PAN
ARCHIVES OF ACOUSTICS
Vol. **44**, No. 3, pp. 511–519 (2019)
DOI: 10.24425/aoa.2019.129266

Soundscape Analysis of Selected Landforms on Spitsbergen

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(*received October 22, 2018; accepted February 24, 2019*)

This article shows acoustic measurements from Svalbard archipelago in the Arctic, located in the Arctic Ocean. The aim of the research was to show the Svalbard soundscape as well as to record and analyse the spatial-temporal dynamics of the acoustic environment, the human impact on the soundscape and to collect baseline data for future comparative research. Svalbard is interesting for many science disciplines because it has an arctic climate and, at the same time, it is relatively easily accessible. Climatologists, geologists, glaciologists, biologists and even anthropologists could find interesting themes to investigate here. Additionally, the soundscape of Spitsbergen is worthy of detailed examination. This paper presents comparative analysis of the soundscape of various spots near Longyearbyen in Management Area 10. The soundscape analysis of selected valleys shows the strong influence of human activity on the soundscape as well as the variability and characteristic features of the natural Arctic soundscape.

Keywords: Arctic soundscape; soundscape analysis; Svalbard; Spitsbergen; Longyearbyen.

1. Introduction

The Svalbard archipelago is a unique place in the world and its soundscape is worth capturing before it changes as a result of human activity and global warming. The global changes first appear in arctic regions; therefore, these areas are the focus of attention for many scientists. In addition, these regions are exposed to destructive changes related to human activities – this especially applies to the quickly developing tourism activity (Maciejowski, 2017). At the same time, thanks to their relative isolation, these areas have managed to preserve both their pristine landscape and their soundscape. This is a fact worth emphasising because there are not many places in the world where the sounds of the natural environment have not been masked by sounds related to human activity. Pijanowski *et al.* (2011) warn that we are in danger of replacing natural biological sounds with anthropophony. The term ‘anthropophony’ should be defined here as sound made by humans; this is in contrast to biological voices named biophony and sound from the geophysical environment (like the sound of waves or wind) named geophony (Farina, 2014). A similar approach and terminology can also be found in the analysis of Polish natural reserves (Bernat, 2013).

Over the last three years, a group of scientists from the Department of Mechanics and Vibroacoustics from AGH University of Science and Technology have conducted three scientific expeditions to Spitsbergen – two during the winter and one during the summer. The performed field acoustic measurements included: acoustic monitoring of Longyearbyen; sound pressure level measurements for a noise map of the settlements of Longyearbyen, Pyramiden and Barentsburg; ambisonic recordings and soundscape analysis of places of interest because of tourism; ice cave impulse response measurement.

The Svalbard Archipelago and its biggest island – Spitsbergen – are located on the Arctic Ocean, north of the Arctic Circle. The unique Spitsbergen soundscape is characterised by the lack of noise pollution that is typical of continental Europe. The acoustic environment in which geophony dominates and biophony and anthropophony sporadically occur is very interesting for researchers.

Previous acoustic research projects in Arctic areas have focused on infrasound measurements of glacier activity (Głowacki *et al.*, 2015; Vinogradov, Kremenetskaya, 2013; Tegowski *et al.*, 2012) or underwater recordings of animal activity (Szczucka, 2011; Szczucka *et al.*, 2017). This article presents an analysis of sounds covering selected Arctic landforms. Our conceptual framework of soundscape analysis is based on the sound division proposed by R. Murray Schafer. In his famous book 'The Tuning of the World' (Schafer, 1977), he proposed the division of sounds into three categories. This method has been supplemented by classical methods used in environmental acoustics. Furthermore, the unique Arctic soundscape has been immortalised using the modern 'ambisonics' method of spatial sound recording (Blauert, Rabenstein, 2012). The soundscape was recorded in A- or B-format (four channels: W, X, Y and Z) which allows very accurate sound field reproduction through sound field synthesis. Moreover, it also allows estimation of the direction of the sound source (Wierzbicki *et al.*, 2013) and further analysis in reference to the listening environment. The next section describes the employed methods and instruments. In the third section, there are details about the examined areas together with their soundscape analysis. The last section presents a summary and conclusions.

2. Method

Sound pressure level (SPL) measurements and ambisonic recordings were made during the summer (polar day – July/August 2016 & 2018) and the winter (March 2017 & 2018). SPL measurements were made using a SVAN 977 Class 1 sound level meter. Ambisonic recordings were made using Soundfield SPS200 1st order ambisonic microphones. Signals were registered with the ZOOM H6 recorder at a 48 kHz sample rate and 24-bits resolution.

Both qualitative and quantitative analyses of results were performed. Initially, the sounds identified in the area were grouped according to their origin. Biophony, geophony and anthropophony were differentiated. The main quantitative analysis was based on the description of soundscape that was created by Robert Murray Schafer (1970; 1973). Sounds were divided into three categories: keynote sounds, sound signals, and soundmarks. Keynote sounds are defined as background sound perceived unconsciously. Sound signals are foreground sounds that are perceived consciously. Soundmarks are unique sounds characteristic for a particular place. The relationship between landscape and soundscape was also investigated (Krause *et al.*, 2011).

For qualitative analysis, we used data from a sound level meter. Basic parameters were recorded every second – these included: the equivalent sound pressure level for the observation time (L_{Aeq}), the maximum value of the sound pressure level ($L_{\max}$), the minimum value of the sound pressure level ($L_{\min}$) and the peak value of the sound pressure level (L_{peak}). We were looking for the spatial and temporal diversity of the acoustic environment for all selected landscapes (Pijanowski *et al.*, 2011; ISO 12913-1, 2014).

3. Research places

Three different landforms were chosen to show the diversity of the Arctic soundscape (Fig. 1). All of the analysed places are located close to Longyearbyen and are easily accessible for the average tourist. However, for reasons of personal safety, a weapon is required; this is because there are a lot of wild animals in the Arctic, including the most dangerous – the polar bear.

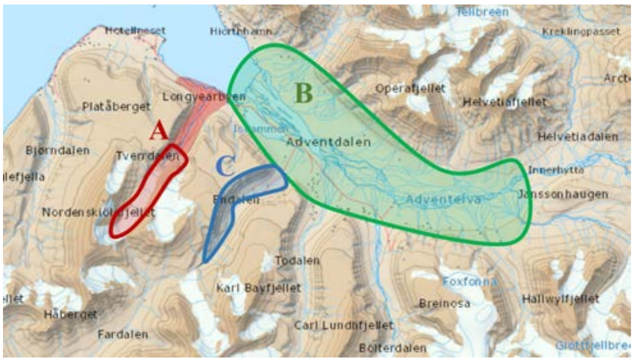

Fig. 1. Locations of the three investigated landforms: A – Longyearbreen and Sarkofagen, B – Adventdalen and C – Endalen (terrain map copied from (TopoSvalbard, n.d.)).

Acoustic analyses for three different soundscapes were conducted; these soundscapes were glacial and both with and without traffic noise. The chosen landforms were:

1) Longyearbreen and Sarkofagen – Longyearbreen is a glacier located at the top of the Longyear valley (Longyeardalen). In that valley, the largest settlement in Svalbard, Longyearbyen, is situated. In winter, the popular snowmobile route to the Russian settlement, Barentsburg, leads through this glacier. Sarkofagen is a mountain that dominates the valley and the glacier.
2) Endalen is a valley located a few kilometres east of Longyeardalen. Scientific buildings and a closed mine are located at the entrance to the valley. Snowmobiles are prohibited there as the valley is located in a special ski area.
3) Adventdalen is the largest of the valleys described in this paper. A well-used road, a dog kennel, a snowmobile park, a water reservoir and facilities of tourist companies are located there.

4. Results and analysis

Qualitative acoustic analysis started with the identification of all soundscape components within each valley to collect all biophony, geophony and anthropophony. The identified sounds were then divided into three groups: keynote sounds, sound signals, and soundmarks.

4.1. Longyeardalen and Sarkofagen

The Longyeardalen soundscape is mainly determined by the largest settlement – Longyearbyen. It is the main tourist centre for Svalbard explorers. Anthropophony dominates here. The soundscape analyses of the Longyearbyen settlement as well as results of SPL measurements and noise maps for the summer and winter are presented in (Czopek *et al.*, 2018). In this paper, only the upper part of the valley (Longyearbreen) and the Sarkofagen Mountain are analysed.

In Longyearbreen, geophony dominates in summer, but in winter, when ambient sounds are lower, there is a lot of anthropophony from the nearby settlement and snowmobile routes. No biophony was found here in neither summer nor winter. In summer, there is a lot of geophony: the noise of glacial rivers and streams, and wind. While in winter, when the glacial streams are frozen and the ground is covered by snow, the only sound from the geophysical environment is sometimes the sound of wind. This reveals the urban noise that is masked by stream noise in summer. Additionally, the winter soundscape is dominated by the roar of snowmobile engines. Table 1 shows classifications of the recognised sounds according to Schafer. Summer and winter soundscape maps are presented in Figs 2 and 3.

Table 1. Longyearbreen – classification of identified sounds.

Sound type	Biophony	Geophony	Anthropophony
Summer			
Keynote Sounds	–	Glaciers streams, wind	–
Sound Signals	–	–	–
Soundmarks	–	–	–
Winter			
Keynote Sounds	–	Wind	Urban noise in the distance
Sound Signals	–	–	Snowmobiles
Soundmarks	–	–	–

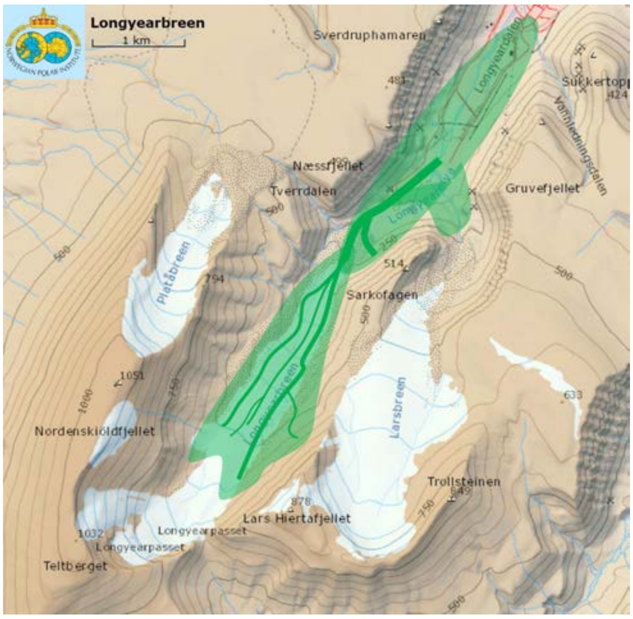

Fig. 2. Soundscape map of Longyearbreen in summer – spatial distribution of different sound types: green – keynote sounds (terrain map copied from (TopoSvalbard, n.d.)).

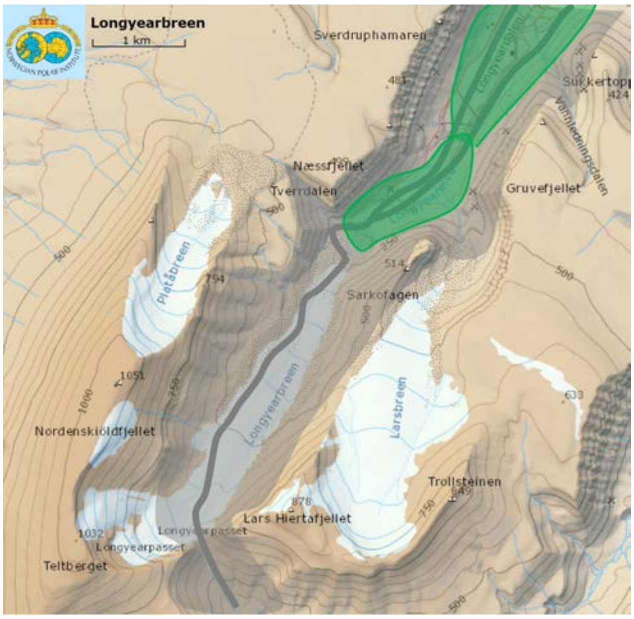

Fig. 3. Soundscape map of Longyearbreen in winter – spatial distribution of different sound types: green – keynote sounds, grey – sound signals (terrain map copied from (TopoSvalbard, n.d.)).

Figure 4 shows the sample SPL time history measured on Sarkofagen in summer. The distance from the Sarkofagen peak to Longyearbreen is around 750 metres the most direct route while the height difference is around 270 meters. In the summer geophony, glacier stream noise creates sounds from 100 Hz to 1 kHz and wind below 50 Hz. The background noise level is around 30 dB SPL.

Figure 5 shows a sample SPL time history measured on Sarkofagen in winter. Anthropophony dominates here – the silence is often interrupted by the noise of snowmobiles that creates sounds of up to 2 kHz. Wind creates sounds with frequencies below 50 Hz. The background noise level is around 33 dB SPL.

Background noise in winter could be even lower if not for the high level of snowmobile traffic on glacier. Therefore, the average level in winter is slightly higher than in summer.

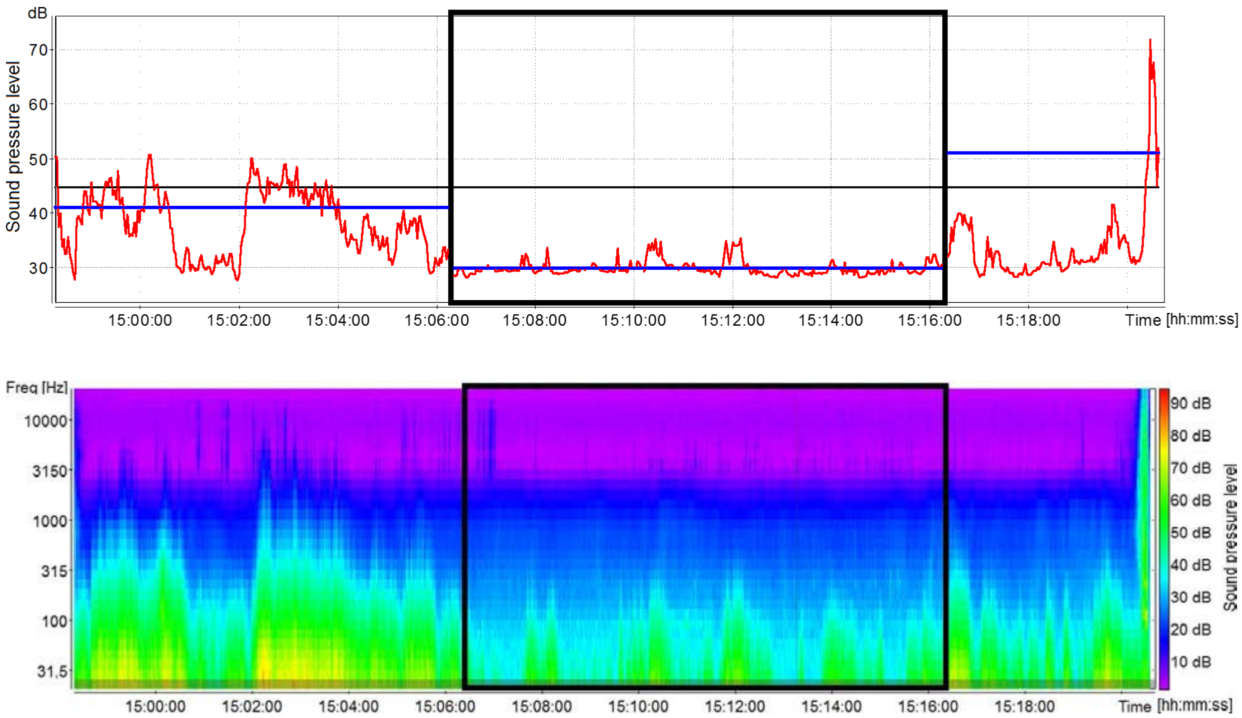

Fig. 4. Sarkofagen – summer SPL measurement time history (top) and spectrogram (bottom). At the beginning and at the end of the measurement, disturbances are visible (steps and conversations of researchers). The correct measurement is marked with a black rectangle; red line – L_{Aeq}, back and blue line – average value.

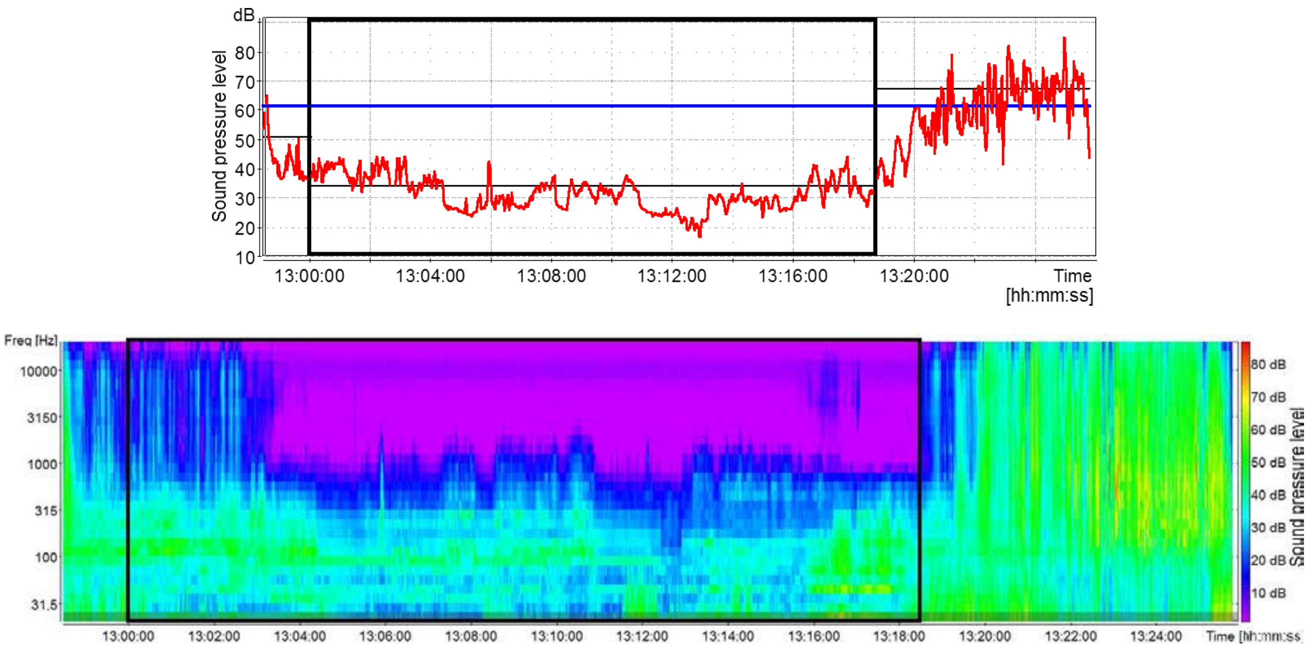

Fig. 5. Sarkofagen – winter SPL measurement time history (top) and spectrogram (bottom). At the beginning and at the end of the measurement, disturbances are visible (steps and conversations of researchers). The correct measurement is marked with a black rectangle; red line – L_{Aeq}, back and blue line – average value.

4.2. Adventdalen

Adventdalen is a large, open valley with a road, dog kennel, snowmobile park and a water reservoir. In summer, Adventdalen is dominated by biophony – geese and seabirds. Additionally, barking and howling dogs can be heard in the dogs' kennel located on the outskirts of the settlement Longyearbyen. Geophony –

noise of river and wind – is not particularly loud because the river is wide and has a gentle flow. However, the wind from the fjord could sometimes be strong.

In winter it is a very busy place because popular snowmobile tours and dog sled tours start here. The soundscape is dominated by anthrophony: cars, buses, and especially snowmobiles. The geophones consist only of wind noise. Barking and howling dogs in dog kennels and during popular dog-sled tours are forms of biophony. Table 2 shows classifications of recognised sounds according to Schafer. Summer and winter soundscape maps are presented in Figs 6 and 7.

Table 2. Adventdalen – classification of identified sounds.

Sound type	Biophony	Geophony	Anthropophony
Summer			
Keynote Sounds	–	Streams, wind	–
Sound Signals	–	–	Cars, buses
Soundmarks	Seabirds, geese, barking dogs	–	–
Winter			
Keynote Sounds	–	Wind	–
Sound Signals	–	–	Cars, buses, snowmobiles
Soundmarks	Barking dogs, dog sled tours	–	–

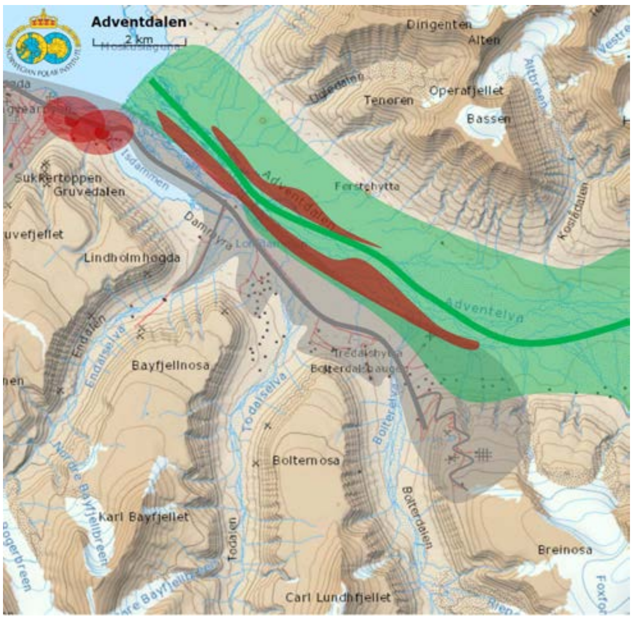

Fig. 6. Soundscape map of Adventdalen in summer – spatial distribution of different sound types: green – keynote sounds, grey – sound signals, red – soundmarks (terrain map copied from (TopoSvalbard, n.d.)).

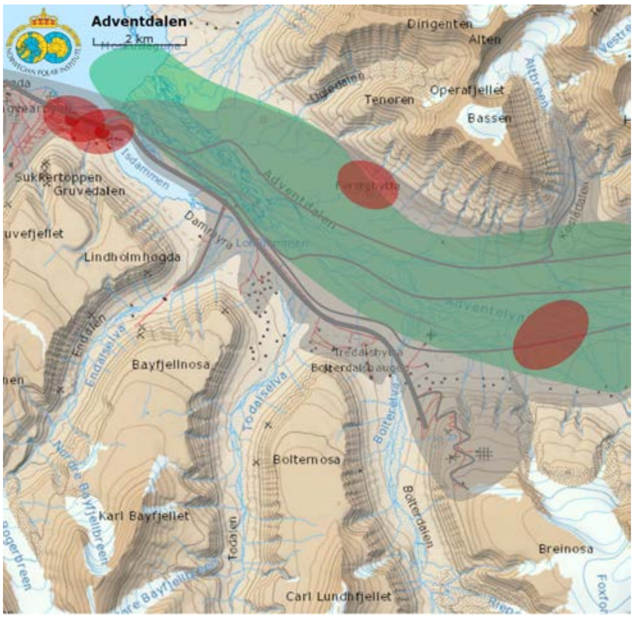

Fig. 7. Soundscape map of Adventdalen in winter – spatial distribution of different sound types: green – keynote sounds, grey – sound signals, red – soundmarks (terrain map copied from (TopoSvalbard, n.d.)).

The most intense tourist traffic is observed in winter and early spring. Figure 9 presents the SPL measurement time history relating to the point located between the road and main snowmobile route – a photograph of this point is shown in Fig. 10. The measurement shows that in late February, snowmobile movement occurs almost 24 hours a day; only between 3 and 5 a.m. the traffic volume is smaller.

4.3. Endalen

In Endalen, we found only sounds of river and streams, and gentle wind (geophony) during the summer. However, due to the terrain, the water noise in the valley is loud. *It was decided to* qualify it as soundmarks. In the winter, by contrast, we found almost no sounds – the only sound in addition to wind was the creaking of snow that we caused. This valley was unusually quiet and free from anthropogenic noise. For this reason, 'silence', in the sense of a lack of human and industrial noise, was included as a soundmark of Endalen. Table 3 shows classifications of recognised sounds according to Schafer. The soundscape map for summer is presented in Fig. 10.

Time history and spectrogram of summer ambient sound (Fig. 12) and winter ambient sound (Fig. 13) shows that in winter, low frequency dominates. Whereas, in summer, mid and low frequencies dominate. In September, it is a noisy valley with a lot of streams and a rapid river. Geophony from 125 Hz to 5 (8) kHz dominates here; gentle wind (frequencies below 50 Hz) could be also observed. By contrast, in

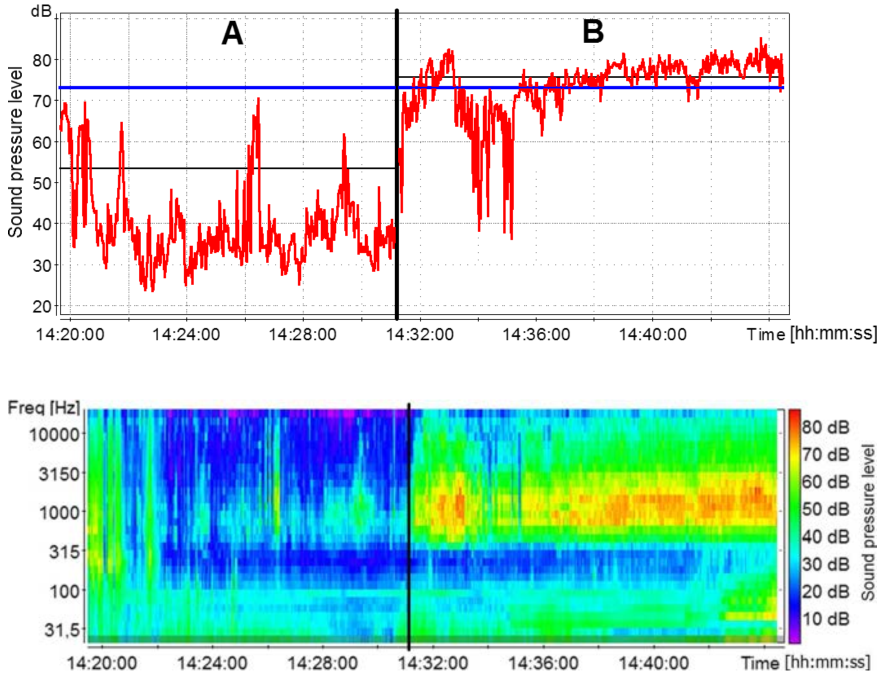

Fig. 8. Adventdalen – winter SPL measurement time history (top) and spectrogram (bottom); red line – L_{Aeq}, back and blue line – average value.

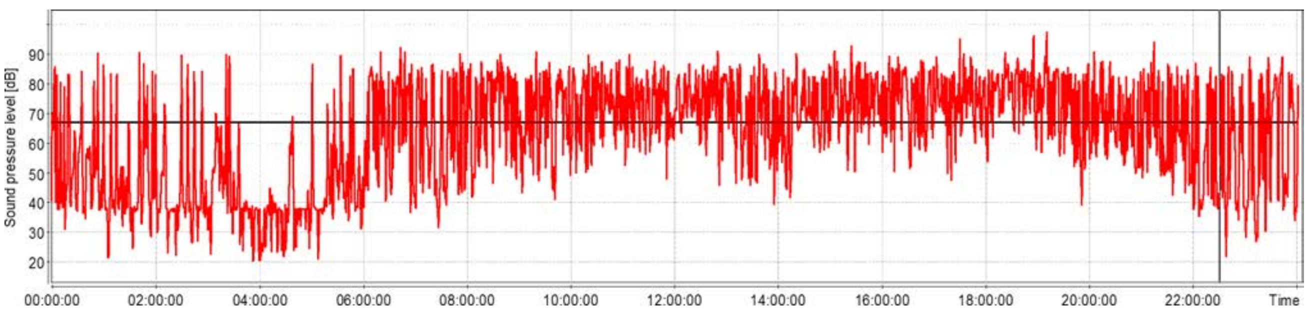

Fig. 9. 24-hour measurement of sound pressure level recorded in Adventdalen: red line – L_{Aeq}, black line – average value.

Table 3. Endalen – classification of identified sounds.

Sound type	Biophony	Geophony	Anthropophony
Summer			
Keynote Sounds	–	The sound of the river, streams and wind	–
Sound Signals	–	–	–
Soundmarks	–	–	–
Winter			
Keynote Sounds	–	The sound of wind	–
Sound Signals	–	–	–
Soundmarks	–	–	'Silence'

Fig. 10. A photo of a measuring point located between the road and main snowmobile route in Adventdalen (fot. Maciej Bernaś).

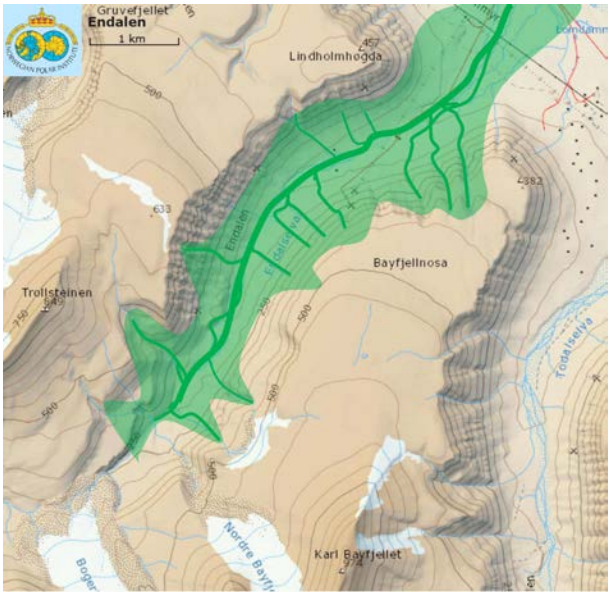

Fig. 11. Soundscape map of Endalen in summer – spatial distribution of different sound types: green – keynote sounds (terrain map copied from (TopoSvalbard, n.d.)).

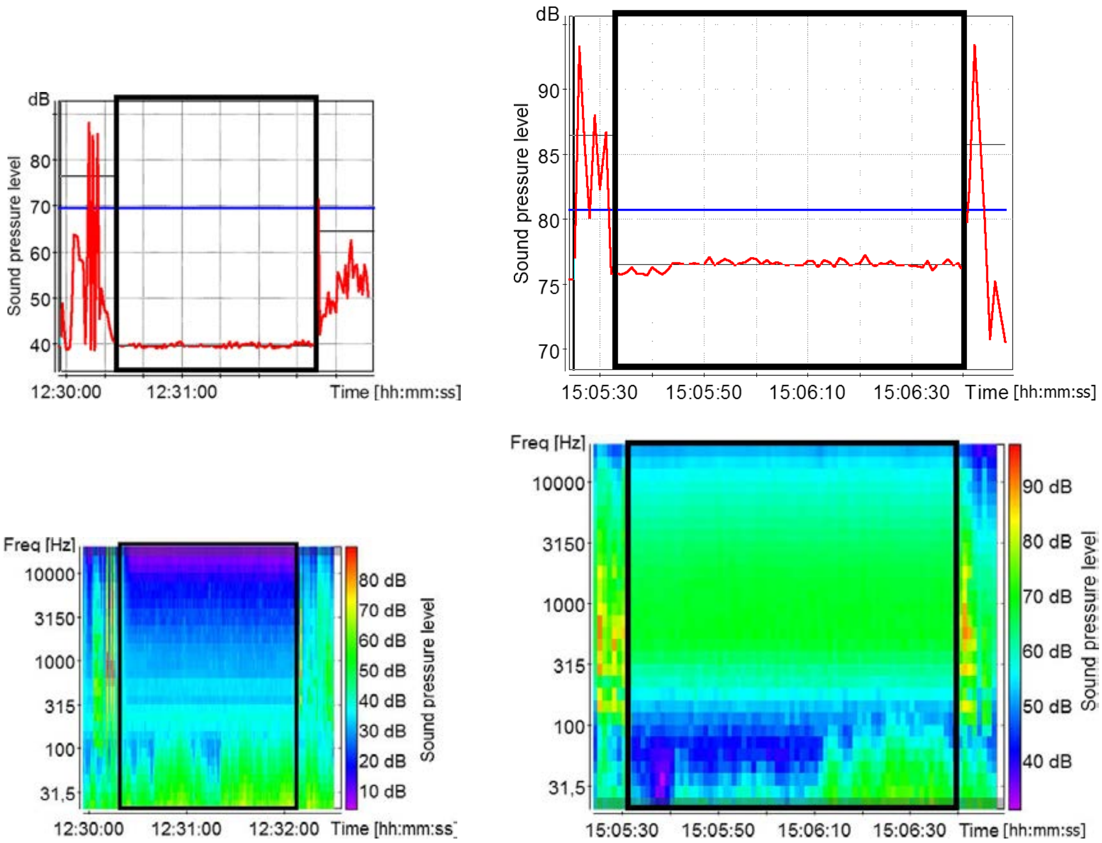

Fig. 12. Endalen – summer SPL measurement time history (top) and spectrogram (bottom). At the beginning and at the end of the measurement, disturbances are visible (steps and conversations of researchers). The correct measurement is marked with a black rectangle; red line – L_{Aeq}, back and blue line – average value.

the winter, when streams freeze, it becomes a silent place. Moreover, loud tourism is not allowed here because Endalen is located in the protected area where only non-motorised recreation such as skiing or dog-sledding is allowed (*Driving a snowmobile...*, n.d.). In this special area, snowmobiles are prohibited. The only noisy source of sound is wind. During the winter, the average level of sound pressure is around 33 dB SPL

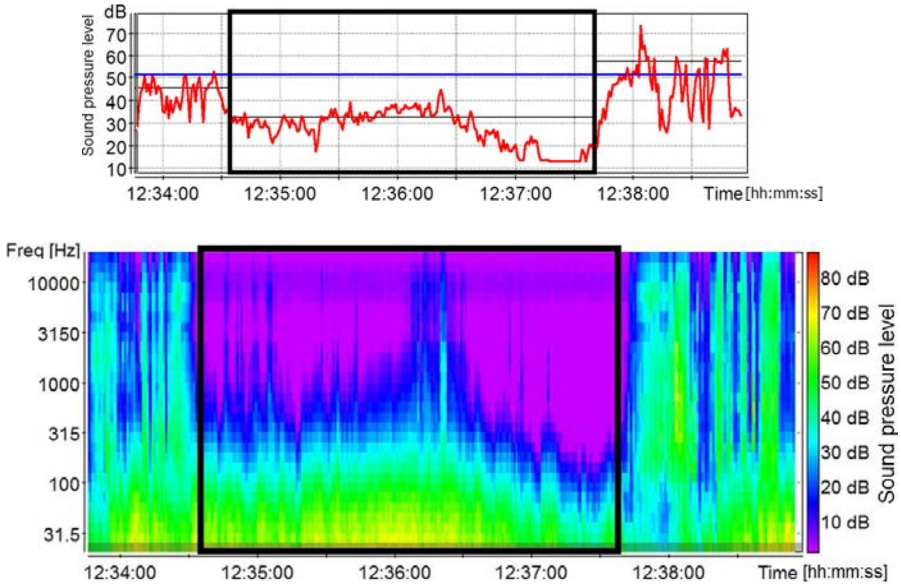

Fig. 13. Endalen – winter SPL measurement time history (top) and spectrogram (bottom). At the beginning and at the end of the measurement, disturbances are visible (steps and conversations of researchers). The correct measurement is marked with a black rectangle; red line – L_{Aeq}, back and blue line – average value.

while during the summer, it is from 40 to even 75 dB SPL (depending on the distance from the river and streams). Thus, winter ambient noise level is much lower than it is in summer. In February and March, when the day is quite long and the snow cover is still sufficient, this is a dream valley for winter sports and experiencing the unique Arctic silence.

5. Conclusions

The first comprehensive acoustic studies describing the Arctic soundscape are presented in this paper. These studies constitute a starting point for further, long-term observations. It needs to be highlighted that a baseline for future work on the acoustics of the Svalbard archipelago has been determined. Continuous observation as to how the soundscapes evolve is as important as other research that serves to preserve and protect biodiversity.

The current research was mostly conducted in stable summer and winter weather conditions. Due to the nature of the dominant noise sources, the acoustic conditions recorded during the study are not likely to differ significantly in the remainder of these seasons. The measurements performed thus far allow hypotheses to be formed with extremely different acoustic conditions and dominant sources depending on weather changes, both during one year and long-term changes. The performed measurements and analyses constitute a high quality reference for future work on the acoustics of the Svalbard archipelago. This is a topic that has not yet been raised in literature on the subject, although, in other fields of study, the Arctic has been observed thoroughly.

It should also be remembered that the constantly progressing changes on the Earth, such as global warming, appear first in the Arctic. In the near future, these soundscapes could be lost forever. Our ambisonic recordings of the Arctic soundscape could become some kind of acoustic fossils for future generations.

Soundscape analysis of the three selected valleys shows the strong influence of human activity on the natural soundscape. This should be taken into account in the context of data about growing tourism in this region (Visit Svalbard, n.d.). America's national parks, as one of the first, noticed the problem of the impact of increased tourism not only on the landscape but also on the soundscape. They emphasised that only sight and hearing together allow the full perception of nature (Olson, Reid, 2013). Anthropogenic sound sources – especially during winter – become the predominant element of the soundscape. Relevant legal regulations to control noise pollution are highly required.

Future research:

- Long-term measurements should be completed outside Longyearbyen and acoustic measurements of the daily activity of bird breeding colonies during polar day should be made.
- Measurements during transitional periods, intense melting of snow in spring and freezing streams and rivers in autumn, should be performed.

Acknowledgments

This research was partly supported by AGH University grant no. 15.11.130.820.

References

1. Bernat S. (2013), *Awareness of noise hazards and the value of soundscapes in Polish national parks*, Archives of Acoustics, **38**, 4, 479–487.
2. Blauert J., Rabenstein R. (2012), *Providing surround sound with loudspeakers: a synopsis of current methods*, Archives of Acoustics, **37**, 1, 5–18.
3. Czopek D., Małecki P., Piechowicz J., Wiciak J. (2018), *Acoustic environment of Spitsbergen – selected issues* [in Polish: *Środowisko akustyczne Spitsbergenu – wybrane zagadnienia*], The AGH University of Science and Technology Press, Cracow.
4. *Driving a snowmobile in Svalbard* (n.d.), Retrieved June 12, 2018, from: Governor of Svalbard, https://www.sysselmannen.no/globalassets/sysselmannen-dokument/trykksaker/driving-a-snowmobile-in-svalbard.pdf.
5. Farina A. (2014), *Soundscape ecology: principles, patterns, methods and applications*, Springer Science & Business Media, Dordrecht–New York.
6. Głowacki O., Deane G.B., Moskalik M., Blondel Ph., Tęgowski J., Błaszczyk M. (2015), *Underwater acoustic signatures of glacier calving*, Geophysical Research Letters, **42**, 3, 804–812.
7. ISO 12913-1 (2014), *Acoustics – Soundscape – Part 1: Definition and conceptual framework*, International Organization for Standardization, Switzerland.
8. Krause B., Gage S.H., Joo W. (2011), *Measuring and interpreting the temporal variability in the soundscape at four places in Sequoia National Park*, Landscape Ecology, **26**, 9, 1247.
9. Maciejowski W. (2017), *Tourist attractions and forms of tourism in the Svalbard archipelago (Norway)* [in Polish: *Walory turystyczne i formy turystyki w archipelagu Svalbard (Norwegia)*], [in:] *Studies on tourism. Geographical and regional works* [in Polish: *Studia nad turystyką. Prace geograficzne i regionalne*], pp. 123–134, Instytut Geografii i Gospodarki Przestrzennej Uniwersytet Jagielloński, Krakow, 35–39.
10. Olson S., Reid P. [Eds.], (2013), *Protecting national park soundscapes*, National Academies Press.
11. Pijanowski B.C. *et al.* (2011), *Soundscape Ecology: The Science of Sound in the Landscape*, BioScience, **61**, 3, 203–216.
12. Schafer R.M. (1970), *The book of noise*, Price Print, Vancouver.
13. Schafer R.M. (1973), *The music of the environment*, Universal Edition.
14. Schafer R.M. (1977), *The tuning of the world*, Alfred A. Knopf, New York.
15. Szczucka J. (2011), *Noise of diving arctic birds*, Hydroacoustics, **14**, 229–236.
16. Szczucka J., Hoppe Ł., Schmidt B., Fey D.P. (2017), *Acoustical estimation of fish distribution and abundance in two Spitsbergen fjords*, Oceanology, **59**, 4, 585–591.
17. Tegowski J., Deane G.B., Lisimenka A., Blondel Ph. (2012), *Spectral and statistical analyses of ambient noise in Spitsvergen Fjords and identification of glacier calving events*, [in:] Proceedings of the 11th European Conference on Underwater Acoustics, pp. 1667–1672.
18. TopoSvalbard (n.d.), http://toposvalbard.npolar.no.
19. Vinogradov Y., Kremenetskaya E. (2013), *Infrasound research in Spitsbergen*, [in:] EGU General Assembly Conference Abstracts, **15**.
20. Visit Svalbard (n.d.), www.visitsvalbard.no.
21. Wierzbicki J., Małecki P., Wiciak J. (2013), *Localization of the Sound Source with the Use of the First-order Ambisonic Microphone*, Acta Physica Polonica A, **123**, 6, 1114–1117.