THE „BIONIC SONAR" PROJECT, PHASE ONE: INITIAL RESEARCH ON MARINE MAMMAL ACOUSTICS

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Results of theoretical and experimental investigation on marine mammal acoustics are presented and briefly concluded. The described research is a part of interdisciplinary scientific project titled „Bionic Sonar". The goal of the project is to develop a new kind of hydroacoustic sources with specified frequency characteristics and directivity patterns, inspired by the vocal and echolocation systems of the marine mammals. The presented theoretical investigation focuses on underwater communication and navigation capabilities of dolphins and grey seals. The experimental research concerning underwater vocalizations of the grey seals was performed in the Hel Marine Station of the Institute of Oceanography of the University of Gdańsk. Underwater sounds were recorded using hydrophones placed in the pools in which only the grey seals were present. The recorded vocalizations have been extracted from the recordings and analyzed for a number of distinguishing characteristics. The obtained results are compared to the results of other related investigations described in literature.

INTRODUCTION

The „Bionic Sonar" is an interdisciplinary scientific project aimed at developing a new kind of hydroacoustic sources with specified frequency characteristics and directivity patterns, inspired by the vocal and echolocation systems of the marine mammals. The research is performed by scientists representing different fields of science, such as acoustics, biophysics, electronics and marine zoology. The present paper describes some issues related with realisation

of the first phase of the project, which aims to investigate selected biological mechanisms and anatomical details responsible for generation and transmission of different acoustic signals used by the marine mammals for underwater navigation and communication.

The first part of the article briefly describes selected results of the theoretical investigations on the marine mammal acoustics, focusing on echolocation and vocalization capabilities of dolphins and seals. State of the art on the subject is presented basing on the descriptions of different research projects available in literature. The second part of the paper introduces selected results of experimental research concerning underwater vocalizations of the grey seals, which was performed in the Hel Marine Station of the Institute of Oceanography of the University of Gdańsk on February, 2013. Examples of recorded acoustic signals are presented and analysed for a number of distinguishing acoustical parameters. Obtained results are compared to the data available in literature.

Fig. 1. The „Bionic Sonar" project logo.

1. THEORETICAL INVESTIGATIONS

The first reports showing that the sense of hearing may play an important role in navigation capabilities of some animals were presented in the second half of the 18^{th} century by Italian and Swiss scientists Lazzaro Spallanzani and Charles Jurine. The researchers were investigating the abilities of bats to avoid collisions with obstacles while flying in completely dark rooms. They showed, that if the ears of bats were plugged with wax then the animals become unable to detect objects in the darkened environment. However, due to the fact that no sounds emitted by the bats were heard during the experiments the scientists could not explain this hypothesis, which was rejected and forgotten for over hundred years [1].

It was not until 1938 when the problem of non-visual navigation of bats was finally solved by Pierce and Griffin [2], who were using an piezoelectric detector to record the ultrasonic pulses emitted by the animals. The evidence that the dolphins reveal similar capabilities of echolocation was presented soon after by McBride [3]. Since the early 1950s the interest in marine mammal acoustics began to grow rapidly, which resulted in increasing number of scientific investigations devoted to the problem. However, despite the great efforts, there are still many unsolved problems and questions regarding the biological mechanisms of generating and transmitting acoustic signals underwater.

The dolphins emit a wide variety of different acoustic signals, including pulses and whistles used for social communication and clicks used for echolocation. The whistles are narrow-

band signals with frequency range 5 – 30 kHz, while the amplitude spectrum of the different sonar clicks may be in the range up to 200 kHz with peak frequency between 20 and 120 kHz. The reported source levels of the sonar signals reach 225 dB re 1 μPa at 1 m. The interesting fact is that the acoustic parameters of the signals emitted by a single animal can be adjusted to suit the changing environmental characteristics [1].

The biological mechanisms responsible for generation of the acoustic signals by dolphins are not yet completely understood. Different researchers present different, often divergent hypothesis. A broad reviews of the various theories were presented among others by Au [1] and Morris [4]. Two most probable regions of sound production indicated and supported by various experimental research are larynx (see, for example, [6]) and the nasal sac system (see, for example, [7]). The most recent research support the nasal sac theory. The generated acoustic signals are transmitted to the surrounding water through the system of fatty tissues situated at the forehead and called the melon. This part of dolphin's anatomy realizes functions of impedance matching and focusing of the acoustic pulses [9], [10].

The emitted and reflected sonar pulses are received and analyzed by the dolphins in order to extract the information about the surrounding environment. The perception of the acoustic waves is realized - just like in case of other mammals - in the inner ear, by the cochlea. However, the transmission path of the sound from the surrounding water to this region is quite unique. As it has been indicated by different experimental research the most important role in this mechanism plays the lower jaw with a fatty channel forming the waveguide for the acoustic pulses (see, for example, [8]). Processing of information from the echolocation system by the dolphins is complex and - again - not yet fully understood. The considered animals reveal many interesting and surprising capabilities in this field - such as, in example, automatic gain control of the received signals. Examples of various studies on those topics may be found in [11], [12], [13] and [14].

The other species of the marine mammals considered in the present study are the grey seals. Much less attention and scientific effort have been given to the vocalization capabilities of those animals than to the dolphins, discussed previously. There are very few studies devoted to this topic, examples of such works are those of Asselin et al. [5] and Schneider [15]. The significant problem in investigating the underwater sounds emitted by the grey seals is that those animals remain rather silent, with an exception of their breeding period.

Asselin et al. studied the underwater vocalizations of the grey seals in their natural habitat, in the southern Gulf of St. Lawrence, Canada. They have distinguished seven different types of vocalizations. The classification was based on the fundamental frequency value, time duration of a single call, numbers of repetitions and the presence of harmonics in the recorded signals. The researchers indicated that the emitted sounds are usually connected with different interactions between the animals but they have also suggested that some of the recorded signals, which they have called „clicks", may be used by the seals to find their way under the ice cover. The possible echolocation capabilities of the grey seals seem to be interesting, but the parameters of the considered acoustic signals - with frequency range of 200 Hz to 10 kHz - differ significantly from the parameters of the biosonars used by the other marine mammals. The other reported vocalizations were „rups" (two types), „rupes" (two types), roars and growls with frequency range of 100 Hz to 3000 kHz, loud, impulsive knocks and „trrots" which are described as sounds similar to those emitted by a jackhammer. The selected acoustic signals were also reported by the other researchers conducting similar studies (see, for example [15] and [16]).

The variety of the reported underwater vocalizations of the grey seals indicates, that the

animals are probably using different complex biological mechanisms in order to generate the different observed acoustic signals. However, the detailed description of those mechanisms as well as the exact purpose of all of the vocalizations remain unknown.

2. EXPERIMENTAL RESEARCH

The experimental research on the underwater vocalizations of grey seals have been performed in the seal centre of the Hel Marine Station of the Institute of Oceanography of the University of Gdańsk. The measurements were taken at three pools with a depth varying from approximately 1 meter to about 3 meters. The total number of four female and two male grey seals were present in the pools and they were the only animals in the considered area. The seals from the Hel Marine Station are presented in figure 2.

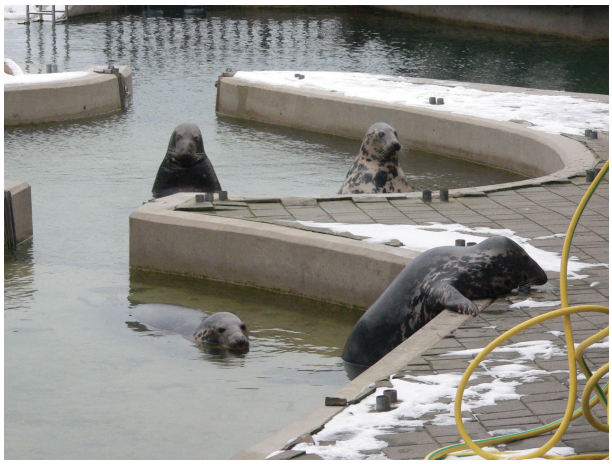

Fig. 2. Grey seals from the Hel Marine Station.

The measurements were carried out using Aquarian Audio H2A hydrophones, which were connected to different recording equipment, including Zoom H2N handheld recorder, B&K Pulse system and audio interfaces of the laptops. Some of the hydrophones were placed stationary in different pools, while the one connected to the handheld recorder was used to create a mobile measurement device, built in the likeness of a fishing rod. The process of recording underwater vocalizations using the mobile device is illustrated in figure 3. The recorded sounds were continuously monitored with headphones.

Over eight hours of underwater recordings have been collected. The initial analysis of a part of the audio files allowed to extract more than one hundred of vocalizations of the observed grey seals. The recorded sounds can be divided into several groups. Most of them can be quite clearly associated with the call types proposed by Asselin et al. [5].

The loudest observed underwater vocalizations were the calls emitted by the male seals, sounding like a jackhammer. They were probably the mating calls and as such they will be refferred to later on. They were also the only acoustic signals generated by the considered animals underwater that could be heard on the surface without any equipment. The parameters of those vocalizations match the parameters of sounds called by Asselin et al. as „trrots" [5]. The sample waveforms of such recorded signals are presented in figure 4.

The time vs. frequency spectrogram of the exemplary recorded mating call sound is presented in figure 5. As it can be seen most of the energy of the considered signal is concentrated below 3 kHz. The duration of the observed mating calls was between 1 to 3 seconds. This data

Fig. 3. Recording of the underwater vocalizations of the grey seals using constructed mobile measurement system.

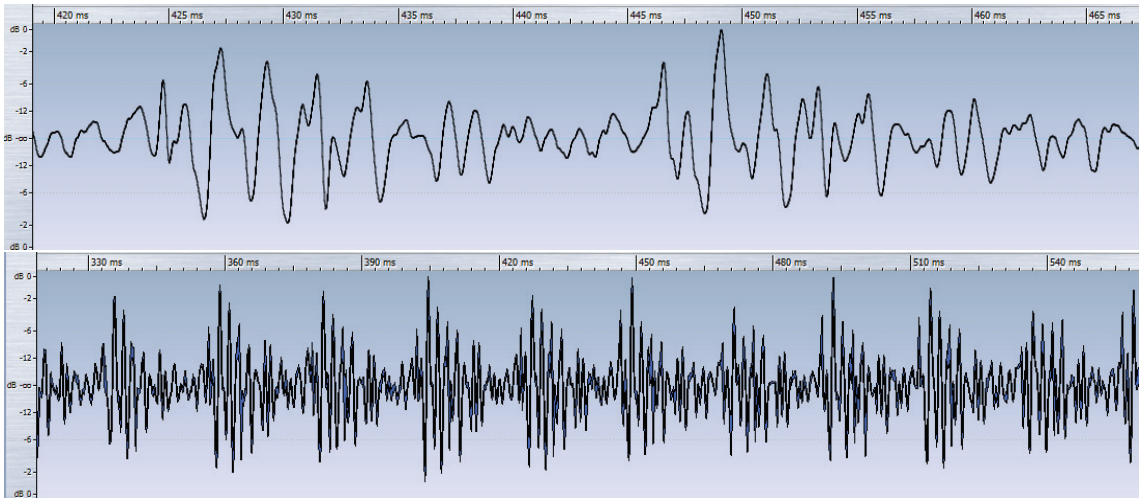

Fig. 4. Exemplary waveforms of recorded mating calls emitted by the male grey seals: a close-up at a 50 ms part (top) and the sequence of pulses with length of 250 ms (bottom).

agree with those given by Asselin et al. [5]. The mating calls were emitted underwater in series by both observed male grey seals during their periods of activity at different times of the day, usually after feeding.

Figure 6 presents the time vs. frequency spectrogram of the same recorded mating call in the bandwidth from 20 Hz to 3,5 kHz. The considered period of time is equal 1,8 s. The spectral components of the acoustic signal remain stable during this time. In the frequency range below 180 Hz only one significant peak is present at 44 Hz. In the bandwidth between 180 Hz and 1600 Hz the highest concentration of the acoustic energy is observed. There are no harmonics at significant level in the considered acoustic signal.

Besides the described mating calls many other kinds of underwater vocalizations of the grey seals have also been observed and recorded, including different howling, roaring and clicking sounds. The frequency ranges of all of the considered acoustic signals are below 10 kHz, however the bandwidths of various vocalizations differ significantly. In some of those signals a high level of harmonics can be seen. The time durations of the observed vocalizations differ from hundreds of milliseconds up to a few seconds. Also the levels of the recorded sounds vary significantly, but except the described mating calls no other acoustic signals emitted by the seals

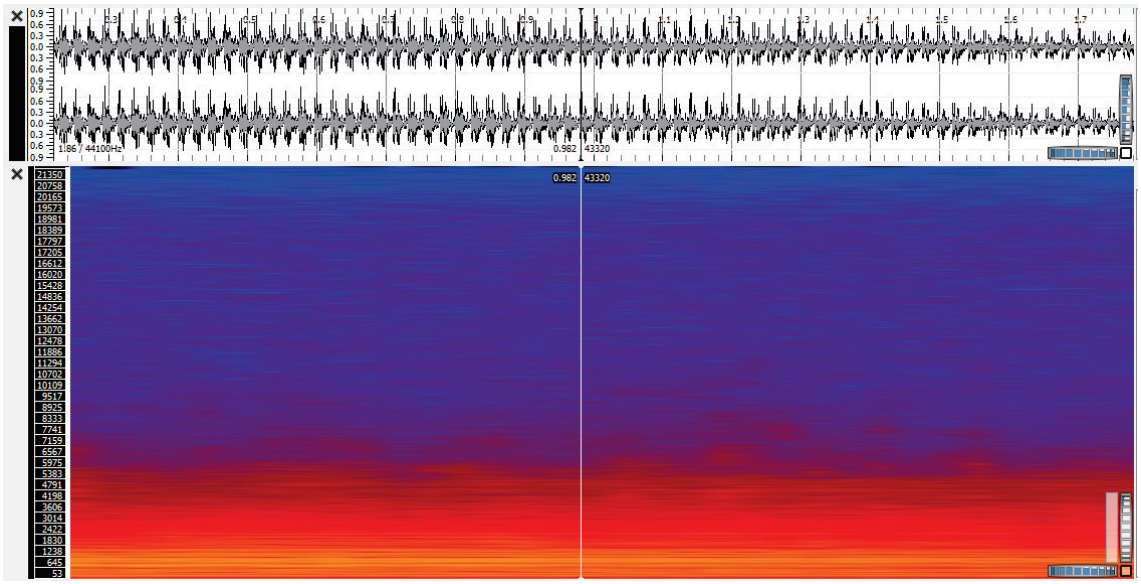

Fig. 5. Time vs. frequency spectrogram of an exemplary recorded mating call sound emitted by a male grey seal: full audible frequency range.

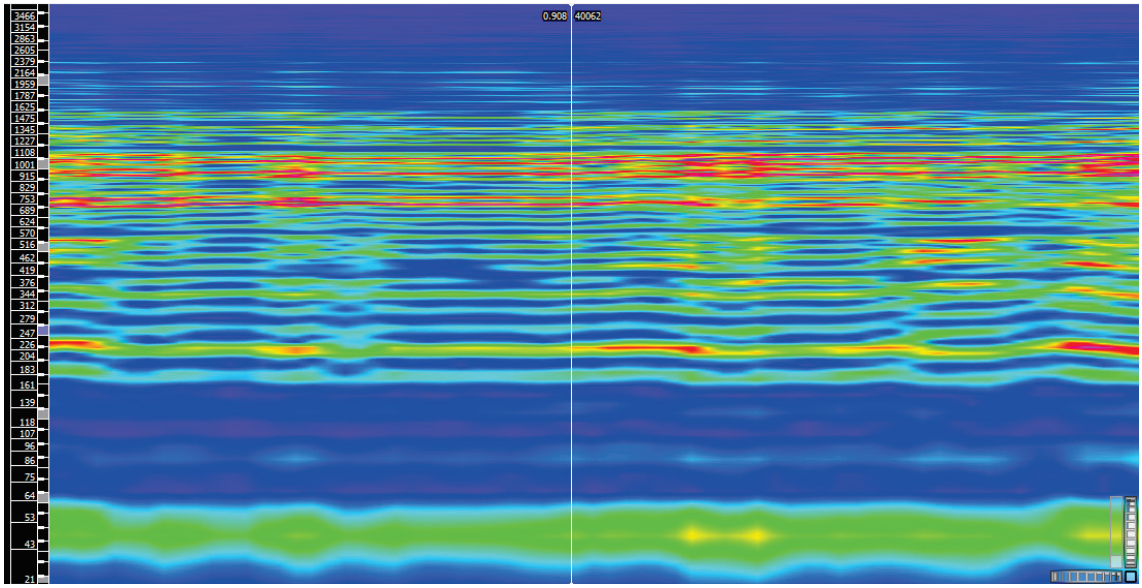

Fig. 6. Time vs. frequency spectrogram of an exemplary recorded mating call sound emitted by a male grey seal: 20 Hz - 3,5 kHz bandwidth.

underwater were heard on the surface.

An exemplary waveform and time vs. frequency spectrum of an another type of recorded underwater calls of the grey seals are presented in figure 7. This signal can be described as a series of low frequency clicks emitted in a time period of a few seconds with intervals of hundreds of milliseconds. The bandwidth of approximately 1 kHz is relatively low, compared to the other observed vocalizations. The parameters of the considered acoustic signal vary significantly from the parameters of the recorded mating calls, which may be connected with different biological mechanisms responsible for sound generation.

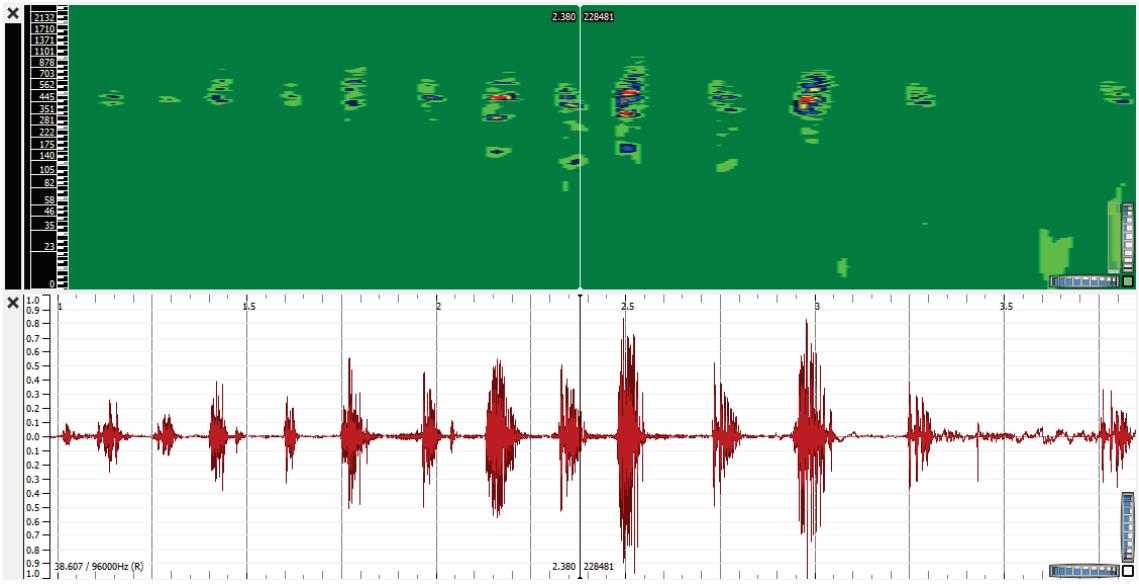

Fig. 7. Waveform and time vs. frequency spectrogram of an exemplary recorded vocalization of a grey seal.

3. CONCLUSIONS

Some basic theory on marine mammals acoustics and exemplary results of experimental research on grey seals underwater vocalizations have been presented. The development of scientific investigations on the related issues dates back to 1950's, to the discovery of the echolocation capabilities of dolphins. Since then, lot of effort have been devoted to describe the biological mechanisms responsible for the observed phenomena. However, many problems are still to be solved. The interesting fact is that in some specific environmental conditions the biological sonars used by dolphins seem to be much more effective that any man-made sonar.

Among the research concerning different species of marine mammals relatively low attention has been given to the underwater vocalizations of the grey seals. Mechanisms of sound emission by those animals and parameters of the generated acoustic signals are much less described in the literature than the related issues concerning dolphins or other cetaceans. One of the possible reasons for this is that the seals remain rather silent during most of the year, with exception of the breeding period.

The experimental research devoted to the acoustic signals emitted underwater by grey seals have been performed in the Hel Marine Station of the Institute of Oceanography of the University of Gdańsk. Some exemplary results of the hydroacoustic measurements and recordings are introduced in the present paper. The obtained data agree with the available state of the art and indicate that the seals are using different biological mechanisms to generate wide variety of sounds. Some of them, which are assumed to be the mating calls of the male seals, are loud enough to be heard on the surface and sound like a jackhammer. The frequency range of all of the observed signals is approximately from 40 Hz to 10 kHz.

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