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Avian Diversity Monitoring in Mountain Beech Forests using Acoustic Indices: a Case Study in the Belasitsa Nature Park, Bulgaria

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Abstract: Acoustic methods are widely used to study bird communities. They are particularly helpful in remote and hard reachable regions. In this study, we evaluated four acoustic indices (Acoustic Complexity Index, Acoustic Diversity Index, Acoustic Evenness Index and Bioacoustic Index) for biodiversity assessment in mountain beech (*Fagus sylvatica*) forests inside Belasitsa Nature Park, Bulgaria. We used twelve autonomous recording units and deployed four each in three forest types: old-growth forests in Kongura Reserve, mature managed forests (80–130 years of age) and premature managed forests (50–60 years of age). First, we verified that there were correlations between the acoustic indices and bird species richness detected by manual spectrogram scanning and listening of series of 3-min sound samples. Then, we compared the values of acoustic indices among the three forest types, finding higher bird species richness and abundance in old-growth forests and mature managed forests. We found no significant difference in the bird species composition in the three beech forest types, but more hole-nesting birds and species of conservation concern were identified in the old forests. We demonstrated that acoustic indices could be used for avian diversity monitoring and conservation management in mountain beech forests.

Key words: Autonomous sound recorders, Belasitsa, Bird species richness, Ecoacoustics, Passive acoustic monitoring

Introduction

Birds are excellent bioindicators for changes in environmental quality. They are widespread, highly diverse and mobile and so have the potential to capture many underlying ecosystem processes. Among vertebrates, birds can be easily identified, surveyed and censused. There is also a great deal of life history information available on birds, and much long-term monitoring data available. Birds are typically positioned at or near the top of the food chain or high trophic levels in food webs. This makes birds sensitive to environmental change – both anthropogenic and natural (Venier & Pearce 2004, Gregory & Strien 2010, Mekonen 2017, Schulze et al. 2019). Many researchers have focused on monitoring bird species richness and distribution in an attempt to highlight differences in environmental conditions (Furness et al. 1993, Major 2001, Gregory & Strien 2010, Bregman et al. 2014). The ability of birds to vocalize makes passive acoustic monitoring via autonomous recording units (ARUs) suitable as a method of monitoring of their populations. Several studies have shown that the quantity and quality of monitoring data can be comparable or even improved by replacing field observers with sound re-

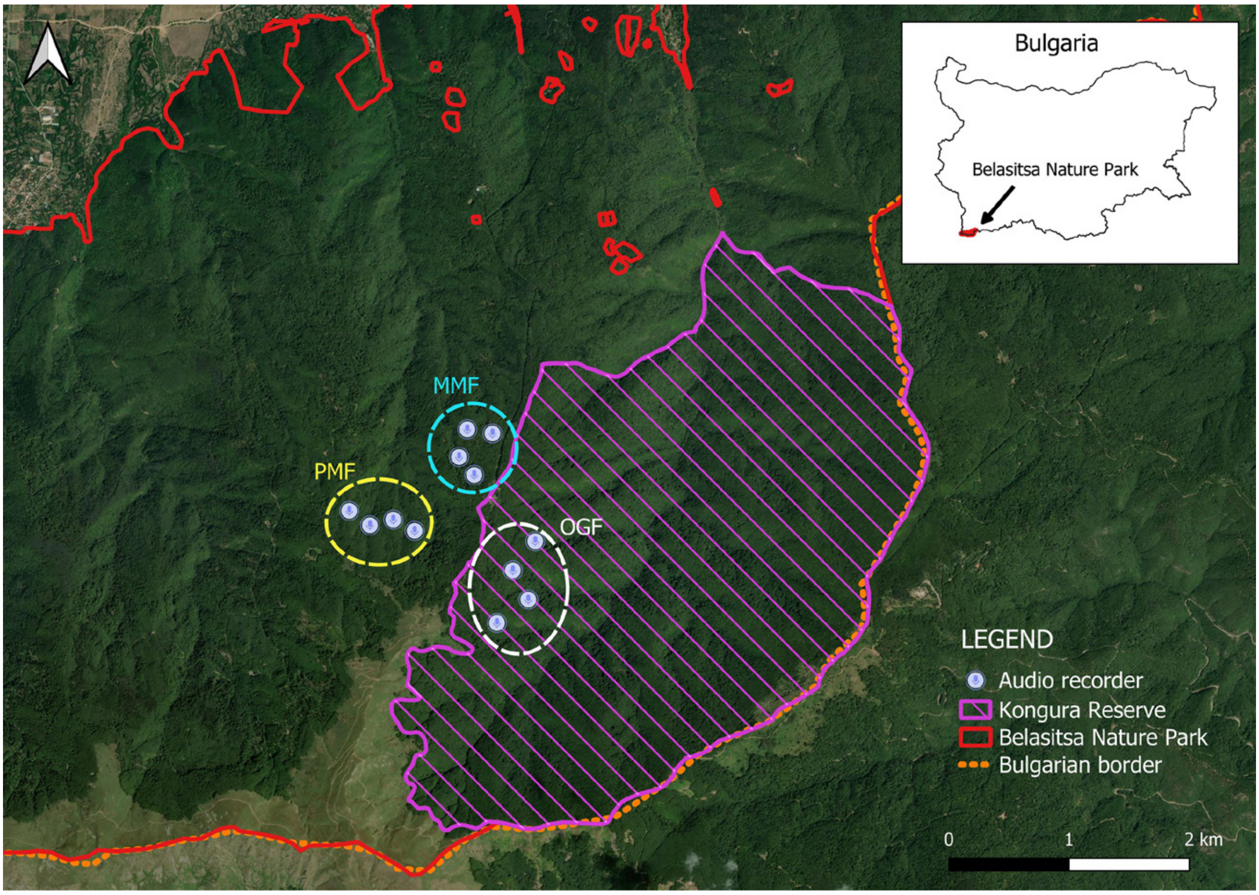

Fig. 1. Locations of the audio recorders in old-growth forests (OGF), mature managed forests (MMF) and premature managed forests (PMF) in Belasitsa Nature Park, Southwestern Bulgaria.

corders (Haselmayer & Quinn 2000, Acevedo & Villanueva-Rivera 2006, Alquezar & Machado 2015, Darras et al. 2018). ARUs have a number of benefits for avian ecological research, including the ease of repeat sampling across spatial and temporal scales, permanent record, reduced observer bias and reduced field time. A downside is the increased processing time by generating large datasets. Listening to recordings is a common processing approach and probably still the best option for studies of bird community composition (Shonfield & Bayne 2017). A variety of software is available for bioacoustic analyses, including some equipped with tools for sound analysis and automated species recognition (Orbist et al. 2010, Knight et al. 2017, Manzano-Rubio et al. 2022). The use of automated recognition software is not appropriate for long-term community monitoring, because it is more restricted to the recognition of one or few species of interest rather than the entire species assemblage (Alquezar & Machado 2015). Acoustic indices (AIs) can be used for ecological research and biodiversity monitoring, based on the assumption that higher species richness will produce a broader range of signals resulting in a greater acoustic diversity (Gasc et al. 2013, Sueur et al. 2008, 2014). AIs are useful for rapid species richness assessment because they allow quantitative analysis of acoustic data, without time-consuming process of detecting calls of individual species (Bradfer-Lawrence et al. 2019, 2020). The effectiveness of acoustic indices is variable and recent studies show various dependencies, ranging from insignificant to strong ones (Eldridge et al. 2018, Diaz et al. 2022, Gaspar et al. 2023).

Ecoacoustic techniques using autonomous sound recorders and acoustic indices for rapid estimation of avian diversity are particularly helpful in remote and hard reachable regions with rugged terrain (as Belasitsa Mountain, Bulgaria). Because the Bulgarian part of Belasitsa Mountain was in the border zone, access was limited until early 1990s. Therefore, knowledge about the avifauna is insufficient. First Prostov (1963) explored the bird species composition in sweet chestnut (*Castanea sativa*) and common beech (*Fagus sylvatica*) dominated forests on altitude between 300 to 800 m in Belasitsa Mountain. Much later, in 2010, bird density and species composition were studied only in the sweet chestnut forests (Nikolov et al. 2011).

The aim of this study was to investigate the efficacy of acoustic indices for avian diversity monitoring in the mountain beech forests in Belasitsa Nature Park. Within two breeding seasons, autonomous sound recorders were deployed in three types of beech forests affected to variable degrees by human activities (old-growth forests, mature managed forests, premature managed forests). The specific objectives were: verifying that acoustic indices correlate with bird species richness calculated on the base of manual spectrogram scanning and listening of the acoustic recordings, comparing the acoustic index values among the three forest types and examining if acoustic indices differ between two breeding seasons.

Materials and Methods

Study area

The study was conducted in Belasitsa Nature Park, Southwestern Bulgaria. It is located on the border between climatic zones. Warm and humid Mediterranean air collides with cool and sometimes severe Continental climate. Acoustic data was collected on the northern slopes of Belasitsa Mountain, including in the upper part of the Kongura Reserve (Fig. 1). The study area extends from northwest to southeast, between 41.3560N, 23.1710E and 41.3345N, 23.2003E. The topography of the location is mountainous, and the altitude varies between 1100 m to 1450 m. The forests are mostly beech dominated. At some places, they are admixed with sweet chestnut, sycamore (*Acer pseudoplatanus*), Norway maple (*Acer platanoides*), goat willow (*Salix caprea*), hornbeam (*Carpinus betulus*), hop hornbeam (*Ostrya carpinifolia*) and hazelnut (*Corylus avellana*). Parts of the forests in the study area were subjected to clear cut some 60 years ago, others have been managed by group-selection system and the rest are located in old growth areas.

Sampling design

We used twelve Wildlife Acoustics Song Meter (SM) Micro recorders with built-in omnidirectional microphone (sensitivity -10.0 ±4 dB; signal-to-noise ratio greater than 73dB) and deployed four each at randomly chosen points in three forest types. These forest types were old-growth forests in Kongura Reserve, mature forests managed by irregular-shelterwood system (80-130 years of age) and premature even-aged managed forests (subjected to clearcut some 60 years ago). ARUs were attached each time on a same tree at approximately 2.0 m off the ground. The distance from one recorder to the closest neighbouring recorder was 200 m (Abrahams 2018). The soundscapes at each recording point were recorded during bird breeding period in 2022 (from 23 March to 11 June) and 2023 (from 23 March to 11 June). The ARUs were programmed to make 3-min recordings at 15-min intervals between samples every day – 5 hours around sunrise and 5 hours around sunset, since this is the period of maximum vocal activity of the most bird species (Robbins 1981). Data was saved in Waveform Audio File (.wav) format on SD cards at a sampling rate of 48 kHz, gain 18 dB.

We collected 38,880 audio recordings, with a total of 1944 hours, during March-June 2022, and 37548 audio recordings with a total of 1877 hours during March-June 2023. In May 2023, the audio recorders had stopped working before we changed the batteries, so there was a gap of few days. When comparing the both breeding seasons, we removed these few days from the 2022 dataset as well.

Acoustic analysis

We randomly selected one day recordings from each of the recorded months in 2022 and 2023 (23 March, 15 April, 13 May, 7 June), to cover different periods and detect both diurnal and nocturnal birds. All ARU recordings were analysed by a single observer (K.P.) using Ocenaudio (Audio editing software, Federal University of Santa Catarina (LINSE)) and Sennheiser HD 450 BT headphones (Sennheiser electronic GmbH & Co. KG, Wedemark, Germany). Identification for doubtful species was performed manually by comparing recordings with bird songs available on on-line bioacoustic library Xeno-Canto Foundation. Totally, 3840 sound samples were analysed by manual spectrogram scanning as well as replaying and listening to calls. These were 160 3-min sound samples per recording point in 2022 and 160 3-min sound samples per recording point in 2023. In each 3-min sound sample the observer (K.P.) identified by songs and calls all bird species and listed them. Finally, if there was any uncertainty about the species responsible for vocalizations the opinion of an expert (B.N.) with a prior knowledge of the site was asked. Kaleidoscope Pro 5.6.0 software (Wildlife Acoustics, Massachusetts, USA) was used for the whole dataset to calculate four frequently used acoustic indices: the Bioacoustic Index BI (Boelman et al. 2007), the Acoustic Complexity Index ACI (Pieretti et al. 2011), the Acoustic Diversity Index ADI (Villanueva-Rivera et al. 2011) and the Acoustic Evenness Index AEI (Villanueva-Rivera et al. 2011). All indices were calculated for frequency range 0-10 kHz. FFT (fast Fourier transformation) of 1024 samples was applied. Calculating the ACI the cluster size was adjusted to 10 s. Both the ADI and the AEI were calculated using 1000 Hz frequency step and -50 dB threshold by software default.

Statistical analysis

All statistical analyses were conducted with the software STATISTICA, Version 12 (StatSoft Inc., Tulsa, OK, USA). Spearman rank order correlation test was applied between indices and total number of bird species detected manually on 3840 3-min sound samples recorded during 2022 and 2023. Kruskal-Wallis ANOVA test was used to investigate differences in the acoustic index values among the three beech forest types (old-growth forests, mature managed forests and premature managed forests). Both Tukey Test and Dunn's Method were applied as pairwise multiple comparison procedures. To determine variations in acoustic indices between both breeding seasons (2022, 2023) we performed Wilcoxon matched pairs test.

Results

Bird species diversity

We identified manually on sound samples 29 bird species in the old-growth forests, 30 species in the mature managed forests and 21 species in the premature managed forests during the breeding season in 2022. During the breeding season of 2023, 31 species in the old-growth forests, 32 species in the mature managed forests and 29 species in the premature managed forests were identified by sound samples (Table 1).

Correlation of acoustic indices with bird species richness

There was a significant positive correlation between bird species richness and the BI, ACI and AEI. For the ADI, the correlation with bird species richness was significantly negative. For the two years, similar results have been observed (Tables 2, 3).

Differences in acoustic indices among forest types

There was a significant difference in acoustic indices among the three beech forest types during the breeding season in 2022 (ACI: KW-H (2, N = 38880) = 1011.05; $p < 0.001$; ADI: KW-H (2, N = 38880) = 162.27; $p < 0.001$; AEI: KW-H (2, N = 38880) = 188.47; $p < 0.001$; BI: KW-H (2, N = 38880) = 943.23; $p < 0.001$). The ACI, AEI and BI showed highest values for mature managed forests and lowest values for premature managed forests. The ADI showed the lowest values for the mature managed forests and the highest values for the premature managed forests (Fig. 2). For each acoustic index all pairwise comparisons (Tukey Test) were significant at $p < 0.05$.

Significant difference in acoustic indices was also found between the three beech forest types during the breeding season in 2023 (ACI: KW-H (2, N = 37548) = 1037.76; $p < 0.001$; ADI: KW-H (2,

Table 1. All bird species determined manually in 3840 3-min sound samples in 2022 and 2023

Scientific name	Old-growth forests	Mature managed forests	Premature managed forests
Buteo buteo	*	*	*
Columba palumbus	*	*	*
Cuculus canorus	*	*	*
Strix aluco	*	*	*
Dendrocopos leucotos	*	*	
Dendrocopos major	*	*	*
Dendrocoptes medius	*	*	*
Dryobates minor		*	
Dryocopus martius	*	*	*
Picus canus	*	*	*
Picus viridis	*	*	*
Troglodytes troglodytes	*	*	*
Erithacus rubecula	*	*	*
Turdus merula	*	*	*
Turdus philomelos	*	*	*
Turdus viscivorus	*	*	*
Phylloscopus collybita	*	*	*
Sylvia atricapilla	*	*	*
Regulus ignicapilla	*		*
Ficedula semitorquata	*	*	
Muscicapa striata	*	*	
Aegithalos caudatus	*	*	*
Cyanistes caeruleus	*	*	*
Parus major	*	*	*
Periparus ater	*	*	*
Poecile palustris	*	*	*
Sitta europaea	*	*	*
Certhia brachydactyla	*	*	*
Certhia familiaris	*	*	
Oriolus oriolus		*	*
Garrulus glandarius	*	*	*
Corvus corax		*	*
Fringilla coelebs	*	*	*
Pyrrhula pyrrhula			*
Coccothraustes coccothraustes	*	*	*

Table 2. Spearman's correlations between acoustic indices and bird species richness during 2022

Pair of variables	Valid N	Spearman R	t(N-2)	p-value
ACI & bird species richness	1920	0.63	35.93	< 0.001
ADI & bird species richness	1920	-0.48	-24.09	< 0.001
AEI & bird species richness	1920	0.48	23.75	< 0.001
BI & bird species richness	1920	0.66	38.59	< 0.001

Table 3. Spearman's correlations between acoustic indices and bird species richness during 2023

Pair of variables	Valid N	Spearman R	t(N-2)	p-value
ACI & bird species richness	1920	0.61	33.59	< 0.001
ADI & bird species richness	1920	-0.48	-23.97	< 0.001
AEI & bird species richness	1920	0.47	23.41	< 0.001
BI & bird species richness	1920	0.66	38.50	< 0.001

Table 4. Comparison of acoustic index values in 2022 (ACI1, ADI1, AEI1, BI1) and 2023 (ACI2, ADI2, AEI2, BI2)

Pair of Variables	Valid N	T	Z	p-value
ACI1 & ACI2	37484	300243968	24.36	< 0.001
ADI1 & ADI2	29327	211652149	2.33	0.02
AEI1 & AEI2	29328	204349017	7.37	< 0.001
BI1 & BI2	37484	305494926	21.85	< 0.001

N = 37548) = 57.02, $p < 0.001$; AEI: KW-H (2, N = 37548) = 53.28, $p < 0.001$; BI: KW-H (2, N = 37548) = 1156.69, $p < 0.001$). The ACI, AEI and BI showed highest values for old-growth forests and lowest values for premature managed forests. The ADI showed the lowest values for the old-growth forests and the highest values for the premature managed forests (Fig. 3). For most acoustic indices (ACI, ADI and BI) all pairwise comparisons (Dunn's Method) were significant at $p < 0.05$. For the AEI the differences between the old-growth and premature forests were not statistically significant ($p > 0.05$), in contrast to the premature – mature and mature – old-growth ones ($p < 0.05$).

Variation of acoustic indices between two breeding seasons

The acoustic indices (ACI, ADI, AEI and BI) varied systematically between the both breeding seasons. Wilcoxon tests showed higher values in 2023 (Table 4). Comparison of the bird species richness detected manually revealed the same (N = 1267, T = 161492.5, Z = 18.44, $p < 0.001$).

Discussion

We tested the efficacy of autonomous sound recorders and acoustic indices for rapid assessment and monitoring of the avian diversity in old-growth, mature managed and premature managed beech forests in Belasitsa Mountain. All acoustic indices (ACI, ADI, AEI, BI) correlate with bird species richness detected in 3-min sound samples. The BI correlated with bird species richness the best. In the same way, a case study from the Białowieża forest revealed a correlation between bird species richness and the BI, ACI, and ADI (Budka et al. 2023). Jorge et al. (2018) found that AEI correlated with species richness in the Brazilian Atlantic Rainforest. In our study we compared the acoustic index values among the three beech forest types. The BI, ACI and AEI showed the highest values in the mature managed forests, followed by the old-growth forests and lowest values in the premature managed forests during the breeding season in 2022. Higher values indicate higher avian species richness and abundance. Contrariwise, the ADI showed highest values in the pre-

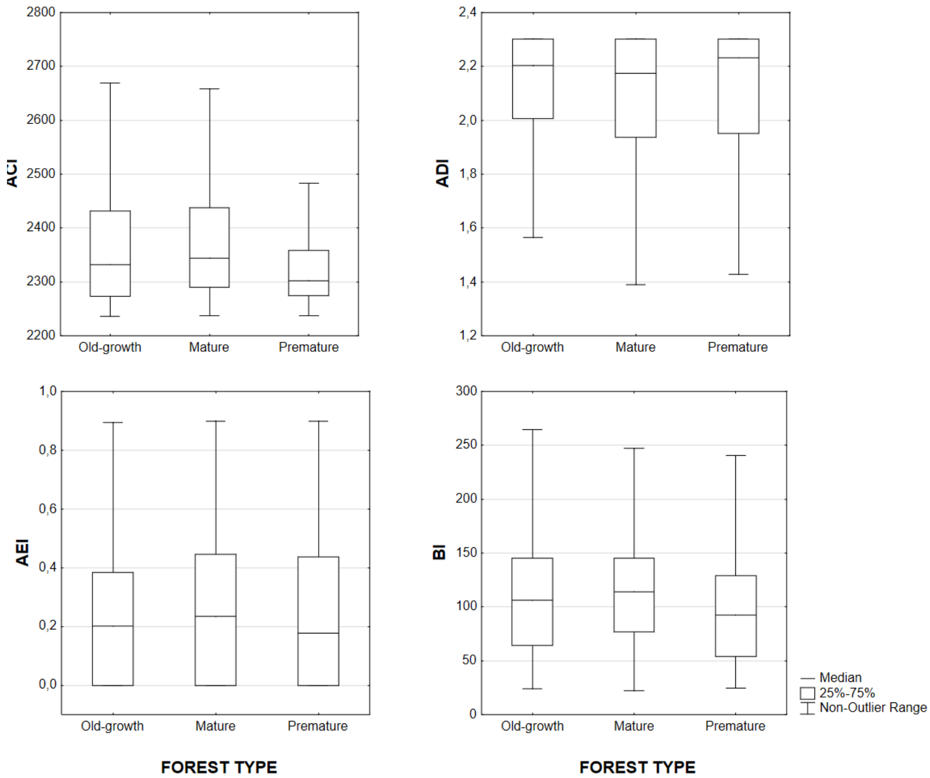

Fig. 2. Comparison of acoustic indices (ACI, ADI, AEI, BI) between three beech forest types (old-growth forests, mature managed forests and premature managed forests) during the breeding season in 2022.

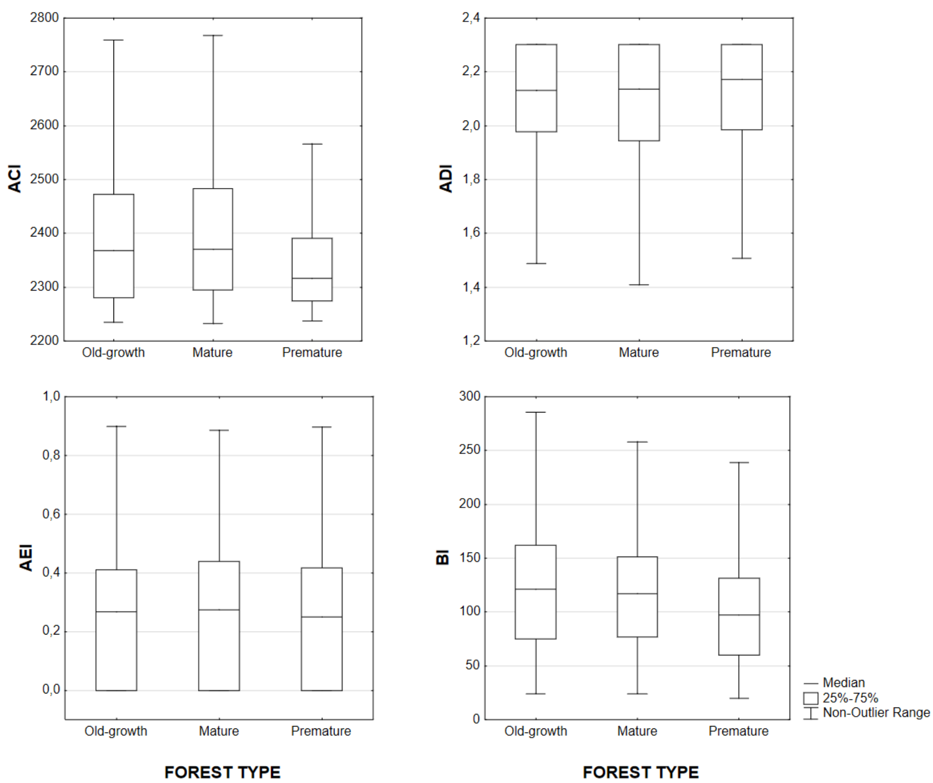

Fig. 3. Comparison of acoustic indices (ACI, ADI, AEI, BI) between three beech forest types (old-growth forests, mature managed forests and premature managed forests) during the breeding season in 2023.

mature managed forests, followed by the old-growth forests and lowest values in the mature managed forests. An even signal (either noisy across all frequency bands or completely silent) give higher values, whereas complex songs that span a wide range of frequency generate lower values (Bradfer-Lawrence et al. 2019). During the breeding season in 2023 the BI, ACI and AEI showed the highest values and the ADI – the lowest values in the old-growth forests. The results showed minimal differences between the acoustic index values in the mature managed forests and the old-growth forests during both breeding seasons. Higher bird species richness and abundances in these types of forests are probably explained by much higher amount of deadwood and old massive trees.

Studies from Germany revealed low species numbers and abundances in conventionally managed mature beech forests (20 species). In contrast, near-natural beech forests in old strict forest reserves have higher species number and a higher total abundance of breeding birds. The strict forest reserves of Heilige Hallen and Fauler Ort in north-east Germany contain beeches up to 350 years old, as well as numerous snags and root pads of fallen trees and large amount of deadwood. A total of 32 breeding species have been recorded in both sites. In managed beech forests of the same region, in which a proportion of "late" (terminal and disintegration) forest development phases was retained for conservation reasons, 27-34 species were breeding. These values were intermediate between those found in purely conventionally managed forests and in strictly protected reserves (Wesołowski et al. 2018).

Brunet et al. (2010) reviewed several studies from European beech forests and summarized that bird species richness in general is not affected by management intensity in beech forests, but management has a negative effect on the richness of hole-nesting species.

We found no significant difference in the bird species composition in the three beech forest types (Table 1). However, the following hole-nesting bird species were detected in the mature managed forests and the old-growth forests, but not in the premature managed forests: white-backed woodpecker (*Dendrocopos leucotos*), semi-collared flycatcher (*Ficedula semitorquata*) and spotted flycatcher (*Muscicapa striata*). Lesser spotted woodpecker (*Dryobates minor*) was detected only in the mature managed forests. White-backed woodpecker and semi-collared flycatcher are endangered species, which are included in the Red Data Book of Bulgaria (Georgiev & Iankov 2015, Spiridonov et al. 2015). Both species prefer forests with a predominance of old and dead trees (Melleti & Penteriani 2003, Aghababyan 2018, Georgiev et al. 2018, Gerdzhikov et al. 2018). Similarly, a comparison of the bird fauna in an old-growth reserve in Slovenia with an adjacent slightly managed forest found no significant difference in the richness and density of bird species; however, more hole-nesting birds, more species feeding on and under bark, more wood pigeons and many more rare and endangered species were found in the old-growth forest remnant (Boncina 2000).

Comparing the two breeding seasons (2022 and 2023) resulted in higher acoustic index values and more species of birds in 2023. There are different suggestions for the exact reason behind the temporal variations of bird populations (Ram et al. 2017). Therefore, we need more data collection and analyses to detect trends.

We conclude that ecoacoustics can be a valuable tool in a long-term avian diversity monitoring in mountain beech forests. Results showed that acoustic indices (ACI, ADI, AEI and BI) can be successfully used as proxies for biodiversity metrics and reflect differences in environmental quality. Our study contributes to gaining experience of using passive acoustic monitoring via ARUs for making forest management decisions, conservation of avifauna and minimizing the negative impact of forestry practices.

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