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Acoustic Description of the Soundscape of a Real-Life Intensive Farm and Its Impact on Animal Welfare: A Preliminary Analysis of Farm Sounds and Bird Vocalisations

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Acoustic Description of the Soundscape of a Real-Life Intensive Farm and Its Impact on Animal Welfare: A Preliminary Analysis of Farm Sounds and Bird Vocalisations

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"El conocimiento no se basa sólo en la verdad, sino también en el error."

Carl Jung

Abstract

Poultry meat is the world's primary source of animal protein due to the low cost and it is widely eaten at global level. However, intensive production is required to supply the demand although it generates stress to animals and welfare problems which have to be reduced or eradicated for better birds health. In this study, bird welfare is measured by some indicators: CO_2, temperature, humidity, weight, deaths, food and water intake. Additionally, we approach the acoustic analysis of the bird's vocalisations as a possible metric to add to the aforementioned parameters. For this purpose, an acoustic recording and analysis of an entire production cycle of an intensive broiler Ross 308 poultry farm in the Mediterranean area has been performed. The acoustic dataset generated has been processed to obtain the Equivalent Level (L_{eq}), the mean Peak Frequency (PF) and the PF variation, every 30 minutes. This acoustical analysis aims to evaluate the relation between traditional indicators (death, weight and CO_2) and acoustical metrics (equivalent level impact - L_{eq} -, Peak Frequency - PF-) of a complete intensive production cycle. As a results relation between CO_2 and humidity versus L_{eq} has been found, as well as decrease in the vocalisation when the intake of food and water is large.

Resumen

La carne de aves de corral es la principal fuente mundial de proteína animal debido a su bajo costo y es consumida ampliamente a nivel mundial. Sin embargo, se requiere una producción intensiva para abastecer la demanda aunque genera estrés a los animales y problemas de bienestar que deben ser reducidos o erradicados para una mejor salud de las aves. En este estudio, el bienestar de las aves se mide mediante algunos indicadores: CO_2, temperatura, humedad, peso, muertes, ingesta de alimentos y agua. Adicionalmente, abordamos el análisis acústico de las vocalizaciones del ave como una posible métrica para sumar a los parámetros anteriormente mencionados. Para ello se ha realizado un registro y análisis acústico de todo el ciclo de producción de una granja avícola de producción intensiva Ross 308 de pollos broilers en zona mediterránea. El conjunto de datos acústicos generado ha sido procesado para obtener el Nivel Equivalente (L_{eq}), la Frecuencia de Pico (PF) media y la variación de PF, cada 30 minutos. Este análisis acústico tiene como objetivo evaluar la relación entre los indicadores tradicionales (muerte, peso y CO_2) y métricas acústicas (impacto de nivel equivalente - L_{eq} -, Frecuencia pico - PF-) de una producción intensiva durante un ciclo completo. Como resultado se encontró una relación entre CO_2 y humedad versus L_{eq}, así como una disminución en la vocalización cuando la ingesta de alimentos y agua es grande.

Resum

La carn d'aus de corral és la principal font mundial de proteïna animal a causa del seu baix cost i és consumida àmpliament a nivell mundial. No obstant això, es requereix una producció intensiva per proveir la demanda encara que aquesta genera estrès als animals i problemes de benestar que han de ser reduïts o eradicats per a una millor salut de les aus. En aquest estudi, el benestar de les aus es mesura mitjançant alguns indicadors: CO_2, temperatura, humitat, pes, morts, ingesta d'aliments i aigua. Addicionalment, abordem l'anàlisi acústic de les vocalitzacions de l'au com una possible mètrica per sumar als paràmetres anteriorment esmentats. Per això s'ha realitzat un registre i anàlisi acústica de tot el cicle de producció d'una granja avícola de producció intensiva Ross 308 de pollastres broilers en zona mediterrània. El conjunt de dades acústiques generat ha estat processat per obtenir el Nivell Equivalent (L_{eq}), la Freqüència de Pic (PF) mitjana i la variació de PF, cada 30 minuts. Aquest anàlisi acústic té com a objectiu avaluar la relació entre els indicadors tradicionals (mort, pes i CO_2) i mètriques acústiques (impacte de nivell equivalent - L_{eq} -, Freqüència pic - PF-) d'una producció intensiva durant un cicle complet. Com a resultat es va trobar una relació entre CO_2 i humitat versus L_{eq}, així com una disminució en la vocalització quan la ingesta d'aliments i aigua és gran.

Keywords

Broiler, chicken, sensor, processing, signal, PLF, audio, stress, microphone, songs, call, vocalitzations, farm, welfare, animal, veterinary, poultry, industrial.

Palabras clave

Broiler, pollo, sensor, procesado, señal, PLF, audio, estrés, micrófono, cantos, llamada, vocalizaciones, granja, bienestar, animal, veterinaria, avicultura, industrial.

Paraules clau

Broiler, pollastre, sensor, processat, senyal, PLF, àudio, estrès, micròfon, cants, crides, vocalitzacions, granja, benestar, animal, veterinària, avicultura, industrial.

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Abbreviations

C1	Campaign One
C2	Campaign Two
CO_2	Carbon dioxide
Eq	Equation
FFT	Fast Fourier Transform
H1	House One
H2	House Two
L_{eq}	Equivalent pressure level
MAX	Maximum
OIE	Office International des Epizooties
PLF	Precision Livestock Farming
ppm	Parts per million
PCM	Pulse Code Modulation
PF	Peak Frequency
SD	Secure Digital

Dedicado a todas las personas que me han enseñado que no todo es blanco o negro sino que puede ser azul, el color del mar y del cielo. En especial a los que ya no están Gerardo, José y Maruja.

Chapter 1

Introduction

The protein of animal origin has a greater biological value than vegetable proteins. From a biological view, it has a greater presence and proportion of essential amino acids in particular those that our organism cannot produce and it is highly recommended to ingest them with a diet. Meat is a source of animal protein, however it is recommended to reduce the consumption of red meat due to its higher content in saturated fats in favour of white meat such as chicken or turkey [1].

The poultry industry is in charge of supply white meat for all the world population. The meat production has evolved over the past century from small productions in local areas to a highly sophisticated vertically integrated supply chain. This industry gathers: *I* commercial hatcheries *II* feed mills, *III* breader farms, *IV* live bird grower facilities, *V* transportation of birds, *VI* processing plants to poultry meat products, *VII* meat delivery [2].

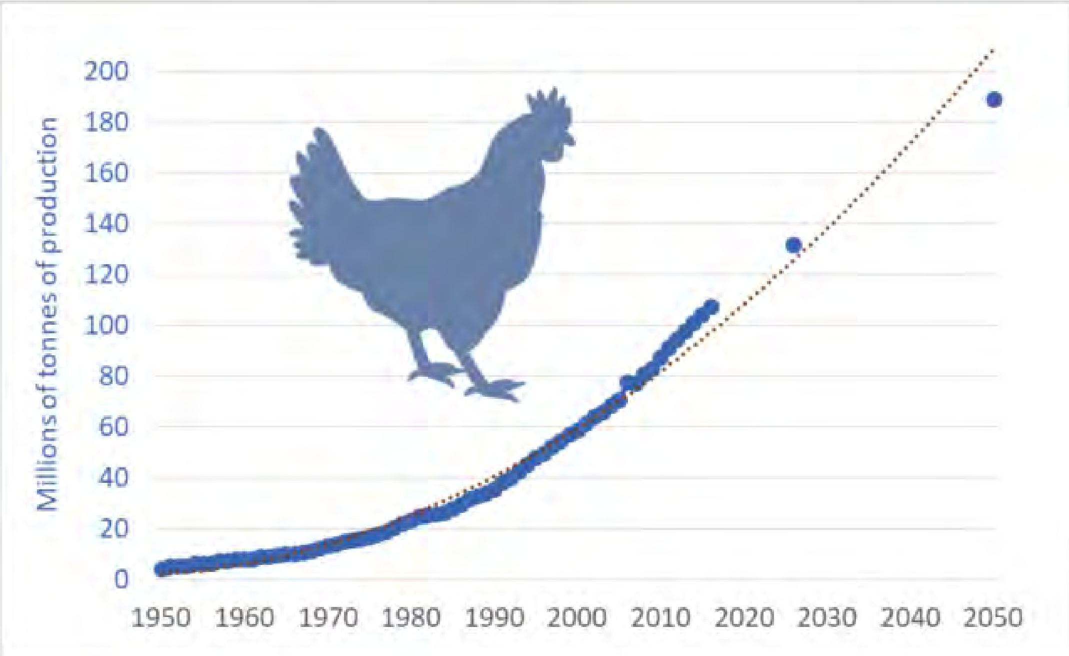

FIGURE 1.1: 100 years of chicken production. Source: [3]

The demand for poultry food due for the low price and the nutritional properties projects a continuous expansion of the poultry market [4, 3]. Nowadays, The European Union is one of the world's largest poultry meat producers and a net exporter of poultry products with annual production of around 13.4 million tons [5]. In recent years, genetic selection has been performed during years to increase the growth rate in the shortest possible time [6] in the context of poultry meat industry [7]. This demand for white meat has led to more genetic selection for fast early growth rate that may provoke the appearance of several spontaneous, idiopathic muscle abnormalities along with an increased susceptibility to stress-induced myopathy [8], in modern chicks strains. Causes of mortality related to fast growth are mainly Sudden Death Syndrome [9] and ascites [10]. Nevertheless intensive production is also a source of stress for the animals. Some of these factors such as stocking density, environmental deterioration, unsuitable social environments, thermal stress can be major sources of stress [11].

Intensive production is required to achieve the demand (Figure 1.1) and poultry health should be approached in a multidisciplinary way to ensure animal health and wealth [7]. According with OIE: *An animal is in a good state of welfare if it is healthy, comfortable, well nourished, safe, able to express innate behaviour, and if it is not suffering from unpleasant states such as pain, fear and distress* [12]. Some routine management practices are stressful to the birds [13] and it also result in an economic cost to the industry that cannot be ignored [14, 15]. There are some management practice that reduce stress in the animals and also are easy to be monitored in a farm. The ventilation of poultry houses, could influence the gas emissions of the birds intensive production such as CO_2, CH_4 or N_2O [16]. Carbon dioxide production CO_2 is used in poultry as a gas meter to determine the ventilation flow of the farm according to the International Commission of Agricultural Engineering [17]. Ventilation renews gas concentrations by reducing pollutant gas levels and increasing the amount of oxygen on the farm. For instance, detecting a low value of CO_2 indicates good ventilation and is a sign of good animal welfare.

The welfare of animals has become an important fact for society in many countries of the world. This fact, together with the automatising of most of the animal monitoring processes, can support the farmer in the care of the animals. Following this idea, bioacoustics studies the biological significance and the characteristics of sounds emitted by living organisms [18], and can be a relevant issue to complement the traditional measurements (CO_2, temperature, etc) of the environmental characteristics in the farm. Threat signals [19], information about feeding [20] or sexual selection [21] are only some examples of the possible applications of this field.

More particularly, the field of birds is one of the few groups of animals known to exhibit vocal learning, used for communication for territoriality, high density, food/water restriction, heat-cold stress, alarm signaling, among others [22]. The birds' song is recorded using a non-invasive method, with the aim of analyzing their song and correlating the data. Several indicators about bird vocalisations have already been reported dependencies in literature with birds weight, as a conclusion of their welfare [23].

Technology can monitor livestock and the farming environment in real time. Moreover, mathematical decision algorithms can supply relevant information to the farmer or automatically active the control centralised system. This descriptions refers to the concept called Precision Livestock Farming (PLF) and it was coined at the start of the 21st century, with the first conference [24]. In other words, a PLF system ensure that "every process within a livestock enterprise, which havecan have a large positive or large negative effect on productivity and profitability, is always controlled and optimised within narrow limits" [25].

1.1 Context

1.1.1 Farm Animal Welfare

In 2004, the European Commission launched the Welfare Quality Protocol (WQ ®) [26]. The project developed different protocols to ensure the welfare of animals based on: *I)* good feeding *II)* good housing *III)* good health *IV)* appropriate behaviour. Therefore, WQ ®is largely accepted by the scientific community as the state-of-art approach in welfare assessment and should therefore play a role in welfare management in the future. Welfare assessment on farms is also rapidly evolving due to the development and utilisation of new information technologies (ITs) [27].

The use of technology that assist farmers in real time, managing animals, increasing production and animal health is called Precission Livestock Farming [28]. PLF consist of three functionalities: sensing and monitoring, analysis, decision making, and intervention. Since last decade electrical sensors, cameras, microphones among others are more common in farm.

Terminology that is more common with PLF is: acoustic monitoring, audio signal processing, automated monitoring, automated welfare, big data, biosensor, control chart, image analysis, infrared thermal imaging, infrared thermography, integrated management system, intelligent farming, machine vision, noise analysis, optical flow, precision feeding, precision nutrition, real-time monitoring, RFID, sensor, signal analysis, smart farming, sound analysis, transmission colour value, vocalization analysis according with [28]. Moreover, as smart sensors collect data in real-time, large amounts of data will be generated. Big data technique will be required to produce data driven decisions according to welfare and productivity parameters. Additionally, the devices that will be incorporated into smart farm management systems will be connected to the Internet (IoT) allowing the remote access to the farm and sensors networks [29].

Some companies and collectives fight for improving farm animal welfare and campaign to change the most intensive forms of farming. According to world animal protection [1]: Farm animals raised humanely are healthier. This movement that humanises farms also benefits the world.

- Raising animals humanely can use less feed, fuel and water than intensive farming, reducing costs and pollution.
- Humane farms can create jobs, boost profits and keep local food supplies healthy.
- By farming crops and livestock, humane farms can reduce environmental damage – recycling nutrients and improving the soil.
- Greenhouse gas emissions are often reduced when animals are healthy and have good welfare.

This project aims to improve animal welfare finding relations between stress and welfare indicators with standard management indicators. Commercialisation of sustainable white meat is important due to the increasing tendency of the market.

[1] www.worldanimalprotection.org/our-work/animals-farming-supporting-70-billion-animals/farm-animal-welfare

1.1.2 Stress as a factor of well-being

Stress affects in a negative way the welfare of the animals and also implies an economical cost to the industry that can not be ignored [30].

To exemplify, some of the routine management practices realised by humans to control the intensive production of the poultry birds (death count, visual control rounds, maintenance...) together with the concentration of environmental gases due to the animal gases generation are stressful to the animals [31]. As a definition, stress refers to the way an organism responds to environmental stimuli that it perceives as a real or anticipated threat to its survival or well-being [32].

The birds vocalization is a useful tool to improve the state of health and well-being. The sound produced by the animals is a biological signal that can be easily measured from distance and therefore will not cause any additional stress to the animals [33]. Analysing sound is a powerful tool to interpret behaviour, health conditions and animal welfare. [34]

The science studying the behaviour and animal communication through acoustic signal is the bioacoustics. This discipline is being known worldwide due to the biodiversity studies and conservation and the implementation of new technology [35]. In recent years, the study of animals singing has been considerably improved thanks to the new technique of recording and analysis and the IoT environment [31]. Microphones is a good sensor as it is contactless, relative cheap, independent on lighting conditions and allows the monitoring of large groups with a single sensor [36].

A scientific study investigated the relation between vocalisations and the emotional state in goats (*Capra hircus*) by capturing physiological parameters like heart rate along with sound recordings of the animals. During the experiment, the animal was placed in four different situations (control, negative food frustration, negative isolation and positive food anticipation). As a result, goats call where different depending on the emotion. More details of this experiment can be found in [37].

Poultry birds are one of the few groups of animals known with vocal communication. *Fontana et al* in article [23] show different spectrum's of broilers patterns vocalizations as shown in Figure [**fontanavocali**]. From the acoustic variety in expressiveness of the birds, studying the stress of the animals will be a point of interest in this project.

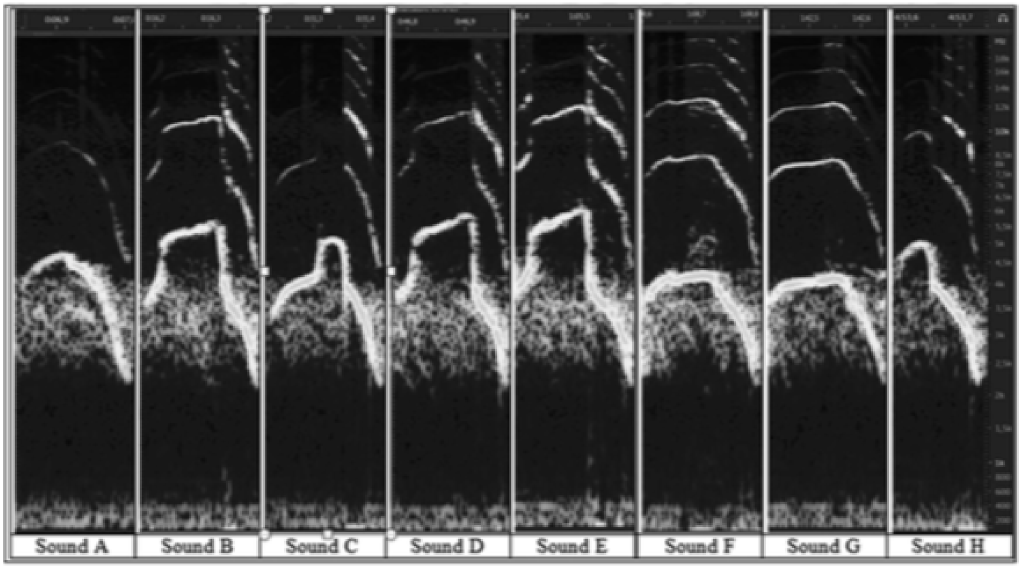

FIGURE 1.2: Adobe ®AuditionTM CS6 software. Spectrograms of the eight types of sounds recognised with the manual labelling of sounds collected during Day 1 of recordings. Source: [23]

1.2 Objectives

The global trend of sustainability, animal welfare and meat quality has grown in developed countries during last decade due to the increase of white meat consumption in intensive production. This project was born as a response to this current.

Each day more companies are transforming to digital. As it is well known, technology is a powerful tool for capturing, processing, analysing and predicting data among others. The poultry industry is also moving forward to the digitalization. This project captures, post-process and analyses an entire campaign of broiler birds for improving animal welfare and improve the industry.

In this study, we design and analyze the recording campaign of an entire production cycle in a Mediterranean farm during the winter season to obtain the acoustic data. This acoustical analysis aims to evaluate the relation between traditional indicators (death, weight and CO_2), acoustical metrics (equivalent level impact - L_{eq} -, Peak Frequency - PF-) and farm management information (food and water intake, temperature, humidity) of a complete intensive production cycle of around 40,000 Ross 308. All acoustic data recorded will later be processed and analysed considering the other metrics of the farm management. This work is the preliminary analysis of the correlation between all these available parameters about the farm environment and management, and the bird's growth and vocalisations. In order to model the bird's welfare in intensive production farms, the wider the available information about the life of the animals, the more accurate the dependencies may be found.

1.3 Global project view

This project has been implemented during 11 months. Details of the project stages are described below:

- **Investigation:** A research description of the industry and vets needs of the actual animal welfare state is required to progress in the studies and also to keep close to the companies that will invest in new technologies creations.
- **Field study and farm description:** The field work is based in installing, capturing and saving all the acoustic data of a bird's house and also obtaining all the possible data from the farm manager system. It is relevant to analyse different farms location, facilities and human predisposition to ensure the achievement of the objectives.
- **Experiment Design:** The importance of obtaining promising results lies in a good experiment design. The experiment has to be simple, cannot disturb the farm routine, needs to be easily replicated and pretends to capture the maximum broilers vocalisations reducing the other sounds interference.
- **Sound recording campaign:** A poultry production cycle takes 42 days to be accomplished. The recording system will be installed 10 days before bird's entrance to check the system and have it ready for the cycle capture. A non-stop recording with only some technical resets will take place to save all the data in external hardware.
- **Data Processing:** The raw acoustic data is processed using the Matlab software [38].
- **Analysis:** The processed data will be analysed and studied together with the data that comes from the farm management system. The study aims to found the correlations between both indicators.
- **Conclusions:** Final results based in the correlations will be explained and detailed. Explanation of related parameters will be found.

1.4 Project structure

This project is structured as follows. The related work used as framework of this project is detailed in Chapter 2. The specification of the farm where the project has been implemented is detailed in Chapter 3. The acoustical analysis of the recording can be found in Chapter 3. The birds welfare data analysis is detailed in Chapter 4. Discussion of the key aspects of this work is detailed in Chapter 5 and the conclusion and future work can be found in Chapter 6.

Chapter 2

Related Work

In recent years, the welfare of farm animals has become an important issue for societies in many countries of the world. Animal welfare is tightly relation with livestock farm sustainability. The Welfare awareness is rapidly increasing and new technology is being created. Automating animal monitoring processes, such as acoustic analysis of their vocalizations, can greatly assist the farmer in this type of task. Therefore, it is important to review the acoustic analysis of commercial chicken farming. Previous studies will guide and focus the project being more efficient and adopting their best practices.

2.1 Acoustic Analysis of Farm Management

In nature, the vocal sounds produced by different animal species are related to certain functions, such as threat signals (alarm calls) to different predators. Also can be detected in presence of some specific antipredator some calls of distress, alert, or mobbing calls [19]), information about feeding (food-associated calls [20]) or sexual selection [21]. In many species, these sounds can reveal attributes related to the caller's identity, sex, age, reproductive status or social dominance [39].

Alarm calls vocalisations have been an important point of interest to researchers and they have continued studding due to the importance of:

- Alarm calls can divide the continuous stream of behaviour into meaningful units.
- Alarm calls let study cognitive mechanisms to understand animals activity.
- Alarm calls can help to determine the well-being of the animal.

Therefore, vocalization, the active generation of sounds with specific organs, becomes an expression of an internal state of an animal generated spontaneously or motivated by an external event [40]. Many of these vocalisations have a complex structure that includes different acoustic elements and there are many hypotheses related to the adaptive function of such complexity. According to *Fedurek et al* [41] the possible hypothesis are:

- Acoustic complexity has evolved to facilitate individual recognition, especially in large societies. Some animals variate the call in individually distinct due to the communicative and social complexity.
- Call complexity is a product of sexual selection and reflects the caller's quality.

- Similar to human language, complexity enhances communicative potential of calls by callers combining basic acoustic elements to get complex structures or by combining individuals calls into sequences.

The study of emotions in animals is related to the evolution of species and consequently to the evolution of animal vocalisations. In terms of arousal, it is likely that vocal correlations with negative mood states such as alarm calls or infant begging calls, emerged earlier during evolution than positive vocalizations. For more information, the reader is referred to [42], which presents a review of the current state of knowledge on vocal correlations of emotions in humans and other mammals.

In recent years, animal welfare has become a very important issue for the scientific community and the general public. The consumer perceptions of animal welfare and environmental impact may influence consumers regarding their product choices. A trend of awareness is rising day by day. See Figure 2.1

Human affective responses	Mean (sd) Don't know responses	
	Pigs	Fish
I don't feel anything	2.81 (1.38) 12	2.98 (1.40) 21*
I feel guilty	2.90 (1.42) 12	2.48 (1.31) 23*
I feel responsible	3.26 (1.39) 17	2.87 (1.40) 16*
I feel compassion	3.83 (1.49) 8	3.23 (1.57) 16*

* $p < 0.05$.

FIGURE 2.1: Survey result to consumers experience affective responses to animal welfare issues. Source: [43]

Analysing results of Figure 2.1, human affective response is much more higher in meat than in Fish. Although there is a similar compassion of the animals. Animal welfare for consumers is very important in Mammals as pigs as their guilty feelings are higher. It is important to accept that public are an important stakeholder with interests in the food chain, and drive demand for specific foods and commodities

This generalised demand for greater respect for animals covers multiple areas such as the treatment of domestic animals, or those that are kept in zoos, but this request becomes more relevant in all aspects related to farm-raised animals [43, 44].

As a consequence, administrations have adopted a series of recommendations and directives to protect farm animals. The general trends of EU Directives for the rearing of farm animals extracted from [45] are:

- Increase living space per animal.
- Permit interactions between animals encouraging group housing.
- Give more freedom of movement.
- Provide animals with an enriched environment
- Feed animals a regimen consistent with their physiological and behavioural needs.

- limit painful intervention.

Although regulations promoted for each country are directly related to the level of public concern for the welfare of farmed animals. Social demands often influence the programs of political parties and therefore the action of governments. For example, this pressure is much higher in countries like the UK and Germany than others like Spain or Italy [46]. In any case, new initiatives are emerging around supranational organizations that group public and private institutions like the Welfare Quality® Network [1], which define four animal welfare principles: good housing, good feeding, good health and appropriate behaviour.

Bioacoustics, which is the study of animal sound communication, is performed in farm environments by using recorders capable of automatically recording audio data [47]. An example of a prototype (Figure 2.2 capable of recording and storing audio with remote access is detailed in [34].

FIGURE 2.2: Acoustic recording prototype for deployment in a Poultry Farm Source: [34]

Animal welfare monitoring can be substantially improved through an increased use of automated methods and, therefore, one promising area in particular is the use of automated analysis of animal vocalizations. A first step improving animal welfare is to maintain animals free of pain, injury or disease. In [48], a literature review includes different types of indicators that allow pain assessment in some mammals, birds and fish. Vocalizations are included in a set of behavioral indicators (Figure 2.3) along with posture, isolation, lack of appetite, or others. This study concludes that these indicators have the best chances of detecting pain early with a combination of

[1]www.welfarequality.net

them or even just one. For instance, in main farm mammals (pigs, cattle or lambs), there are changes in the number and duration of vocalizations, the intensity and the spectral characteristics. These kind of vocalization changes are also observed in hens during removal of feathers or picking.

Physiological indicators	Behavioural indicators
Hormonal concentrations in blood, saliva or urine	Vocalizations
Adrenal axis: ACTH, cortisol	Number and duration
Sympathetic axis: adrenaline, noradrenaline	Intensity
Blood energetic metabolites	Spectral characteristics
Glucose, lactate	Postures
Free fatty acids	Abnormal lying (legs tucked under the body, etc.)
Blood concentrations of inflammatory markers[1]	Abnormal standing (not on all legs, rigid, etc.)
Haptoglobin, fibrinogen, IL-1, etc.	Behaviours
Activity of the autonomous nervous system	Frequent licking, scratching, rubbing
Heart rate	Avoidance and escape
Respiratory rate	Tonic immobility
Arterial blood pressure	Lack or excessive locomotion
Internal, cutaneous or eye temperature	Aggressiveness
Pupil diameter	Agitation or lack of activity
Sweating, skin electric conductivity	Prostration
Muscle tremor	Isolation
Brain activity	Loss of appetite, etc.
EEG	

ACTH = adrenocorticotropic hormone; IL = interleukin; EEG = electroencephalogram.
Adapted from Mellor *et al.* (2000), Prunier *et al.* (2002) and Hay *et al.* (2003).
[1]Inflammatory markers indicate the existence of an inflammatory state that may generate pain.

FIGURE 2.3: List of physiological and behavioural changes that may indicate the existence of pain in mammals Source: [48]

As observed in Figure 2.3 vocalisations patterns can be an indicator of animal pains and it implies a reduction of animal welfare. Detecting the pain patterns in vocalisations can determine with more resolution the level of animal well-being.

Other state-of-the-art studies centered in vocalization of different farm animal species can be found in [40, 47]. In this kind of research, it is essential to identify screams due to pain or stressful situations from other sounds [49] and also to know the vocal behaviour of farm animals (cattle [50], pigs [49], chickens [23]). One of the main current trends in this research field is heading towards the development of farm animal vocalisation classification algorithms, combining different audio parameters with automatic classification systems [51].

2.2 Acoustic Analysis of Bird Vocalisations for Welfare Evaluation

Among the different farm animals, our research is addressed to acoustic analysis in poultry farms focusing on the Broiler Ross 308. Therefore, we start from the study of the information that relates their vocalizations and their relation with welfare. Fontana *et al.* [23] present a complete study of the young bird vocalisations in an attempt to find some patterns depending on the age (1 day or 5 days of life) and the situation of the chickens (isolated or in group). They found 12 different frequency patterns concluding that the type of vocalizations changes from "call sounds" to "distress calls" as the birds grow. Furthermore, audio samples (spectrograms) of chicken vocalizations have been used to distinguish healthy from infected (infectious bronchitis) birds [52]. Lee *et al.* [14] use more acoustic parameters to automatically detect stress in laying hens. The acoustic parameters are separated between time and frequency domain. Acoustic parameters helps to model the different vocalisations and to classify different classes of calls.

- Time domain features
  - RMS is an amplitude modulated by a Gaussian random process.
  - Power sound Power defined as formula cited in [14]
  - Energy defined as formula cited in [14]
  - Absolute extremum refers to the absolute value of the maximum amplitude from the sound.
  - Intensity is the sound intensity is the sound power per unit area.
  - Shimmer is the average absolute difference between the amplitudes of consecutive periods, divided by the average amplitude.
  - Jitter is the average absolute difference between consecutive periods, divided by the average period.
  - HNR measures the ratio of the harmonic signal power and the noise power in the observation
  - Pitchis the relative concept of frequency.
- Frequency domain features
  - Formant F1 to F4 are characterized by the frequency of the peak, the resonance factor, and the relative amplitude level of the sound. Formant are diferent between animals as it is realted to the biology of the animal respiration conduct. The frequency of acoustic resonance was extracted between 0 to 5,000 Hz
  - PSD, PSD1 to PSD39: The PSD is the average power for the sound within a certain time and frequency range, expressed as Pa2 / Hz . 39 PSDs are due to the extracted of acoustic data every 100 Hz between 100 to 4,000Hz.

De Moura *et al.* [53] presented a study that correlates the environmental temperature with the behavior and vocalization of chicks. They detected changes in the intensity and the frequency of their vocalizations when temperature decreases. In this case, chicks try to warm up by gathering and in order to reduce the heat loss of the flock. There are other important sounds apart from vocalizations such as pecking that can be used to monitor the food intake of the chickens [54] by placing a microphone in the feeder instead of a device attached to each animal. This is a key point to achieve an non- invasive system capable of continuous audio measurements.

As an example of some non-invasive system some prototype can be found in the literature.

- Acoustic recordings obtained using a Rapberry Pi based recorder to monitor the Turacoin in the center of Kenya in Hartlaub [55].
- Acoustic sensor prototype ROBIN: Recording and Observing Bird Identification to classify different birds calls using Raspberry Pi [56].

- WASN: Wireless Acoustic Sensor Network based in the use of an FPGA to monitor endangered species in real time [57].

In a recent work, Herborn *et al.*. [22] present a single acoustic marker that co-varies with a range of physical, behavioural and emotional welfare concerns. This marker, called by the authors as 'iceberg indicator' is the spectral entropy measured after clean the low frequency sound of machinery. With this acoustic parameter they showed a linear correlation with the manual distress call count in the first 4 days of placement and therefore be able to predict low weight gain and high mortality for the next days.

In our opinion, there are some interesting approaches that include the use of sound analysis on commercial chicken farming, but there is still a long way to go to achieve a complete and robust system that helps farmers to improve the welfare of chicks. This statement is in line with the conclusions of the review presented by Rowe *et al.* [58] about Precision livestock farming (PLF) technology development in poultry farming. They conclude that the main goal of PLF development is improving animal welfare, although the availability of commercial systems available to the farmer is still very scarce.

Chapter 3

Materials and Methods: Farm description

Automated chicken farms allow the continuous monitoring and measurement of the environment affecting poultry production. In this study a farm with the following technical specifications was chosen in order to be able to contrast and compare the data with the metrics of the acoustic animal vocalizations.

3.1 Environment: Farm Selection Description

The acoustic analysis has been performed in a Mediterranean farm of the BonArea Agrupa corporation [1]. BonArea Agrupa highlights for carry out and controls all the feeding, breeding and feeding of the animals, the production of products, the logistics and direct sales up to the final consumer; all without any intermediary and with a complete and unique vertical integration model in the world.

BonArea has given access for this project to a 42,840 commercial chicken farming during an entire Ross 308 production cycle [59], which represents a total of 44 days of life. The study was held in the winter season last January to the beginning of March 2020. The average temperature in the outer farm was between 6 and 15 ºC, the humidity close to 0 % and a rainfall average of 10 % [2].

The farm chosen (Figure 3.1) has almost two identical chicken houses of 20 m x 120 m total size each, both of which are fully instrumented with the following machinery: *i)* underfloor heating, with hot water production by use of propane gas, *ii)* an additional heating system with hot air generators, *iii)* forced ventilation by tunnel system, *iv)* heat exchanger installed in one of the buildings. There is also a sensor network that records CO_2 levels, the humidity, the inner and the outer temperature. The network sensors and some manual rules introduced to the system by the farmer automatize the farm management in terms on activation of ventilation, heating and light. Food and water supply are also automatized and guaranteed throughout all the production cycle for all the birds, by means of refilling the containers when the food is scarce. This farm has deployed sensors of temperature, humidity and CO_2. The characteristics of this farm provides a suitable environment for this study. The automation reduces the human factor in farm management and provides data of the environment and productivity factors that can be analysed together with the animals vocalization metrics.

[1] www.bonarea-agrupa.com

[2] Meteorological data obtained from on May 25th 2020 https://es.climate-data.org/europe/espana/cataluna/sidamon-662610/

FIGURE 3.1: Frontal view of the project Farm, Source: [60]

In order to certify the equivalence of the measurements, the sensors will be identically installed in each animals house to collect the raw data in order to provide redundancy of data, in case one of the measurements presents problems during the recording campaign. One farm will be analysed (H1) with a backup for any inconvenience of (H2). The vocalizations of the chickens will be recorded throughout the cycle, in order to evaluate the background equivalent level L_{eq} [61] and the frequencies of the vocalizations and their dependencies with other environmental measurements.

FIGURE 3.2: Picture of day 21 in H1 house; the birds live with the microphone installation. It is recording continuous raw acoustic data.

3.2 Materials: Equipment Description

The goal of the recording campaign was to collect both vocalizations and background noise of commercial chicken farming throughout their life-cycle, in order to evaluate the evolution of the entire production time for further analysis. The recording is a mere reflection of the audio inside the farm. The vocalizations captured by the microphone are group vocalizations due to the animal density and sensor location. For this reason, single identifications could not be performed. Nevertheless, the purpose of this work is to evaluate the entire animals welfare, not individual bird tracking.

A professional handheld recorder (Zoom H5) [62] was used, connected to a directional microphone Behringer ultravoice XM1800S with a frequency response of 80-15 kHz and a sensibility of 2.5 mV/Pa [63]. The sounds emitted by birds in each house were recorded with one microphone each, deployed at one meter high from the ground and at the center to the house. Figure 3.3 shows the acoustic sensor deployment. The location was chosen to avoid chicken interfering with microphone - biting, singing just next to it, etc. - and also to provide a wide background of sound recordings. The microphone diagram pattern was selected in order to reduce the maximum the interference of other source sounds as machinery due to its cardiod shape. Similar acoustic implementation techniques have been used in other studies [64, 65].

The Zoom H5 handheld recorder was configured to record the entire production cycle with as few data stops as possible. Although the recorder stopped when it reached the 32 Gb of data due to the maximum continuous recording storage, in this project setup it takes approximately 6 days to stop. To ensure the continuously audio recording after 5 days, the system was stopped for a periodical technical reset. The data was collected from the SD to a hard disk and after a small stop of approximately 15 minutes the system was reactivated. By default these 5 days are stored in audio pieces of 6.75 hour duration for further processing. The recording format was PCM-16 and the sampling rate was set to 44.1 kHz. The post processing analysis required a time reference of each measure to obtain reliable results especially when comparing with other data collected in the farm. For that purpose, each audio was saved with the metadata of the storing time of the file. By the end of the project, the 44 days of chicken vocalizations generated around 400 Gb of data describing the events and the welfare of the chickens on the farm.

The selected farm has a work dynamic where CO_2, temperature, humidity, losses and weight are measured in each animal production cycle. These five data variables have been provided by the farm. CO_2, temperature and humidity measurements are carried out automatically every 15 minutes, the mortality of animals is obtained daily and the average weight weekly. The CO_2, temperature and humidity network sensors (see Figure 3.6) are distributed through the room and all the data is collected in a hard disk via a management software for the daily management of the farm. Getting the value of this sensors do not require an extra cost to the farmer day work.

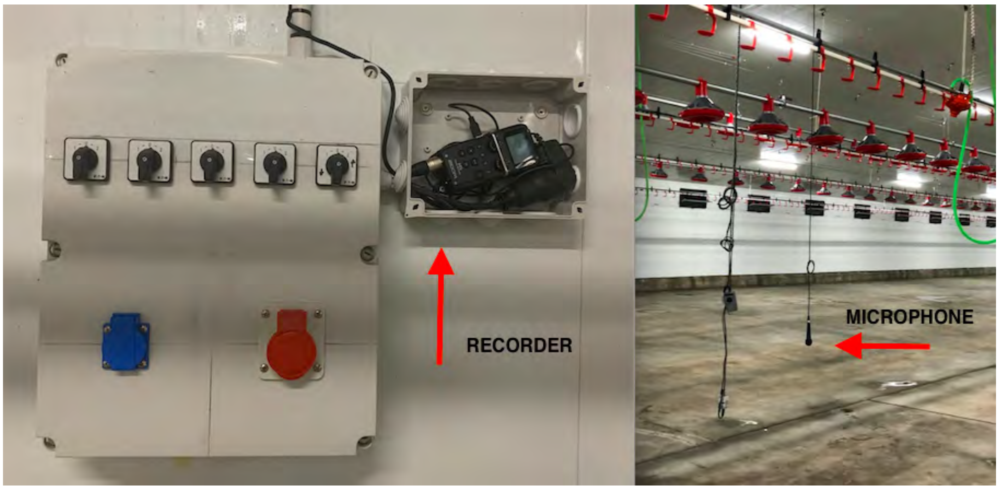

FIGURE 3.3: Acoustic equipment deployment in the farm H1. On the left, the recorder location. On the right, the microphone hanged from the ceiling, in order to avoid phyiscal interaction with the birds.

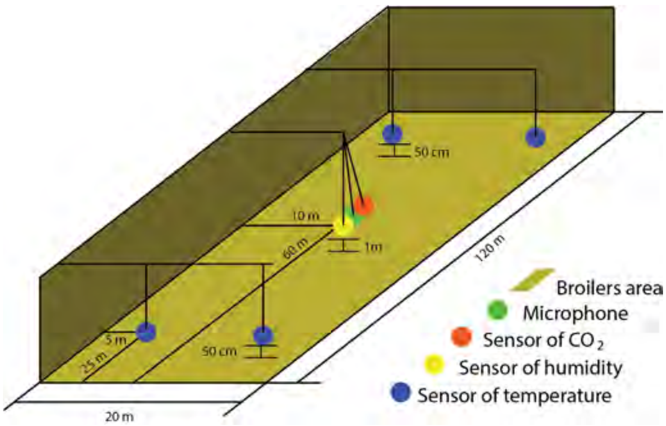

FIGURE 3.4: Diagram of the sensors location in the H1 farm; microphone, CO_2 sensor, humidity and temperature sensor.

The animals weight and mortality are manually obtained. Birds weight evaluation has to be representative from all the chicken house. The calculation method uses an electronic scales to weight $N = 100$ from different points of the chicken house to get a representative measure of the entire farm and calculate the mean value (see equation 3.1).

$$Weight_{mean} = \frac{1}{N}\sum_{i=1}^{N} BirdsW_i \tag{3.1}$$

Significant results have to use at least $N = 100$ animals or 1% of the population [66]. For each calculation the digital scale is calibrated and birds are sampled from at least three different points of the house. The frequency of weight calculation during the cycle is set weekly as important weights variances are found in periodicity.

Part of the farmer's daily routine is to check around the farm early in the morning. Daily farm inspection enables the farmer to detect possible diseases, supply chain problems, any birds problems and find and remove dead chickens, this reduces gases generated of the birds decomposition. The farmer documents the number of deaths and the statistically average weight of the animals as data for each production cycle. This information is supplied by the farmer to this study.

FIGURE 3.5: Picture of day 4 in H1 house; the birds live with the microphone installation. It is recording continuous raw acoustic data. First reset of the production cycle.

3.2.1 Methods: Acoustic Analysis of the Recordings

Recording birds songs as a collective is a non-invasive method, that can measure animal acoustic parameters and relate them for example with welfare without modifying their natural behaviour as how has been done in other studies [11, 15, 13]. In this particular study, we want to find a dependency between the acoustic characteristics and the usual indicators of the farm. If an acceptable dependency is found between indicators it will be easy to comprehend the broilers welfare and if possible improve their help.

Acoustic metrics defined to measure the raw acoustic data

After the production cycle, 44 days of raw acoustic data were obtained. The system was reset 9 times during the entire project and a total amount of 160 files were saved. Each file takes up 2.15 Gb, configured as mono channel sampled at 44.1 kHz and 16 bits has a duration of 6 h 45 min and 46 s. From these 160 files, there are 9 files that were manually reset and therefore have a variable length due to the time of the technician's operation.

The system presented a failure on the 10 th and 11 th days due to a technical issue other than the known technical stops used to reset the hardware. All the usable data was processed using MATLAB® [38].

Equivalent level in the farm

The acoustic equivalent level L_{eq} is defined as a value of the sound pressure level of a continuous, steady sound that, within a specified time interval, has the same mean square sound pressure as a sound under consideration whose level varies with time [67, 68]. As the following Eq 3.2 states, it is a logarithmic measurement.

$$L_{eq} = 10log\left(\frac{1}{T}\int_0^T \frac{P_i(t)^2}{P_{ref}^2}dt\right) \tag{3.2}$$

In this study the time interval chosen for the L_{eq} is 30 min. This interval has been decided in order to obtain the same resolution as the two CO_2 samples, as well as for computational reasons in this stage of the project. The data processing has been executed in a Personal Computer running Windows of 8 Gb of RAM and microprocessor intel ® i5.

These acoustic feature indicates the intensity of the sound averaged in 30 minutes according to a sound pressure of reference. As most of the recorded and analyzed sounds are birds vocalizations, it depicts the intensity the animals singing. The microphone was not been calibrated for this project for the following reasons:

- The handheld recorder is designed for audio recording not as a measurement instrumentation.
- The recorder can not fine-tune the sensibility of the microphone.
- The cardioid microphone used is a commercial voice microphone, not a Class 1 microphone, as those microphones have an unidirectional pattern non desired for the project requirements. Likewise the L_{eq} measurements in this study aim to evaluate equivalent level variations, not requiring a high accuracy measurement as in a Class 1 device.

FIGURE 3.6: Zoom H5 handheld recorder and Microphone Behringer ultravoice XM1800S. Source: [62, 63]

Peak frequency during the recording campaign

There are almost 12 different chicken vocalizations identified in the literature that have a different spectral pattern [23]. See again Figure 1.2. Statistical analysis showed a significant correlation (P<0.001) between the frequency of vocalisation and the age of the birds [23]. Birds peak frequencies vocalization range between 2.7 - 4.3 kHz. According to the results of this study, it was found that the main frequency of the sounds emitted by birds is inversely proportional to their age and weight; specifically, the more they grew, the lower the frequency of the sounds made by the birds.

In the present study, the spectral bandwidth acquired is limited by the recorder configuration to 22.05 kHz, due to the sampling frequency at 44.10 kHz. To avoid interference of other sounds sources - machinery, people talking, etc.- raw audio data is filtered using a bandpass filter. The first filter (Figure 3.7) proved with a response of 1 to 11 kHz, did not filter correctly to extract the birds vocalisations. It was not enough narrow and the peak frequency obtained was outside the birds vocalisations range. Some false peak frequencies obtained where higher to 5 Khz, probably an harmonic with more energy of the vocalisation.

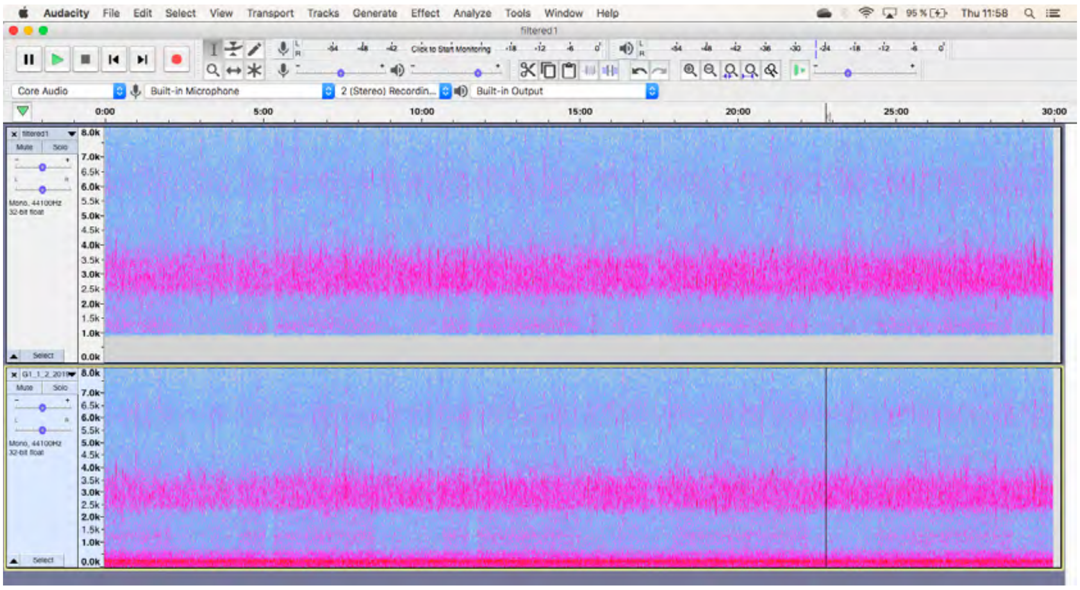

FIGURE 3.7: Audacity [69] spectro-temporal view of two audio data. Top one is filtered from 1 to 11 kHz and the bottom one without filtering.

The second was a successful filter with a response of 2 to 5 kHz, reducing potential interference noise at frequencies other than those generated by animals. Peak frequency extracted correspond to the real vocalisations of the birds.

To obtain the peak frequency, the following algorithm is applied (see the equivalent block diagram in Figure 3.8):

1. Data is segmented using Hamming windows of 4 minutes [70] and overlap of 40% between consecutive windows.

2. Data is filtered using a band pass filter from 2 to 5 kHz.

3. A FFT algorithm of 1024 points is applied [71].

4. The maximum value of the window is extracted.
5. Buffering of 30 minutes.
6. Calculate the mean peak frequency of the 30 minutes.

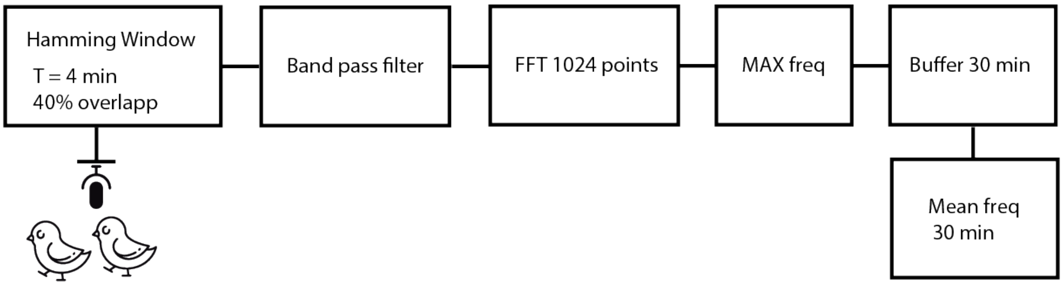

FIGURE 3.8: Peak frequency detection algorithm implementation

Identification of machinery sound data

The acoustical data acquisition method has been specifically designed to capture the birds vocalizations. Unfortunately, some sounds of the fan, feeders and several bar vibration of the feeders are also recorded. The microphone position (vertical to the ground) and its cardioid pattern (available on datasheet [63]) reduce the influence of acoustic events that do not correspond to vocalizations of the closest animals [72].

This non desired captured events are easy to identify and also to exclude from the analysis. Figure 3.9 shows a sample of the average L_{eq} values over 24 hours. In this sequence, the machinery sound data is identified as the sound that stand out for their high and long-lasting equivalent level. The non desired event is highlighted in red and corresponds to the sound of airborne feed in the supply chain.

The acoustic profile is studied in more detail in terms of L_{eq} and frequency variations. The maximum frequency is found between 4 - 4.5 kHz with variations of more than 1 kHz. Meanwhile, terms of L_{eq} the range corresponds from 60 to 80 dB with small variations ($\pm$ 2.5 dB). For the current analysis few audio frames are discarded not to bias the results in proportion.

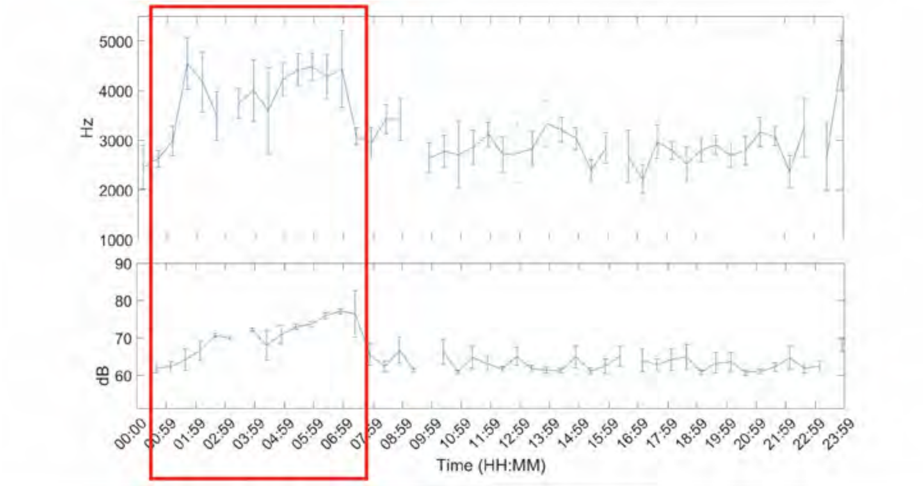

FIGURE 3.9: Temporal L_{eq} sample in which the increase due to machinery is clearly identificable.

Evaluation of the Acoustic Raw Data

Analysing the $L_{eq30min}$ and maximum frequency each 30 min over the entire production cycle show the evolution of the sound pressure, and highest frequency generated by the birds according to their life expectancy. Figures 3.10 - 3.12 reflect this study. The white cells represent data are missing files, that could not been computed due to the hardware limitation of the processing unit of the acquisition system.

Figure 3.10 shows the sound pressure evolution generated by the birds in a complete production cycle. There were 42,840 animals until day 33th, when the density of animals is reduced. Therefore, during the last days of their life cycle, there were less chickens in the house and as a consequence, sound pressure was reduced.

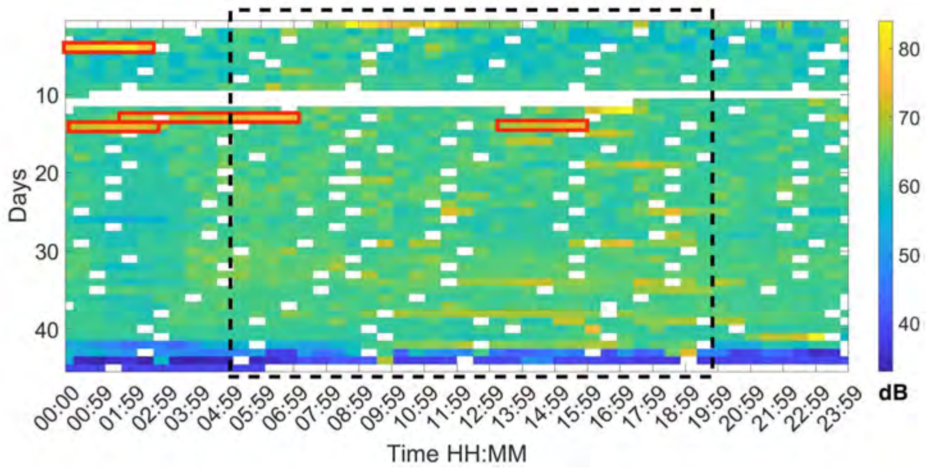

FIGURE 3.10: Map of the L_{eq} at 30 min intervals during the 44 days of a complete production cycle.

As shown in Figure 3.10 there is no age-related increase in the level of pressure of chickens as the mean level is not increased with time. From five in the morning until nine in the evening coinciding with the period of more activity we can appreciate an increase in L_{eq} of more than 7 dB. The temporal area with more activity is highlighted in a black discontinued rectangle. We have highlighted with red rectangles some periods that present high acoustic level due to the machinery identification. A careful analysis of these segments, louder and clearer vocalizations can be heard from the chickens closest to the microphone.

However, Figure 3.11 firmly shows an age-related decrease in peak frequency throughout the whole production cycle. Otherwise there is not a relevant variation on a daily basis. The frequency obtained on the first and last day of life of animals is higher with respect to the average values of those days. High-stress moments reflect an increase in the frequency of vocalization in the data.

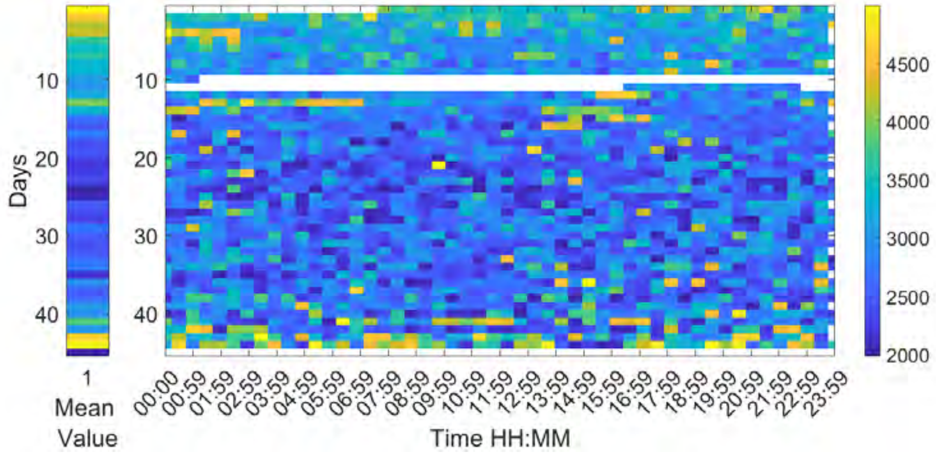

FIGURE 3.11: Map of the maximum frequency at 30 min intervals during the 44 days of a complete production cycle.

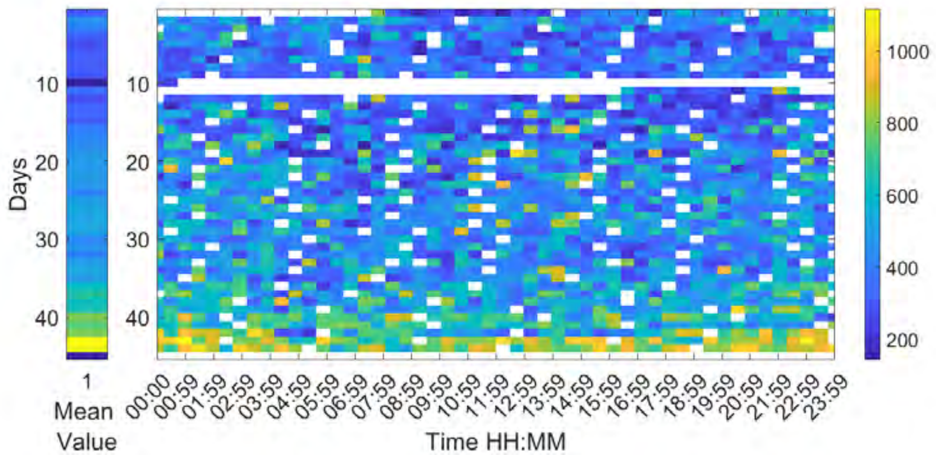

FIGURE 3.12: Map of the variance in frequency at 30 min intervals during the 44 days of a complete production cycle.

Apart from the mean value of the peak frequency, it is also relevant to measure its variance with the further intention of detecting possible correlations with other parameters being evaluated. Each 30 min segment of data has been processed in 4 min windows and the variance of the peak frequency has been calculated (see Figure 3.12). In general, an age-related increase is observed, as well as an increase during the night with respect to the day. However, picking up the birds at the end of production and birds arrival to the farm shows the highest frequency variations of all samples. High frequency variations could indicate animal stress as picking up and birds arrivals are moments of animal stress.

Chapter 4

Results: Birds Welfare Environmental and Production Data Analysis

This chapter describes the traditional data farm indicators of a production cycle: temperature, humidity, weight, CO_2, food and water intake. All traditional data are obtained on a regular basis as indicators that help the farmer during the production cycle. This data has been provided by the farmer and do not represent an extra cost to the farm workflow.

This study analyses the acoustical data with the farm management data: L_{eq} and max frequency, with the traditional data. Some relevant relations of this two blocks of data that have been found in this analysis:

- Correlation between max frequency of vocalization versus food and water intake.
- Correlation between CO_2 versus L_{eq}.
- Correlation between Humidity versus L_{eq}.

Direct relations between variables within the same group have also been identified. This chapter detail all relevant similarities founds in the cross-data study.

4.1 Farm management data

Data shown in this section: CO_2, temperature, humidity, weight, deaths count, food and water intake has been provided by the farm manager and extracted from the farm's automated control system. Traditional data values indicates a good production cycle to be analyzed and studied as a standard uncomplicated breeding.

Figure 4.1 shown the evolution of the CO_2. Carbon dioxide (CO_2) can be generated in different situations: exhaled by the chickens, the release of manure and the gas-fired combustion. An increase in this gas is observed when the manure is moved.

The high concentration of CO_2 at the beginning of breeding corresponds to the need to maintain an indoor temperature of 32 ºC during the first 5 days of life of the chickens and 30 ºC between 5 to 10 days, so the ventilation rate should be low in order to optimize the indoor temperature, an effect that is more pronounced in colder months. The need of having a hot ambient in the first day of the cycle is due

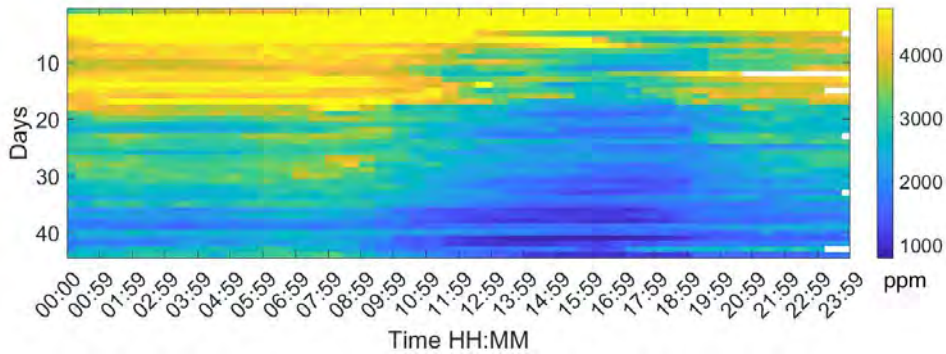

FIGURE 4.1: Map of the mean CO_2 values for each day of the campaign. One value each 30 min.

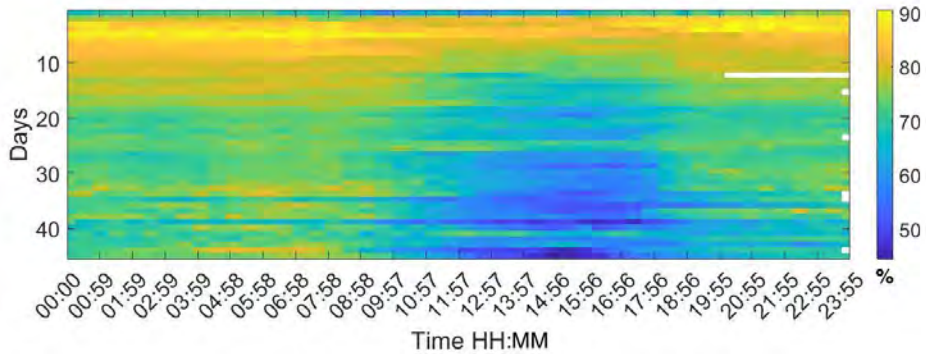

FIGURE 4.2: Map of the humidity values for each day of the campaign. One value each 30 min.

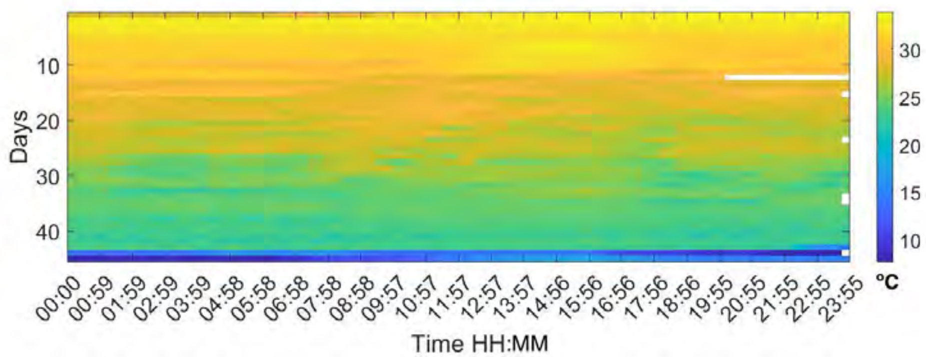

FIGURE 4.3: Map of the temperature values for each day of the campaign. One value each 30 min.

to the lack of thermoregulation of the chicks during the first days of life.

Higher concentrations of CO_2 are detected as from day 10 from eight in the evening to ten in the morning reducing the gas concentration to 3,000 ppm due to the ventilation. Day 20 of life onward show the highest reduction. Ventilation patterns reduce the concentration of gases. The manure movements are performed during the morning by the farmer and also reflect the increase of gas concentration in that time slot.

Similar patterns can be observed with the humidity in Figure 4.2. The highest values are recorded in the first week and it is continuous during the entire day. From day 10 onward a decrease of more than 10% is found between 10 to 18 hours, evolving the window of humidity the last days of the cycle with two more hours of lower humidity measurement.

Otherwise, temperature has a different pattern shown in Figure 4.3. Young birds have little ability to regulate their internal temperature and they need heat, at a temperature of approximately 32 ºC, at their first week of life and the farm provides it externally. Temperature onward is slowly reduced until day 25 when a peak in temperature is reached (from seven to eight). Since day 30, temperature is lowered and homogeneous during the rest of the day.

Animal death count is shown in Figure 4.4, first week of birds have the highest mortality by premature death, although it decreases in an almost exponential manner. Starting the second week, the number of deaths per day is sporadic. From the second week and on two more local maximums are found in day 17 and 37. In comparison with the total amount of birds, the number of deaths from second week and on are not significant.

Week cycle	Mean kg
Week 1	0,047
Week 2	0,153
Week 3	0,410
Week 4	0,853
Week 5	1,397

TABLE 4.1: Average birds weight in kg per week per unit. Information gathered from the farm management system.

Animal weight average measurements are shown in Table 4.1. Birds weights are variant between animals, the average weight values represents the total of animals. The mean value is calculated using 100 birds. This process requires time and is only performed once per week. Week 4 birds have the optimal weight for chicken asado and week 5 birds dimensions and weight are optimum for processing white meat.

Figure 4.5 shows the mean food intake per bird each day. Reduction of the intake is found in the last 3 days due to the manual reduction of animals in farm, which is not reflected in the system. A linear growth behaviour can be observed until day 31, when maximum food production is reached, obtaining a peak value of around 150 g. From day 33 to 38 food intake is stabilized to 140 g.

Similar pattern can be observed in Figure 4.6. The graph shows the mean water intake per bird each day. The last 3 days reflect the animal reduction as seen in Figure 4.5 The growing linear model lasts until day 33 with the maximum bird water intake in day 33, to days later compared with food intake in Figure 4.5. Then the water consumption is stabilized to 230 ml until day 39.

4.1.1 Evaluation of the correlation between acoustic data and welfare information

Circular correlation is calculated as [73] describes. Let $y(k)$ and $x(k)$ be N-point signals, and let $x_p(k)$ be the periodic extension of $x(k)$. The circular cross-correlation of $y(k)$ with $x(k)$ is denoted $c_{yx}(k)$ and defined in Eq 4.1

$$c_{yx}(k) \triangleq \frac{1}{N}\sum_{i=0}^{N-1} y(i)x_p(i-k), \;\; 0 \leq k < N \tag{4.1}$$

This study has computed all the correlations between traditional and acoustical data. Significant results are shown from Figure 4.7 to 4.14. And a detailed list of the non clear correlation is also provided.

In Figure 4.7 we observe a clear correlation between CO_2 and humidity; the maximum values for all the days fall nearly in the center of the circular correlation, which leads us to infer that they are two measured parameters in the farm that present similarities in their performance. This means that when the levels of the CO_2 are greater, so is the humidity. A certain time delay was recorded on a number of days, this variation of maximum 5 hours, where the humidity is delayed in its performance in comparison with CO_2. Carbon dioxide is produced by the exhalation of the animals, so the greater the exhalation larger the contribution of humidity. When the ventilation is switched on, the CO_2 and the humidity are reduced in the building, with some delay.

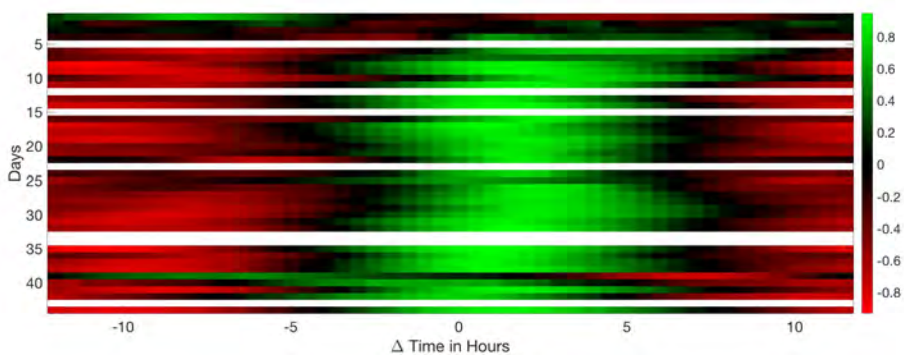

FIGURE 4.7: Results of the circular correlation $C0_2$ - Humidity

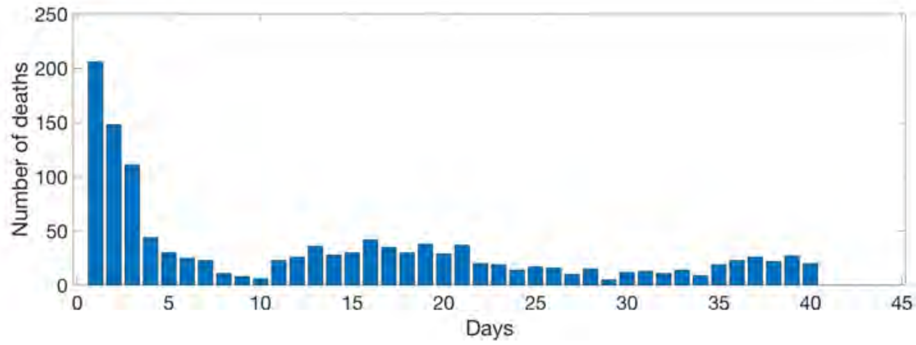

FIGURE 4.4: Animal death count per day. Data obtained from the farm management.

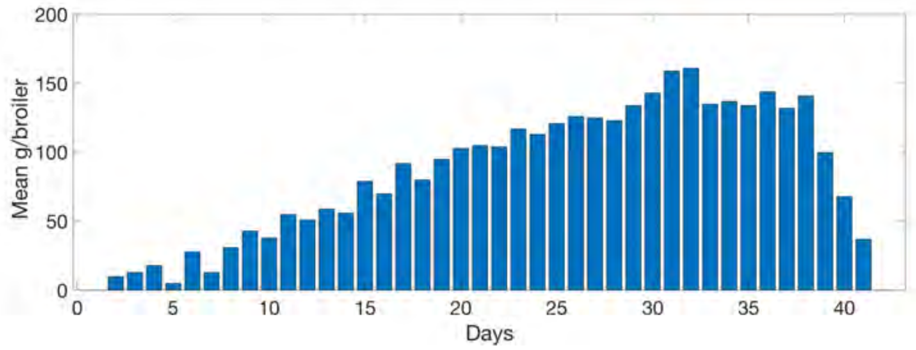

FIGURE 4.5: Mean birds food intake per day. Data obtained from the farm management.

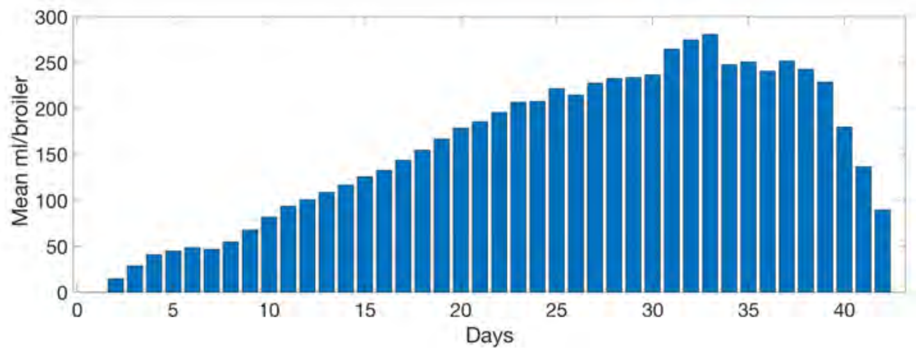

FIGURE 4.6: Mean birds water intake per day. Data obtained from the farm management.

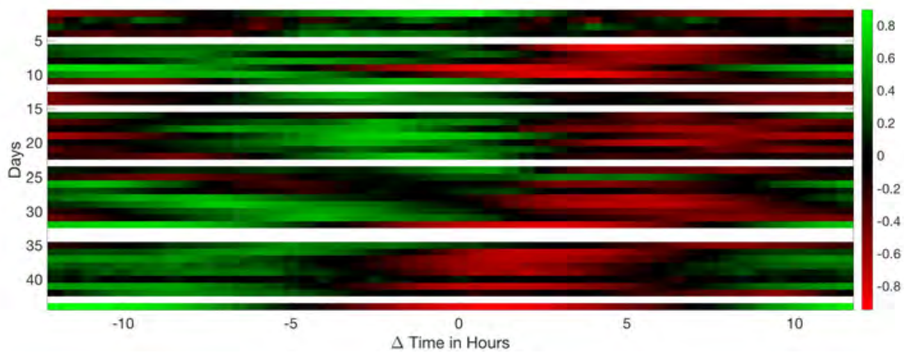

FIGURE 4.8: Results of the circular correlation CO_2 - Temperature

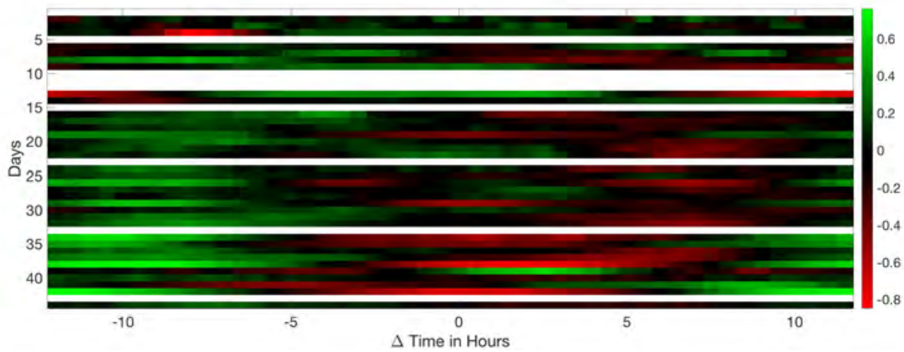

FIGURE 4.9: Results of the circular correlation CO_2 - L_{eq}

In Figure 4.8 we can observe a correlation between CO_2 and temperature, in this case there is an inverse dependency. CO_2 is in advance of the temperature, when CO_2 increases the value, in a delay between 5 and 10 h, the temperature decreases. Outer temperature is considerably low, henceforth air flow injected to the farm is cold. After ventilation is reduced and the Co2 falls, its CO_2 value after a few hours the temperature rises again.

Figure 4.9 show a slight inverse similarity of the CO_2 referenced to the equivalent level L_{eq}, with a different performance for the entire production cycle. When CO_2 is maximum, the sound of birds vocalization is minimum and in reverse. More vocalization is an indicator of bird activity and increases the L_{eq}. Therefore when the CO_2 is reduced, the vocal activity increase. One possible explanation is that high values of CO_2 reduces birds activity and it is appreciated with a reduction of the number of vocalisations L_{eq}. It is documented that CO_2 concentrations above 3,000 ppm do not affect in a negatively way the performance of the animal. Concentrations over 3,000 ppm reduces the animal welfare and also appears some medical issues to the birds.

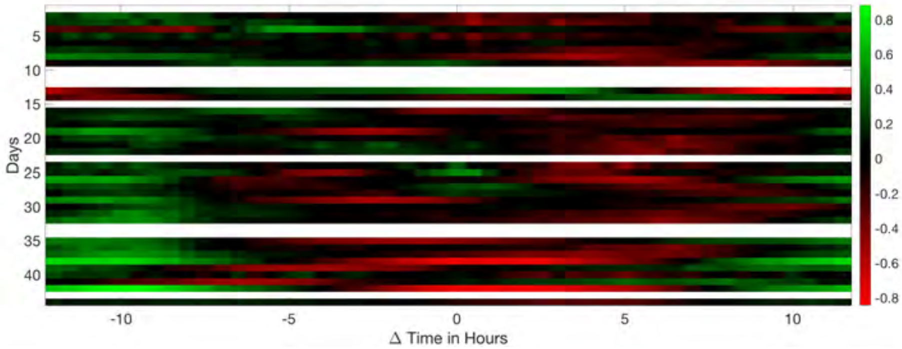

FIGURE 4.10: Results of the circular correlation Humidity - L_{eq}

A similar pattern can be seen in the Figure 4.10, an inverse correlation is detected between humidity and the L_{eq}. The lower the humidity the higher the sound level generated by the animals. High humidity percentage generates discomfort to animals, also too much moisture in the chicken house contributes to the clamping of the bed and to ammonia problems. The animals are more vocally active when humidity values decreases.

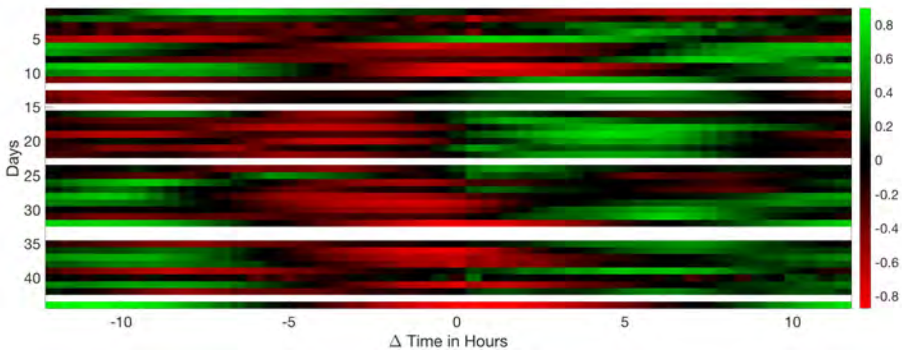

FIGURE 4.11: Results of the circular correlation Temperature - Humidity

Figure 4.16 shows a clearly inverse dependency between temperature and humidity. When temperature is at its maximum, the humidity is at its and vice-versa. As the air temperature rises, the amount of water that a given amount of air is able to retain increases. A 10ºC rise in temperature results in an approximate increase in air temperature halves the relative humidity.

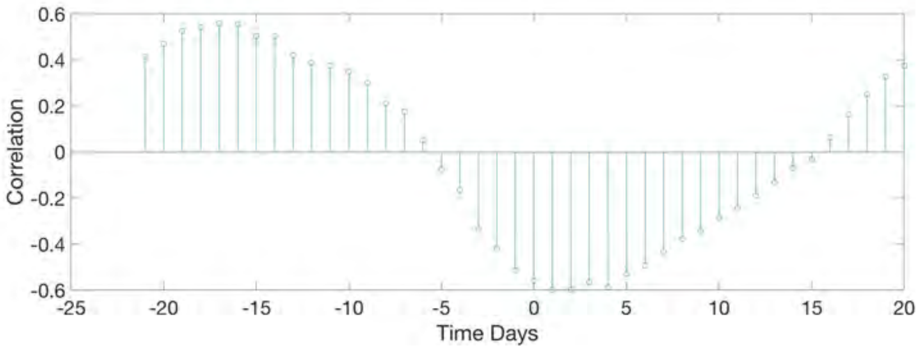

FIGURE 4.12: Results of the circular correlation food - max freq

Figure 4.12 shows an inverse relation between food intake and the mean max frequency vocalized by birds per day. When food intake is maximum, frequency is minimum. Max frequency is delayed two days from food. High frequency indicates high-pitched vocalizations that are related to stress, so they eat more when they are more relaxed.

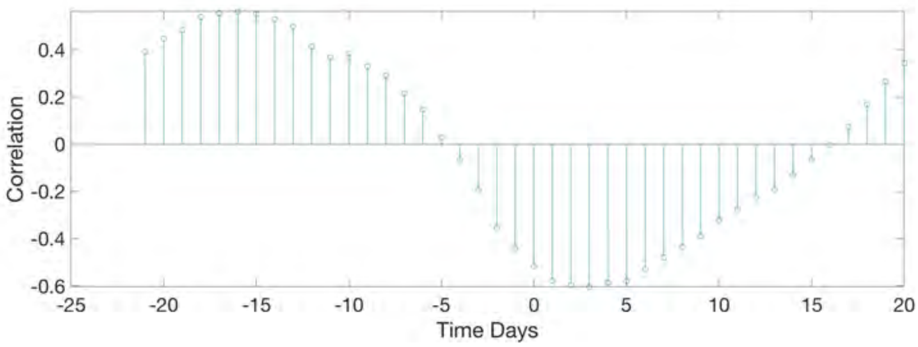

FIGURE 4.13: Results of the circular correlation water - max freq

Figure 4.13 follows a similar pattern as the food consumption (Figure 4.12) an inverse relation between water intake and the mean maximum frequency vocalized by animals per day. When food intake is maximum, frequency is minimum. Maximum frequency is delayed by 2 days with respect to the water max values intake.

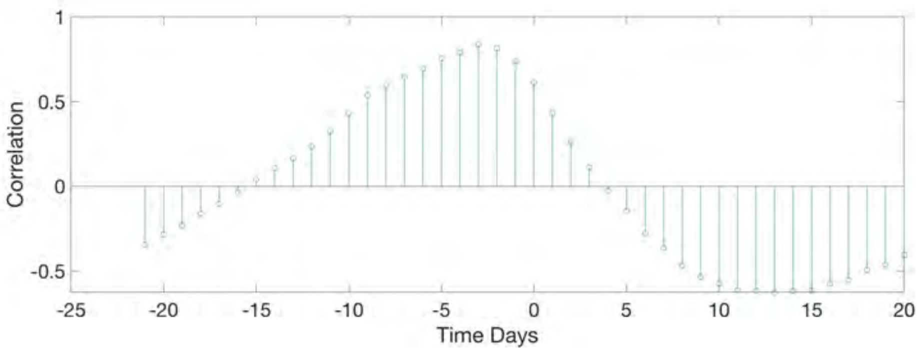

FIGURE 4.14: Results of the circular correlation food - weight intake

Figure 4.14 shows a correlation that does not depend on acoustic parameters but on the normal operation of the farm. It was an expected result, but noteworthy. Data indicates a direct dependency between food and weight with a significant correlation value. When food intake increases it also does the weight. Although weight is delayed 3 days with respect to the food intake values. This correlation corroborates the food - weight dependencies seen in literature, transforming cereal protein to animal protein.

Circular Correlations shows any statistical relationship, whether causal or not, between two random variables or bi-variate data. A correlation result between +0.5 and -0.5 are soft correlations that for this analysis cannot link or demonstrate a relation between the two parameters under study.

This analysis has also performed the following correlations. None of the below circular correlation presents consistent correlation among this production cycle.

- CO_2 - Max Frequency (Figure 4.15)
- Max Frequency - Humidity (Figure 4.16)
- L_{eq} - Temperature (Figure 4.17)
- Max Frequency - Temperature (Figure 4.18)
- CO_2 - death (Figure 4.19)
- weight - L_{eq} (Figure 4.20)
- food - death (Figure 4.21)
- water - death (Figure 4.22)
- water -L_{eq} (Figure 4.23)
- Food - L_{eq} (Figure 4.24)

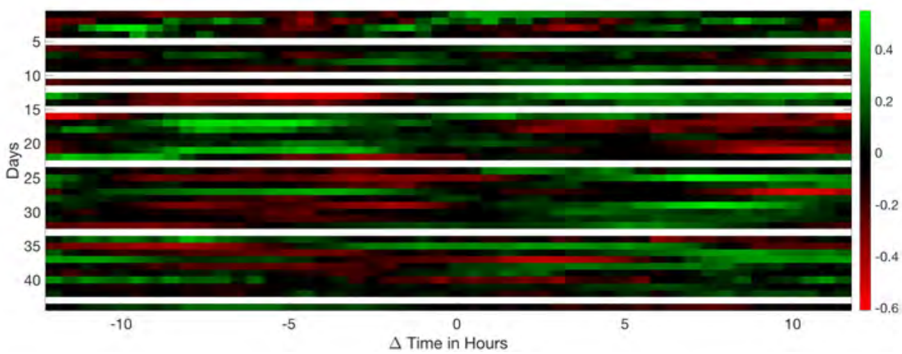

FIGURE 4.15: Results of the circular correlation CO_2 - Max Frequency

Figure 4.15 shows the correlation between CO_2 - PF, maximum result range between $\pm$ 0.4 and have not a similar pattern thought the production cycle. Third week a linear dependency is found where max frequency is in advance for 5 hours respect to Carbon Dioxide. Meanwhile in fourth and fifth week CO_2 is in advance to PF in 5 hours. This different patterns can be due to the management of the farm depending to the age of the birds.

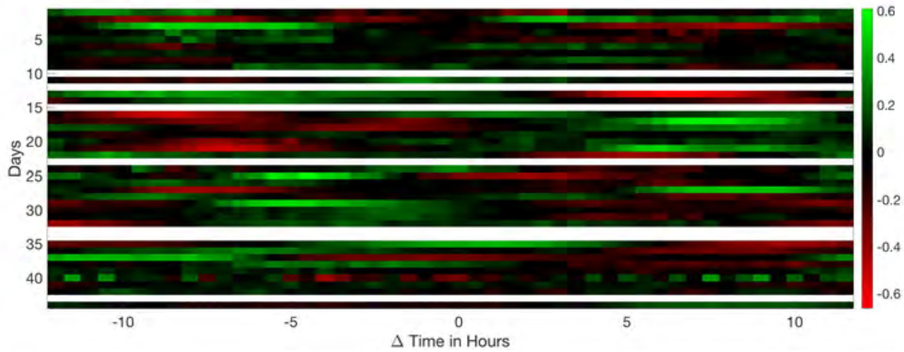

FIGURE 4.16: Results of the circular correlation Max Frequency - Humidity

Figure 4.16 shows the correlation between PF - Humidity. Max and min values of this figure are ± 0.6 and random distributed during the days of the study. Most of the day the correlation values are close to zero. Probably humidity values do not affect the PF vocalised by the animal.

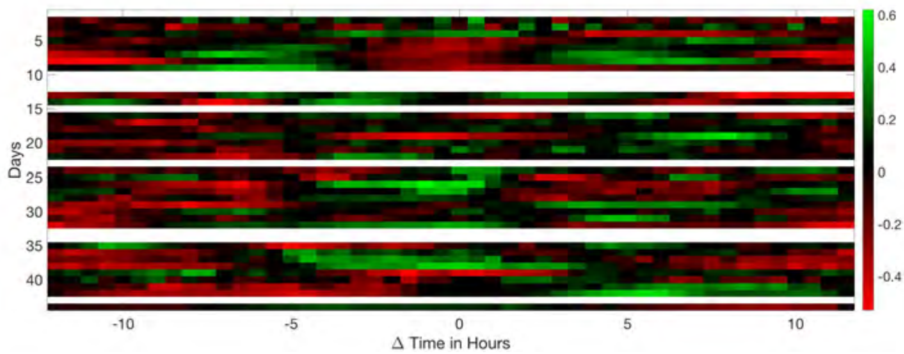

FIGURE 4.17: Results of the circular correlation L_{eq} - Temperature

Figure 4.17 shows the correlation between L_{eq} - Temperature. Most of the days shows an inverse relation with values of -0.4. When temperature increases the L_{eq} is reduced. High values of temperature reduce the activity and the intensity of the animals calls.

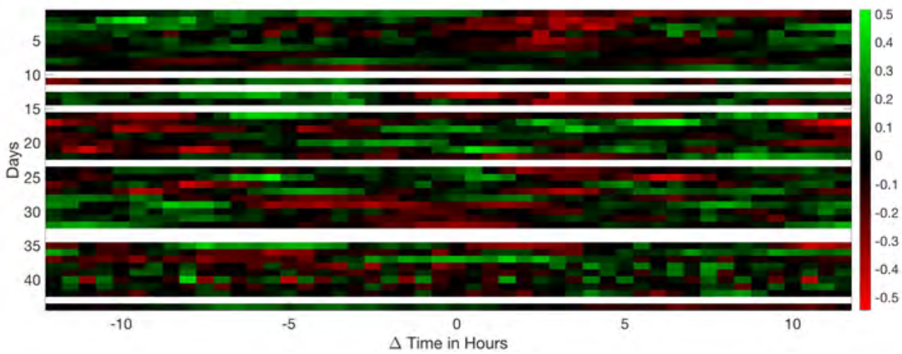

FIGURE 4.18: Results of the circular correlation Max Frequency - Temperature

Figure 4.18 shows the correlation between PF - Temperature. The result is a map with a pattern that remembers a chess board. Most of the dependencies are not stable in time. There isn't a clear relation between this two dependencies.

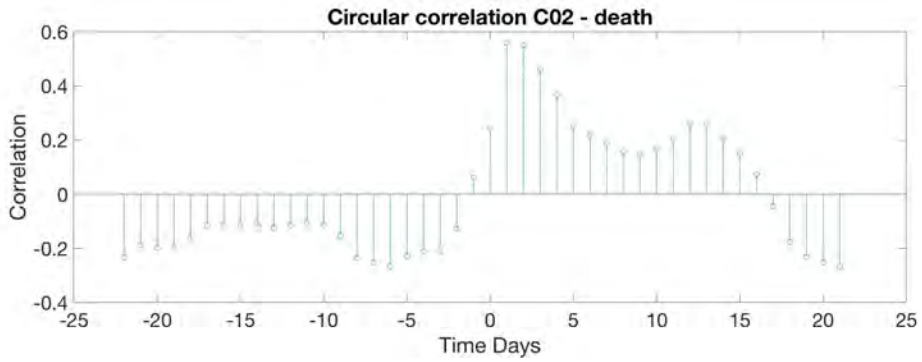

FIGURE 4.19: Results of the circular correlation CO_2 - death

Figure 4.19 shows the correlation between CO_2 - Death. Maximum relation of CO_2 is delayed two days respect the death. This correlation is not real. The death of the birds is not produced due to the high concentration of CO_2, first days of life animals die mostly for premature reasons.

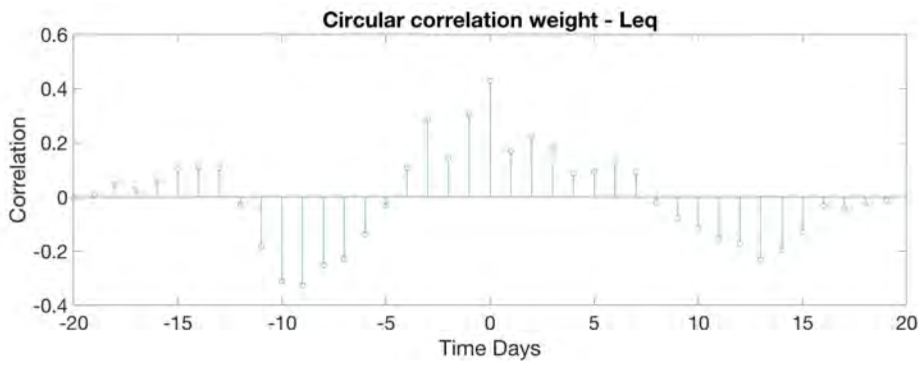

FIGURE 4.20: Results of the circular correlation weight - L_{eq}

Figure 4.20 shows the correlation between animals weight - L_{eq}. When the weight is maximum it is the L_{eq} without any delay. The value of the correlation is below 0.6.

Young birds are less developed and the sound pressure level that can generate is also reduced.

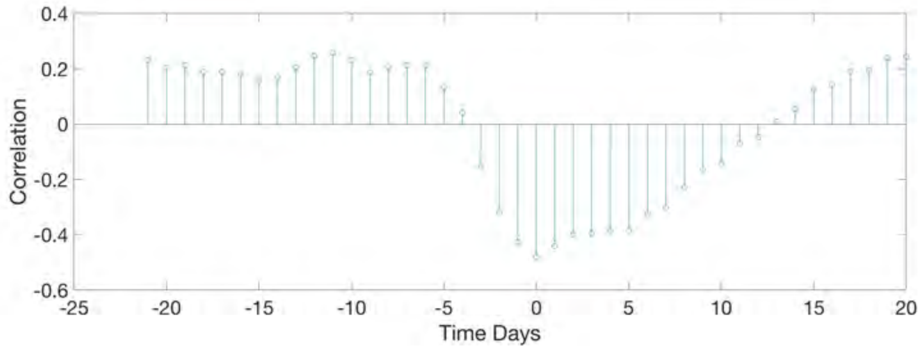

FIGURE 4.21: Results of the circular correlation food - death

Figure 4.21 shows the correlation between food - death. There is a soft inverse relation that indicates that death is maximum when food is minimum. This is also related with the fact that first days of life animals die mostly for premature reasons.

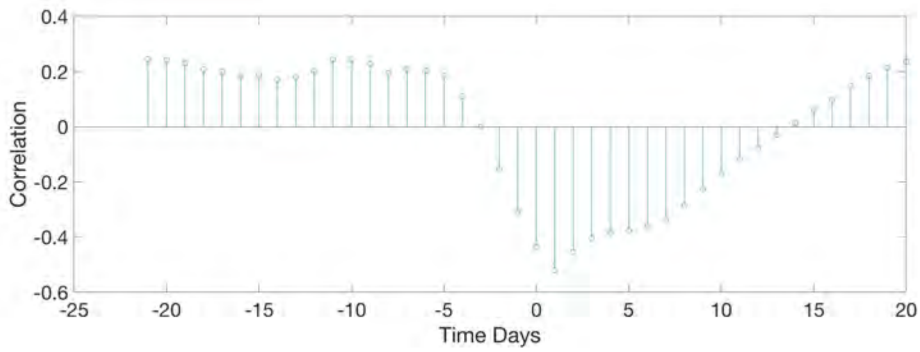

FIGURE 4.22: Results of the circular correlation water - death

Figure 4.22 shows the correlation between water - death. This Figure is very similar to the food - death (4.21). Food and water intake have a very similar form.

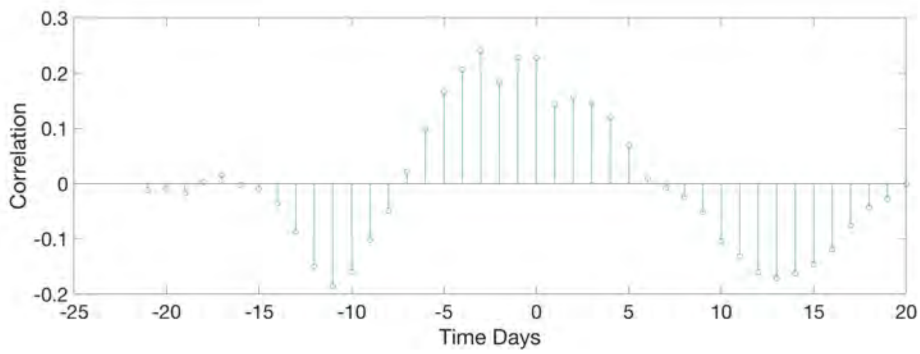

FIGURE 4.23: Results of the circular correlation water - L_{eq}

Figure 4.23 shows the correlation between water - L_{eq}. This is a very soft correlation (0.3). There is not valid relation.

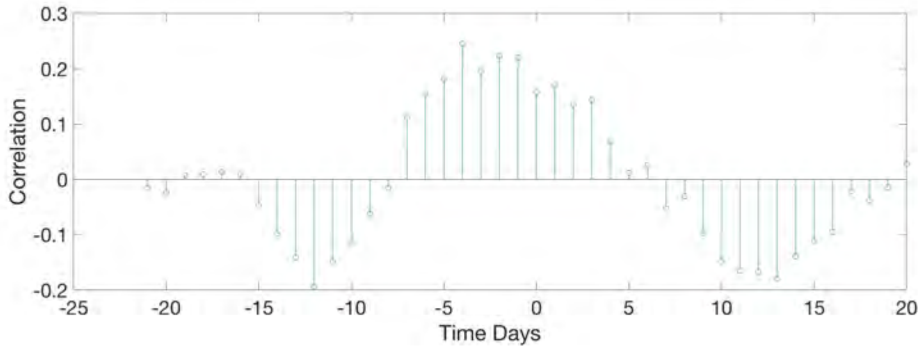

FIGURE 4.24: Results of the circular correlation Food - L_{eq}

Figure 4.24 shows the correlation between food - L_{eq}. This Figure is very similar to the water - leq (4.22). This is also a not valid relation.

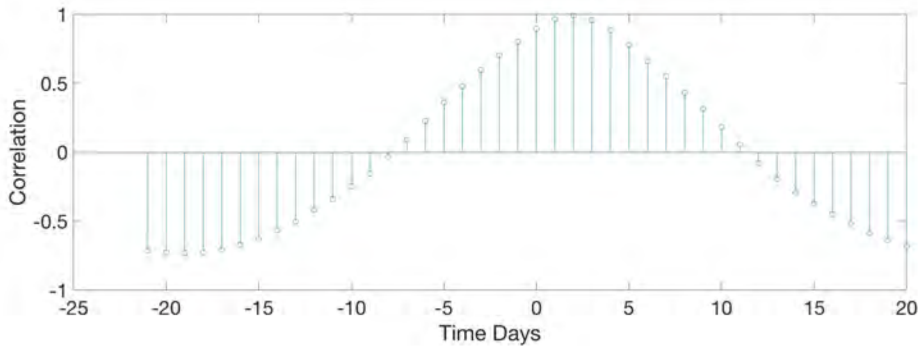

FIGURE 4.25: Results of the circular correlation water - food

Figure 4.25 shows the correlation between water and food. As it have been seen, both variables have a high index of similarity. Food maximum is in advance respect maximum of water intake in 2 days. This correlation with value close to 1 determines also that the algorithm implemented with Matlab [38] is correct.

4.1.2 Evaluation of the stability or variation inter seasons of Acoustic parameters

A broiler Ross 308 takes approximately 44 days to complete the production cycle [74]. In a natural year a farm can hold in average six different birds lots. The recording campaigns of this study are held in Spain over 2020. The climate between summer and winter is the opposite and it is an ideal scenario for a comparative study. In summer the farm is exposed to an external temperature of 31ºC - 14ºC and a humidity of 4% - 55% meanwhile in winter is 13ºC - 1ºC and a humidity of 0% [1].

[1]Data obtained in average climate searcher https://es.weatherspark.com

The two campaigns of acoustic data recording have been performed in the same house farm, maintaining the deployed equipment and the genetic of birds. First campaign (C1) was scheduled during January and February 2020. Second campaign (C2) was scheduled during July and August 2020. Both cycles had a standard performance in terms of conversion index.

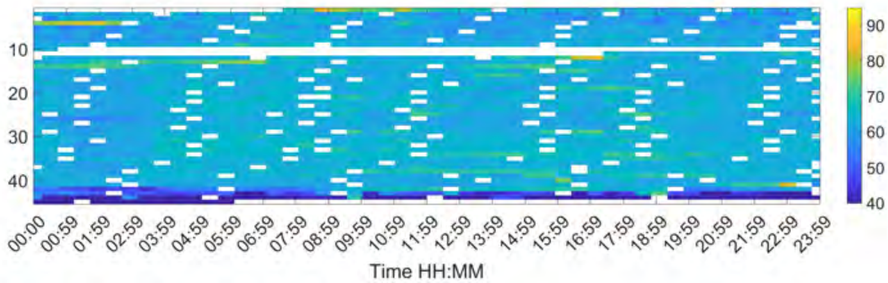

FIGURE 4.26: Map of the L_{eq} values for each day of the first campaign (C1). One value each 30 min.

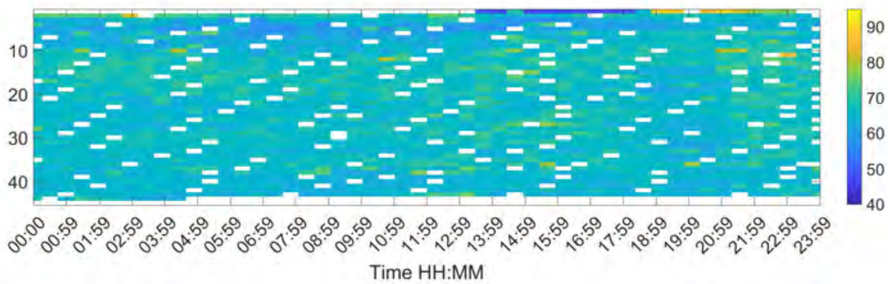

FIGURE 4.27: Map of the L_{eq} values for each day of the second campaign (C2). One value each 30 min.

Figures 4.26 and 4.27 shows a map of L_{eq}. Values below 40 dB corresponds to moments without or with less birds in the Farm. In general L_{eq} do not present variations in age related. Even so, winter campaign has an increase of value measured during daylight, meanwhile in summer this pattern is not found but more peaks of high values are found.

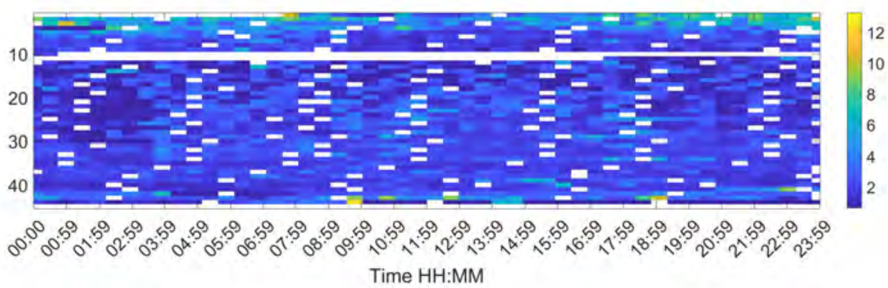

FIGURE 4.28: Map of the L_{eq} variation for each day of the first campaign (C1). One value each 30 min.

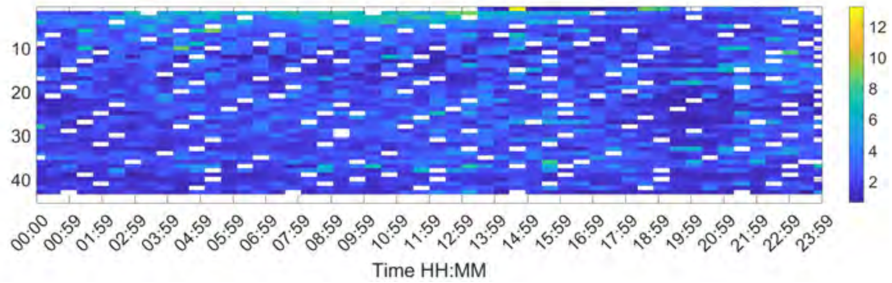

FIGURE 4.29: Map of the L_{eq} variation for each day of the second campaign (C2). One value each 30 min.

Figures 4.28 and 4.29 shows a map of ΔL_{eq}. In both campaigns, the highest variations corresponds to the arrival of the birds. Also can be observed a reduction value the first 20 days. From then on an increase of level variation can be observed during daylight.

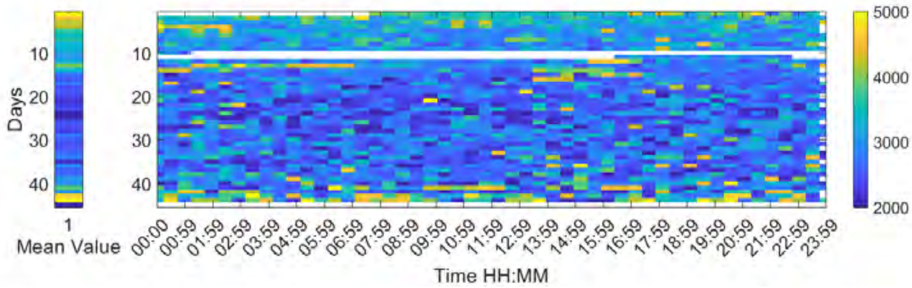

FIGURE 4.30: Map of the PF values for each day of the first campaign (C1). One value each 30 min.

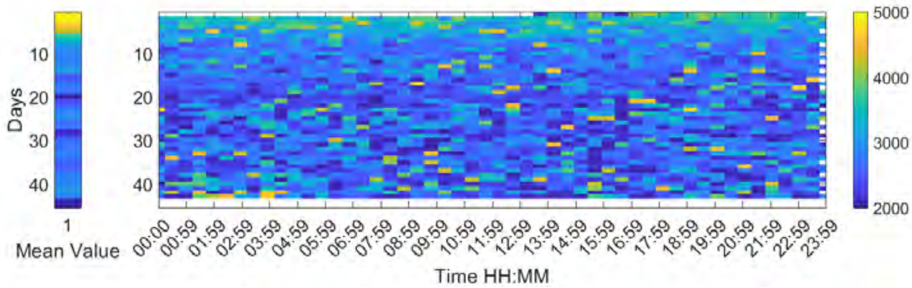

FIGURE 4.31: Map of the PF values for each day of the second campaign (C2). One value each 30 min.

Figures 4.30 and 4.31 show a map of PF where the highest and long-lasting frequency are observed the first days of bird's life. The summer campaign presents more sporadic peak values than the winter one.

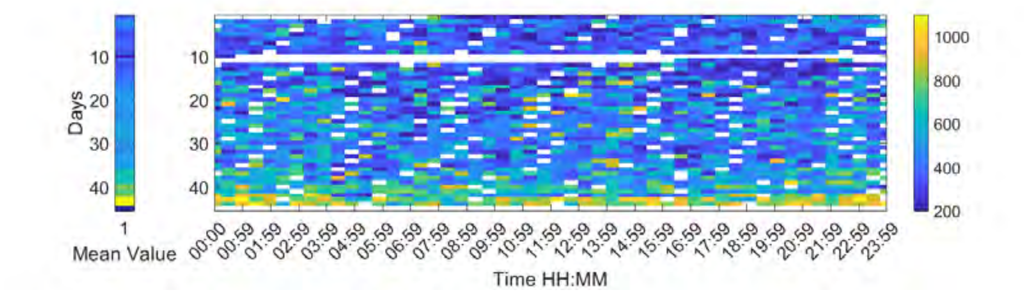

FIGURE 4.32: Map of the PF variation values for each day of the first campaign (C1). One value each 30 min.

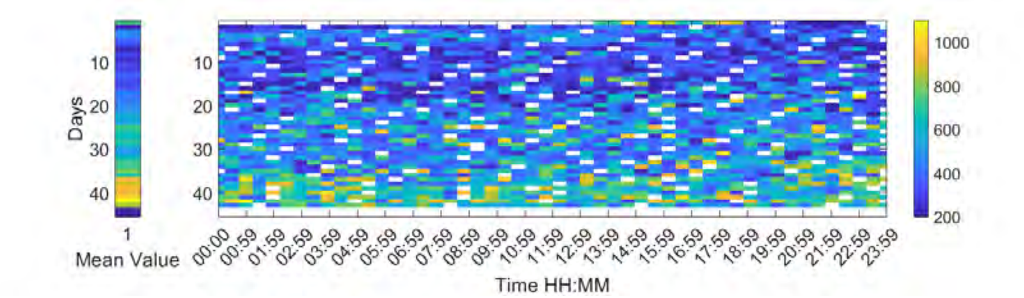

FIGURE 4.33: Map of the PF variation values for each day of the second campaign (C2). One value each 30 min.

Figures 4.32 and 4.33 show a map of the ΔPF. Highest variations are observed in both campaigns at the end of the production cycle (last 5 days) and an increase of PF variation according with the birds age is also a pattern found in both campaigns.

Chapter 5

Discussion

In this work, a relation between farm indicators and acoustical metrics has been investigated. During the acoustic data acquisition the prevailing sound was the birds vocalization, although some machinery sound data was also captured. To reduce and eliminate the undesired sounds, a band pass filter is implemented. The acoustical impact of the machinery increases the L_{eq} and distorts the peak frequency of that acoustic fragment, to avoid the analysis of this sounds as vocalization a manual labelling process has been implemented. The labelling consisted in visual detection of long lasting L_{eq} and then listen to the associated audio to verify if it was generated by any machinery of the farm. For the future this process can be improved with an automatic system. Once the system is trained with the basic noise machine sources of the farm. An automatic detection with a high accuracy rate could ensure that non machinery data is processed afterwords and in a quicker way.

Once we had obtained the audio files with vocalization predominance an analysis in terms of L_{eq} and max frequency (PF) has been performed. After obtaining the acoustic indicators of L_{eq} and PF, an analysis of variation: ΔL_{eq} and ΔPF indicates how evolve and variate the indicators during the same day and between days. The peak frequency varies in function of birds day of life, a decreasing value is related with increasing age, a reduction of more than 1 kHz over the whole cycle.

This observation connected with the biological growth of the birds. When animals grow also increase the thoracic cavity. This enhance reduces the pitch of the animal vocalisation. Furthermore, a variation is detected between light and dark lighting, with increased vocalization variation during darkness, also the L_{eq} is high during light darkness of the farm. Frequency variations indicates variations in pitch calls and could indicate more vocal activity with the animal. Thus, high frequency variation (+600Hz) are more present from week three to five. At this age birds are more active. As a result, frequency could be an indicator of birds days of life.

Farm management practice depends on the following conditions: season of the year, animal performance and the experience of the farmer. Air the farm in winter reduces gases and also introduces cool air inside the house refreshing the ambient, meanwhile in summer ventilation introduces hot air and warm the farm. Farmers adjust the fans and heaters to maximize the production in terms of economical costs and health. In the first week of production animals are more susceptible to illness or sudden death, and they also require high ambient temperature to regulate internal temperature, 80% of death are premature in the first week. High values of farm management, high values of temperature, humidity and CO_2 reduce the vocal activity of the animal. Good farm management is relevant as reducing high values of temperature, humidity and CO_2, increases the birds acoustic level. Bad management could lead to heat stress problem to the birds if the temperature index (in Fahrenheit) plus the humidity value sum exceeds 160. In winter, ventilating the farm reduces the CO_2 but it also reduce the temperature of the house as the incoming air is cold. The amount of water kept in the air depends on the temperature, the higher the temperature, the higher the humidity.

Birds vocalization represent the activity of the birds and also indicate distress calling caused heat or cold stress, threat, pain, among others. Vocalization can be detected through the peak frequency. An inverse relation has been found between the maximum frequency and food/water intake. The higher the food / water intake, the lower the peak frequency. A low peak frequency could indicate less stress and better welfare of the birds.

The acoustic data compared between two identical campaigns corresponding to winter and summer seasons shows some relevant stability of the acoustic description parameters.

The L_{eq} captured at the arrival of the birds is the highest and long-lasting (around 5 h) period of the analysis and has the same pattern in both campaigns. Meanwhile in winter there is an increase of the metrics during the daylight, the summer season do not show this pattern metric and more peaks are detected without any rule. Studying the variation of ΔL_{eq} it also has the highest and long-lasting variations during the first two days of birds' life. After the 20th day of life, we observe the same pattern between campaigns, a greater increase of ΔL_{eq} during daylight.

The PF captured the first fourth days of life indicates high values of frequency vocalisations in newborns. This days the birds' calls are due to their transport, stress and lack of familiar contact. The PF is in average lower during the winter campaign than in the summer. Also the C2 have more sporadic peaks of high frequencies than in winter. The ΔPF has the major increase the last three days of the production cycle where the birds are bigger in age and volume and more problems of coexistence can appear. There is also a pattern in the variation of PF of both campaigns, where ΔPF increases in function of the age of the animal.

This preliminary comparison results encourage us to study deeply the relationship between the several parameters measured in [75], in order to detail the time-evolution of the several metrics that have shown relevant for the birds well-fare evaluation.

Chapter 6

Conclusion and future work

Nowadays farm indicators (CO_2, food and water consumption, temperature, humidity) are used to monitor animal production and to maximize it, with a special focus on animal welfare. An acoustic recording of a entire production cycle (44 days) of broilers Ross 308 has been performed to include in the metrics the data that the acoustic vocalization of the animals, in terms of level and peak frequency. A special care has been considered to record all the time of the production cycle, to avoid losing any sound coming either from birds or from machinery (or even from humans). This fact is relevant, due to the contribution of this work, which is to evaluate the relationship of the acoustic data with the farm management parameters (food and water intake, temperature, humidity), and also against the traditional indicators of deaths, evolution of the weight of the animals and CO_2 in the environment.

Acoustic data has been captured with a cardioid microphone positioned in the centre of the farm and analysed to obtain the vocalization indicators. Even so, the microphone captured the machinery sounds and according with the objective of analysing the vocalisations without interference of the animals, a post processing algorithm filtering the low and high frequencies over the vocalisation range was the a good practice for clear undesired sounds. All indicators, both acoustical and traditional farm ones, are analysed and compared, and several interesting relations have been found that could enhance the evaluation of the animal welfare.

In this work we have obtained a couple of relevant preliminary conclusions:

In the correlation study: first, a relation between CO_2 and humidity versus L_{eq} shows an increasing of L_{eq} when humidity or CO_2 are lower. High values of CO_2 and humidity reduce the acoustical activity of the birds, these high values generate discomfort of the birds and reduce the animal welfare. Another relationship indicates that the higher the intake of food and water, the less frequency is found in the vocalizations. A reduction in PF, is related with quiet birds. So, animals consume more food and water when they are less stressed.

In the inter season acoustic study the maps of L_{eq}, PF, ΔL_{eq} and ΔPF shows some slight differences that could be used to detect in what season the data is captured and to describe the acoustic variations due to the weather. Even with small variations, the acoustic values follow a similar pattern showing data stability, for instance, PF shows a similar pattern map between C1 and C2, having the second campaign more sporadic peaks in frequency. The stability in data between opposite campaigns will provide a easy algorithm for animal welfare.

Further work will be focused on non-linear dependencies that all the gathered data can contain, after this first approach, using artificial intelligence algorithms. A deep study of the non-linear dependencies between variables will be performed. As we plan in some months to start another campaign in the framework of a new EuroStars project, several other considerations about the data collection and recording campaign design will be taken into account. In addition more comparative of inter seasons recording campaign will be performed to ensure data stability.

Machinery noise in the farm should be exhaustively studied, and for this purpose, the labelling of any farm machine sounds will be conducted on the basis of a recording campaign without animals. Machinery noise can bias the results of the raw acoustic data analysis, and despite it has been considered in this work when it modifies substantially the L_{eq}, mixtures of sounds among bird vocalisations and any mechanical noise should be at least identified.

Another issue to be improved is the number of acoustic sensors deployed in the farm. Multiple microphones enables multi-point recordings for having more spatially mapped levels and a better representation of the acoustic activity. For this new context, we plan to have at least 3 sensors in the same room of the farm in order to have redundancy in terms of acoustic measurements and possible metrics; in this sense, also the granularity of the data of the new environment will change the temporal windows to take into account for the study, and the value chosen of 30 minutes may have to change to a more suitable time frame. Finally, a ISO standard for environmental noise recording will be required to be able to cross-site comparisons. Moreover, the results of this study will be compared to other productions cycles that will be carried on to determinate the stabilization of the findings.

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Appendix A

Articles published by the author

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Article

Acoustic Description of the Soundscape of a Real-Life Intensive Farm and Its Impact on Animal Welfare: A Preliminary Analysis of Farm Sounds and Bird Vocalisations

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Abstract: Poultry meat is the world's primary source of animal protein due to low cost and is widely eaten at a global level. However, intensive production is required to supply the demand although it generates stress to animals and welfare problems, which have to be reduced or eradicated for the better health of birds. In this study, bird welfare is measured by certain indicators: CO_2, temperature, humidity, weight, deaths, food, and water intake. Additionally, we approach an acoustic analysis of bird vocalisations as a possible metric to add to the aforementioned parameters. For this purpose, an acoustic recording and analysis of an entire production cycle of an intensive broiler Ross 308 poultry farm in the Mediterranean area was performed. The acoustic dataset generated was processed to obtain the Equivalent Level (L_{eq}), the mean Peak Frequency (PF), and the PF variation, every 30 min. This acoustical analysis aims to evaluate the relation between traditional indicators (death, weight, and CO_2) as well as acoustical metrics (equivalent level impact (L_{eq}) and Peak Frequency) of a complete intensive production cycle. As a result, relation between CO_2 and humidity versus L_{eq} was found, as well as decreases in vocalisation when the intake of food and water was large.

Keywords: L_{eq}; farm management noise; bird well-fare; stress; vocalisation frequency; poultry farm; weight; food and water intake

1. Introduction

In recent years, genetic selection has been performed over the years to increase the growth rate in the shortest possible time [1] in the context of the poultry meat industry [2]. The demand for poultry food due for its low price and nutritional properties, projects a continuous expansion of the poultry market [3]. This demand for white meat has increasingly led to genetic selection for a fast early growth rate that may provoke the appearance of several spontaneous, idiopathic muscle abnormalities along with an increased susceptibility to stress-induced myopathy [4] in modern chick strains. Causes of mortality related to fast growth are mainly Sudden Death Syndrome [5] and ascites [6]. Nevertheless intensive production is also a source of stress for animals. Some of these factors such as stocking density, environmental deterioration, unsuitable social environments, and thermal stress can be major sources of stress [7]. Moreover routine management practices are stressful for birds [8,9]. An important management practice is the ventilation of poultry houses, as this could influence the gas emissions of birds and the subsequent intensive production of, for example, CO_2, CH_4, or N_2O [10]. Carbon dioxide production CO_2 is used in poultry as a gas meter to determine the ventilation flow of the farm according to the International Commission of Agricultural Engineering [11]. Ventilation renews gas concentrations by reducing pollutant gas levels and increasing the amount of oxygen on the farm. For instance, a low value of CO_2 indicates good ventilation and is a sign of good animal welfare. All such technologies that support a closer attention to the animals, not only for better welfare and health but also for sustainability, are included in the Precision Livestock Farming (PLF) concept. For more details about these new trends that prioritise more attention to animals rather than only watching the numbers, an extensive review by Norton et al. can be found in [12].

The welfare of animals has become an important fact for society in many countries of the world. This fact, together with the automatising of most animal monitoring processes, can support the farmer in the care of animals. Following this idea, bioacoustics studies the biological significance and the characteristics of sounds emitted by living organisms [13], and can be a relevant issue to complement the traditional measurements (CO_2, temperature, etc.) of environmental characteristics in a farm. Threat signals [14], information about feeding [15], or sexual selection [16] are only some examples of the possible applications of this field. More details about the acoustic analysis in the framework of farm management and more precisely, about the acoustic analysis of birds vocalisations are given in the related work.

More particularly, the field of birds is one of the few groups of animals known to exhibit vocal learning, used for communication for territoriality, high density, food/water restriction, heat-cold stress, alarm signalling, among others [17]. The bird song is recorded using a non-invasive method, with the aim of analysing their song and correlating data. Several indicators about bird vocalisations have already been reported with dependencies in literature with birds weight, as a conclusion of their welfare [18]. In this study, we design and analyse the recording campaign of an entire production cycle in a Mediterranean farm during the winter season to obtain acoustic data. This acoustical analysis aims to evaluate the relation between traditional indicators (death, weight, and CO_2), acoustical metrics (equivalent level impact (L_{eq}), Peak Frequency (PF)), and farm management information (food and water intake, temperature, and humidity) of a complete intensive production cycle of around 40,000 Ross 308. All acoustic data recorded will later be processed and analysed, considering other metrics of the farm management. This work is the preliminary analysis for the correlation between all these available parameters about a farm environment and management, and bird growth and vocalisations. In order to model bird welfare in intensive production farms, the wider the available information about the life of the animals, the more accurate the dependencies may be found.

This paper is structured as follows. The related work used as framework of this project is detailed in Section 2. The specification of the farm where the project has been implemented is detailed in Section 3. The acoustical analysis of the recording can be found in Section 3.3. Bird welfare data analysis is detailed in Section 4. Discussion of the key aspects of this work is detailed in Section 5 and the conclusion as well as future work can be found in Section 6.

2. Related Work

In recent years, the welfare of farm animals has become an important issue for societies in many countries of the world. Automating animal monitoring processes, such as acoustic analysis of their vocalisations, can greatly assist farmers in this type of task. Therefore, it is important to review the acoustic analysis of commercial chicken farming.

2.1. Acoustic Analysis of Farm Management

In nature, the vocal sounds produced by different animal species are related to certain functions, such as threat signals (alarm calls to different predators [14]), information about feeding (food-associated calls [15]), or sexual selection [16]. In many species, these sounds can reveal attributes related to the caller's identity, sex, age, reproductive status, or social dominance [19]. Therefore, vocalisation, the active generation of sounds with specific organs, becomes an expression of an internal state of an animal generated spontaneously or motivated by an external event [20]. Many of these vocalisations have a complex structure that includes different acoustic elements and there are many hypotheses related to the adaptive function of how such complexity [21] have developed over years. The study of emotions in animals is related to the evolution of species and consequently to the evolution of animal vocalisations. In terms of arousal, it is likely that vocal correlations with negative mood states such as alarm calls or infant begging calls, emerged earlier during evolution than positive vocalisations. For more information, the reader is referred to [22], which presents a review of the current state of knowledge on vocal correlations of emotions in humans and other mammals.

In recent years, animal welfare has become a very important issue for the scientific community and general public. This generalised demand for greater respect for animals covers multiple areas such as the treatment of domestic animals or those that are kept in zoos, but this request becomes more relevant in all aspects related to farm-raised animals [23,24]. As a consequence, administrations have adopted a series of recommendations and directives to protect farm animals [25], although regulations promoted for each country are directly related to the level of public concern for the welfare of farmed animals. Social demands often influence the programs of political parties and therefore the action of governments. For example, this pressure is much higher in countries like the UK and Germany than others like Spain or Italy [26]. In any case, new initiatives are emerging around supranational organisations that group public and private institutions like the Welfare Quality® Network (www.welfarequality.net), which define four animal welfare principles: Good housing, good feeding, good health, and appropriate behaviour.

Bioacoustics, which is the study of animal sound communication, is performed in farm environments by using recorders capable of automatically recording audio data [27]. Animal welfare monitoring can be substantially improved through an increased use of automated methods and, therefore, one promising area in particular is the use of automated analysis of animal vocalisations. A first step to improving animal welfare is to maintain animals free of pain, injury, or disease. In [28], a literature review includes different types of indicators that allow pain assessment in some mammals, birds, and fish. Vocalisations are included in a set of behavioural indicators along with posture, isolation, lack of appetite, or others. This study concludes that these indicators have the best chances of detecting pain early with a combination of them or even just one. For instance, in main farm mammals (pigs, cattle, or lambs), there are changes in the number and duration of vocalisations, intensity, and spectral characteristics. These kind of vocalisation changes are also observed in hens during the removal of feathers or picking. Other state-of-the-art studies centred in vocalisation of different farm animal species can be found in [20,27]. In this kind of research, it is essential to identify screams due to pain or stressful situations from other sounds [29] and also to know the vocal behaviour of farm animals (cattle [30], pigs [29], and chickens [18]). One of the main current trends in this research field is heading towards the development of farm animal vocalisation classification algorithms, combining different audio parameters with automatic classification systems [31].

2.2. Acoustic Analysis of Bird Vocalisations for Welfare Evaluation

Among the different farm animals, our research is addressed to acoustic analysis in poultry farms. Therefore, we start from the study of information that relates their vocalisations and their relation with welfare. Fontana et al. [18] present a complete study of the young bird vocalisations in an attempt to find some patterns depending on the age (1 day or 5 days of life) and the situation of the chickens (isolated or in group). They found 12 different frequency patterns concluding that the type of vocalisations changes from "call sounds" to "distress calls" as the birds grew. Furthermore, audio samples (spectrograms) of chicken vocalisations have been used to distinguish healthy from infected (infectious bronchitis) birds [32]. Carpentier et al. [33] presents an algorithm to monitor chicken sneezing sounds assuming an environment where there are several noise sources and multiple birds vocalisations. Another issue to take into account is the highly unbalanced nature of the raw acoustic dataset. The algorithm is designed to support in the diagnose of poultry health in farms, especially focused on respiratory diseases, which are a major health problem.

Lee et al. [34] use more acoustic parameters to automatically detect stress in laying hens. Abdel-Kafy et al. [35] found a highly significant negative correlation between the peak frequency of vocalisations and the weight and age of turkeys. Du et al. [36] also address stress in laying hens by means of their vocalisation analysis, with the final goal of assessing their thermal comfort condition. They apply a nine source-filter structure to both temporal and spectral features, and a Support Vector Machine to classify the different animal responses.

De Moura et al. [37] presented a study that correlates the environmental temperature with the behaviour and vocalisation of chicks. They detected changes in the intensity and frequency of their vocalisations when temperature decreases. In this case, chicks try to warm up by gathering and in order to reduce the heat loss of the flock. There are other important sounds apart from vocalisations such as pecking that can be used to monitor the food intake of the chickens [38] by placing a microphone in the feeder instead of a device attached to each animal. This is a key point to achieve a non- invasive system capable of continuous audio measurements.

In a recent work, Herborn et al. [17] present a single acoustic marker that co-varies with a range of physical, behavioural, and emotional welfare concerns. This marker, called by the authors as iceberg indicator is the spectral entropy measured after the clean low frequency sound of machinery. With this acoustic parameter, they showed a linear correlation with the manual distress call count in the first 4 days of placement and therefore were able to predict low weight gain and high mortality for the following days.

In our opinion, there are some interesting approaches that include the use of sound analysis on commercial chicken farming, but there is still a long way to go to achieve a complete and robust system that helps farmers to improve the welfare of chicks. This statement is in line with the conclusions of the review presented by Rowe et al. [39]. They analyse the degree of development of the Precision Livestock Farming (PLF) technology in poultry farming. They conclude that the main goal of PLF development is improving animal welfare over increasing production, although the availability of commercial systems available to farmers is still scarce. With respect to the sensors used in poultry PLF, they found that cameras were used in a large proportion of the studies (42.42%) while the use of microphones was less popular (14.02%). Another review, comprising 57 studies, found that only 8% used sound technology [40]. Therefore, the general trend in PLF is the capture of a lot of data from different kind of sensors that must be processed with big data and internet of things technologies to facilitate the smart management of poultry [41].

3. Materials and Methods

Automated chicken farms allow the continuous monitoring and measurement of the environment affecting poultry production. In this study a farm with the following technical specifications was chosen in order to be able to contrast and compare the data with the metrics of the acoustic animal vocalisations.

3.1. Environment

The acoustic analysis was performed in a Mediterranean farm of the BonArea Agrupa corporation (www.bonarea-agrupa.com) of 42,840 commercial chicken farming during an entire Ross 308 production cycle [42], which represents a total of 44 days of life. The study was held in the winter season last January to the beginning of March 2020. The average temperature in the outer farm was between 6 and 15 °C, the humidity close to 0% and a rainfall average of 10% (Meteorological data obtained from on 25 May 2020, https://es.climate-data.org/europe/espana/cataluna/sidamon-662610/).

The farm chosen has almost two identical chicken houses of 20 m × 120 m total size each (see Figure 1), both of which are fully instrumented with the following machinery: (i) Underfloor heating, with hot water production by use of propane gas, (ii) an additional heating system with hot air generators, (iii) forced ventilation by tunnel system, and (iv) a heat exchanger installed in one of the buildings. There is also a sensor network that records CO_2 levels, and the humidity, as well as the inner and outer temperature. The network sensors and some manual rules introduced to the system by the farmer automatise the farm management in terms on activation of ventilation, heating, and light. Food and water supply are also automatised and guaranteed throughout all the production cycle for all birds by means of refilling the containers when the food is scarce. The characteristics of this farm provides a suitable environment for this study. The automation reduces the human factor in farm management and provides data of the environment and productivity factors that can be analysed together with animal vocalisation metrics.

In order to certify the equivalence of the measurements, the sensors were identically installed in each animal house to collect raw data in order to provide redundancy of data, in case one of the measurements presents problems during the recording campaign. One farm was analysed (H1) with a backup for any inconvenience of (H2). The vocalisations of the chickens were recorded throughout the cycle, in order to evaluate the background equivalent level L_{eq} [43] and the frequencies of the vocalisations and their dependencies with other environmental measurements.

Figure 1. Picture of day 21 in H1 house. The birds live with the microphone installation. It is recording continuous raw acoustic data.

3.2. Materials

The goal of the recording campaign was to collect both vocalisations and background noise of commercial chicken farming throughout their life-cycle, in order to evaluate the evolution of the entire production time for further analysis. The vocalisations captured by the microphone are group vocalisations due to the animal density and sensor location. For this reason, single identifications could not be performed. Nevertheless, the purpose of this work is to evaluate the entire animals' welfare, not individual bird tracking.

A professional handheld recorder (Zoom H5) [44] was used, connected to a directional microphone Behringer ultravoice XM1800S with a frequency response of 80–15 kHz and a sensibility of 2.5 mV/Pa [45]. The sounds emitted by birds in each house were recorded with one microphone each, deployed one meter high from the ground and at the centre to the house. Figure 2 shows the acoustic sensor deployment. The location was chosen to avoid chickens interfering with the microphone (biting, singing just next to it, etc.) and also to provide a wide background of sound recordings. The microphone diagram pattern was selected in order to reduce maximum interference of other source sounds, such as machinery due to its cardiod shape. Similar acoustic implementation techniques have been used in other studies [46,47].

The Zoom H5 handheld recorder was configured to record the entire production cycle with as few data stops as possible. Although the recorder stopped when it reached the 32 Gb of data due to the maximum continuous recording storage, in this project setup it takes approximately 6 days to stop. To ensure continuous audio recording after 5 days, the system was stopped for a periodical technical reset. The data was collected from the SD to a hard disk and after a small stop of approximately 15 min the system was reactivated. By default these 5 days were stored in audio pieces of 6.75 h duration for further processing. The recording format was PCM-16 and the sampling rate was set to 44.1 kHz. The post processing analysis required a time reference of each measure to obtain reliable results especially when comparing with other data collected in the farm. For that purpose, each audio was saved with the metadata of the storing time of the file. By the end of the project, the 44 days of chicken vocalisations generated around 400 Gb of data describing the events and welfare of the chickens on the farm.

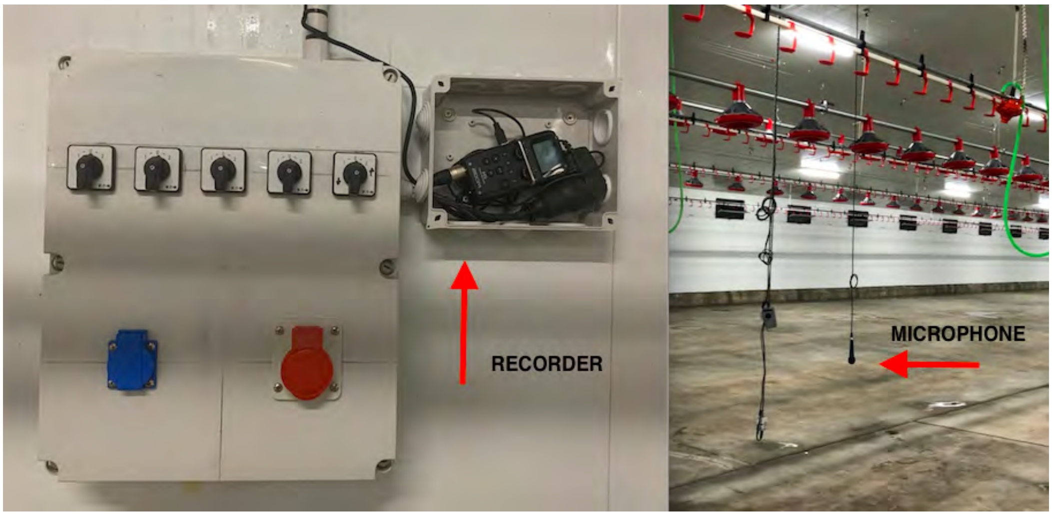

Figure 2. Acoustic equipment deployment in the farm H1. On the left, the recorder location. On the right, the microphone hanging from the ceiling in order to avoid physical interaction with the birds.

The selected farm has a work dynamic where CO_2, temperature, humidity, losses, and weight are measured in each animal production cycle. These 5 data variables were provided by the farm. CO_2, temperature and humidity measurements were carried out every 15 min, the mortality of animals was obtained daily, and the average weight weekly. The CO_2, temperature, and humidity network sensors (see Figure 3) were distributed through the room and all data were collected in a hard disk via a management software for the daily management of the farm.

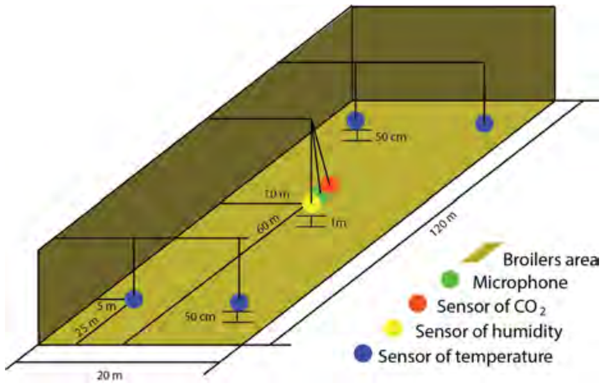

Figure 3. Diagram of the sensors location in the H1 farm, microphone, CO_2 sensor, humidity, and temperature sensor.

The animals' weight and mortality were manually obtained. Birds' weight evaluation has to be representative from all the chicken house. The calculation method uses an electronic scales to weigh $N = 100$ animals and calculate the mean value (see Equation (1)):

$$Weight_{mean} = \frac{1}{N} \sum_{i=1}^{N} BirdsW_i \tag{1}$$

Significant results have to use at least $N = 100$ animals or 1% of the population [48]. For each calculation the digital scale was calibrated and birds were sampled from at least 3 different points of the house. The frequency of weight calculation during the cycle was set weekly as important weights variances were found in periodicity.

Part of the farmer's daily routine is to check around the farm early in the morning. Daily farm inspection enables the farmer to detect possible diseases, supply chain problems, any birds problems, and find and remove dead chickens, which reduces gases generated of the birds decomposition. The farmer documents the number of deaths and the statistically average weight of the animals as data for each production cycle. This information is supplied by the farmer to this study.

3.3. Methods

Recording birds songs is a non-invasive method, that can measure animal acoustic parameters and relate them for example with welfare without modifying their natural behaviour as done in other studies [7–9]. In this study, we want to find a dependency between the acoustic characteristics and the usual indicators of the farm.

3.3.1. Acoustic Metrics Defined to Measure the Raw Acoustic Data

After the production cycle, 44 days of raw acoustic data were obtained. The system was reset 9 times during the entire project and a total amount of 160 files were saved. Each file takes up 2.15 Gb, configured as mono channel sampled at 44.1 kHz and 16 bits has a duration of 6 h 45 min and 46 s. From these 160 files, there are 9 files that were manually reset and therefore have a variable length due to the time of the technician's operation.

The system presented a failure on the 10th and 11th days due to a technical issue other than the known technical stops used to reset the hardware. All the usable data were processed using MATLAB® [49].

L_{eq} in the Farm

The acoustic equivalent level L_{eq} is defined as a value of the sound pressure level of a continuous, steady sound that, within a specified time interval, has the same mean square sound pressure as a sound under consideration whose level varies with time [50,51]. As Equation (2) states, it is a logarithmic measurement:

$$L_{eq} = 10log\left(\frac{1}{T}\int_0^T \frac{P_i(t)^2}{P_{ref}^2}dt\right) \tag{2}$$

In this study the time interval chosen for the L_{eq} is 30 min. This interval has been decided in order to obtain the same resolution as the two CO_2 samples, as well as for computational reasons in this stage of the project. These acoustic feature indicates the intensity of the sound averaged in 30 min according to a sound pressure of reference. As most of the recorded and analysed sounds are birds vocalisations, it depicts the intensity animals singing.

The microphone was not been calibrated for this project for the following reasons: (i) the handheld recorder is designed for audio recording not as a measurement instrumentation, (ii) the recorder can not fine-tune the sensibility of the microphone, and (iii) the cardioid microphone used is a commercial voice microphone, not a Class 1 microphone, as those microphones have an unidirectional pattern non desired for the project requirements. Likewise the L_{eq} measurements in this study aim to evaluate equivalent level variations, not requiring a high accuracy measurement as in a Class 1 device.

Peak Frequency During the Recording Campaign

There are almost 12 different chicken vocalisations identified in the literature that have a different spectral pattern [18]. Statistical analysis showed a significant correlation ($p < 0.001$) between the frequency of vocalisation and the age of the birds [18]. Birds peak frequencies vocalisation range between 2.7–4.3 kHz. According to the results of this study, it was found that the main frequency of the sounds emitted by birds is inversely proportional to their age and weight, specifically, the more they grew, the lower the frequency of the sounds made by the birds.

In the present study, the spectral bandwidth acquired is limited by the recorder configuration to 22.05 kHz, due to the sampling frequency at 44.10 kHz. To avoid interference of other sounds sources (machinery, people talking, etc.), raw audio data is filtered using a bandpass filter with a response of 2 to 5 kHz, reducing potential interference noise at frequencies other than those generated by animals.

To obtain the peak frequency, the following algorithm is applied (see the equivalent block diagram in Figure 4):

1. Data is segmented using Hamming windows of 4 min [52] and overlap of 40% between consecutive windows;
2. Data is filtered using a band pass filter from 2 to 5 kHz;
3. A FFT (Fast Fourier Transform) algorithm of 1024 points is applied [53];
4. The maximum value of the window is extracted;
5. Buffering of 30 min;
6. Calculate the mean peak frequency of the 30 min.

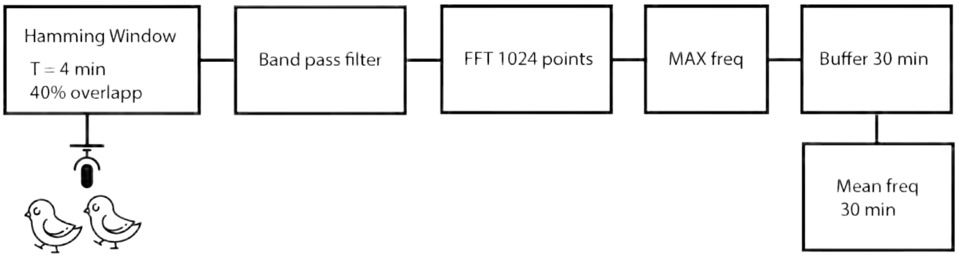

Figure 4. Peak frequency detection algorithm implementation.

Identification of Machinery Sound Data

The acoustical data acquisition method has been specifically designed to capture the birds vocalisations. Unfortunately, some sounds of the fan, feeders, and several bar vibration of the feeders are also recorded. The microphone position (vertical to the ground) and its cardioid pattern (available on datasheet [45]) reduce the influence of acoustic events that do not correspond to vocalisations of the closest animals [54].

This non desired captured events are easy to identify and also to exclude from the analysis. Figure 5 shows a sample of average L_{eq} values over 24 h. In this sequence, the machinery sound datum is identified as the sound that stand out for a high and long-lasting equivalent level. The non desired event is highlighted in red and corresponds to the sound of airborne feed in the supply chain.

The acoustic profile is studied in more detail in terms of L_{eq} and frequency variations. The maximum frequency is found between 4–4.5 kHz with variations of more than 1 kHz. Meanwhile, terms of L_{eq} the range corresponds from 60 to 80 dB with small variations (±2.5 dB).

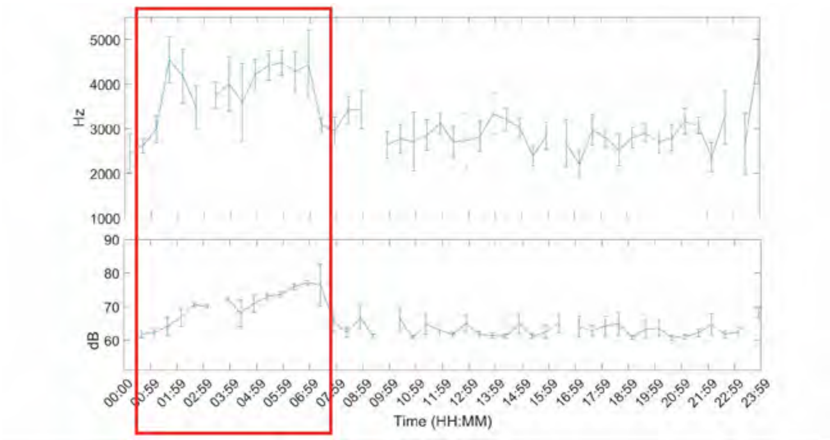

Figure 5. Temporal L_{eq} sample in which the increase due to machinery is clearly identificable. In the horizontal axis we find the time and in the vertical axis the frequency (**top**) and the L_{eq} (**bottom**).

3.3.2. Evaluation of the Acoustic Raw Data

Analysing the $L_{eq30\text{min}}$ and maximum frequency each 30 min over the entire production cycle show the evolution of the sound pressure, and highest frequency generated by the birds according to their life expectancy. Figures 6–8 reflect this study. The white cells representing data are missing files, that could not been computed due to the hardware limitation of the processing unit of the acquisition system.

Figure 6 shows the sound pressure evolution generated by the birds in a complete production cycle. There were 42,840 animals until day 33, when the density of animals is reduced. Therefore, during the last days of their life cycle, there were less chickens in the house and as a consequence, sound pressure was reduced.

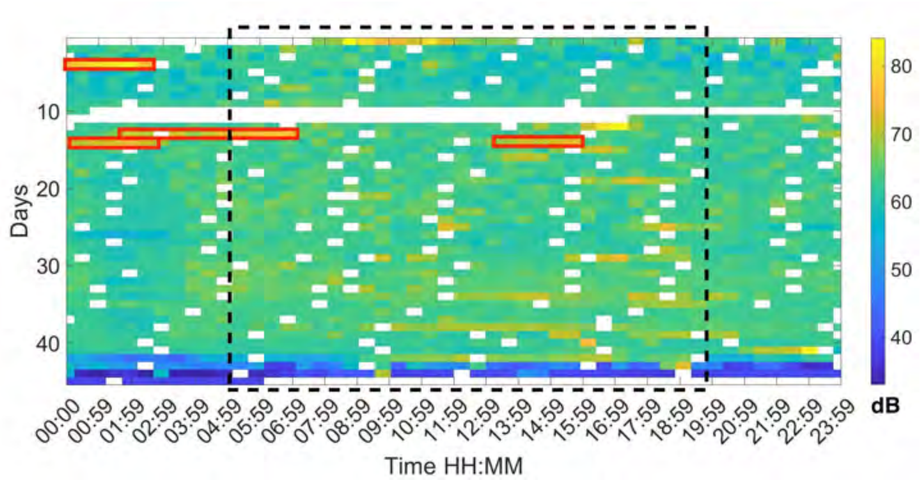

Figure 6. Map of the L_{eq} at 30 min intervals during the 44 days of a complete production cycle. The red rectangles correspond to the areas where there is a high L_{eq} measurement due to machinery.

As shown in Figure 6 there is no age-related increase in the level of pressure of chickens as the mean level is not increased with time. From five in the morning until nine in the evening coinciding with the period of more activity we can appreciate an increase in L_{eq} of more than 7 dB. The temporal area with more activity is highlighted in a black discontinued rectangle. We highlighted with red rectangles some periods that present a high acoustic level due to the machinery identification. A careful analysis of these segments, louder and clearer vocalisations can be heard from the chickens closest to the microphone.

However, Figure 7 firmly shows an age-related decrease in peak frequency throughout the whole production cycle. Otherwise there is not a relevant variation on a daily basis. The frequency obtained on the first and last day of life of animals is higher with respect to the average values of those days. High-stress moments reflect an increase in the frequency of vocalisation in the data.

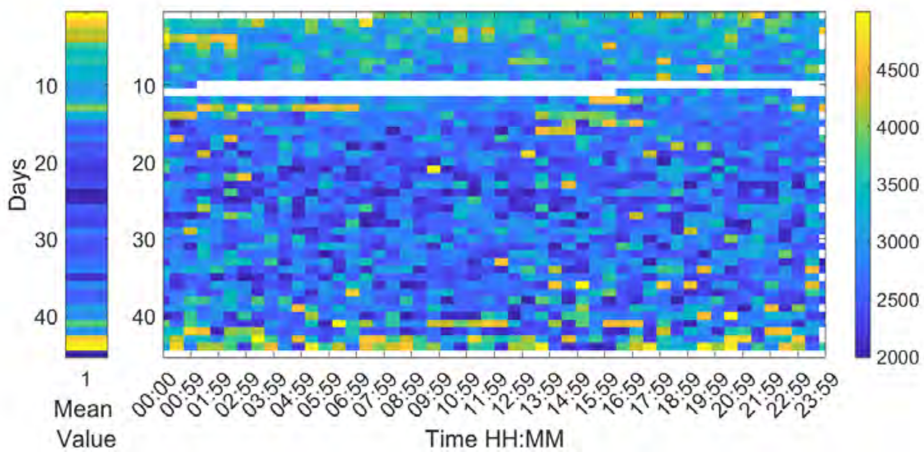

Figure 7. Map of the maximum frequency at 30 min intervals during the 44 days of a complete production cycle. The horizontal axis shows the hours of the day and night, and the vertical axis shows the days of the cycle.

Apart from the mean value of the peak frequency, it is also relevant to measure its variance with the further intention of detecting possible correlations with other parameters being evaluated. Each 30 min segment of data has been processed in 4 min windows and the variance of the peak frequency has been calculated (see Figure 8). In general, an age-related increase is observed, as well as an increase during the night with respect to the day. However, picking up the birds at the end of production shows the highest frequency variations of all samples.

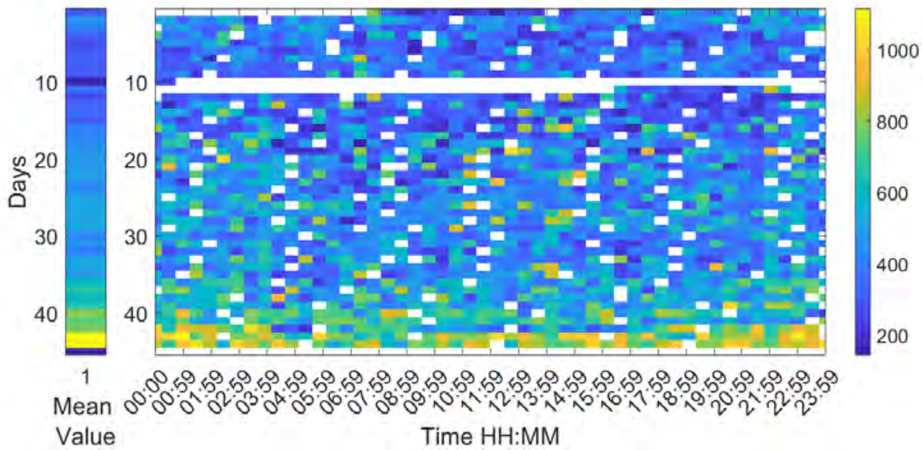

Figure 8. Map of the variance in frequency at 30 min intervals during the 44 days of a complete production cycle. The horizontal axis shows the hours of the day and night, and the vertical axis shows the days of the cycle.

4. Experiments and Results

This section describes the traditional data farm indicators of a production cycle: Temperature, humidity, weight, CO_2, food, and water intake. All traditional data were obtained on a regular basis as indicators that help the farmer during the production cycle. These data were provided by the farmer.

This study analyses the acoustical data with the farm management data: L_{eq} and max frequency, with the traditional data. Some relevant relations of this two blocks of data that have been found in this analysis are: (i) Correlation between the maximum frequency of vocalisation versus food and water intake, (ii) CO_2 versus L_{eq}, and (iii) humidity versus L_{eq}. Direct relations between variables within the same group have also been identified. This sections detail all relevant similarities found in the cross-data study.

4.1. Farm Management Data

Data shown in this section: CO_2, temperature, humidity, weight, deaths count, food, and water intake has been provided by the farm manager and extracted from the farm's automated control system. Traditional data values indicates a good production cycle to be analysed and studied as a standard uncomplicated breeding.

Figure 9 shows the evolution of the CO_2. Carbon dioxide CO_2 is exhaled by the chickens, the release of manure, and the gas-fired combustion. An increase in this gas is observed when the manure is moved.

A high concentration of CO_2 at the beginning of breeding corresponds to the need to maintain an indoor temperature of 32 °C during the first 5 days of life of the chickens and 30 °C between 5 to 10 days, so the ventilation rate should be low in order to optimise the indoor temperature, an effect that is more pronounced in colder months.

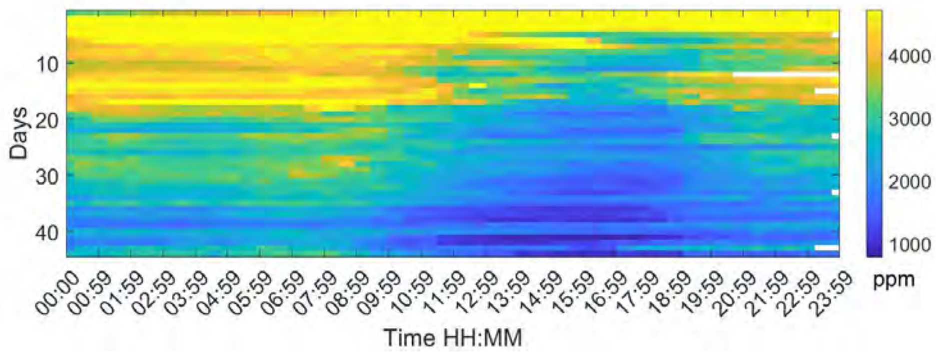

Figure 9. Map of the mean CO_2 values for each day of the campaign. The horizontal axis shows the hours of the day and night, displaying a value every 30 min, and the vertical axis shows the days of the cycle.

Higher concentrations of CO_2 are detected as from day 10 from eight in the evening to ten in the morning reducing the gas concentration to 3000 ppm due to the ventilation. Day 20 of life onward show the highest reduction. Ventilation patterns reduce the concentration of gases. The manure movements are performed during the morning by the farmer and also reflect the increase of gas concentration in that time slot.

Similar patterns can be observed with the humidity in Figure 10. The highest values are recorded in the first week and it is continuous during the entire day. From day 10 onward a decrease of more than 10% is found between 10 to 18 h, evolving the window of humidity the last days of the cycle with two more hours of lower humidity measurement.

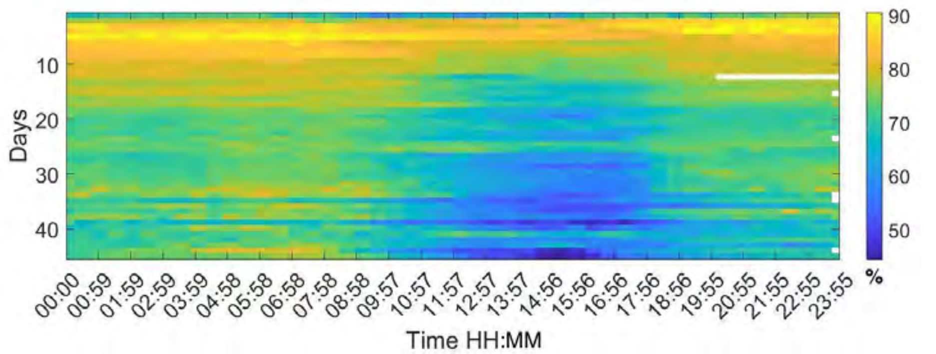

Figure 10. Map of the humidity values for each day of the campaign. The horizontal axis shows the hours of the day and night, displaying a value every 30 min, and the vertical axis shows the days of the cycle.

Otherwise, temperature has a different pattern shown in Figure 11. Young birds have little ability to regulate their internal temperature and they need heat, at a temperature of approximately 32 °C at their first week of life and the farm provides it externally. Temperature onward is slowly reduced until day 25 when a peak in temperature is reached (from seven to eight). Since day 30, temperature is lowered and homogeneous during the rest of the day.

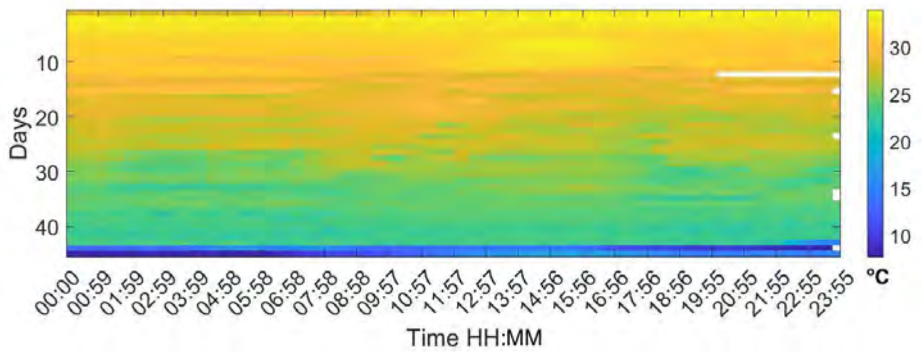

Figure 11. Map of the temperature values for each day of the campaign. The horizontal axis shows the hours of the day and night, displaying a value every 30 min, and the vertical axis shows the days of the cycle.

Animal death count is shown in Figure 12, where in the first week birds have the highest mortality by premature death, although it decreases in an almost exponential manner. Starting the second week, the number of deaths per day is sporadic. From the second week and onwards two more local maximums are found in day 17 and 37.

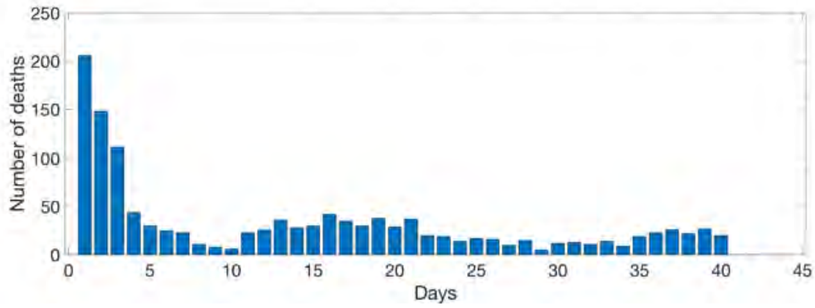

Figure 12. Evolution of the animal death count per day. Data evaluated daily by the farm management.

Animal weight average measurements are shown in Table 1. Birds weights are variant between animals, the average weight values represents the total of animals. The mean value is calculated using 100 birds. This process requires time and is only performed once per week.

Table 1. Average birds weight, measured in kg. The birds are weighted once per week, and the given value is the result of the average for several birds. Information collected from the farm management system.

Week Cycle	Mean (kg)
week 1	0.047
week 2	0.153
week 3	0.410
week 4	0.853
week 5	1.397

Figure 13 shows the mean food intake per bird each day. Reduction of the intake is found in the last 3 days due to the manual reduction of animals in a farm, which is not reflected in the system. A linear growth behaviour can be observed until day 31 when maximum food production is reached, food consumption, obtained a peak value of around 150 g. From day 33 to 38 food intake stabilised to 140 g.

A similar pattern can be observed in Figure 14. The graph shows the mean water intake per bird each day. The last 3 days reflect the animal reduction as seen in Figure 13. The growing linear model lasts until day 33 with the maximum bird water intake in day 33, to days later compared with food intake in Figure 13. Then the water consumption stabilised to 230 mL until day 39.

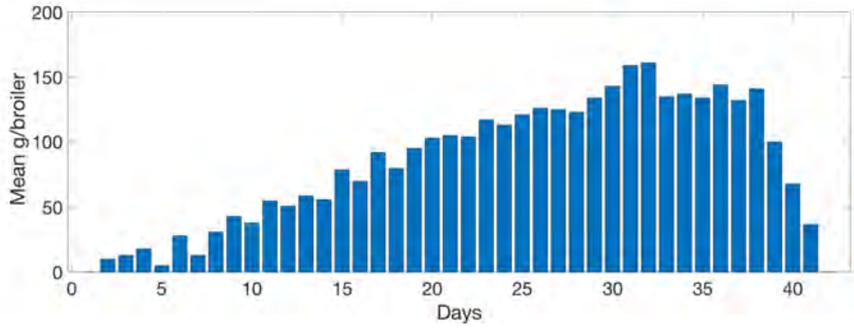

Figure 13. Evolution of the mean food intake per day by the birds. Data collected daily by the farm management.

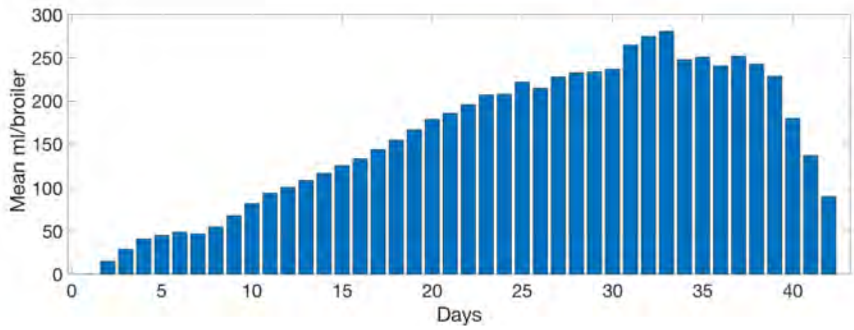

Figure 14. Evolution of the mean water intake per day by the birds. Data collected daily by the farm management.

4.2. Evaluation of the Correlation between Acoustic Data and Welfare Information

Circular correlation is calculated as [55] describes. Let $y(k)$ and $x(k)$ be N-point signals, and let $x_p(k)$ be the periodic extension of $x(k)$. The circular cross-correlation of $y(k)$ with $x(k)$ is denoted $c_{yx}(k)$ and defined in Equation (3):

$$c_{yx}(k) \triangleq \frac{1}{N} \sum_{i=0}^{N-1} y(i) x_p(i-k), \ \ 0 \leq k < N \tag{3}$$

This study computed all the correlations between traditional and acoustical data. Significant results are shown from Figures 15–22. And a detailed list of the non clear correlation is also provided.

In Figure 15 we observe a clear correlation between CO_2 and humidity, and the maximum values for all the days fall nearly in the centre of the circular correlation, which leads us to infer that they are two measured parameters in the farm that present similarities in their performance. This means that when the levels of the CO_2 are greater, so is the humidity. A certain time delay was recorded on a number of days, this variation of maximum 5 h, where the humidity is delayed in its performance in comparison with CO_2. Carbon dioxide is produced by the exhalation of the animals, so the greater the exhalation larger the contribution of humidity. When the ventilation is switched on, the CO_2 and the humidity are reduced in the building.

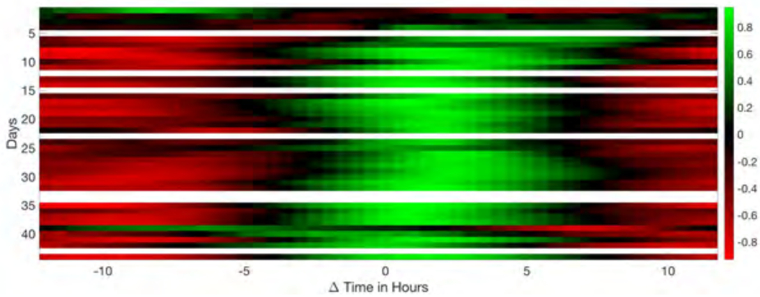

Figure 15. Results of the circular correlation CO_2—humidity. Horizontal axis corresponds to the $\Delta Time$ measured in hours, evaluating the delay between CO_2 and humidity. Vertical axis stands for the days of the cycle.

In Figure 16 we can observe a correlation between CO_2 and temperature, in this case there is an inverse dependency. CO_2 is in advance of the temperature, when CO_2 increases the value, in a delay between 5 and 10 h, the temperature decreases. Outer temperature is considerably low, henceforth air flow injected to the farm is cold. After ventilation is reduced and the CO_2 falls, its CO_2 value after a few hours the temperature rises again.

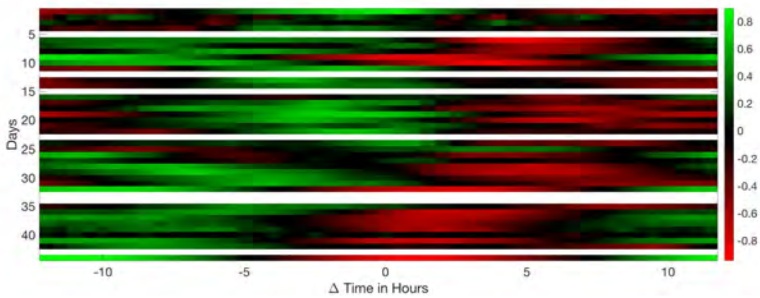

Figure 16. Results of the circular correlation CO_2—temperature. Horizontal axis corresponds to the $\Delta Time$ measured in hours, evaluating the delay between CO_2 and temperature. Vertical axis stands for the days of the cycle.

Figure 17 show a slight inverse similarity of the CO_2 referenced to the equivalent level L_{eq}, with a different performance for the entire production cycle. When CO_2 is at a maximum, the sound of birds vocalisation is minimum and in reverse. More vocalisation is an indicator of bird activity and increases the L_{eq}. Therefore when the CO_2 is reduced, the vocal activity increases.

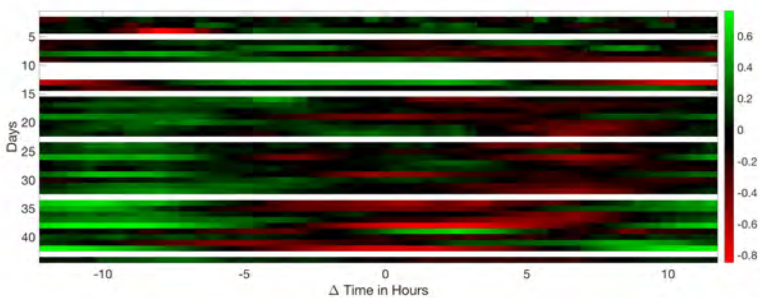

Figure 17. Results of the circular correlation CO_2—L_{eq}. Horizontal axis corresponds to the $\Delta Time$ measured in hours, evaluating the delay between CO_2 and L_{eq}. Vertical axis stands for the days of the cycle.

A similar pattern can be seen in Figure 18, an inverse correlation is detected between humidity and the L_{eq}. The lower the humidity, the higher the sound level generated by the animals. Too much moisture in the chicken house contributes to the clamping of the bed and to ammonia problems. The animals are more vocally active when humidity values decreases.

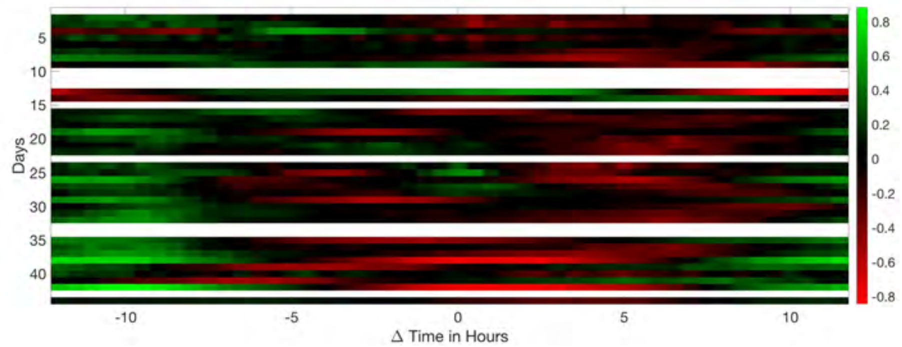

Figure 18. Results of the circular correlation humidity—L_{eq}. Horizontal axis corresponds to the $\Delta Time$ measured in hours, evaluating the delay between humidity and L_{eq}. Vertical axis stands for the days of the cycle.

Figure 19 shows a clearly inverse dependency between temperature and humidity. When temperature is at its maximum, the humidity is at its and vice-versa. As the air temperature rises, the amount of water that a given amount of air is able to retain increases. A 10 °C rise in temperature results in an approximate increase in air temperature halves the relative humidity.

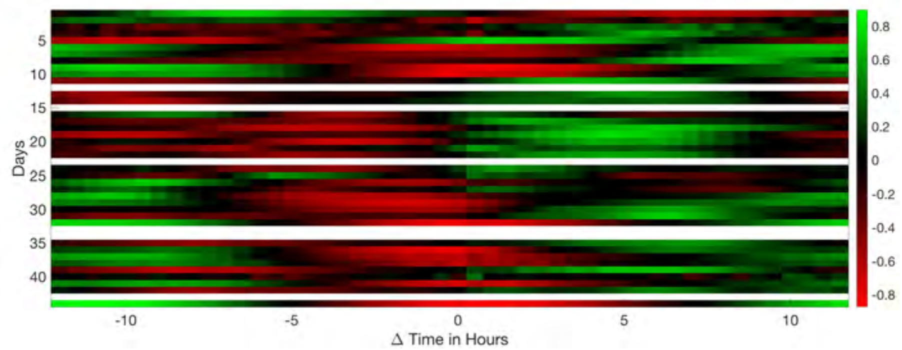

Figure 19. Results of the circular correlation temperature—humidity. Horizontal axis corresponds to the $\Delta Time$ measured in hours, evaluating the delay between temperature and humidity. Vertical axis stands for the days of the cycle.

Figure 20 shows an inverse relation between food intake and the mean max frequency vocalised by birds per day. When food intake is at a maximum, frequency is minimum. Max frequency is delayed two days from food. High frequency indicates high-pitched vocalisations that are related to stress, so they eat more when they are more relaxed.

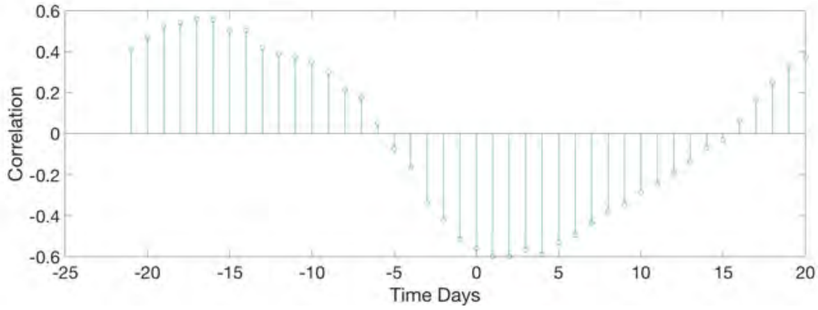

Figure 20. Results of the circular correlation food—max freq. Horizontal axis corresponds to the time (in days), evaluating the delay between the food intake and the maximum frequency detected.

Figure 21 follows a similar pattern as with the food consumption (Figure 20) an inverse relation between water intake and the mean maximum frequency vocalised by animals per day. When food intake is maximum, frequency is minimum. Maximum frequency is delayed by 2 days with respect to the water max values intake.

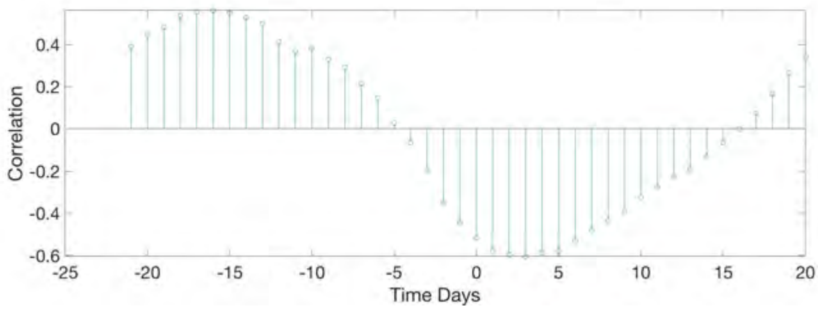

Figure 21. Results of the circular correlation water—max freq. Horizontal axis corresponds to the time (in days), evaluating the delay between the water intake and the maximum frequency detected.

Figure 22 shows a correlation that does not depend on acoustic parameters but on the normal operation of the farm. It was an expected result, but noteworthy. Data indicates a direct dependency between food and weight with a significant correlation value. When food intake increases it also does the weight. Although weight is delayed 3 days with respect to the food intake values. This correlation corroborates the food-weight dependencies seen in the literature, transforming cereal protein to animal protein.

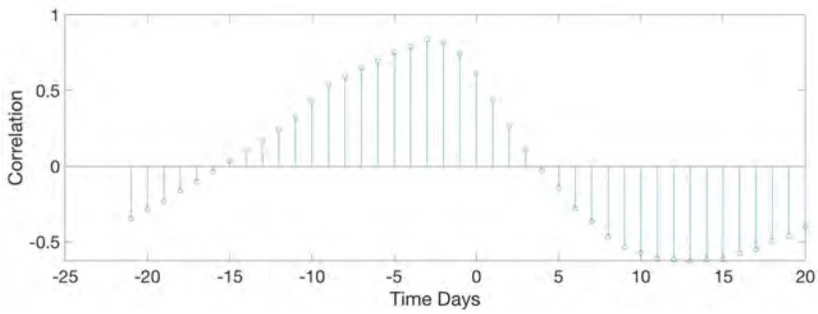

Figure 22. Results of the circular correlation food—weight. Horizontal axis corresponds to the time (in days), evaluating the delay between the food intake and the mean weight of the birds.

5. Discussion

In this work, a relation between farm indicators and acoustical metrics has been investigated. During the acoustic data acquisition the prevailing sound was the birds' vocalisation, although some machinery sound data was also captured. The acoustical impact of the machinery increases the L_{eq} and distorts the peak frequency of that acoustic fragment, therefore to avoid the analysis of this sounds as vocalisation a manual labelling process was implemented. For future, an automatic system could be implemented for a better and quick detection of the machinery sounds, especially with a previous training with the basic noise corresponding to the mechanics of the farm.

Once we had obtained the audio files with vocalisation predominance an analysis in terms of L_{eq} and max frequency was performed. The peak frequency varies in function of birds day of life, a decreasing value is related with increasing age, a reduction of more than 1 kHz over the whole cycle. Furthermore, a variation is detected between light and dark lighting, with increased vocalisation during darkness. Frequency could be an indicator of birds days of life. The L_{eq} is high during the light darkness of the farm.

Farm management practice depends on the following conditions: Season of the year, animal performance and the experience of the farmer. Air in the farm in winter reduces gases and also introduces cool air inside the house refreshing the ambient, meanwhile in summer ventilation introduces hot air and warms the farm. Farmers adjust the fans and heaters to maximise production in terms of economical costs and health. In the first week of production, animals are more susceptible to illness or sudden death, and they also require high ambient temperature to regulate internal temperature, 80% of death are premature in the first week. High values of farm management, high values of temperature, humidity, and CO_2 reduces the vocal activity of the animal. Good farm management is relevant as reducing high values of temperature, humidity and CO_2, increases the birds acoustic level. Bad management could lead to heat stress problem to the birds if the temperature index (in Fahrenheit) plus the humidity value sum exceeds 160. In winter, ventilating the farm reduces the CO_2 but it also reduce the temperature of the house as the incoming air is cold. The amount of water kept in the air depends on the temperature, the higher the temperature, the higher the humidity.

Bird vocalisation represents the activity of the birds and also indicates distress calling caused by heat or cold stress, threat, pain, among others. Vocalisation can be detected through the peak frequency. An inverse relation has been found between the maximum frequency and food/water intake. The higher the food/water intake, the lower the peak frequency. A low peak frequency could indicate less stress and better welfare of the birds.

6. Conclusions and Future Work

Nowadays farm indicators (CO_2, food, and water consumption, temperature, humidity) are used to monitor animal production and to maximise it, with a special focus on animal welfare. An acoustic recording of an entire production cycle (44 days) of broilers Ross 308 was performed to include in the metrics the data of animal acoustic vocalisation in terms of level and peak frequency. Special care has been considered to record the entirety of the production cycle so as to avoid losing any sound coming either from the birds or from machinery (or even from humans). This fact is relevant, due to the contribution of this work, which is to evaluate the relationship of the acoustic data with the farm management parameters (food and water intake, temperature, humidity), and also against the traditional indicators of deaths, evolution of the weight of the animals, and CO_2 in the environment.

Acoustic data was captured with a cardioid microphone positioned in the centre of the farm and analysed to obtain the vocalisation indicators. All indicators, both acoustical and traditional farm ones, were analysed and compared, and several interesting relations were found that could enhance the evaluation of the animal welfare.

In this work we have obtained a couple of relevant preliminary conclusions. First, a relation between CO_2 and humidity versus L_{eq} shows an increasing of L_{eq} when humidity or CO_2 are lower. High values of CO_2 and humidity reduce the acoustical activity of the birds, these high values generate discomfort of the birds and reduce animal welfare. Another relationship indicates that the higher the intake of food and water, the less frequency was found in the vocalisations A reduction in PF was related with quiet birds. Thus, animals consume more food and water when they are less stressed.

Further work will be focused on non-linear dependencies that all the gathered data can contain, after this first approach, using artificial intelligence algorithms. A deep study of the non-linear dependencies between variables will be performed. As we plan in some months to start another campaign in the framework of a new EuroStars project, several other considerations about the data collection and recording campaign design will be taken into account. Machinery noise in the farm should be exhaustively studied, and for this purpose, the labelling of any farm machine sounds will be conducted on the basis of a recording campaign without animals. Machinery noise can bias the results of the raw acoustic data analysis, and despite it being considered in this work when it modifies substantially the L_{eq}, mixtures of sounds among bird vocalisations and any mechanical noise should be at least identified.

Another issue to be improved upon is the number of acoustic sensors deployed in the farm. Multiple microphones enables multi-point recordings for having more spatially mapped levels and a better representation of the acoustic activity. For this new context, we plan to have at least three sensors in the same room of the farm in order to have redundancy in terms of acoustic measurements and possible metrics. In this sense, also the granularity of the data of the new environment will change the temporal windows to take into account for the study and the value chosen of 30 min may have to change to a more suitable time frame. Finally, an ISO standard for environmental noise recording will be required to be able to cross-site comparisons. Moreover, the results of this study will be compared to other productions cycles that will be carried on to determinate the stabilisation of the findings.

Author Contributions: G.J.G.-P. led the field work collecting the audio data, labelling, processing the dataset, and participated in writing the entire paper. R.M.A.-P. and I.I.S. supported the signal processing section and participated in writing and reviewing the entire paper. T.P.M. supported the field work and reviewing the entire paper. M.C.P. suggested part of the study and reviewed the paper. All authors have read and agreed to the published version of the manuscript.

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Abbreviations

The following abbreviations are used in this manuscript:

FFT	Fast Fourier Transform
L_{eq}	Equivalent pressure level
CO_2	Carbon dioxide
ppm	Parts per million
PCM	Pulse Code Modulation
SD	Secure Digital
H1	House One
H2	House Two
PF	Peak Frequency
MAX	Maximum
Eq	Equation

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Appendix B

Conferences published by the author

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Preliminary Acoustic Analysis of Farm Management Noise and Its Impact on Broiler Welfare †

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Abstract: Farm management practices done by machinery generate a high acoustical impact on animals. The acoustic variations in terms of equivalent level (L_{eq}) and the different types of noise can affect the well-being of broilers by means of reducing the food and water ingest. In this work, we create a dataset in which we conduct a preliminary analysis of the acoustical impact generated by the farm management in an intensive broiler poultry farm of 25,000 birds. The project collects acoustic data during the first two weeks of the birds life, focusing the study on the first week. To create the dataset, we randomly select some files from each day of the study and they are analysed and labelled manually using an audio analysis software. The acoustical events defined in collaboration with the farmer and vet are the fan and the food and water supply, and definitions are based on duration, impact, and Signal to Noise Ratio (SNR). The analysis concludes that the main acoustical source in a broilers' farm is the fan, and that it has a non-negligible acoustical impact. Nevertheless, the most frequent acoustical noise source active is food supply, but with less L_{eq} impact.

Keywords: acoustic impact; L_{eq}; farm management noise; broiler well-fare; poultry farm

1. Introduction

The food demand is projected to double over the next 50 years [1]. The increase in the demand of poultry meat over the past decade has been due to the low cost, the positive nutritional profiles, and the suitability in farming [2]. Intensive production is required to achieve the demand, and poultry health should be approached in a multidisciplinary way to ensure animal health [3]. According to OIE, an animal is in a good state of welfare if it is healthy, comfortable, well nourished, safe, and able to express innate behaviour, and if it is not suffering from unpleasant states such as pain, fear, and distress [4]. Certain routine management practices are stressful to birds [5], and they result in economic costs that cannot be ignored [6]. However, conventional methods for the quantification of stress are not suitable as they allow for detection only after the animals have been negatively affected [6].

In this first approach, we design the recording campaign in a farm, taking into account the several sounds caused by the machinery. The farm noise is recorded, accurately labeled, and processed using a non-invasive method, with the goal of analyzing the impact of several mechanization sounds in the farm on the background noise. Afterwards, we evaluate the number of occurrences, the duration of each sound, and the signal-to-noise ratio (SNR), as well as the acoustic equivalent level impact (L_{eq}). In this sense, in the field of bioacoustics, some technology has been designed to improve poultry welfare. For more details, the reader is referred to [7].

This paper is structured as follows. The method and materials required to obtain the dataset and the corresponding process are detailed in Section 2. The database generation and the acoustic features used in this work are detailed in Sections 3 and 4, respectively. The discussion of the key aspects of this first approach is detailed in Section 5, and the conclusion and future work can be found in Section 6.

2. Materials and Methods

The preliminary acoustic analysis has been performed on a Mediterranean farm of 25,000 broilers during their first 9 days of life. The sounds emitted by the broilers and the farm machinery were recorded one meter away from the animals with one low cost microphone connected to a Raspberry Pi (3B) [8]. The design of the hardware of the project is inspired by [9], with a special focus on the flexibility and adaptability of the model, as well as its capability of recording long audio sequences. The recording was made using a Python script coded with the open source library PyAudio available on [10]. The code recorded streams in a non-compression file system (wav) of 30 min continuously during the whole experiment using a 16 bit Digital-to-Analog Converter (DAC) and a 44,100 KHz sampling rate. The file generated was tagged with the day and time of the recording.

The identification of sound was done by listening to the file and observing the time-amplitude, spectrum, and the L_{eq1s} graph with Audacity, which is an open source program available on [11]. Acoustic evaluation and the L_{eq1s} graph was executed with the labeled audio segments with Matlab, a program available on [12].

3. Farm Management Sound Database Generation

Poultry intensification requires the use of machinery to improve the efficiency of farm management, but it generates a moderate to high impact in the L_{eq} of the environmental noise. A dataset of all the noise generated by the farm mechanical equipment found in this first nine days of observation has been generated. It is important to analyze the sound properties and the possible impact of all types of noise, the SNR, the duration, and the occurrences on the animals.

3.1. Data Labeling

The raw sound recorded by the microphone consists of acoustic events, some of which are complex to identify. The knowledge of a farmer and a vet have been required to correctly label the sound of the fan, the feeders, the drinkers ,and the sound vibrations of the bar of the feeders.

A manual labeling process has been conducted over 45 audio files, which corresponds to 22.5 hours of audio, labeled using up to 125 labels. The labeling method was not exhaustive over all the collected data, because the aim of this first approach was focused on analyzing the several different events occurring due to the farm management noise. The labeling was conducted with the goal of finding the types of events described by the farmer; nevertheless, once a file was labeled, all the events were labeled with their proper name. The reader is referred to [13] for more details on the data labelling.

Figure 1 shows an example of the labeling process. Audacity [11] shows a time-amplitude and spectrum graph, and a Matlab [11] figure presents the equivalent level of the same audio segment. The Spectrum view clearly identifies the fan, the bar vibration, and the water class due to the frequency distribution of the noise. The L_{eq1s} is important to identify the beginning and ending of each label. Food noise is identified by the impulse at the start and end of the time-amplitude and L_{eq1s} graph, as there is no clear spectrum identification. The process of listening is a crucial stage before labeling to ensure that the audio corresponds to the visual identification of the class.

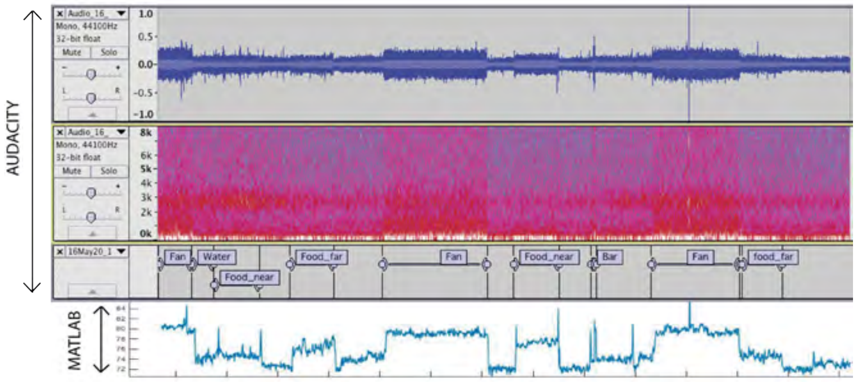

Figure 1. Capture of the data labeling process using Audacity [11] and Matlab [12]. A time-amplitude, spectrum, and L_{eq1s} graph is required to identify the classes.

3.2. Data Classes Defined

Five classes have been clearly identified apart from the background noise according to the farmer indications. The fans, feeders, drinkers, and lights are activated and disabled automatically depending on the farmer's rules introduced in the smart system, depending on the temperature, the humidity, and the hours of rest, among others. After the examination of several samples of feeder noise, it was observed that acoustic levels vary in the function of the location of the sound source in two blocks, so there was a split between two classes.

Data labeled is classified as follows: "Fan," generated by the blower blades and motors; "Food close," generated by the food load of the feeder near the microphone; "Food far," generated by the food load of the feeder far from the microphone; "Water," generated by the water load of the drinker; "Bar vibration," the Structural vibration of the bar of the feeder captured where the microphone is held. The list of classes in the function of the number of files segmented and the duration of the samples of each category are shown in Table 1.

Table 1. Audio samples obtained after segmentation.

Class	Number of Samples	Total Duration (min)
Fan	30	154.05
Food close	38	39.1
Food far	39	27.03
Water	15	32.69
Bar vibration	3	9.85
Total	125	262.72

4. Acoustic Para Evaluations

Three parameters were taken into account to describe each event. The first parameter describes how persistent the noise is in terms of duration. The second metric is based on calculating the SNR. The resultant value indicates the ratio of the power of the event to the power of the background saliency.

The last metric determines the impact of the event on the equivalent L_{eq} noise level. The calculation of each feature is described below, and the reader is referred to [14] for more details.

4.1. Duration Measurement

The duration of the event is calculated as the difference between the starting temporal stamp and the ending one. The duration of the event depends on the typology of the sound and the conditions of the farm as the machinery is activated automatically.

4.2. SNR Calculation

The calculation of the SNR is defined considering the event not stationary. The pressure level is calculated with Equation (1) where N is the number of samples, and $x(t)$ is the piece of the segmented audio of the event.

$$P_x = \sum_{t-1}^{N} \left(\frac{x(t)^2}{N} \right) \quad (1)$$

SNR is defined as below, where P_{event} is the acoustic power of the class event, and P_{bkn} is the acoustic power of the former and latter segments of the class with background noise only.

$$SNR = 10 \log_{10} \left(\frac{P_{event}}{P_{bkn}} \right) \quad (2)$$

Note that the SNR (see Equation (2)) could be negative if the power of the background noise near the event is higher than the power of the event itself. This may happen with low-energy sounds such as the *water* class.

4.3. Impact Calculation

The impact determines the contribution of an individual event to the equivalent noise level calculated during the 30 minutes of the audio file. It is computed as the difference (see Equation (3)) between the $L_{eq,event}$ of the segment with the event and the $L_{eq,\overline{event}}$ of the same audio segment where the event is replaced with a linear interpolation from the first to the last sample of the original data. A more detailed calculation explanation can be found in [13,14].

$$\Delta L_{eq} = L_{eq,event} - L_{eq,\overline{event}} \quad (3)$$

5. Discussion

We evaluated the parameters of the acoustic data, as detailed in Section 4, and the results obtained are shown in Table 2. The data has been collected in a standard production cycle according to Spanish regulation [15]. The temperature and humidity were monitored between 34–39 ºC and 40–51%, respectively.

The results shown in Table 2 correspond to the mean value of each metric (duration, SNR, and impact) during the first nine days of the broilers' life and using the aggregated data of diurnal, nocturnal, and daily data files.

Fan presents the longest event (5.13 min) and the event with a better SNR (6.43 dB) and with a high impact (1.177 dB); the fact that it does not active during the night contributes to the rest of the animals. Following the class with the greatest impact is the Bar vibration with a long duration (4.8 min), mostly during the day, the high SNR (+3 dB), and the highest impact (1.35 dB). Food close and Food far reduces the duration in comparison with the durations previously mentioned, and there is a higher demand (in duration) over the course of the night. SNR is higher in the close class, and it is a better metric as the impact is null. Water is the event with a lower impact, as it has an SNR and an impact metric that are negligible.

Table 2. Metric details for each acoustic class.

Classes	Duration (min)			SNR (dB)			Impact (dB)		
	Diurnal	Nocturnal	Daily	Diurnal	Nocturnal	Daily	Diurnal	Nocturnal	Daily
Fan	5.135	-	5.135	6.434	-	6.434	1.177	-	1.177
Food close	0.567	1.330	1.029	3.269	7.419	5.690	0.157	0.173	0.166
Food far	0.644	0.731	0.693	2.408	3.152	2.822	0.026	0.091	0.051
Water	2.863	1.582	2.180	0.247	0.253	0.250	−0.047	0.011	−0.005
Bar vibration	4.819	0.218	3.285	3.762	3.026	3.516	1.351	0.035	0.912

In Figure 2, we can observe the SNR, the impact, and the duration of all events labeled by class. Three big areas can be spotted. The first contains events of less than 40s—Food far, Food near, and Water—with a negligible SNR and impact; we could hypothesize that these events do not affect the animals. The small circles are due to the negative values of impact. The second area contains events more than 40 and less than 100 s and are divided into two subareas: one with less than 6 dB in SNR and the other with a high SNR and impact (which corresponds to the night events). In all these areas, the classes identified are Food far and Food near. In the third area, events with more than 100 s correspond to Fan and Bar vibration, and SNR and impact values are the highest of all other events.

It is noteworthy that, in the second area, the most dense classes have non-negligible values. Reducing the number of this events would reduce the acoustic impact on the animals substantially.

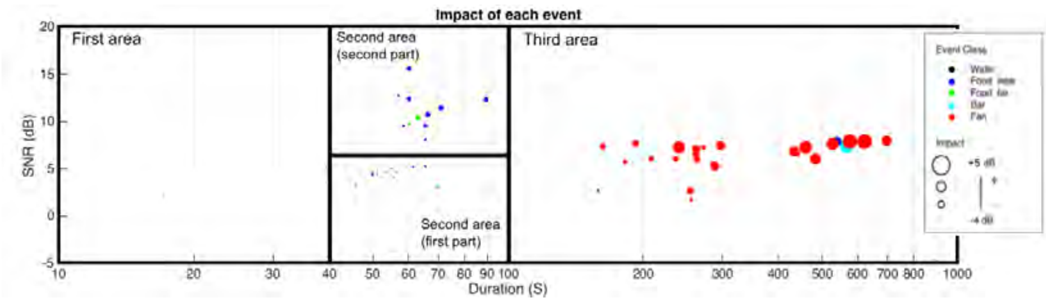

Figure 2. SNR, impact, and duration graph per class.

Based on the data analyzed, the classes can be sorted by the acoustical impact in the following order.

$$Fan \geq Bar\ Vibration \geq Food\ close \geq Food\ far \geq Water \tag{4}$$

6. Conclusions and Future Work

The dataset obtained in this work during the first nine days of the broilers' lives is a first approach to determining the distribution of noise on a farm due to the farm management noise. The acoustic event with the highest impact is *Fan*, with mean values of 5.13 min in duration, 6.43 dB in SNR, and 0.94 dB in impact. *Fan* cannot be reduced in terms of usage, as it reduces the concentration of gas decomposition among others inside the farm, but can be redesigned to generate less noise in terms of equivalent level L_{eq}. The most frequent noise is the food supply with non-negligible metric values. The repetition of the same noise constantly reduces the silent intervals as broilers grow and augment the ingestion of food, activating more frequently the feeder.

This preliminary data results have to be further studied. Future work will focus on collecting more acoustic data over the entire production cycle (six weeks) to study broiler growth and on the effect of their vocal modifications on account of farm management. This data will then be correlated with gas emissions and broiler deceases.

Author Contributions: G.J.G.-P. led the field work by collecting the audio data, and by labeling and processing the dataset, and participated in writing the paper. R.M.A.-P. supported the signal processing component and participated in writing and reviewing the paper. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest: The authors declare that there is no conflict of interest.

Abbreviations

The following abbreviations are used in this manuscript:

DAC	Digital to Analog Converter
L_{eq}	Equivalent pressure level
OIE	World Organization for Animal Health
P_{bkn}	Acoustic power of the background noise near event.
P_{event}	Acoustic power of a class event.
SNR	Signal to Noise Ratio
WAV	Windows Wave

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Appendix C

Conferences pending to be published by the author

Engineering Proceedings

MDPI

Proceedings

Acoustic Description of Bird Broiler Vocalisations in a Real-Life Intensive Farm and Its Impact on Animal Welfare: A Comparative Analysis of Recordings

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Abstract: The poultry meat industry is one of the most efficient biological systems to transform cereal protein into high quality protein for human consumption at a low cost. However, to supply the increasing demand of white meat intensive production is required and also it generates stress to animals, which can be major sources of welfare problems. In this study, a comparative acoustic analysis of two entire production cycle of an intensive broiler Ross 308 poultry farm in the Mediterranean area has been performed. The following step to consolidate the analysis is to stablish a clear comparison among the performance of the indicators (L_{eq}, L_{eq} variation, Peak Frequency (PF) and PF variation) in the conditions of two different recording campaigns corresponding to summer and winter entire production cycles. The acoustic maps of PF, L_{eq} and the related variations should be validated in an inter-campaign comparison, which may also arise the possibility of changes due to the season of the year.

Keywords: bird well-fare; peak frequency; equivalent level vocalisation; PLF

1. Introduction

The demand for poultry meat due for the low price and the nutritional properties projects a continuous expansion of the poultry market [1,2]. In recent years, genetic selection has been performed during years to increase the growth rate in the shortest possible time [3] in the context of poultry meat industry [4]. As well as, the welfare of animals has become an important fact for society in many countries of the world. According to the world animal protection [5] organisation the farm animals raised humanely are healthier. This fact, together with the automatising of most of the animal monitoring processes, can support the farmer in the care of the animals.

Following this idea, bioacoustics studies the biological significance and the characteristics of sounds emitted by living organisms [6], and can be a relevant issue to complement the traditional measurements of the farm. Threat signals [7], information about feeding [8] or sexual selection [9] are only some examples of the possible applications of this field. More particularly, bird area is one of the few groups of animals known to exhibit vocal learning for communication [10]. The birds' vocalization is a useful tool to improve the state of health and well-being. The sound produced by the animals is a biological signal that can be easily measured from distance and therefore will not cause any additional stress to them [11].

In this study a comparative analysis in acoustic terms of L_{eq}, ΔL_{eq}, Peak Frequency (PF), ΔPF has been performed between two production cycle over winter and summer season in a Spanish farm.

Results show the variations and stability of the acoustic descriptions over seasons where different animal lots are grown in opposite climates.

This paper is structured as follows. The recording campaigns design required to obtain the data is detailed in Section 2. The results of the comparison of the two campaigns are available in Section 3. Finally, the discussion of the key aspects of the comparative is found in Section 4.

2. Recording Campaigns Design

A broiler Ross 308 takes approximately 44 days to complete the production cycle [12]. In a natural year a farm can hold in average six different birds' lots. The recording campaigns of this study are held in Spain over 2020. The climate between summer and winter is the opposite and it is an ideal scenario for a comparative study. In summer the farm is exposed to an external temperature of 31ºC - 14ºC and a humidity of 4% - 55% meanwhile in winter is 13ºC - 1ºC and a humidity of 0% [1].

2.1. Time Schedule Required

The two campaigns of acoustic data recording have been performed in the same house farm, maintaining the deployed equipment and the genetic of birds. First campaign (C1) was scheduled during January and February 2020. Second campaign (C2) was scheduled during July and August 2020. Both cycles had a standard performance in terms of conversion index.

2.2. Farm and Equipment Description

The acoustic analysis has been performed in a Mediterranean farm of the BonArea Agrupa corporation [2] of approximately 42,000 commercial chicken farming of Ross 308 [13]. The characteristics of this farm provide a suitable environment for this study, because the automation reduces the human factor in farm management, and therefore, the man-made noise. So, the acoustic environment of the farm allows us to obtain suitable animals vocalization metrics.

A professional handheld recorder (Zoom H5) [14] was used, connected to a directional microphone Behringer ultravoice XM1800S with a frequency response of 80-15 kHz and a sensibility of 2.5 mV/Pa [15]. The sounds emitted by birds were recorded with one microphone, deployed at one meter high from the ground and at the center to the house. The system captured data 24/7 throughout the entire cycle with some technical resets, due to performing restrictions of the recorders.

More details about the Farm and Equipment description can be found in the former article of the same authors [16], which was devoted to the analysis of the first recorded cycle.

3. Results

In this section we present the results of the first comparison between the two recording campaigns, in which we map both the L_{eq} value each 30 minutes for both campaigns, and also the L_{eq} variation. We also map the PF every 30 minutes for both campaigns, and its variation values.

Figures 1 and 2 shows a map of L_{eq}. Values below 40 dB correspond to moments without or with less birds in the farm. In general, L_{eq} do not present variations in age related. Even so, winter campaign has an increase of value measured during daylight, meanwhile in summer this pattern is not found but more peaks of high values are found.

Figures 3 and 4 show a map of the metric ΔL_{eq}. In both campaigns, the highest variations corresponds to the arrival of the birds. Also, the value is reduced the first 20 days. From then on, an increase of level variation can be observed during daylight.

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1 Data obtained in average climate searcher https://es.weatherspark.com,Accessed2020-09-15
2 BonArea Agrupa www.bonarea-agrupa.com, Accessed 2020-09-15

Figures 5 and 6 show a map of PF where the highest and long-lasting frequency are observed the first days of bird's life. The summer campaign presents more sporadic peak values than the winter one.

Figures 7 and 8 show a map of the ΔPF. Highest variations are observed in both campaigns at the end of the production cycle (last 5 days) and an increase of PF variation according with the birds' age is also a pattern found in both campaigns.

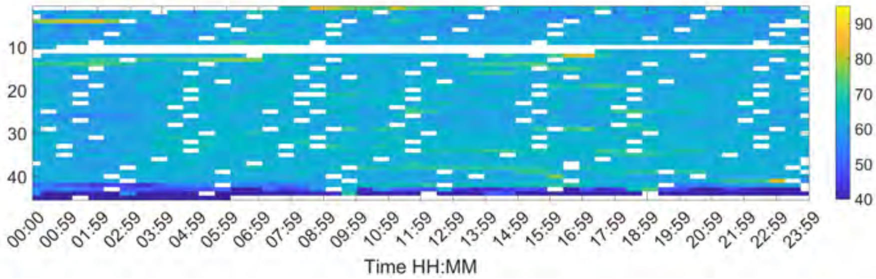

Figure 1. Map of the L_{eq} values for each day of the first campaign (C1). One value each 30 min.

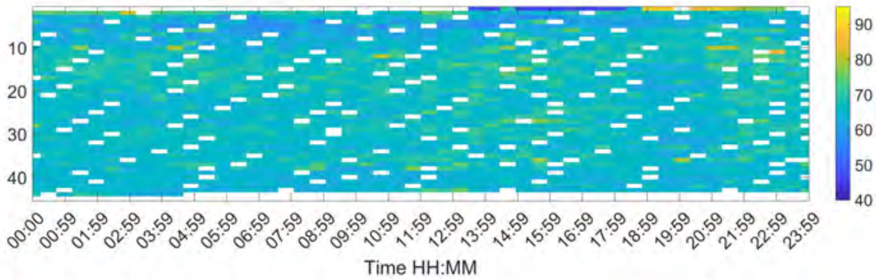

Figure 2. Map of the L_{eq} values for each day of the second campaign (C2). One value each 30 min.

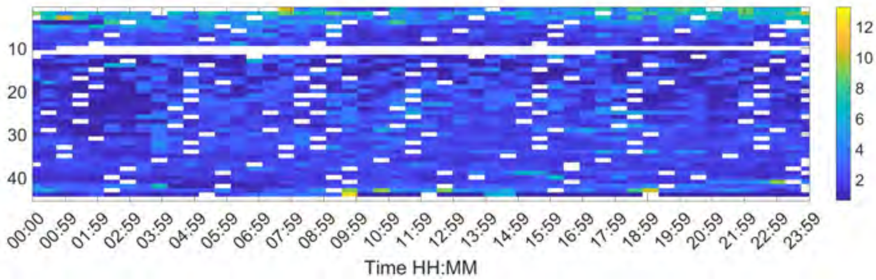

Figure 3. Map of the L_{eq} variation for each day of the first campaign (C1). One value each 30 min.

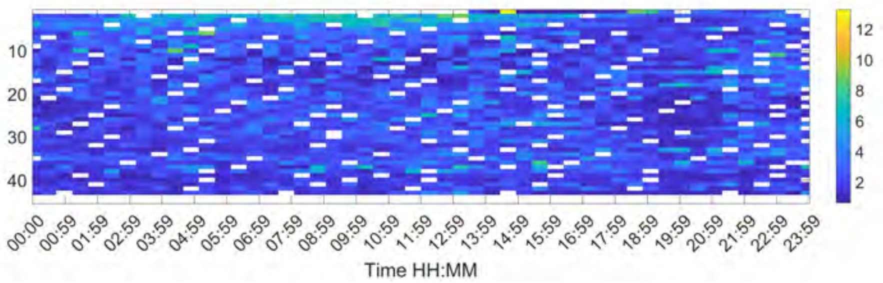

Figure 4. Map of the L_{eq} variation for each day of the second campaign (C2). One value each 30 min.

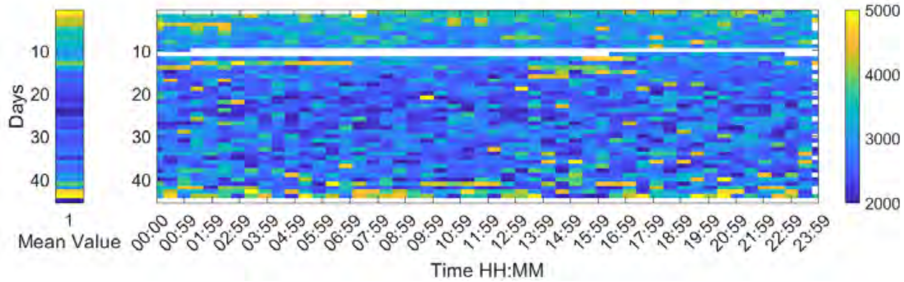

Figure 5. Map of the PF values for each day of the first campaign (C1). One value each 30 min.

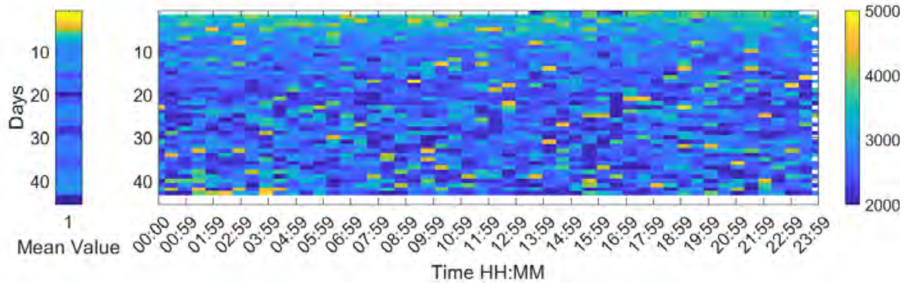

Figure 6. Map of the PF values for each day of the second campaign (C2). One value each 30 min.

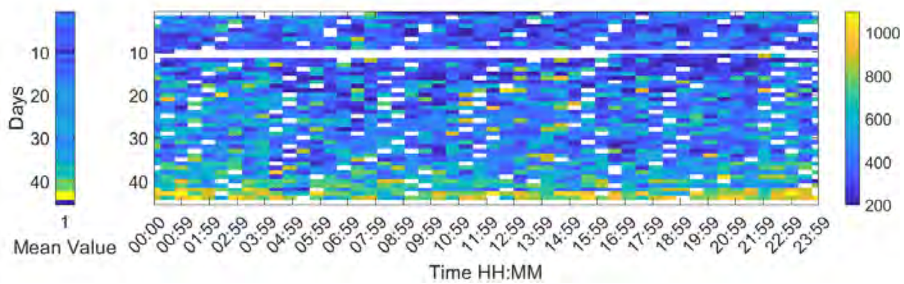

Figure 7. Map of the PF variation values for each day of the first campaign (C1). One value each 30 min.

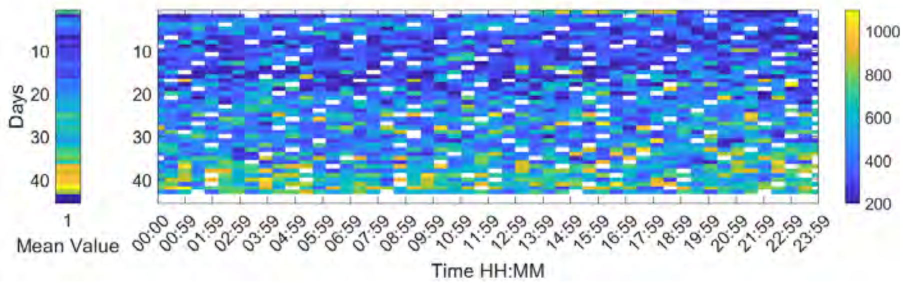

Figure 8. Map of the PF variation values for each day of the second campaign (C2). One value each 30 min.

4. Discussion

The L_{eq} captured at the arrival of the birds is the highest and long-lasting (around 5 h) period of the analysis and has the same pattern in both campaigns. Meanwhile in winter there is an increase of the metrics during the daylight, the summer season do not show this pattern metric and more peaks are detected without any rule. Studying the variation of ΔL_{eq} it also has the highest and long-lasting variations during the first two days of birds' life. After the 20th day of life, we observe the same pattern between campaigns, a greater increase of ΔL_{eq} during daylight.

The PF captured the first fourth days of life indicates high values of frequency vocalisations in newborns. This days the birds' calls are due to their transport, stress and lack of familiar contact. The PF is in average lower during the winter campaign than in the summer. Also the C2 have more sporadic peaks of high frequencies than in winter. The ΔPF has the major increase the last three days of the production cycle where the birds are bigger in age and volume and more problems of coexistence can appear. There is also a pattern in the variation of PF of both campaigns, where ΔPF increases in function of the age of the animal.

This preliminary comparison results encourage us to study deeply the relationship between the several parameters measured in [16], in order to detail the time-evolution of the several metrics that have shown relevant for the birds well-fare evaluation.

Author Contributions: Gerardo Ginovart-Panisello led the field work collecting the audio data, labelling, processing the dataset and participated in writing the entire paper. Rosa Ma Alsina-Pagès has supported the signal processing part and participated in writing and reviewing of the entire paper. Tesa Panisello has supported the field work and reviewing the entire paper.

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Conflicts of Interest: The authors declare no conflict of interest.

Abbreviations

The following abbreviations are used in this manuscript:

L_{eq}	Equivalent pressure level
C1	Campaign One
C2	Campaign Two
PF	Peak Frequency

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