This paper presents the analysis of noise data recorded by the Autonomous Hydroacoustic System (AHS) deployed in the Spitsbergen fjord close to the little auk’s colony. It focuses on the sounds generated by these small Arctic birds diving for food. The noise signals from the frequency band 0.4–12.5 kHz are used to find spectral characteristics of diving birds. Different statistical methods of data mining and dimension reduction are applied to discern bird noise from the other sources (ships, rain, wind, etc.). Bird’s noise signal is characterised by a narrow intensive peaks with a maximum at 1–4 kHz.

INTRODUCTION

Arctic noise is usually associated with ice cracking, glaciers calving, stormy conditions and wind waves breaking. These are the main mechanisms of noise generation in high latitudes, but some other source of underwater noise also exists. This noise is caused by diving birds.

The Polish-Norwegian project ALKEKONGE is focused on the interrelations between physical environment, biological content of sea water and seabirds population, all in the context of the climate change. An Arctic bird, little auk (Alle alle), is considered a keystone species in the subpolar ecosystems. It breeds on land and feeds on water. Its staple diet comprises mainly the large species of zooplankton – copepods. Little auk is endangered by the warming of climate due to the intense inflow of the Atlantic water to the Arctic. While the Arctic species of zooplankton are replaced by the Atlantic ones due to changes in oceanographic processes, the condition of the little auk is a marker of a changing climate. Changes in oceanic prey distribution force birds to fly longer distances to reach feeding areas where their preferred prey is most abundant causing increased energetic demands.

The technique of little auk dives is not clear, but it is known that it is wing-propelled one and that they dive to the depth of over 30 metres, releasing the clouds of noisy air bubbles. The main goal of this research is to classify various types of noise spectra and to
select the noise signals generated by the diving birds from the background of ambient and man-made noise recorded in the Arctic waters of west Spitsbergen.

1. DATA COLLECTION, PROCESSING AND ANALYSIS

The experiment took place in Isfjorden in the vicinity of a large colony of breeding little auks (Fig. 1). The Autonomous Hydroacoustic System (AHS) equipped with echosounder and two hydrophones was anchored at the depth of 60 m, about 1 mile from the shore. The operation started at 13:00 on 17 July and ended at 10:50 on 28 July 2007 [5]. AHS worked in repeated 10-minute cycles of active and passive measurements performed alternatingly in five 2-minute subcycles. Three 2-minute noise samples were taken every 10 minutes.

Both the echosounder and the hydrophones detected the gas bubbles generated by birds diving for their prey. Registration and interpretation of the echoes made it possible to follow the traces of bubbles released from the bird wings during diving, to determine the speed of their ascent (dependent on bubble size) and the depth of diving. Analysis of the echosounder records showed that the birds dived to the depth of up to 34 m [6].

The noise signals were sampled by a two-channel 16-bit ADC with the frequency of 32 kHz in the case of two hydrophones, or 85 kHz when only one hydrophone was used [4]. Afterwards, they were post processed using MATLAB procedures. At the first stage, the FFT was applied to sub-samples of signals, each of them consisting of 16384 (16x1024) points. There were 4716 series (over 150 hours) of noise measurement recorded. For each series the averaged spectrum and various spectral signatures were obtained. They were averaged in 512 frequency bands (over 32 samples). The characteristic frequencies, signal intensity, spectrum slope and central frequencies were determined. The Noise Spectrum Level was received by the digital filters with central frequencies logarithmically spaced in the frequency range from 0.4 – 31.5 kHz, ensuring nonoverlapping coverage in the whole registered frequency band.

Approximation of the Noise Spectrum Level in the selected frequency intervals by the linear regression

\[ Y(f) = p \log_2 f + P \]  

allows to determine the spectrum slope coefficients \( p \). Change of the spectrum level per octave is then \( p \cdot \log_2 2 \).

The introductory inspection revealed quite a big variety of the spectrum shapes, especially the spectrum power level and the spectrum slopes in different frequency intervals. The majority of cases described the typical undisturbed calm situations with smooth shape, but some were affected by different noise sources. The disadvantage of the chosen location was a heavy ship traffic, which contaminated the natural noise background during the experiment. Additionally, on the eighth day of experiment a very strong chirp signal appeared (7–9 kHz), probably from a distant research vessel.

After many series of the thorough tests four frequency bands were chosen as the most characteristic for different mechanisms of noise generation: 360 Hz–1 kHz, 1–5 kHz, 5–9 kHz, 9–12 kHz.

In these intervals the undisturbed ambient sea noise is characterised by the mean spectral slope of \(-1.8\) dB per octave in the frequency interval [0.36–1 kHz], \(-4.2\) dB per octave in [1–5 kHz], \(-3.9\) dB per octave in [5–9 kHz] and \(-3.1\) dB per octave in the frequency band [9–12 kHz]. A typical calm spectrum is shown in Fig. 2 together with the linear approximations in chosen subintervals.
Fig. 1. Spitsbergen (left) and Isfjorden (right), where the experiment took place (red asterisk)

Fig. 2. Typical calm spectrum of the ambient noise with marked slope coefficients for the intervals 0.36–1 kHz, 1–5 kHz, 5–9 kHz and 9–12 kHz

Systematic peaks with different intensity and width appear during the whole series of measurement in the interval 1–4 kHz (Fig. 3). These are the resonant frequencies of gas
bubbles with radii 0.8–3 mm. So, the shape and frequency of their spectra fit well to the gas bubble generated presumably by the diving birds.

All the 4716 registered spectra were initially classified in a way described above, but this system of finding the special cases occurred to be inefficient. In this situation, the automatic criteria of eliminating the undesired events, mainly of anthropogenic origin, and selecting the diving birds noises became absolutely necessary. In order to discern birds against the noise background, the analyses of the statistical moments of various orders as well as of the deviation from the long term running mean were performed. Also the normalised variance values were determined in chosen frequency intervals, after removing the trend:

\[ V_n = \text{var} [\text{NSL}(f) - Y(f)] \]  \hspace{1cm} (2)

Preliminary cluster analysis was focused on dividing the whole set of data into categories connected with the noise generation mechanisms. It was performed by use of two methods: k-means and Partitioning Around Medoids [1, 2]. For each of four chosen frequency bands the following parameters were studied:

- \( A_{\text{beg}} \) – noise level at the beginning of the interval,
- \( A_{\text{final}} \) – noise level at the end of the interval,
- \( M_1, M_2, M_3, M_4 \) – statistical moments of the successive orders,
- \( p \) – spectrum slope (1),
- \( V_n \) – detrended spectrum variance (2).

\[ 10^3 \quad 10^4 \]

\[ 35 \quad 40 \quad 45 \quad 50 \quad 55 \quad 60 \quad 65 \]

\[ \text{[dB re 1 \mu Pa^2/Hz]} \]

\[ 10^3 \quad 10^4 \]

\[ 35 \quad 40 \quad 45 \quad 50 \quad 55 \quad 60 \quad 65 \]

\[ \text{Noise Spectrum Level} \]

**Fig. 3. Examples of spectra generated by diving birds**
2. RESULTS

The normalised detrended variance (2) occurred to be the most distinguishing parameter of the dives. Fig. 4 presents the obtained distributions of the variances. Each histogram has the same number of classes equal to 30. It can be seen that the values less than 1 dominate in all frequency bands, but, in two highest intervals, the disturbed cases are really marginal, and in the lowest two cases – below 5 kHz – there are quite many such situations, 2117 for $f \in [360 \text{ Hz} – 1 \text{ kHz}]$ and 1088 for $f \in [1 \text{ kHz} – 5 \text{ kHz}]$. The slope coefficients $p$ of the spectra were determined by the linear regression (1) in selected frequency bands for all spectra (Fig. 5) and for the calm ones, which are characterised by the $V_n < 1$ in all four intervals. The distributions of the slope coefficients are almost identical in both cases, but in the case of smooth spectra the interval of their values becomes narrower. It means that the condition $V_n < 1$ eliminates the majority of extreme situations. Mean values and medians of the slope coefficients $p$ are shown in Table 1.

Table 1. Spectrum slope coefficients in four frequency bands

<table>
<thead>
<tr>
<th>band [kHz]</th>
<th>mean slope</th>
<th>median slope</th>
</tr>
</thead>
<tbody>
<tr>
<td>all spectra</td>
<td>calm spectra</td>
<td>all spectra</td>
</tr>
<tr>
<td>0 – 1</td>
<td>6.6</td>
<td>5.8</td>
</tr>
<tr>
<td>1 – 5</td>
<td>–14.5</td>
<td>–14.4</td>
</tr>
<tr>
<td>5 – 9</td>
<td>–17.0</td>
<td>–16.9</td>
</tr>
<tr>
<td>9 – 12</td>
<td>–11.8</td>
<td>–13.9</td>
</tr>
</tbody>
</table>

Fig. 4. Distributions of normalised variance $V_n$ for all records in 4 frequency bands
The cluster analysis using the method of Partitioning Around Medoids was performed with various numbers of clusters. From twenty different numbers of partitions, the partition into 8 clusters was the most efficient. It allowed to discriminate 5 main groups of noise sources. Fig. 6 illustrates the dependence between two first variables of the new ensemble. Each point on this chart describes a specific object of the analysed set of spectra (it can be seen in the zoomed section in the lower part of this picture). This allows to identify the spectra representative for the obtained clusters. The majority of spectra typical for the gas bubbles resonating at the frequencies below 4 kHz are concentrated in the second cluster (91 points) – gray circles in Fig. 6. The ‘still’ cluster comprises the spectra with smooth shape, with the initial NSL value of about 57 dB. ‘rain’ cluster is characterised with increasing noise level above 10 kHz [4], and ‘wind’ – very high NSL in the entire frequency band, with 70 dB value for the lowest frequencies.

There is no exact evidence that the characteristic noise detected in the frequency interval 1–4 kHz is produced by little auks, because we have not carried out the simultaneous ornithological observations. Nevertheless, in this area, adjacent to the large bird colony, the abundant population of diving little auks was observed during our acoustic experiment.
3. SUMMARY

Over 150 hours of the ambient noise have been recorded in Isfjorden (Svalbard) in the vicinity of little auk colony. Spectral and statistical analyses allowed to discern various types of the disturbances from the background of typical situations – natural sounds (wind, rain and diving birds) and anthropogenic sources (ships and sonars).

Many spectral statistical parameters have been scrutinized in four chosen frequency bands. Their values were applied in the preliminary cluster analysis by use of k-means and PAM methods. This allowed to discern particular mechanisms of noise generation: till 1 kHz – ships, 1–5 kHz – gas bubbles released from the wings of diving birds, 5–9 kHz – chirp sonar and 9–12 kHz – rain. In the majority of cases these intervals are characterised by different
spectrum slope coefficients, the weakest below 1 kHz, and the strongest in the interval 5–9 kHz. The detrended variance values less than 1 can be attributed to the silent situations, the greater values are connected with some additional noise sources.

The presented analysis needs further discussion and verification. Direct ornithological observations and validation of the acoustic measurements are also needed.

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REFERENCES