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Acoustic Indicators in the Analysis of the Acoustic Environment of the Koscieliska Valley in the Tatra National Park

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Abstract The development of our civilization and increasing noise pollution are strongly connected. In 2021, the Tatra National Park was visited by a record number of tourists – about 4 million 600 thousand. The previous record was broken in 2018 – then the Polish Tatra Mountains were visited by 3 million 800 thousand. people. The aim of the paper is the analysis of noise pollution and soundscape of the most popular national park in Poland – Tatra National Park. The Koscieliska Valley was selected for the study, because it is the second area in the park in terms of the number of tickets sold according to the statistics kept by the Tatra National Park. The paper presents the results of the analysis of acoustic measurements and ambisonic recordings made during four seasons using classical method and the soundscape method. In addition, psychoacoustic parameters and soundecology indicators such as: loudness, sharpness or roughness, ACI (acoustic complexity index), NDSI (normalized difference soundscape index), BIO (bioacoustic index), ADI (acoustic diversity index), AEI (acoustic evenness index) were calculated.

Keywords: ecoacoustics, noise, soundscape.

1. Introduction

Since the 28ht of April 2022, a uniform text of Act on Nature Protection [1] has been in effect. The aforementioned Act distinguishes the following forms of nature protection: national parks, nature reserves, landscape parks, areas of protected landscape, Natura 2000 areas, nature monuments, documentary sites, ecological grounds, natural and landscape complexes, species protection of plants, animals and fungi. Of the listed forms of nature protection, national parks and landscape parks are particularly important, especially in view of the size of the protected areas. According to this law, a national park comprises an area of outstanding natural, scientific, social, cultural and educational values, with an area of not less than 1,000 hectares, in which all nature and landscape features are protected. National parks are usually established to conserve biodiversity, resources, inanimate nature and landscape features, to restore natural resources and components, and to restore deformed natural habitats, plant habitats, animal habitats or fungi habitats [1]. The protection plan for the national parks includes the designation of strict, active and landscape protection areas. On areas bordering the national park, the buffer zone of the national park is designated.

There are 23 national parks in Poland, they are distinguished by a relatively small area – from over 2 thousand ha (Ojcowski National Park) to about 60 thousand ha (Biebrza National Park). National Parks cover a mere 1% of Poland's territory [2]. In national parks or in the natural environment in general, we look for places of peace and quiet, and sometimes for scientific inspiration [3, 4]. Hence, due to their exceptional natural values, the national parks have been attracting large numbers of visitors for many years, resulting in a steady increase in the number of tourists in their area. Currently, the attendance in Polish National Parks varies in individual parks – from less than 12 thousand people to about 4,60 million visitors a year. The highest turnout was noted down in Tatra National Park in 2021.

Tatra National Park (in Polish: Tatrzański Park Narodowy; abbr. TPN) is the one of the largest national parks in Poland located in the Tatra Mountains in southern Poland and was established on 30th of October 1954. It was created to preserve Poland's only high alpine area with the deepest caves, numerous lakes, streams, creaks and karst springs, as well as natural and cultural features unique in the country and Europe, and with their rich biodiversity. About 70% of the park is covered by forests and mountain pine scrub, and the remaining 30% are alpine grasslands, rocks and water.

TNP is bordered to the Slovakia Tatra National Park (TANAP-I). Since 1993 the mountain range of Tatras, together with the Polish part of the Tatra National Park, has been identified as natural, biosphere reserve of UNESCO [5]. Tourism in the TPN is organized and supervised by the authorities of the national park – all

tourist entrances to the park are monitored through the sale of admission tickets. Based on data from ticket sales in the Tatra National Park, the most popular trails are as follows: the red coloured trail to Morskie Oko and the green coloured trail on the section Koscielisko Kiry – shelter in the Ornak glade which constitutes about 52% of the total entry traffic to the Tatra National Park [6].

There is an increasing concern among politics and environmental researchers that one of the elements of environmental protection is the protection of the acoustic environment [7-11]. Of particular interest for the protection of a high-quality acoustic environment is the use of soundscape approach and eco-acoustic indicators [12-15]. Soundscapes can contain several sounds that can occur at the same time or separately in time. Depending on the perception of the sound and its uniqueness soundscape can be divided into: natural, sensitive, endangered, unique, recreational, representative, cultural, and everyday soundscapes [13-15]. Within each soundscape, management objectives and monitoring directions for threat as well as value protection are defined [16-18]

Sound events can be analysed from the perspective of their source, function and social context (warning, internal, landmark, relaxing, stress-inducing, status-indicating sounds) as well as associations and symbolism. Also, the spatial and temporal dynamics of occurring sounds can be analysed, and human impact on natural soundscapes is evaluated [11, 19-22].

Based on surveys conducted among the authorities of national parks and their analysis, it can be concluded for most national parks that noise problems are moderate. On the other hand, in the case of four parks, the occurrence of noise was assessed as high (Drawienski, Ojcowski and Karkonoski PN) or very high (Tatrzański PN) [23]. In 2006, a small number of measurements of the sound pressure level were carried out at various points of the Tatra NP. Based on the measurements carried out, it was found that: the acoustic background for the Tatra National Park is 30 – 35 dB, the equivalent sound level on hiking trails is 34.7 – 62.5 dB, tourists grouping: 48.6 – 57.5 dB, car traffic: 64.2 – 70 dB, Ornak glade shelter 48.6 – 53.6 dB [24].

The aim of the paper is the analysis of acoustic indicators and noise pollution of the most popular valley – Koscieliska Valley in the Tatra National Park. The Koscieliska Valley was selected for the study, because it is the second most popular area in the park in terms of the number of sold tickets. Three measurement points were selected in the valley: Koscielisko Kiry entrance to the valley, a glade by the Ornak shelter and the Smreczynski pond. The paper presents the results of the analysis of acoustic measurements and ambisonic recordings made in four seasons using classical method and the soundscape method. In addition, psychoacoustic parameters and eco-acoustic indicators such as: loudness, sharpness or roughness, ACI (Acoustic Complexity Index), NDSI (Normalized Difference Soundscape Index), BIO (Bioacoustic Index), ADI (Acoustic Diversity Index), AEI (Acoustic Evenness Index) [25, 26] were calculated for all the mentioned points and seasons.

2. Methods and measurement

The highest turnout (about 3 million visitors) is noted down in Tatra National Park. The second trail in the TPN, which is characterized by intense tourist traffic, is the green coloured trail on the section Koscielisko Kiry – shelter in the Ornak glade (Tab. 1). In Koscielisko Kiry, 21.7% of total inbound traffic to the TPN was observed. For comparative measurements of acoustics environment three points at Koscieliska Valley have been selected (Tab. 2). The measurements of sounds and their recording were made using the following measuring equipment: sound level meter Svan 971 and Svan 979, Class 1, noise monitoring station Svan 307, Class 1, Soundfield SPS200 1st order ambisonic microphone, ZOOM H6 and F8n recorders.

Table 1. Tourist traffic statistics in Tatra National Park (Hiking tickets).

Tourist traffic statistics – tickets		
Year	TPN	Koscieliska Valley
2021	3 390 243	529 620
2020	2 467 121	429 140
2019	2 748 410	519 929
2018	2 766 761	478 507

Table 2. Tourist traffic statistics in Koscieliska Valley – TPN (Hiking tickets).

Tourist traffic statistics – tickets sold in Koscieliska Valley				
Year	Spring	Summer	Autumn	Winter
2021	92 857	277 854	86 456	72 373
2020	50 309	249 953	47 125	81 623
2019	127 523	274 332	62 194	55 498
2018	131 707	236 662	52 164	57 974

For comparative measurements of acoustics environment three points at Koscieliska Valley have been selected: Kiry – at the entrance to the valley, PTTK shelter on Hala Ornak – a clearing to the left of the entrance to the shelter and Smreczynski Pond – at the observation deck (Fig. 1). During four recording sections following events were recorded: rustle of trees, noise of a stream, wind, sheep grazing, horses passing, footsteps (squeaking snow, crampons), noise of people, screams of children, passing vehicles. Measurements were made at 3 measuring points, taking into account the variability of the seasons. the measurements were made on the following days: November 23, 2019; February 15, 2020; May 23, 2020; September 12, 2020.

Figure 1. Selected measurement points: a) Kiry – at the entrance to the valley, b) PTTK shelter on Hala Ornak – a clearing to the left of the entrance to the shelter, c) Smreczynski Pond – at the observation deck.

Table 3. Sound pressure level values, $L_{\mathrm{Aeq,\,5\,min}}$ [dB (A)], in Koscieliska Valley.

Place	Season			
	Spring	Summer	Autumn	Winter
Kiry – at the entrance to the valley	60.1	61.1	60.1	59.0
PTTK shelter on Ornak Glade – a clearing to the left of the entrance to the shelter	46.7	59.3	48.0	52.4
Smreczynski Pond – at the observation deck	40.5	52.1	45.0	41.7

3. Results

The conducted measurements and analyses allowed for the calculation of SPL, sound spectrograms, and the determination of psychoacoustic parameters. Selected characteristics of SPL changes over time, spectrograms and acoustic parameters are presented in Table 3 and Figures 2 and 3. Calculated psychoacoustic parameters and eco-acoustic indicators are presented in Table 4 and 5.

The analyses of SPL values show that at the measurement point at the entrance to the valley, which is strongly affected by access road noise, SPL values do not depend on the season and remain at 60 dB (A). The greatest variability characterises the SPL values near the PTTK shelter on Hala Ornak and they are related to the intensity of tourist traffic during the season. Here the highest levels are observed in summer and winter respectively: 59.3 and 52.4 dB (A). An increase in SPL value in summer and autumn is noted at the measurement point at Smreczynski Pond. Interpretation of some of these results requires analysis of the time course and spectrograms. Changes in levels are not directly correlated with changes in tourist traffic. It can be noted that the summer increase is related to increased tourist traffic, while the winter and autumn increase is related also to atmospheric conditions.

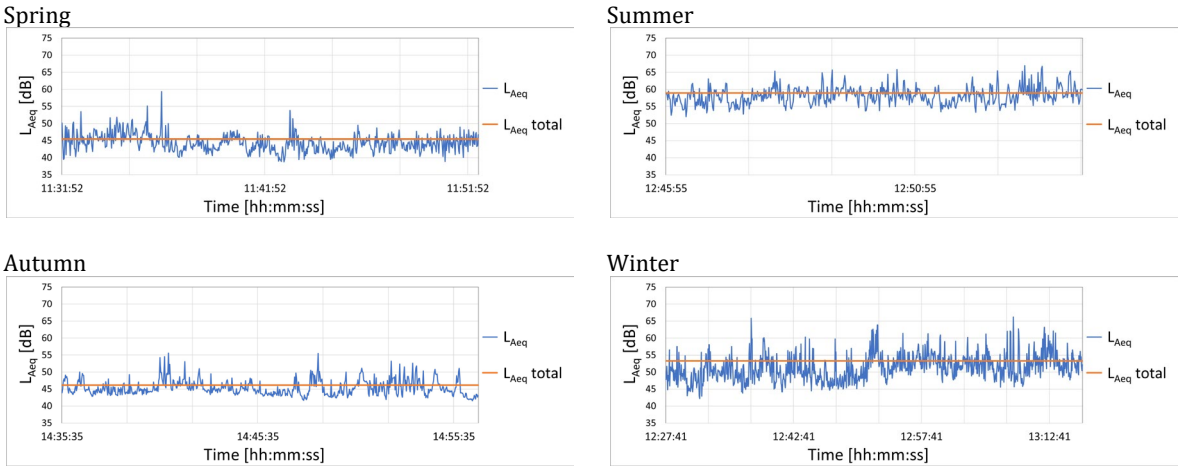

Figure 2. Equivalent level-time course of the sound pressure level at P2 – PTTK shelter on Ornak Glade.

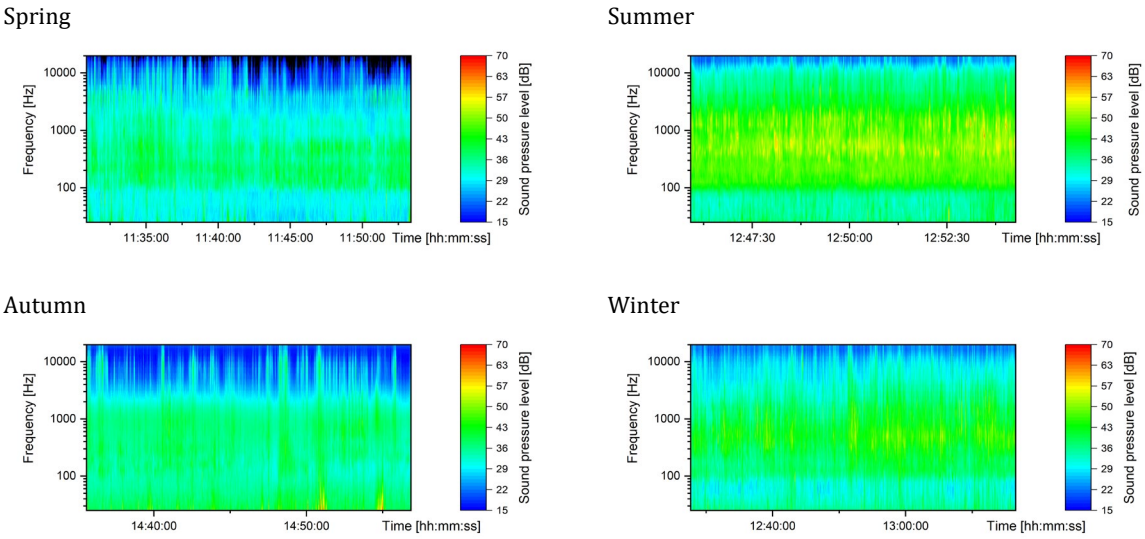

Figure 3. Sound spectrogram at P2 – PTTK shelter on Ornak Glade.

Table 4. Sound pressure level and psychoacoustic parameters in Ornak Glade.

Parameter	Symbol [unit]	Spring	Summer	Autumn	Winter
Sound pressure level (A)	$L_{Aeq,\,3\,min}$ [dB]	46.2	59.5	48.0	50.4
Sound pressure level (C)	$L_{Ceq,\,3\,min}$ [dB]	51.3	61.5	49.7	52.1
5th percentile sound pressure level	L_{AF5} [dB]	50.2	65.6	54.2	57.7
95th percentile sound pressure level	L_{AF95} [dB]	39.3	52.2	40.3	42.9
$N5$ – percentile	N_5 [son]	3.8	9.9	8.3	4.7
$N95$ – percentile	N_{95} [son]	7.3	15.1	8.1	8.7

Table 5. Values of calculated eco-acoustic indicators in Koscieliska Valley. Abbreviations: ACI – Acoustic Complexity Index, ADI – Acoustic Diversity Index, AEI – Acoustic Evenness Index, NDSI – Normalized Difference Soundscape Index, BIO – Bioacoustic Index.

Indicator	Season											
	Spring			Summer			Autumn			Winter		
	1	2	3	1	2	3	1	2	3	1	2	3
ACI	1882	1979	1982	1952	1936	1979	1889	1869	1967	1817	1864	1982
ADI	0.78	0.16	0.02	0.77	0.92	0.32	0.61	1.90	0.02	0.83	0.74	0.27
AEI	0.83	0.89	0.90	0.83	0.81	0.88	0.79	0.49	0.90	0.82	0.83	0.89
NDSI	-0.46	-0.33	-0.15	-0.53	-0.63	-0.51	-0.56	-0.26	-0.14	-0.76	-0.55	-0.50
BIO	6.02	3.31	4.08	3.70	6.08	5.45	3.91	3.85	3.11	3.89	4.00	3.41

The calculated values of the indicators confirm that the acoustic activity is not high. Slightly higher values of ACI factor (Smreczynski Pond) indicate a slightly higher activity of birds. Slightly higher values of the NDSI index indicate the occurrence of higher wind. Low ADI values (Koscieliska Valley entrance, point no. 1) show that the soundscape is not containing many vocalizing species. Higher values of the NDSI coefficient (Smreczynski Pond) indicate greater biophonic activity and minimal noise in 1 – 2 kHz and indicate higher levels of biophonic activity in the soundscape. Similar values of the AVI coefficient show that all three soundscapes are similarly saturated.

4. Conclusions

The research findings indicate that Koscieliska Valley in Tatra National Park is characterised by diverse and unique soundscapes however it is also affected by road traffic and tourism, resulting in noise hazards. The measurements of the sound pressure levels made it possible to examine the daily and seasonal variability of the noise levels. Both unpleasant sounds (people talking, children shouting and crying) and pleasant sounds (birds singing, snow rustling, gentle wind noise) were present at the measurement points mentioned.

There were very high values of the sound pressure level in very popular places of the national park, especially at the entrance to the Koscieliska Valley. There was a noticeable increase in the sound pressure level at PTTK shelter on Hala Ornak in summer by arout 7 dB. It is reasonable to assume that changes in the acoustic conditions prevailing in the Tatra National Park have resulted in a deterioration of living conditions for animals and resting tourists.

It is worth noting that the annoyance of said noise is determined not only by the SPL values but also by its perception. Therefore, noise protection should not be limited to the control of acoustic standards, it should also include the shaping of high-quality soundscapes. Furthermore, attention should be paid to the design of rest areas which should include masking sounds as the green areas are potential tranquil areas.

It is also important to continue studies on soundscapes supported by long term acoustic monitoring and field observations. The studies require an interdisciplinary approach with collaboration of park services and local governments. It is also necessary to develop an implementation of a noise protection strategy in vulnerable areas

Moreover, it was proven that ambisonic recording could be used not only for research purpose, but also in various artistic installations, music compositions etc. As an example, an electronic composition “Tatra” by Katarzyna Sochaczewska was made using ambisonic recordings of unique sounds recorded in the Koscieliska Valley [27, 28]. Natural sounds were used in artistic way. It is an example how to save a unique soundscape for posterity.

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Additional information

The author(s) declare: no competing financial interests and that all material taken from other sources (including their own published works) is clearly cited and that appropriate permits are obtained.

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