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Analysis of the Noise Pollution in the Bielański Forest NATURA 2000 Area in Light of Existing Avifauna (Warsaw, Poland)

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Abstract: There is no doubt that the NATURA 2000 network has been one of the most relevant tools for nature protection. However, the designated areas within the borders of large cities are subjected to many threats. Traffic noise takes on a very important role in this subject, posing the question of whether NATURA 2000 areas should be located in urban areas strongly affected by noise pollution. This particular topic was exposed and analysed at Bielański Forest NATURA 2000 (PLH140041), located in northern Warsaw, where changes in noise distribution for the years 2007–2017 were examined and described by two types of indicators (Lden and Lnight). The data sources used for the analysis were city road noise maps for 2007, 2012 and 2017. Additionally, sound intensity measurements were taken in two separate groups of hot-spots. The first of these comprised locations determined based on an inventory of avifauna; they represented different habitat types, and were characterized by the highest bird activity. The second group of hot-spots consisted of those designated along roads in order to identify the main sources of traffic noise. The obtained results confirmed the high noise-absorbing ability of the existing vegetation. The avifauna surveys covered 19 forest bird species. Five of them were considered to be the most valuable and rare elements of the local avifauna, whereas 14 appeared to be key species for the functioning of biocenosis and, at the same time, determine the uniqueness of the ecosystem. The study showed that the type of habitat rather than differences in noise levels determines the distribution and abundance of key species. Therefore, there is a necessity to focus on actions that guarantee the maintenance of the existing status in order to counteract habitat deterioration. The investigation confirmed the feasibility of creating these kinds of natural protected areas in large cities, despite their exposure to noise pollution.

Keywords: urban forest; NATURA 2000 area; soundscape; birds; biological diversity



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1. Introduction

Urban NATURA 2000 sites and other areas with unique natural values under legal protection are important parts of the green area systems of cities [1]. They play a key role in the shaping of urban biodiversity, as well as climate and hydrological conditions [2,3]. However, the location of NATURA 2000 areas in the city structure makes them vulnerable to many negative factors—both internal and external. The main internal (direct) threats that are also relevant to Warsaw NATURA 2000 sites [4,5] include: inadequate maintenance, the destruction of plants, the introduction of alien and invasive species that supplant native ones, and damage to and the killing or trading of protected wild fauna and flora species. These threats are often related to the additional function of these areas—recreation. Water, soil, air, light and noise pollution are the main indirect factors negatively impacting the environment. Other factors exhibiting the same effect are associated with land use changes, especially the growing urbanization of the areas adjacent to high value nature sites. New developments and a decrease in the biologically active surface have an adverse effect on

water conditions, e.g., a decrease of water retention and a lowering of the ground water levels. The main consequence of these common phenomena is the deterioration of the living conditions and natural habitats of some biota (especially birds).

The study focuses on one of the aforementioned threats—noise pollution. The evaluation of urban diversification in regards to noise pollution is crucial, not only for noise mitigation but also for the assessment of acoustic comfort, which is integral to the overall environmental quality [6]. The issue can be discussed on different scales, including agglomeration, the entire city, individual green areas, or even a single tree. On the urban and local level, there is a strong correlation between noise pollution and land cover. However, greener cities may not always be quieter. This is also a matter of the ratio of green space and built-up surfaces, as well as certain characteristics of green areas. It has been proven that lower noise levels may be achieved in cities with a higher extent of porosity and green space coverage [7]. The higher the density of the greenery that absorbs the acoustic waves expressed by the total surface of leaves the greater the noise level reduction [8]. This is particularly apparent in areas with a high share of forests and agricultural areas in combination with a small share of road network infrastructure [7]. At the same time, grass-covered grounds (lawns) appear to be rather inefficient in terms of noise reduction [8,9]. According to Van Renterghem [10], vegetation can reduce the noise level even by as much as 10 dB.

In cities, the state of the noise pollution from road traffic is presented on noise maps. They are the main source of data for the evaluation of the spatial extent and intensity of this phenomenon, and they provide us with valuable input into the decision making process in urban land use planning and management. One of the questions is what noise level can be acceptable for city green areas, such as parks and forests.

According to the World Health Organization [11], the noise level in recreational areas should not exceed 55 dB. The permissible levels of noise specified in the Polish Act concerning the average maximum traffic noise levels for recreational areas depend on the time of day and are limited to 68 dB during the day and 59 dB at night [12]. The issue is mostly discussed in relation to the human annoyance response, which is, however, a matter of subjective perception, depending on personal preference and opinions [13], specific types of sounds [14,15], the presence of trees natural features, and the tranquility of the area. Therefore, the results of research regarding the respondents' perception of the soundscape of green areas may differ slightly from the results obtained from noise maps and the measurements of sound pressure levels [16].

It can be assumed that noise pollution affects not only humans but also other users of urban spaces, such as wild animals, especially birds. One of the most important elements of the natural environment—from both the human perspective and that of ecosystem ecology—are undoubtedly birds. More than a hundred species (not counting incidental migrants) of these vertebrates have been observed in the cities of Central Europe [17]. It is not a coincidence that one of the two fundamental directives enabling the creation of NATURA 2000 areas is called the Bird Directive; birds are a group of animals of great interest. Their importance for the overall condition of ecosystems (and urban ecosystems) and the indicator of their general well-being cannot be overestimated [18]. The condition of urban avifauna can vary greatly depending on the geographic location, proximity to natural enclaves, availability of free migration corridors and many other factors, both biotic and abiotic—e.g., population size and the intensity of green infrastructure [19]. However, the vast majority of researchers point out that the general trend for urban avifauna is a decline in the richness of species and, consequently, biological diversity [17,20–22]. Again, various factors are cited as the cause, among which are the increasing noise levels [23–25]. Although the effect of noise on individual species varies, it has a negative effect on most species, even if some have managed to adapt to it. Birds respond to increased noise by becoming more skittish and stressed, and may be less likely to feed and breed. Noise may also hinder their ability to perceive danger. Regular exposure to urban noise may cause changes in bird communities and influences local distribution patterns [26]. The effects of noise are of great importance in urban areas because they can lead to a global

homogenization of bird communities, particularly if certain species fail to occupy noisy areas [27]. The increase in noise may also lead to urban bird communities being dominated by a limited number of noise-tolerant species [28]. Quoting Manzanares and Lucia [28], one motivation to study the effect of noise on urban bird communities is to promote urban avian diversity. Thus, it is necessary to understand how birds respond to anthropogenic noise. In the literature, different approaches are being used to achieve this. One of them consists of studying the relation between anthropogenic noise and the structure of birdsong which is important in terms of territorial defense and female attraction [24,26–29]. Taking into account the above facts, special attention should be paid to green areas within cities in terms of their importance as refuges for avifauna.

The main objective of the study is to analyse changes in traffic noise pollution in Bielański Forest, especially in its most valuable part—the NATURA 2000 site, in relation to the diversity of existing avifauna. The following questions were formulated: (1) What are the temporal and spatial variability of the traffic noise pollution in the area of Bielański Forest? (2) What is the distribution of the bird species composition, with a particular focus on rare species in relation to noise pollution? (3) What other factors may be associated with the current state of the bird communities in Bielański Forest?

2. The Study Area

The study concerns an area called Bielański Forest (the general area of the study), located in the northern part of Warsaw, in the immediate vicinity of the Vistula river. Bielański Forest is a remainder of the old Mazovian Primeval Forest, which covers almost 98% of the area of study. Two protected nature sites which overlap partly are designated within the forest: the Nature Reserve—Bielański Forest, with a total area of 130.35 ha and the NATURA 2000 (PLH140041) Special Area of Conservation, with an area of 129.84 ha [30]. The present research covered the latter.

Bielański Forest is an important part of the Warsaw Natural System (WNS). This is a concept that was introduced in Warsaw's Spatial Policy [31] in order to stabilize and enhance environmental processes in the city. The system consists of core and supporting areas, which are the major and most valuable structural elements for the climatic, hydrological and biological performance of the city. It is worth mentioning that core areas consist of areas with the highest natural and landscape values, being part of supra-regional natural connections, such as: the flood terraces of the Vistula River with characteristic plant communities, large and compact forest complexes, valuable meadows and grasslands, the northern and southern section of the Warsaw Escarpment, the most valuable areas of urban greenery, and urbanized areas with a biologically active surface area of no less than 70%. Supporting areas consist of areas of high natural and landscape values, supplementing the structure of the core areas and maintaining their spatial and functional connectivity, such as selected areas of urban greenery and forests, as well as selected urbanized areas with a biologically active surface area of no less than 60% [31]. The main elements of the system are linked by areas that form basic ecological connections. Bielański Forest is one of the core areas of WNS (Figure 1B). The importance of this area in the system and its level of biological diversity are dependent not only on the existing natural environmental resources but also on spatial connections with other biologically active terrains within the city, and those located in its vicinity. Unfortunately, the area is cut off from the Vistula valley (a supra-regional ecological corridor, Special Protection Area of Birds-SPAs NATURA 2000—PLB140004) by Wybrzeże Gdynskie Street—one of the main roads in this part of the city (Figure 1).

Forests cover about 17% of the total city area [32]. The distribution of forests is uneven. They are located mainly in the urban periphery. Bielański Forest is an important link in the natural system of the western outskirts of Warsaw. In its direct neighborhood there is a vast forest complex called Młociński Forest, and about 15 km further is the buffer zone of Kampinoski National Park. Animals which are intentionally migrating or straying from both of these areas, e.g., moose, can be found in Bielański Forest.

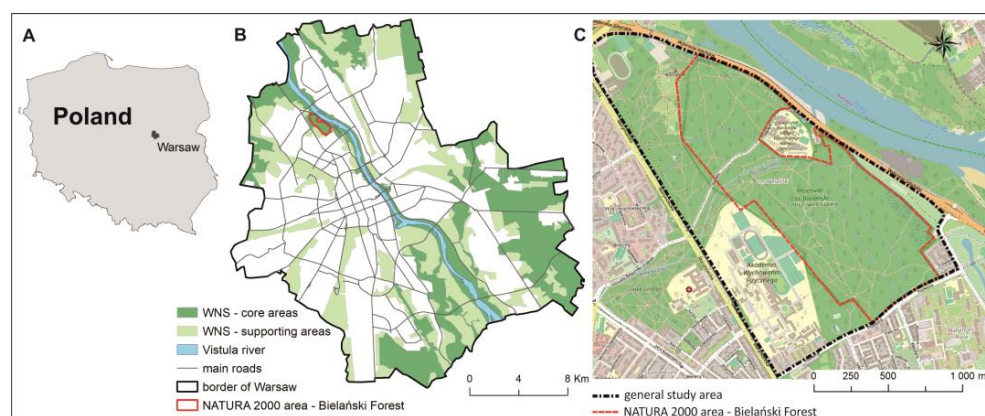


Figure 1. Area of the study (own elaboration): (A)—Warsaw on the map of Poland, (B)—Bielański Forest as an element of Warsaw Natural System (WNS), (C)—map of Bielański Forest.

The study area is diverse in terms of its geomorphology, water conditions and the structure of its habitats. There are four terraces running parallel to the Vistula River: a flood terrace, a higher terrace (an alluvial one), an ice valley of the Vistula, and a moraine plateau called Bielański terrace. The area of the flood terrace is closest to the Vistula, covering the valley of Rudawka Stream. The groundwater level in this area depends on the water level of the Vistula and ranges from 0.0 to 2.0 m below the ground level [5,33]. The area is covered with an elm-ash forest (*Ficario-Ulmetum*), which is rarely found in urban areas. The current water conditions are within the tolerance levels of the plant species occurring in this area. It is the most natural part of Bielański Forest. The area of the higher flood terrace is mostly covered by the oak-hornbeam forest (fertile variant, *Tilio-Carpinetum*) and, in a few locations, by an elm-ash forest (a drier variant of *Ficario-Ulmetum* with hornbeam). Numerous old trees can be found in these parts. In the southern part of the site, above the flood terrace, there is a sandy terrace of the Vistula proglacial valley. In some places, small elongated hills, now overgrown with pine trees, are still visible. The moraine plateau is the highest part of the site in terms of elevation. The terrace is bordered by an escarpment rising 6–15 m above the Vistula River valley. The groundwater level lies at a depth of 5–10 p.p.t., and locally even deeper [33]. This part of the area is covered with high oak-hornbeam forest of a drier variant (*Tilio-Carpinetum Typicum*). Some of the old oak stands are about 300–400 years old.

The water conditions in the studied area have been transformed due anthropogenic pressure, which is associated mainly with the development of multi-family houses and service establishments, as well as the construction and modernization of road and technical infrastructure in the surroundings of the study area. An irreversible decrease of the groundwater level had already been indicated in a study carried out in 1994 [4]. It concerned mainly the Bielański terrace (about a 1.5 m ground water level drop) and, to a lesser degree, the higher flood terrace (about 0.5 m). The smallest changes were observed in the area of the flood terrace. The threats of a disturbance in the hydrological conditions and falling trees leading to changes in the structure and composition of habitat's species as well as a loss of animal habitats, were pointed out by Skorupski et al. [4]. Therefore, the area was assessed as being susceptible to degradation [4]. Changes in the structure of plant communities mainly involving degradation towards drier variants of the oak-hornbeam forest indicate that this negative trend is continuing. Nevertheless, according to the natural evaluation of the landscape, the study area obtained a very high landscape value category [34].

It is estimated that Bielański Forest is a habitat for about 1000 species of invertebrates (the most valuable of which are great the capricorn beetle—*Cerambyx cerdo* and the hermit beetle—*Osmoderma eremita*), and 20 species of mammals—squirrels, several species of bats, deer, foxes, wild boars, and occasionally moose. The least numerous are reptiles and

amphibians, which have suffered from the progressive drainage of the area. Birds are the largest group of local fauna [4].

3. Materials and Methods

The study concerns the following two issues:

1. Changes in the distribution of noise pollution in the area of Bielański Forest with a particular consideration of the NATURA 2000 site.
2. The state of the avifauna in the most valuable part of the area—the NATURA 2000 site.

3.1. The Noise Pollution Analysis

The legal basis for the analysis of changes in noise pollution regarding land-use planning and management is the Ordinance of the Minister of the Environment of 14 June 2007 on the permissible noise levels in the environment [12]. It refers to the environmental noise to which primarily humans are exposed, in particular noise sensitive buildings and areas, such as residential areas, schools, hospitals, public parks and recreational and leisure areas. Despite the fact that the study area is under nature conservation as a nature reserve and a NATURA 2000 area, it is also a popular place of recreation and rest for the citizens of Warsaw. The impact of urban pressure on such areas in Warsaw and the Warsaw Functional Area is high [5,35,36]. In order to establish a long-term and sustainable spatial policy concerning the maintenance of existing recreational and leisure areas and the designation of new ones, the L_{den} and L_{night} indicators are used. The first of these refers to the long-term average sound level calculated for all of the days of the year during daytime-evening-night (L_{den}), whereas the latter is calculated for night time. The current maximum long-term noise levels for recreational and leisure areas affected by roads and railways are 68 dB for L_{den} and 59 for L_{night} , while in the case of noise affected by other facilities, they are 55 dB for L_{den} and 45 for L_{night} [12].

In order to characterize the changes in the noise pollution for the analyzed area during the period of 2012–2017, surface and percentage changes in the areas exposed to different sound levels were determined. Similar analyses were performed by the authors regarding residential areas for road and railway noise [37–39]. The main sources of noise pollution in the area of the study are two roads located along the eastern and southern borders (Wybrzeże Gdyńskie Street and Podleśna Street).

The original data were gained from road noise maps of Warsaw for 2007, 2012 and 2017 [40]. The noise maps for these years were made on the basis of the “French” NMPB-Routes-96 method (SETRA-CERTU-LCPC-CSTB) and the French XPS 31–133 standard, in accordance with Directive 2002/49/EC and the methodological foundations of geographic information science [41,42]. The maps were developed using numerical modeling based on point measurements carried out at the altitude of 4 m above ground level and for a calculation grid with vertical steps of 15 m [43].

The spatial data analysis for Bielański Forest was carried out using ArcGIS version 10.7.1, including the following procedure:

- generating rasters with road noise maps for 2007, 2012 and 2017 for L_{den} and L_{night} indicators;
- the georeferencing of the rasters according to the PUWG_92 mapped coordinate system;
- vectorization—changing raster graphics into vector graphics;
- the determination of changes in the alignment of the selected noise bands in 2007, 2012 and 2017, using the data management tool;
- the designation of areas of changes regarding the assumed noise levels using the coefficient for area variation, according to Formula (1).

$$W_{CA17-12(12-07)} = \left[\frac{A_{L_{den} (L_{night})2017(2012)} - A_{L_{den} (L_{night})2012(2007)}}{A_{a(n)}} \right] \times 100(\%) \quad (1)$$

where $A_{Lden(Lnight)2017(2012)}$ is the area affected by noise pollution at sequential ranges of values according to the Lden or Lnight indicators in 2017 or 2012 (ha), $A_{Lden(Lnight)2012(2007)}$ is the area affected by noise pollution at sequential ranges of values according to Lden or Lnight indicators in 2012 or 2007 (ha), A_a is the basic area of study (ha), and A_n is the NATURA 2000 area (ha).

A negative value of the W_{CA} index means a decrease in the area within the analyzed range of nuisance, and a positive value indicates an increase. In the case of the W_{CA} index for an Lnight noise level up to 60 dB, positive values are considered favorable while negative values stand for a negative trend. In the case of the index calculated for Lden, on the other hand, positive values for a noise level above 60 dB indicate a deterioration of conditions, and negative values indicate an improvement of the acoustic conditions.

In order to supplement the information on noise pollution which is available from the noise maps, field measurements of the sound levels were taken. This was accomplished by utilizing the digital sound analyzer model DSA-50 which allows the following characteristics to be measured:

- $L_{AI\ min}$ —the minimum value of the effective sound level,
- $L_{AI\ max}$ —the maximum value of the effective sound level,
- LAF—the temporary value of the effective sound level,
- L_{CMPK} —the maximum peak sound level.

The measurements were taken during the morning rush hours (7–10 a.m.) in June 2021 at two types of locations:

1. hot-spots determined on the basis of an avifauna inventory—HP1 ÷ HP6,
2. spots adjacent to roads that are a source of traffic noise, i.e., S7 Express Road—Wybrzeże Gdynskie Street from the east (R1-1 ÷ R1-6) and Podleśna Street from the south (R2-1 and R2-2).

3.2. The Surveys of the Avifauna

The previous inventories of avifauna in Warsaw were conducted during the breeding seasons and winter, in 1962–1975, 1988 and 2000 [44]. According to an inventory carried out in 2000, 42 species inhabited the Bielański Forest area (1–1.3 thousand pairs). The most numerous were starlings, blackbirds and chaffinches, whereas the most valuable for Warsaw were five species of woodpeckers, marsh tits, pied and red-breasted flycatchers. Over the period of 1988–2000, the total number of breeding species decreased slightly (from 44 to 42), though the diversity of the species composition has decreased significantly [44,45]. It is important to remark that the above-mentioned studies considered the avifauna of all of Warsaw and did not include detailed information on the bird distribution in Bielański Forest. The report contains the number of pairs per square meters (for common species), or the number of pairs (in the case of rare species or unevenly distributed ones). During the breeding seasons of 1992–1996 in the Bielański Forest Reserve, Mazgajski [46] analyzed changes in the numbers and nest sites of the great spotted woodpecker (*Dendrocopos major* Linnaeus, 1758) and the middle spotted woodpecker (*D. medius* Linnaeus, 1758). The population of the first species was relatively stable (10–14 pairs), with the latter being much more variable (1–2 pairs). The study indicated that the population of the analyzed species is related to the trees that woodpeckers choose as the sites of their nests. *D. major* prefers nesting in oaks, alders and pines, avoiding hornbeams. *D. medius* chooses predominantly oak. The positive effect of large, broadleaf trees on the bird population was, inter alia, confirmed by Kebrle et al. [47].

The presented studies on avifauna were focused on the area located within the boundaries of the NATURA 2000 site. A total of 18 surveys were carried out in May and June 2021, during the breeding season of the birds. Birds are most active during this period, usually marking their breeding territories by singing or its equivalent (“snares” of woodpeckers), and next building nests and raising their offspring. The observations were carried out at different times of the day: at dawn and in the morning, at daybreak, in the evening and at

dusk, and also—though less frequently—in broad daylight, when it is easiest to observe woodpeckers feeding their young.

Due to the protection status of Bielański Forest, the classical transect penetration method [48] was not applicable. In the first stage of the research, the whole study area was inspected whilst being mindful of its environmental variability. At the same time, all of the points where rare species were observed in the entire study area were marked, as well as sites with a particularly high activity of various species. All of the points where individuals of selected species were observed (or heard) were also marked. After analysing the collected material, the highest density and diversity of avifauna (hot-spots) were determined. The six indicated avifauna hot-spots represent the different habitat types of the studied area, and were characterized by the highest bird activity. We also narrowed down the range of species on which we focused in further stages of the study. Five of them—the black woodpecker, green woodpecker, red-breasted flycatcher, pied flycatcher and redwing—were considered rare or very rare in Bielański Forest, and all of their sightings in the entire study area were recorded. In the case of the fourteen remaining species—cuckoo, great spotted woodpecker, wren, hedge-sparrow, robin, blackbird, fieldfare, song thrush, chiffchaff, willow warbler, great tit, blue tit, nuthatch and golden oriole—the focus was on hot-spots (a range of approximately 3000 sq. m., and also the sounds heard from the surrounding areas) and observations of breeding success, i.e., the number of nests found and young observed.

Furthermore, the location and characteristics of the individual hot-spots for avifauna were analysed with regard to the various zones of noise pollution that had been established in the previous stage of the study.

4. Results

The spatial changes of the acoustic climate in Bielański Forest described by the W_{CA} index for time intervals (night— L_{night} and daytime-evening-night— L_{den}) were assessed for two periods, i.e., 2007–2012 and 2012–2017. The results concerning the night-time noise level over the years 2007–2012 indicate some improvement of the situation. There was a significant increase in the area at the lowest noise level (<50 dB) and a slight decrease in the area exposed to noise levels above 60 dB. The situation in terms of $W_{CA L_{night}}$ between the years of 2012 and 2017 was considered stable, although with a negative direction of changes. This is due to a decrease in the areas of low noise levels and an increase in areas exposed to high levels of noise. However, the differences in these changes are small and may be the result of the location of the measuring stations and the method of noise band interpolation. A similar situation occurred in the case of the $W_{CA L_{den}}$ index. The acoustic climate improved in the period 2007–2012, as the area of land with sound below 60 dB increased significantly. The area exposed to the highest noise (above 65 dB) also decreased. In the period of 2012–2017, the situation in terms of the L_{den} indicator deteriorated slightly. The areas exposed to noise levels below 60 dB decreased by about 6% in relation to the entire area of the site, whereas the areas that were exposed to noise levels of over 65 dB increased by about 4%. In the overall assessment, the acoustic climate should be considered stable, but with a slight negative trend (Table 1, Figure 2).

Taking into account the main scope of the study, including the assessment of noise pollution and the avifauna inhabiting the most environmentally valuable part of Bielański Forest, a similar quantitative analysis was carried out for the NATURA 2000 area. In the case of the $W_{CA L_{den}}$ index for the years 2007–2012, there was an increase in areas with a noise level below 60 dB and a decrease in areas exposed to a noise level above 65 dB. At the same time, there was an extension of the area exposed to a noise level in the range of 60–65 dB. In the years 2012–2017, the situation was less favorable, because the extent of the areas affected by the highest noise levels increased slightly, while the area with the lowest sound level decreased to a medium extent.

Table 1. Changes in the areas exposed to road noise according to the L_{night} and L_{den} indicators in 2007, 2012 and 2017 within Bielański Forest (our own elaboration on the basis of maps of noise pollution in Warsaw).

Indicator	Range of Noise Levels (dB)	Symbol	Area Exposed to Road Noise in the Individual Years (ha)			$W_{CA12-07}$ (%)	$W_{CA12-17}$ (%)
			2007	2012	2017		
L_{night}	<50	$A_{L_{night}<50}$	19.10	93.56	83.57	27.51	−3.70
	50–55	$A_{L_{night}50-55}$	121.51	95.64	103.43	−9.56	2.89
	55–60	$A_{L_{night}55-60}$	76.65	48.25	48.13	−10.49	−0.04
	60–65	$A_{L_{night}60-65}$	31.41	20.03	17.74	−4.20	−0.85
	65–70	$A_{L_{night}65-70}$	11.76	5.52	8.94	−2.31	1.27
	>70	$A_{L_{night}>70}$	2.57	0.00	1.19	−0.95	0.44
L_{den}	<55	$A_{L_{den}<55}$	7.03	26.94	15.66	7.36	−4.18
	55–60	$A_{L_{den}55-60}$	64.18	118.92	110.92	20.23	−2.96
	60–65	$A_{L_{den}60-65}$	115.40	69.99	78.57	−16.78	3.18
	65–70	$A_{L_{den}65-70}$	51.07	36.43	36.90	−5.41	0.17
	70–75	$A_{L_{den}70-75}$	16.72	8.73	15.90	−2.95	2.66
	>75	$A_{L_{den}>75}$	8.60	1.99	5.05	−2.44	1.13

Grey cells indicate a negative trend.

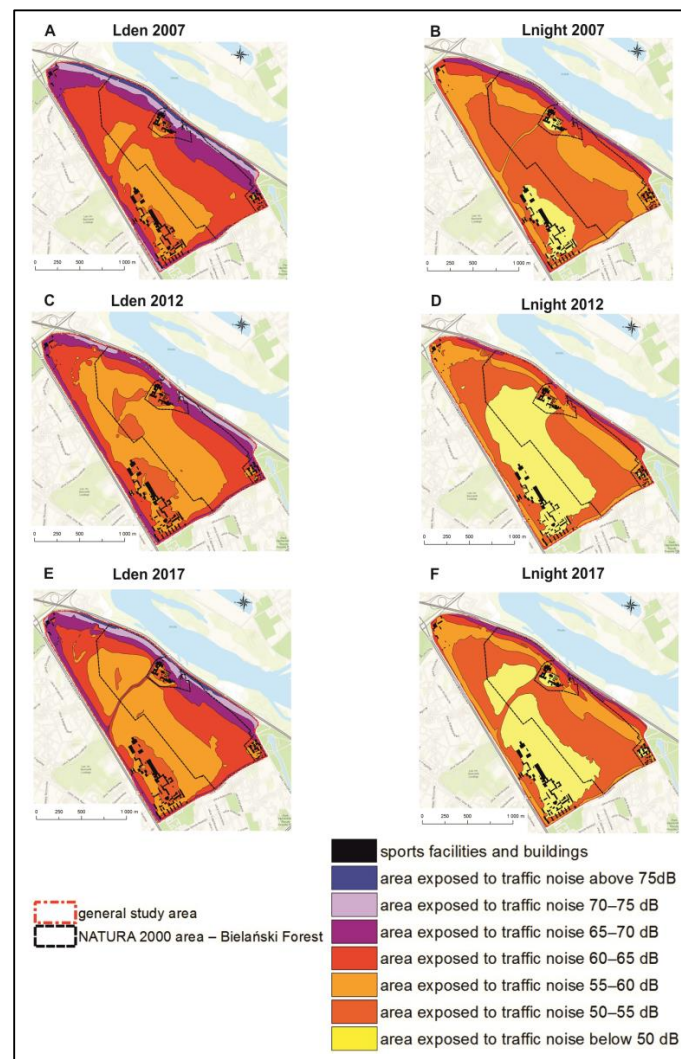


Figure 2. Changes in the areas exposed to road noise, as illustrated by the L_{night} and L_{den} indicators in 2007 (A,B), 2012 (C,D) and 2017 (E,F) within the study area (our own elaboration on the basis of maps of noise pollution in Warsaw).

The analysis of the $W_{CA\ Lnight}$ index for the years 2007–2017 indicated minor changes with regard to the areas of high noise levels (around $\pm 2\%$). Major changes, on the other hand, were observed in the case of the areas with the lowest noise level (<50 dB). In the period 2007–2012, the least noise-polluted area expanded by 35%, but in the years 2012–2017 it shrank by 10%. The reverse situation was observed in the case of the noise levels within the range of 50–60 dB. In the years of 2007–2012, the affected area decreased by 30%, but in the years 2012–2017, it increased again by about 10% (Table 2, Figure 2).

Table 2. Changes in the areas exposed to road noise according to the L_{night} and L_{den} indicators in 2007, 2012 and 2017 in Bielański Forest NATURA 2000 (our own elaboration on the basis of maps of noise pollution in Warsaw).

Indicator	Range of Noise Levels (dB)	Symbol	Area Exposed to Road Noise in the Individual Years (ha)			$W_{CA12-07}$ (%)	$W_{CA17-12}$ (%)
			2007	2012	2017		
L_{night}	<50	$A_{L_{night}<50}$	0	45.40	32.42	34.97	−10.00
	50–55	$A_{L_{night}50-55}$	69.36	53.58	65.46	−12.15	9.15
	55–60	$A_{L_{night}55-60}$	43.95	21.45	22.31	−17.33	0.66
	60–65	$A_{L_{night}60-65}$	11.04	8.42	5.80	−2.02	−2.02
	65–70	$A_{L_{night}65-70}$	4.66	0.99	3.81	−2.83	2.17
	>70	$A_{L_{night}>70}$	0.83	0	0.04	−0.64	0.03
L_{den}	<55	$A_{L_{den}<55}$	0	9.65	1.07	7.43	−6.61
	55–60	$A_{L_{den}55-60}$	25.24	71.34	61.23	35.51	−7.79
	60–65	$A_{L_{den}60-65}$	73.20	33.65	46.82	−30.46	10.14
	65–70	$A_{L_{den}65-70}$	22.70	12.99	13.92	−7.48	0.72
	70–75	$A_{L_{den}70-75}$	5.22	1.99	5.28	−2.49	2.53
	>75	$A_{L_{den}>75}$	3.48	0.22	1.52	−2.51	1.00

Grey cells indicate a negative trend.

The changes in the noise pollution during the analyzed period can also be illustrated by means of selected equal-sound pressure level contours (Figure 3). With regard to the previous and current maximum sound levels for recreational areas [12], spatial analyses were carried out for the following noise bands:

- 60 dB and 70 dB for L_{den} .
- 50 dB and 60 dB for L_{night} .

It can be concluded that, in the case of L_{den} :

- the noise level of 70 dB was generated only from the side of Wybrzeże Gdyńskie Street; the course of the band in the years 2007–2017 was rather stable, and small changes occurred along the north-eastern border of the NATURA 2000 site;
- the course of the sound pressure level contour 60 dB varied in time; the most favorable situation was observed in 2012.

In the case of the noise level calculated for night time (L_{night}), it must be stated that:

- Wybrzeże Gdyńskie Street was the main source of noise affecting the study area
- the course of the noise band 60dBA in the years 2012 and 2017 was rather stable and the changes in relation to the state as of 2007 amounted to a maximum of 50 m;
- the expansion of the area of the 50 dB noise band in the period 2012–2017 was also stable, especially in the northern and southern part of the NATURA 2000 site; in 2007, there were no areas exposed to noise levels below 50 dB.

Data concerning the noise pollution presented on the acoustic maps were supplemented with noise measurements taken in the selected locations within the studied area of the NATURA 2000 site (Table 3). The measurements of the noise levels represented by a temporary value of the effective sound level (the average sound value for a measurement) were performed for the hot-spots along the two main roads (R1-1 ÷ R1-6, R2-1 and R2-2) and also the hot-spots connected with areas hosting the most valuable species of birds (HP 1 ÷ HP 6). The conclusion suggested by the field study is that the obtained results are

in line with the average noise values included in acoustic maps for 2017. The measurement locations are indicated in Figure 3.

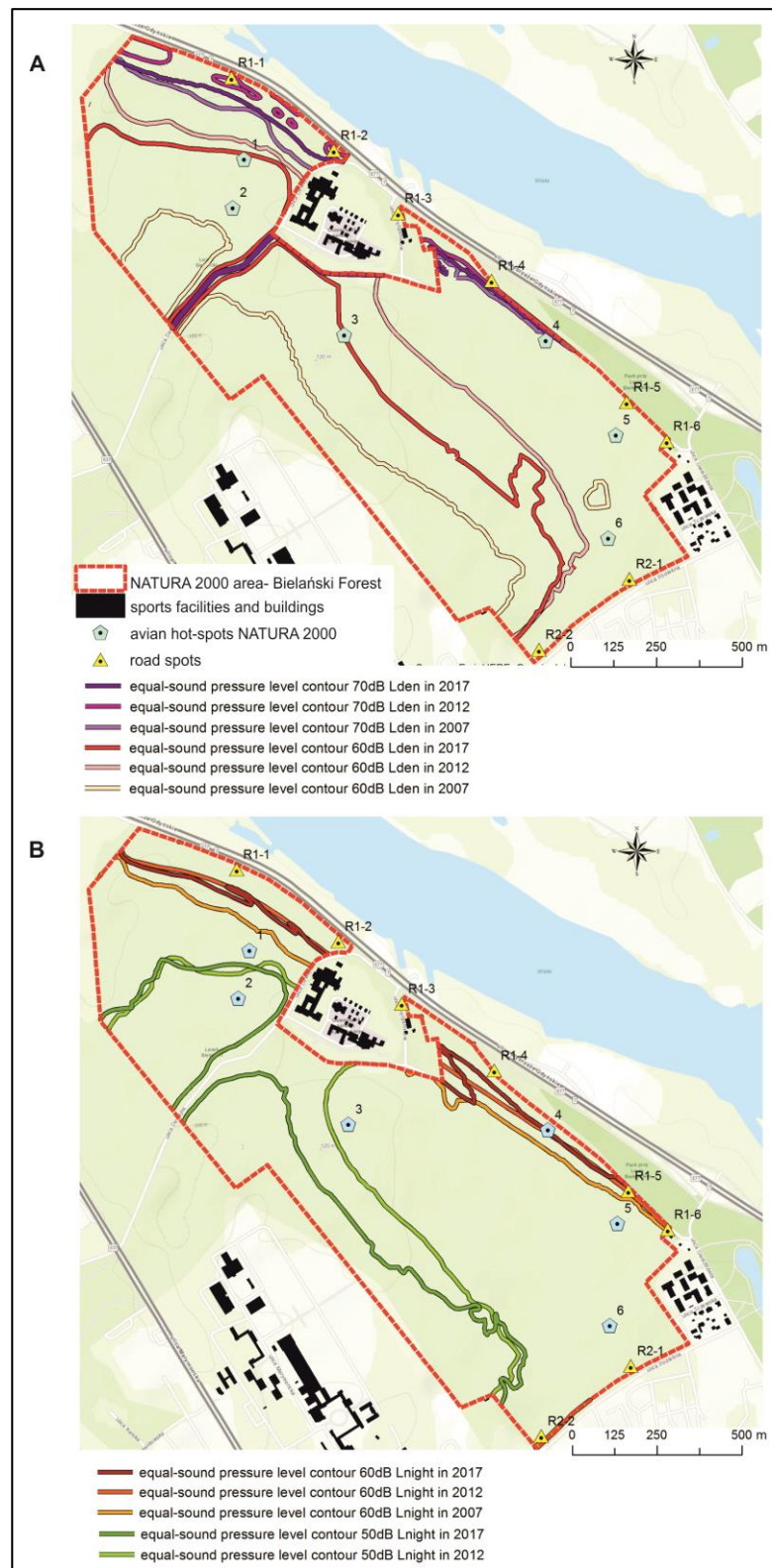


Figure 3. Changes in the location of the selected equal-sound pressure level contours in the years 2007, 2012 and 2017; (A)—for Lden, and (B)—for Lnight.

Table 3. The results of sound level measurements performed in June 2021 for avian hot-spots and road spots within the NATURA 2000 area (our own elaboration).

Main Groups of Measurement Spots	Measurement Spot Identifier ¹	L _{AI min} (dB)	L _{AI max} (dB)	L _{AF} (dB)	L _{CMPK} (dB)
Avian hot-spots	HP 1	49.5	70.8	59.7	86.9
	HP 2	43.8	62.6	52.6	84.2
	HP 3	45.2	67.9	47.8	92.5
	HP 4	47.4	113.3	63.3	138.1
	HP 5	48.6	88.5	54.0	115.3
	HP 6	41.5	72.0	65.7	89.9
Road spots for Wybrzeże Gdynskie Street	R 1-1	63.4	84.0	65.5	94.1
	R 1-2	61.4	70.6	68.2	89.6
	R 1-3	63.9	84.5	66.5	98.2
	R 1-4	63.6	70.2	65.8	92.9
	R 1-5	55.5	94.2	69.0	121.3
	R 1-6	56.3	69.9	59.9	90.6
Road spots for Podleśna Street	R 2-1	49.1	69.9	56.6	93.5
	R 2-2	43.7	69.9	56.6	89.8

¹ The measurement spots are indicated in Figure 3.

As stated earlier, birds are a good indicator of progressive environmental changes, so they were considered a suitable group for studying the impact of noise on biocenosis. Species that are rare in Poland as a whole, and which are sporadically found in urban areas are considered to be the most important from the point of view of the natural attractiveness of the studied area. The distribution of the five bird species selected for the study, which were considered rare or very rare in Bielański Forest, is shown in Figure 4.

The black woodpecker (*Dryocopus martius* Linnaeus, 1758), considered to be one of the symbols of Bielański Forest, and a species which are rarely recorded during the breeding season within large cities -was encountered nine times: twice in the direct vicinity of avian hot-spots II, III and VI and, in other cases, in places overgrown with old trees with a large share of pine trees. The green woodpecker (*Picus viridis* Linnaeus, 1758) was observed seven times, mostly in the immediate vicinity of the Rudawka stream, in the alder or riparian forest. One of the observations was made in hot-spot IV. The least frequently observed species among those selected for the study was the red-breasted flycatcher (*Ficedula parva* Bechstein 1794), which was observed three times in the vicinity of hot-spots IV and V. The pied flycatcher (*Ficedula hypoleuca* Pallas 1764) was observed ten times, primarily within the alder or riparian forest near Rudawka stream, and in the vicinity of hot-spots III and V. The redwing (*Turdus iliacus* Linnaeus, 1758) was observed nine times, near hot-spots I, III and VI, and at several other points in the study area.

The study of the 14 species which were considered representative for Bielański Forest, and the most important from the point of view of the functioning of its biocenosis and attractiveness for nature lovers focused on hot-spots (see: Materials and Methods). The results of the observations are summarized in Table 4.

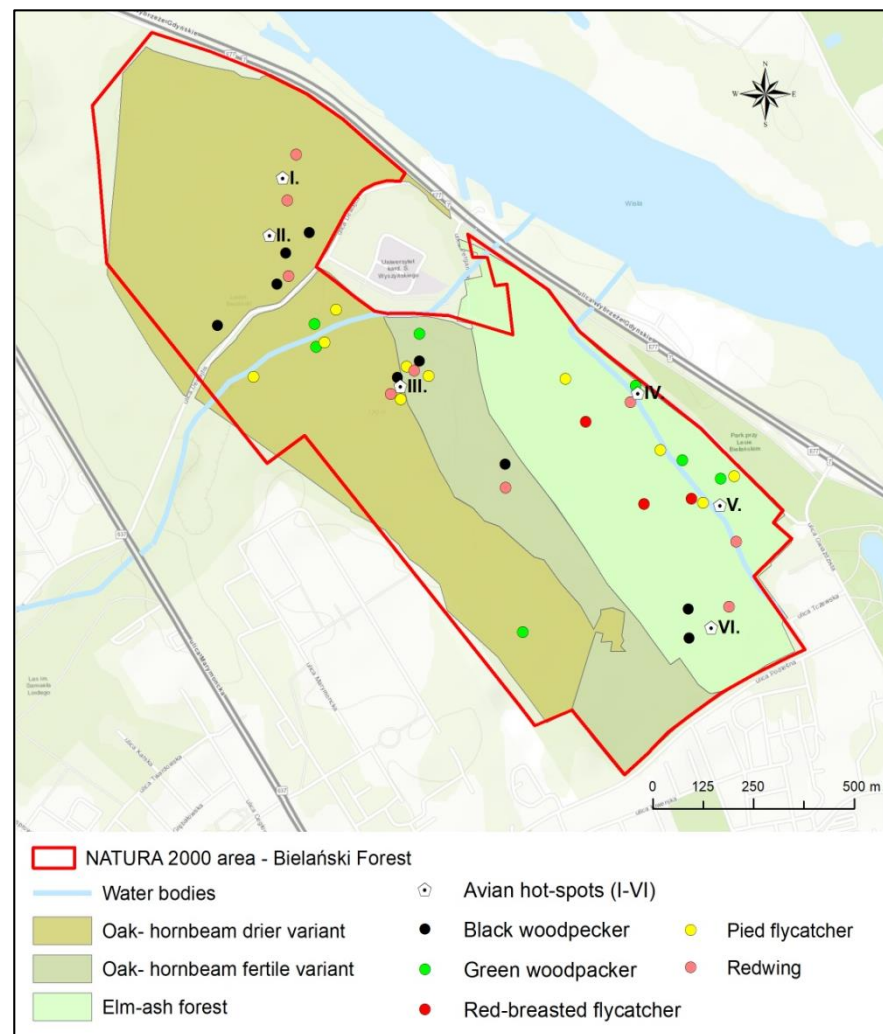


Figure 4. The locations of the five bird species considered particularly important for the biocenosis of Bielański Forest.

Table 4. The results of the bird observations at the hot-spots.

Species	Breeding Status ¹	Estimated Number of Individuals Per Avian Hot-Spot ²	Remarks
Cuckoo <i>Cuculus canorus</i> Linnaeus, 1758	B	I-2; II-4; III-0; IV-0; V-5; VI-2	Does not build nests, breeding success dependent on other species to which it sends eggs
Great spotted woodpecker <i>Dendrocopos major</i> Linnaeus, 1758	B	I-6; II-15; III-6; IV-6; V-11; VI-2	In hot-spots I-V from 1 to 3 hollows with chicks
Wren <i>Troglodytes troglodytes</i> Linnaeus, 1758	US	I-0; II-4; III-2; IV-2; V-1; VI-0	
Hedge sparrow <i>Prunella modularis</i> Linnaeus, 1758	PB	I-4; II-0; III-3; IV-0; V-2; VI-2	
Robin <i>Erithacus rubecula</i> Linnaeus, 1758	B	I-3; II-8; III-1; IV-4; V-10; VI-2	In hot-spots II and V juveniles were observed shortly after leaving the nest

Table 4. Cont.

Species	Breeding Status ¹	Estimated Number of Individuals Per Avian Hot-Spot ²	Remarks
Blackbird <i>Turdus merula</i> Linnaeus, 1758	B	I-9; II-1; III-3; IV- 16, V-2, VI-3	In hot-spot I the nest with 8 young was found, in hot-spot IV 2 nests with 5 and 6 young respectively
Fieldfare <i>Turdus pilaris</i> Linnaeus, 1758	B	I-2; II-8; III-11;IV-0; V-3; VI-9	In hot-spots II and VI nests with young were found, their number was estimated
Song thrush <i>Turdus philomelos</i> Brehm, 1831	B	I-8 *; II-2; III-6; IV-1; V-9; VI-2	* nest with 6 eggs, in hot-spot V nest with 6 young
Chiffchaff <i>Phylloscopus collybita</i> Boie, 1826	PB	I-1; II-3; III-2; IV-2; V-2; VI-0	
Willow warbler <i>Phylloscopus trochilus</i> Linnaeus, 1758	B	I-0; II-8; III-1; IV-2; V-2; VI-2	In hot-spot II the nest with 6 chicks
Great tit <i>Parus major</i> Linnaeus, 1758	B	I-10 *; II-2; III-20 *; IV-10 *; V-2; VI-10 *	* estimated abundance, young heard from occupied hollows
Blue tit <i>Cyanistes caeruleus</i> Linnaeus, 1758	B	I-0; II-10 *; III-2; IV-0; V-2; VI-10 *	* estimated abundance, young heard from occupied hollow and nest box
Nutchatch <i>Sitta europaea</i> Linnaeus, 1758	PB	I-2; II-0; III-2; IV-3; V-2; VI-1	
Golden oriole <i>Oriolus oriolus</i> Linnaeus, 1758	B	I-1; II-3; III-0; IV-2; V-5; VI-1	In hot-spot V 4 young shortly after leaving the nest

¹ B—breeding (nests found, adults observed with food in their beak or juveniles); PB—probably breeding (mating behavior observed, suitable nesting biotope); US—undetermined status (observations during feeding or voice recording); ²—no. of hot-spot – no. of individuals; * indicates the additional explanation to the presented results, which acts as a supplement to better present the specific situation found in the peculiar site of the study area.

5. Discussion

The analysis of the acoustic maps for the years 2007–2017 (Figures 2 and 3, Table 2) and the results of the measurements carried out during the field work in 2021 (Table 3) confirmed that Wybrzeże Gdyńskie Street (checkpoints R1-1 ÷ R1-6) is the main source of noise pollution that affects Bielański Forest. Car traffic on Podleśna Street has a much smaller impact on the studied area. The impact of Marymoncka Street, which is located on the west of the Bielański Forest, is also insignificant. Road noise is variable over time and depends on many factors, such as: the road surface characteristics, the geometry and cross-section of the road, the traffic parameters and conditions, the speed of the vehicles, the type and shape of the surroundings, the weather conditions and others [49–51]. According to the measurements taken in the Wybrzeże Gdyńskie Street, there were 36,969 vehicles moving towards the city center and 37,743 in the opposite direction on an average day in 2012; in 2017, there were 47,647 and 48,082, and in 2019 there were 49,276 and 48,545 respectively [52]. However, in spite of the gradual growth in the daily traffic, the acoustic climate of the analysed area has remained quite stable. The slight improvement in the acoustic climate between 2007 and 2012 may be partly explained by the restoration or replacement of the road surface carried out in 2012 [53], whereas the deterioration of the acoustic conditions in 2017 may have been caused by the increase of the road traffic and a progressive decline in the technical state of the road. In 2020, some construction works took place that may also have resulted in a slight reduction of the noise pollution. According to the obtained results, the spatial range of high noise pollution was limited to the zone located along the main road. Negative changes were limited to a small area. This confirms

the high noise-absorbing ability of the existing vegetation. It is also in line with the studies regarding the relationship between land cover and noise reduction [7–10].

As has already been stated in the initial part of the study, the negative impact of urban noise on birds has been reported by other scientists [23–28,54]. However, the responses to noise can vary between species and the biotope in which a particular avifauna assemblage occurs [55]. The results of the study for five species (Figure 4) which were considered the most valuable in the Bielański Forest area are inconclusive. One of the birds—the red-breasted flycatcher—was observed so sporadically that no firm conclusions could be drawn in its case. It is worth mentioning, however, that the species in question—very few in the scale of the whole country—have been present in Bielański Forest since at least 1988 [44]. It seems symptomatic, however, that the locations of its sightings were wet meadows and alder woodlands, which are consistent with the general habitat preferences of this species [56], even though they are located in a part of the reserve with a strong acoustic impact from the expressway. This could suggest that, for this species, habitat requirements take precedence over possible adverse noise impacts. A similar trend can be observed in the case of the pied flycatcher (which prefers dense deciduous forests, especially oak), while the black woodpecker seems to avoid areas with the highest intensity of acoustic stimuli, although according to its biology, it prefers old coniferous forests, especially with pine and spruce. This is a tendency which has been observed for years with regard to this species in the study area [46]. In the case of the green woodpecker and redwing, it is difficult to draw any scientifically justified conclusions. The analysis of the occurrence of the 14 species which were found to be the most important from the point of view of the functioning of the whole biocenosis is more interesting, seeing as their abundance is high enough to draw more far-reaching conclusions (Table 4).

The conducted research—apart from the analysis of the impact of the noise intensity on the occurrence of key species of avifauna—made it possible to determine the trends in the settlement of the research area by birds in the last 20 years. In 2001, a monograph devoted to the birds of Warsaw [44] was published with detailed information on the abundance and occurrence of individual species within the city. The comparison of the data contained therein with the results of observations from 2021 (Table 4, Figure 4) is a valuable material illustrating the trends in the settlement/withdrawal of various species from areas subject to increasing anthropopressure. In the case of five species—the fieldfare, nuthatch, chiffchaff, willow warbler and song thrush—no significant changes in terms of their abundance in the area under study were found. The aforementioned birds seem to form stable populations in urban green areas, and from year to year, they became a typical element of Warsaw’s avifauna. A very interesting tendency was noted in the case of the redwing—the first breeding of this species in Bielański Forest was observed only at the end of the 20th century [44]. The results of observations from 2021 indicate that it now certainly nests in the studied area, and its population has increased significantly. A minor, though noticeably similar, tendency was also noticed in the case of the cuckoo, black woodpecker (in 2001, there was probably only one breeding pair in the Bielański Forest), and wren. The green woodpecker, for which a downward trend in abundance (two breeding pairs) was shown in the late 20th century, certainly maintains this abundance status and, in all likelihood, is more numerous. A similar situation may be stated for the great spotted woodpecker. Mazgajski [46] writes that, from the 1960s to the end of the 20th century, a population size of 10–14 pairs was maintained; this can be assessed as being higher in 2021. In the case of woodpeckers, an important element that may affect their occurrence in the studied area is the maturation of the stand and a greater number of available hollows (the green woodpecker does not forge them on its own, but uses already existing ones) and trees suitable for woodpeckers which create their own (in the case of the other two species). In the case of the hedge sparrow, the greatest obstacle to the development of urban populations was identified by Luniak et al. [44] as the decrease in suitable breeding biotopes. It seems that this problem does not occur in Bielański Forest, hence the population of this species remains more or less stable. The great tit is the most

common of the investigated species, with its population appearing to be stable. A similar situation occurs in the case of the golden oriole;—Bielański Forest was and still is one of the sites with the biggest population of this species within the administrative borders of Warsaw. The population of the blue tit also seems to be stable, although in the case of this species, there is a clear correlation between the numbers in specific zones of the problem area and the number of available nest boxes. This is an aspect which is often highlighted in the literature [44]. Robins and blackbirds are fairly common species throughout the study area, which is in agreement with the status 20 years ago, and indicates that the populations of both of the mentioned species are stable.

The analysis of the data concerning the noise level (Table 3) would suggest that hot-spot IV, with the highest maximum value of the effective sound level, with a peak of 138.1 dB, will be avoided by birds. Indeed, five species out of the 14 surveyed were absent, i.e.,—the blue tit, chiffchaff, fieldfare, hedge sparrow and cuckoo. However, the remaining nine were present, and species such as the great spotted woodpecker, blackbird, green woodpecker and red-breasted flycatcher were found in large numbers within or adjacent to the hot-spot. The differences in the species composition between the remaining hot-spots were small, although more nests were found in some than in the others (e.g., hot-spot II, with three great spotted woodpecker hollows).

The analysis of the noise distribution seems to indicate that the factor determining the distribution and abundance of the key species in the study area is the type of habitat, rather than the differences in noise levels, which appear to be less important. The last above-mentioned conclusion emphasizes the importance of maintaining the habitats preferred by birds. In the case of Bielański Forest, the ground water level is the key factor determining the quality and occurrence of elm-ash forests and oak-hornbeam forests. However, the water conditions in the forest depend not only on land-use in this area but also in its surroundings. Recommendations concerning land-use planning include actions that are also set up in the current Protection Plan of Bielański Forest Reserve and NATURA 2000 [57], and other related publications [5,34,36]. In the case of areas located in the western and eastern vicinity of Bielański Forest, it is important to limit new developments and introduce specific solutions for sustainable water management that increase bioretention and small-scale water retention. It is also important to maintain the ecological connectivity of the area, especially in the north-western direction toward Młociński Forest and onwards to Kampinoski Forest, inter alia along the area of the NATURA 2000 site PLB140004 PLB1—The Middle Vistula River Valley. This objective also requires the maintenance of existing green areas and introduction of various new types of green areas, including forests and recreational areas.

6. Conclusions

The final conclusions are as follows:

1. Establishing NATURA 2000 areas in cities is justified by the necessity of protecting and maintaining their biodiversity, including valuable and unique plant and animal species, as well as biotops occurring in the given area. At the same time, the natural protection of the given areas is sometimes of great significance for the functioning of the environmental system of the entire city. This pertains not only to the biological subsystem, but also to the climatic and hydrological subsystems. These areas are also used for recreation. The NATURA 2000 area of Bielański Forest is an example of an object with multifunctional significance. The condition of its natural environment is dependent on local and supralocal factors.
2. The analyzed area is located in the direct proximity of the main city roads, and is within the impact zone of increased noise levels. The analysis of the changes in the noise pollution carried out for the years 2007–2017 indicates that despite the gradually increasing traffic, the negative changes in the scope and intensity of the noise are not significant. This results mainly from the existing vegetation cover. Dense

and deciduous forests significantly reduce noise pollution, even at a relatively short distance from roads.

3. The inventory of the avifauna in the area of Bielański Forest confirms the occurrence of many valuable species. The state of the population of the majority of the analyzed species is relatively stable. The key bird species of the NATURA 2000 study area seem to have adapted to urban conditions. A strong correlation between the noise distribution and certain species was not observed.
4. Habitat type is the determining factor for the distribution and abundance of keystone species in the study area—noise levels seem to be less important. Therefore, in the case of Bielański Forest, it is necessary to focus on actions that guarantee the maintenance of the existing status and counteract the deterioration of habitats, especially those of the riparian forests.

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