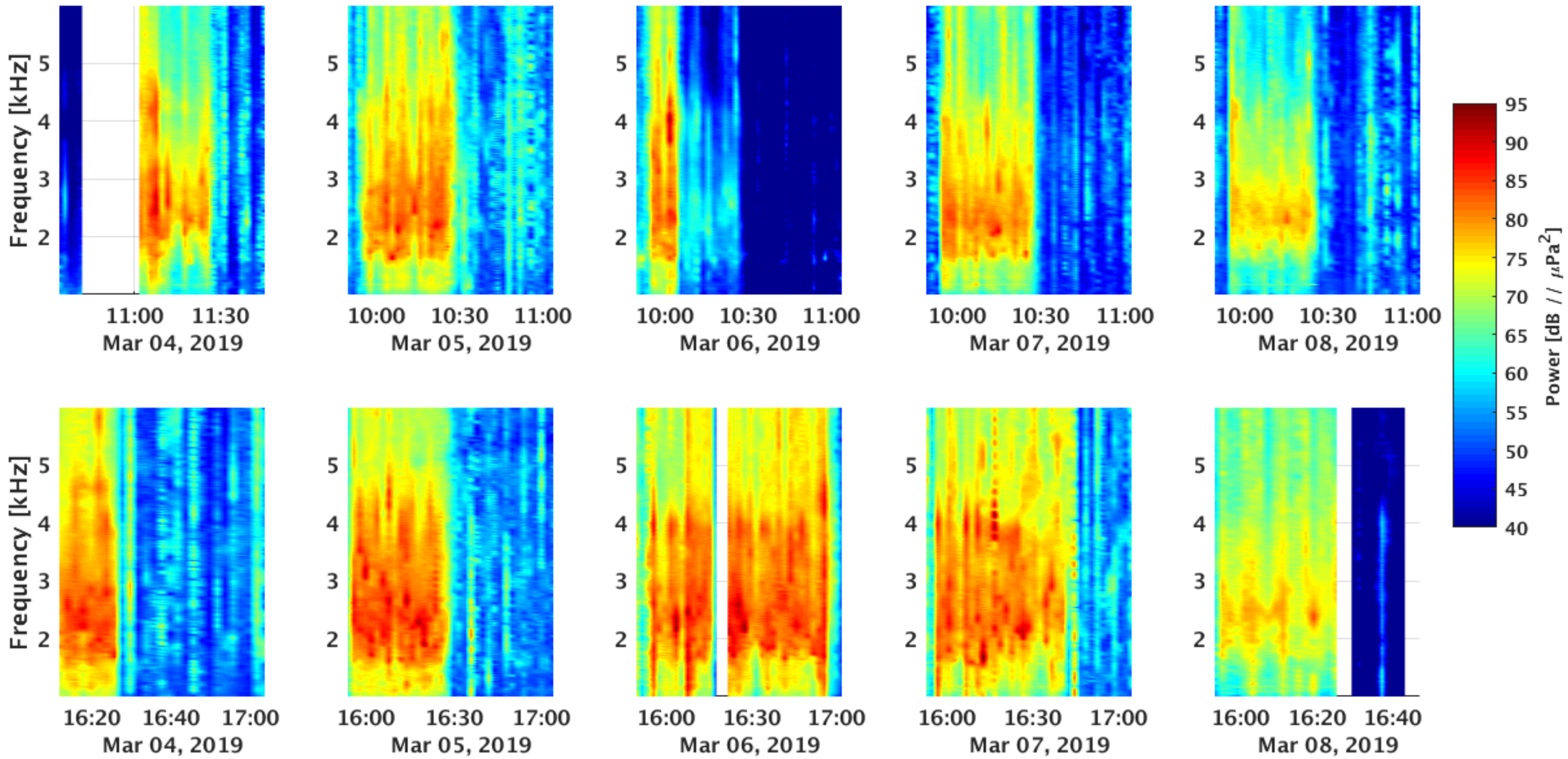

Figure 3.5: *power Welch spectrogram in the 6 kHz band for channel 4, over all days and recording periods.*

A more in depth view may be obtained by looking at the onset of the feeder period. Figure 3.6 shows a series of power Welch spectrograms of 10 s duration for various frequency bands, taken from file 4 of March 5, at 09:55:51 so, just at the start of the feeding period. The upper plot shows a band of 12 kHz where the feeding period start is clearly visible. The second plot from top shows the band [1-6] kHz, where the noise power seemingly random variation along time is clear. The third plot from top, shows a zoom of the band [1-2] kHz where there seems to be an horizontal continuous wave (CW) line, which is also present in the lower most plot in a band [0-1.5] kHz. This analysis may now be

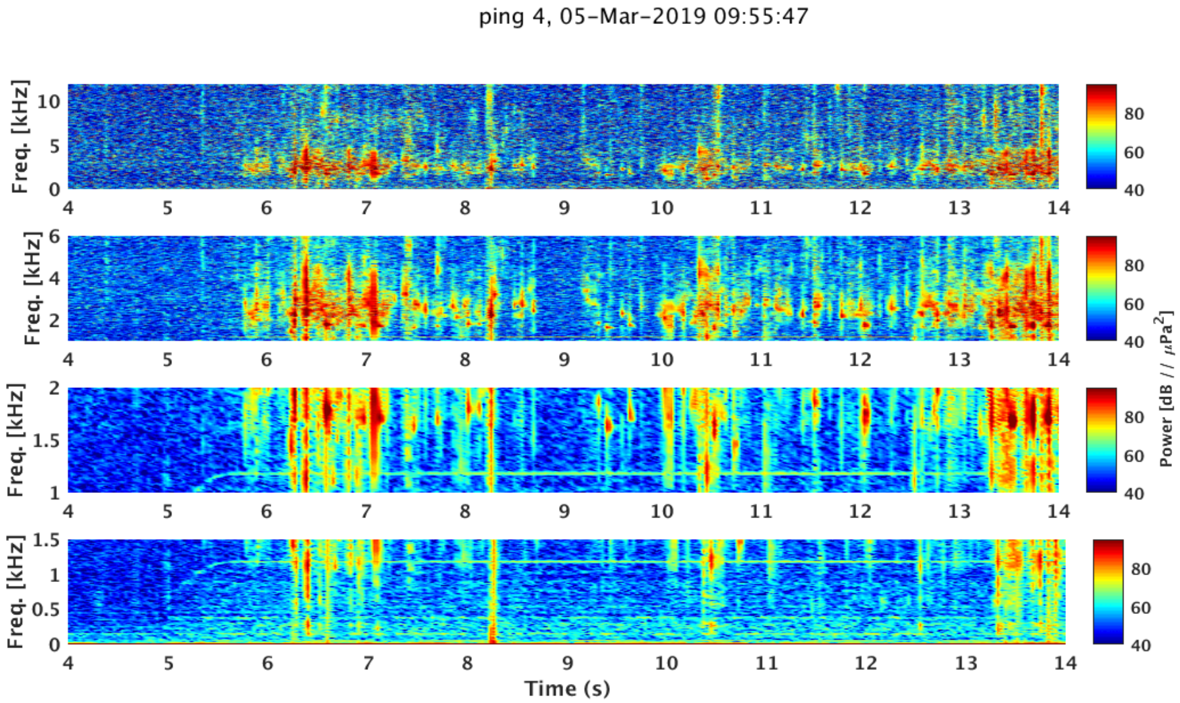

Figure 3.6: *power Welch spectrogram for channel 1 on March 5, for 10 s at 09:55 UTC for various frequency bands from top to bottom: [0-12], [1-6], [1-2] and [0-1.5] kHz.*

complemented by a detailed spectral estimate of the morning of March 5 as shown in Fig. 3.7 that clearly illustrates the period on and off the feeder with strong power spikes during the feeder-on period. Comparing the feeder-on and the feeder-off period Fig. 3.8 shows the mean spectra in the first 23 min (feeder on), in the remaining period (feeder off) and in the whole period (total) for the full band (a) and for the lower 5 kHz band (b). Finally, Fig. 3.9 shows the 5, 25, 50, 75 and 95 percentiles obtained in the morning recording of March 5.

3.1 Discussion

It seems clear from the analysis of Fig. 3.1 that the acoustic power generated during the feeding period covers almost the whole acoustic band with most of the energy concentrated between 1 and 5 kHz, centered in approximately 2.5 kHz where it reaches an SPL of 95 dB re μPa^2. Stopping the feeder pushes the maximum acoustic power down to 50 dB. Some glitches in the recordings may be noticed but overall the data has good quality and may be used for the purpose of the experiment.

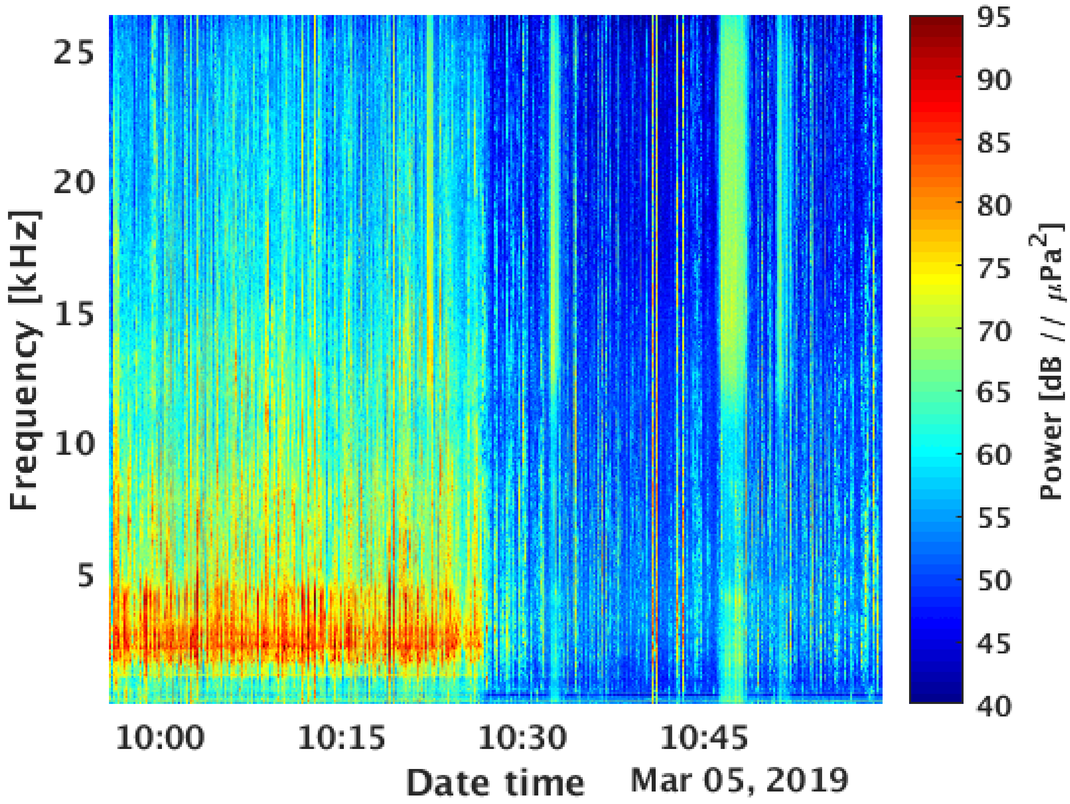

Figure 3.7: *Welch power spectrogram for channel 1 on morning of March 5: 2 s estimate every 5 s for the full band.*

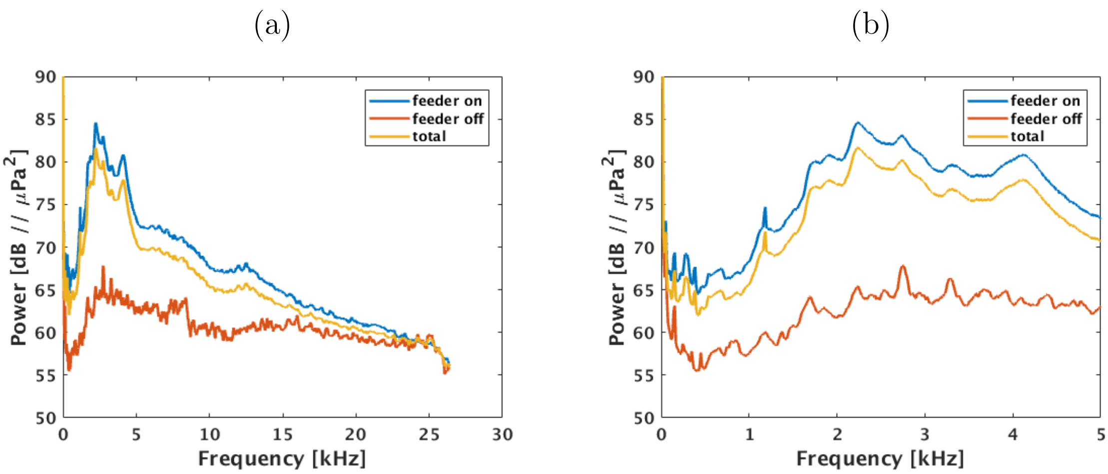

Figure 3.8: *Welch power spectrum average estimate for channel 1 on morning of March 5: 2 s estimate every 5 s in the periods feeder-on, feeder-off and the whole period: for the full band (a) and for the lower 5 kHz band (b).*

The frequency band below, say, 6 kHz show some variability between hydrophones, that is not believed to be due to fish activity but probably to a combination of acquisition system and food drops distribution.

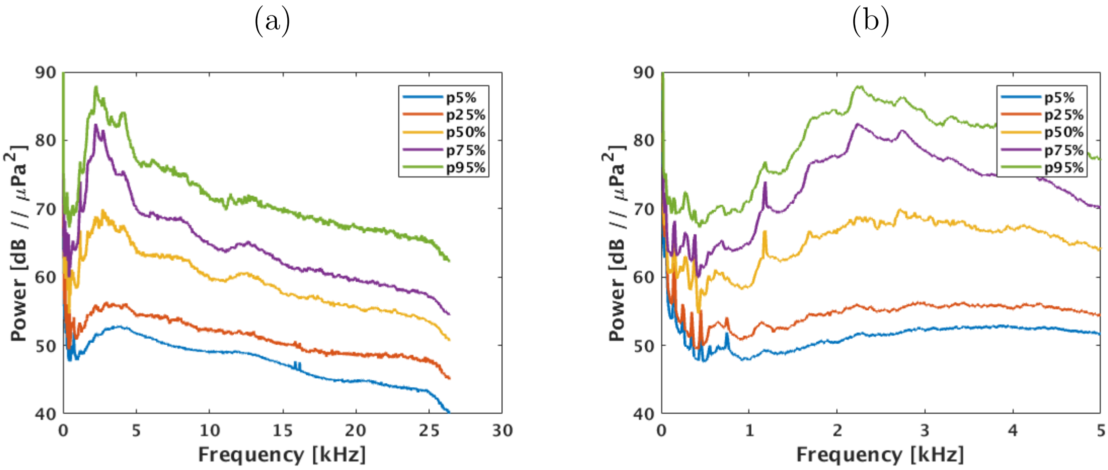

Figure 3.9: *5,25,50,75 and 95% percentiles for power estimates of morning of March 5, with a 2 s on every 5 s: the whole band (a) and in the [0-5] kH band (b).*

The noise due to food drops can be clearly seen in Fig. 3.6 which is characterized by broadband short time duration vertical spectral lines (a spike in time). The spectral width of the food drops signal varies with the distance from the hydrophone, where the higher frequency components are more rapidly attenuated. The launch of the food bullets is not regular: void periods are followed by a higher number of impacts, sometimes time superimposed (which results in further noise power increase). At the feeder on set, the power increases from 50 to 80 dB re $1\mu\text{Pa}^2$. The noise power reaches its highest value at approximately 2.5 kHz but extends, while decreasing, up to, say, 15 kHz. In the same figure, the third plot from top, showing a zoom of the band [1-2] kHz, has a CW line at 1180 Hz with an approximate level of 72 dB. It is believed that this CW line is associated with the out of water feeder noise, which is basically a food bullets blower. At run start we can notice a slow increase of the frequency until it attains the CW, which is associated with the blower picking up speed. The same can probably be seen when the blower is shutdown (not shown).

The full recording of morning of March 5 (always for hydrophone 1) as shown in Fig.3.7 shows the impulsive nature of the noise generated during the feeder activity and the feeder off period. The characteristic spectum of these two periods is shown in Fig. 3.8. The difference between the blue curve and the marron curve represent the noise produced by the ensemble feed drops plus fish. Fish noise may have two components: one high frequency that may appear in the small sub-peak between 10 and 15 kHz, and the other as a low frequency component due to water agitation, that can be better seen in plot (b) between 200 and 400 Hz.

This is reinforced by the percentile curves where the 10-15 kHz sub-peak is only present on the median (50%) and the 75 percentile curves.

Chapter 4

Conclusions

This report aims at performing a preliminary quality check on the data gathered during the experiment carried out at the EPPO in March 4 - 8, 2019. In total, there are over 16 hours of data recorded every morning and afternoon, in coincidence with fish feeding periods. The underwater noise in the feeding periods is up to 30 dB higher than the background noise present during the non-feeding periods, reaching easily 85 dB. Outside of the water the strongest noise is clearly that of the food blower. One of our fears was that that noise could overshadow biological noise. However, the blower could be seen as generating a 72 dB CW acoustic line underwater which, when compared to the 84 dB peak, means that most of the energy recorded underwater is not due to the blower but otherwise to food drops noise and of biological origin. Food drops are believed to be mostly associated with broadband spikes arising at random times and with random amplitudes. Noise related to fish may be separated in two components: one high frequency around 10 - 15 kHz possibly associated skin movement and the low-frequency due to water agitation and skelectal swim blader muscles contraction, at close range. We speculate that low frequency noise induces acoustic particle motion energy that could be picked-up and better separated from other components by suitable vector sensors, in a future experiment.