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Factor analysis of the Zaporizhzhia wind park impact on bats based on the index of their activity and dynamics of species diversity

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Abstract. Based on the studies in the period of 2010-2021, there was obtained some information on the behavior of bats and their species composition at the Zaporizhzhia wind park in the Zaporizhzhia Region, Ukraine. In the study area, there was established the presence of 10 species of bats belonging to 7 genera. The most complete results were obtained in 2019, when 4 field research methods were used, 28 expedition trips were carried out and 4177 bat signals were recorded. In total, the information on 43938 bat signals was collected in 2010-2021. The total operating time of the ultrasonic detectors was 4565 hours. There were calculated indices of the voice activity of bats for three research methods by seasons, different functional zones and phases of the annual cycle of animals. Surveys on transects with the geo-position of each recorded signal made it possible to characterize the distribution of bats over the territory of the wind farm, and the use of the Kernel Density tool allowed to differentiate the wind farm site of the Zaporizhzhia wind park into the zones that are conditionally safe for bats and high-risk zones. There have been determined the periods of the year and time periods of night activity, in which it is advisable to use measures to minimize the negative impact. Using international and own experience, there have been proposed methods for repelling bats away from the wind turbines.

1. Introduction

The complexity of the instrumental study of bats against the background of the legal requirement to assess the impact of WPP on bats makes the organization and implementation of monitoring of their existence conditions in technogenic areas unconditionally urgent.

National legislation clearly declares the need for such work, but unfortunately, there is no methodological standard for collecting and analyzing information [1]. That is why researchers of bats on the territories of wind parks are forced to rely on international practices [2–6]. This paper proposes some methods for carrying out bat research on the territory of the Zaporizhzhia wind park and the results of their application.



2. Survey techniques and standards

The study of bats was carried out on the territory of the Zaporizhia wind park (the Melitopol District, the Zaporizhzhia Region, Ukraine) in 2010-2021 (figure 1).

The main goal of research on the territory of the Zaporizhia wind park was to study the vocal activity of bats in order to find out changes in the ecological state of animal populations, potentially occurring because of the construction and operation of the wind park. The methodology was developed according to the recommendations of "Surveillance and Monitoring Methods for European Bats Guidelines produced by the Agreement on the Conservation of Populations of European Bats (EUROBATS)" [3]. The experience of carrying out similar studies in Germany was also used [4, 6].

Three types of ultrasonic detectors were used to record bat signals: Pettersson D240x (2 units), Pettersson D500x (1 unit) and LunaBat DFR-1 Pro (1 unit). Scanning of the territory was carried out using four methods.

3. Vantage Point Surveys (VP)

In total, 9 vantage points (VP) are located within the wind park (figure 1). A Pettersson D240x detector was used at each vantage point. The operating time of the detector was 10 min. The most complete work was carried out in 2019, when 28 expedition trips to the territory of the wind park were carried out from March 20, 2019 to November 13, 2019. The total time of work at a VP for one trip was 90 minutes, in total for a season - 2430 minutes. In total, 454 echolocation calls were recorded by the detectors.

4. Collection of information on transects

In total, 18 transects have been allocated in the Zaporizhia wind park, which are located along the lines of installation of wind turbines. Figure 1 shows a GPS track that covers all transects. The passage of the transects was carried out at a vehicle speed of 20-25 km/h. This speed allows to reduce the number of extraneous sounds and successfully record the bat echolocation calls. To work on transects, the LunaBat DFR-1 PRO ultrasonic detector with an external microphone (ME-4x in IP65/67 plug; cable length 1.5 m; figure 2) was used. The microphone was installed on a special plate fixed to the roof of the expedition vehicle. In total, 28 expedition trips were carried out in 2019. The total number of bat echolocation calls was 694. The length of individual transects was in the range of 1.6-10.6 km, and their total length was 91.1 km. Operating time for one night was about 6 hours (about 170 hours in 2019).

4.1. Static detector surveys at ground level

At the stationary vantage point, there was used the Pettersson D500x detector, which automatically and in a wide range recorded the echolocation calls of bats in the interval 18:00-06:00 (figure 3). The detector worked 28 nights in 2019. The total operating time was 336 hours. A total of 2882 bat signals were recorded.

4.2. Static detector surveys at height

Usually, the researcher is at the ground level during surveys, and an assessment must be made for the dangerous heights of the movable wind turbine. Accordingly, studies are needed at heights of more than 30-40 m above the ground where the wind turbine is installed. In 2017, for the first time in Ukraine, a broadband automatic detector Pettersson D500x was installed on the meteorological mast of the Zaporizhia wind park at a height of 42 m (figure 4). The detector setup was the same as during the surveys on the ground. In total, 5 nights of space scanning were carried out during the period of active autumn migration on September 19-25, 2017. There was obtained information about 22 echolocation calls of bats.

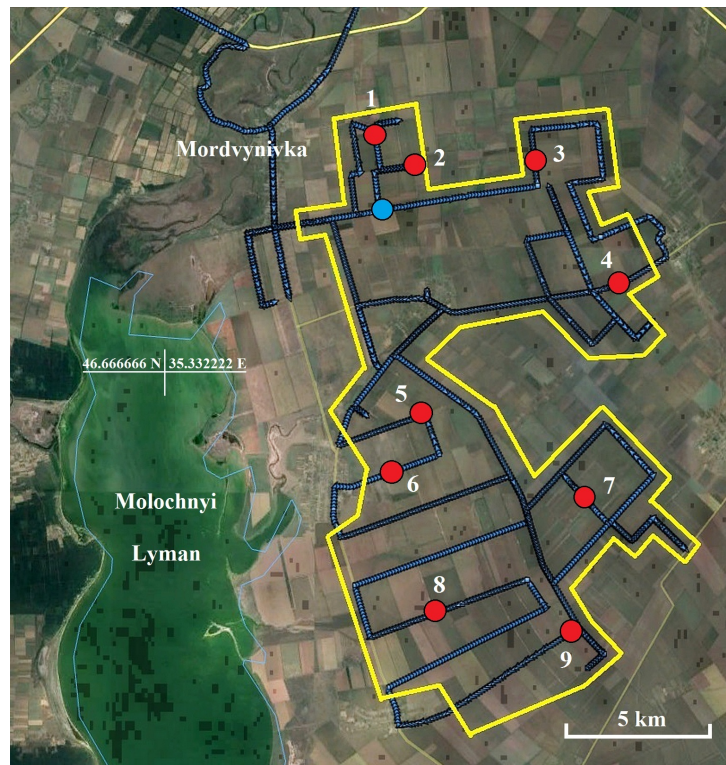


Figure 1. Research area within the Zaporizhia wind park (a yellow line is the boundaries of the wind park; red circle – vantage points; blue circle – the installation site of the Petterson D500x detector; blue line – GPS track of the researchers’ passage along the transect).



Figure 2. Using the LunaBat DFR-1 Pro detector with an external microphone on the Zaporizhia wind park transects in 2019.



Figure 3. A stationary vantage point (Pettersson D500x).



Figure 4. Using the Pettersson D500x detector at the height of 42 m.

In addition to the studies of 2019, we used data obtained in 2010-2021. During this period, ultrasonic detectors of three types recorded a total of 43,938 signals belonged to bats. The total operating time of the detectors was 4565 hours.

5. Research area zoning in terms of bat sound density

To obtain more specific information on the territorial distribution of bats in the project area, we used the Kernel Density method for point objects [7, 8].

The result of applying this technique is the construction of zones of increased activity of bats, both in certain periods and for all observation seasons, on a cartographic basis. Such zoning allows to identify places of potential risk for bats and to provide appropriate recommendations on environmental management and minimization of impacts.

5.1. Methodical substantiation of the Kernel Density technique application

The technique calculates the number of point or polyline objects per unit area (density) using the function of the kernel to fit the surface which gradually narrows to each point or polyline (figure 5).

Conceptually, a smoothed curved surface is selected (built) for each point. The value of the surface is the maximum at the location of the point and decreases with increasing distance from

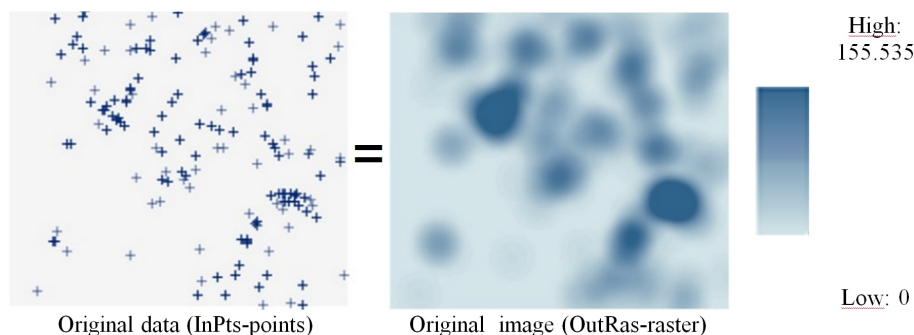


Figure 5. Principles of raster image construction for points that have different values [7].

the point, reaching zero at a distance equal to the specified search radius from the point. Only a circle environment can be used. The volume below the surface is equal to the value of the Population field for a point, or a unit, if set to “NONE”. The density value in each cell of the original raster is calculated by adding the values of all kernels at those points where they are superimposed on the center of the raster cell. The core function is based on the quartet core function described in B W Silverman [8].

If the value of the Population field differs from the NONE value, the value of each element determines the number of point counts. For example, a value of three causes the point to be counted three times. Values can be integers or numbers with a floating point. To characterize the density of bats in different areas of the wind farm and at different times of the year, we gave 2-kilometer parameters of the radius of impact to each point (signal).

The species identification of bats was carried out based on the recommendations of M Barataud [9].

6. Determination of bat activity indicators

It is a common international practice to carry out such studies to determine activity indicators in order to assess the possible impact of a project wind farm on bats objectively.

Based on the results, the activity index for all bats is determined using the following formula:

$$I_x = N_x * 60/T$$

Where: I_x – activity indicator for the species or group of echolocation “x”; N_x – number of bat flights of the species or group of echolocation “x” observed during registration at the *point counting / transect* (or during all registrations taken into account);

T – is the total duration of the analyzed registration at the *point counting / transect* (or all registrations taken into account), indicated in minutes.

Such calculations make it possible to characterize the periods of minimum and maximum activity of bats for further action and measures for the management of natural environmental complexes.

7. Results

Sufficiently extensive field research data are needed for a qualitative assessment of the wind farm impact on bat populations. The most complete studies were in 2019, so we will give a brief description of them.

Table 1 shows the results of three methods that were applied on the territory of the wind park along the passage of the Power Transmission Lines (PTL), partly in settlements and during the expedition vehicle crossings between transects and vantage points.

Table 1. Field research results in 2019.

No	Date, 2019	Trans., min	Trans., sig.	VP*, min	VP*, sig.	SDet*, min	SDet*, sig	PTL*, min	PTL*, sig	ST*	MV*	Total, min	Total, sig
1	20-21.03	264	3	90	0	720	8	120	1	0	0	1194	12
2	27-28.03	256	1	90	0	720	0	–	–	0	0	1066	1
3	08-09.04	344	0	90	7	720	49	–	–	0	0	1154	56
4	11-12.04	350	8	90	9	720	42	–	–	1	1	1162	61
5	24-25.04	344	18	90	11	720	92	–	–	1	0	1155	122
6	29-30.04	350	18	90	15	720	96	57	0	1	0	1218	130
7	16-17.05	353	70	90	39	720	61	–	–	0	1	1164	171
8	28-29.05	295	33	90	24	720	191	–	–	5	6	1116	259
9	30-31.05	310	16	90	31	720	147	–	–	0	0	1120	194
10	04-05.06	318	25	90	15	720	273	73	2	1	6	1208	322
11	11-12.06	295	32	90	12	720	368	–	–	4	1	1110	417
12	10-11.07	302	21	90	6	720	67	–	–	4	6	1122	104
13	25-26.07	318	36	90	20	720	53	73	5	1	1	1203	116
14	29-30.07	302	22	90	16	720	66	–	–	4	2	1118	110
15	04-05.08	295	31	90	17	720	74	–	–	2	0	1107	124
16	12-13.08	391	24	90	35	720	197	73	13	1	1	1276	271
17	24-25.08	295	69	90	15	720	191	–	–	6	9	1120	290
18	29-30.08	353	52	90	28	720	254	–	–	13	8	1184	355
19	03-04.09	350	39	90	18	720	173	–	–	2	4	1166	236
20	09-10.09	344	40	90	21	720	136	–	–	0	1	1155	198
21	19-20.09	350	34	90	19	720	120	57	19	1	1	1219	194
22	24-25.09	350	21	90	33	720	54	–	–	0	1	1161	109
23	05-06.10	348	31	90	18	720	65	–	–	0	0	1158	114
24	15-16.10	355	16	90	11	720	34	–	–	1	0	1166	62
25	20-21.10	264	13	90	27	720	6	120	9	0	0	1194	55
26	27-28.10	256	9	90	5	720	31	–	–	0	0	1066	45
27	11-12.11	302	4	90	0	720	11	–	–	0	0	1112	15
28	12-13.11	350	8	90	2	720	23	100	1	0	0	1260	34
Total		9004	694	2520	454	20160	2882	673	50	48	49	32454	4177

Notes*: Trans – transects; VP – vantage points; SDet – Static detector surveys at ground level; PTL – Power Transmission Lines; ST – registration of signals in settlements; MV – registration of signals when moving between transects and points.

As you can see, a total of 4177 signals were recorded. It is obvious that their maximum number was received at a stationary vantage point (2882 signals), since the detector worked all night. The study of voice activity on the transects gave us 694, and at the vantage points 454 signals.

To characterize the behaviour of bats, absolute indicators are insufficient, so there was used the activity index calculated for all three methods and shown in table 2 and figure 6. The maximum indicator in the first half of the year was in the middle of June (June 11 – 31 passes/h), which falls on the time of departure of young bats after the breeding season. In the second half of the year, the highest activity of bats was recorded at the end of August (August 29 – 19.8 passes/h) and indicates the beginning of autumn migration.

Long-term studies (2010-2021) show that in the second half of the year in August-September, the activity of bats was relatively higher than in the first half of the year. The differences with the data in 2019 are probably due to the fact that the detectors worked exclusively within the Zaporizhia wind park, which was represented by agricultural land. In previous years, the results of the analysis of bat activity also included data collected in settlements, on the coasts of the Molochnyi Estuary and the Sea of Azov. It is in these three biotopes that the foraging and migratory behaviour of bats has always been more active than in agrocenoses [6, 10–12].

Table 2. Field research results in 2019.

No	Date, 2019	Trans., N	Trans., T	Trans., I_x	VP*, N	VP*, T	VP*, I_x	SDet*, N	SDet*, T	SDet*, I_x	Total, N	Total, T	Total, I_x
1	20-21.03	3	264	0,68	0	90	0,00	8	647	0,74	11	1001	0,66
2	27-28.03	1	256	0,23	0	90	0,00	0	623	0,00	1	969	0,06
3	08-09.04	0	344	0,00	7	90	4,67	49	582	5,05	56	1016	3,31
4	11-12.04	8	350	1,37	9	90	6,00	42	572	4,41	59	1012	3,50
5	24-25.04	18	344	3,14	11	90	7,33	92	528	10,45	121	962	7,55
6	29-30.04	18	350	3,09	15	90	10,00	96	511	11,27	129	951	8,14
7	16-17.05	70	353	11,90	39	90	26,00	61	461	7,94	170	904	11,28
8	28-29.05	33	295	6,71	24	90	16,00	191	432	26,53	248	817	18,21
9	30-31.05	16	310	3,10	31	90	20,67	147	428	20,61	194	828	14,06
10	04-05.06	25	318	4,72	15	90	10,00	273	420	39,00	313	828	22,68
11	11-12.06	32	295	6,51	12	90	8,00	368	412	53,59	412	797	31,02
12	10-11.07	21	302	4,17	6	90	4,00	67	425	9,46	94	817	6,90
13	25-26.07	36	318	6,79	20	90	13,33	53	458	6,94	109	866	7,55
14	29-30.07	22	302	4,37	16	90	10,67	66	469	8,44	104	861	7,25
15	04-05.08	31	295	6,31	17	90	11,33	74	486	9,14	122	871	8,40
16	12-13.08	24	391	3,68	35	90	23,33	197	511	23,13	256	992	15,48
17	24-25.08	69	295	14,03	15	90	10,00	191	551	20,80	275	936	17,63

18	29-30.08	52	353	8,84	28	90	18,67	254	567	26,88	334	1010	19,84
19	03-04.09	39	350	6,69	18	90	12,00	173	584	17,77	230	1024	13,48
20	09-10.09	40	344	6,98	21	90	14,00	136	605	13,49	197	1039	11,38
21	19-20.09	34	350	5,83	19	90	12,67	120	639	11,27	173	1079	9,62
22	24-25.09	21	350	3,60	33	90	22,00	54	655	4,95	108	1095	5,92
23	05-06.10	31	348	5,34	18	90	12,00	65	692	5,64	114	1130	6,05
24	15-16.10	16	355	2,70	11	90	7,33	34	724	2,82	61	1169	3,13
25	20-21.10	13	264	2,95	27	90	18,00	6	740	0,49	46	1094	2,52
26	27-28.10	9	256	2,11	5	90	3,33	31	761	2,44	45	1107	2,44
27	11-12.11	4	302	0,79	0	90	0,00	11	802	0,82	15	1194	0,75
28	12-13.11	8	350	1,37	2	90	1,33	23	805	1,71	33	1245	1,59
Total		694	9004		454	2520		2882	16090		4030	27614	
General mean				4.62			10.81			10.75			8.76

Notes*: Trans – transects; VP – vantage points; SDet – Static detector surveys at ground level.

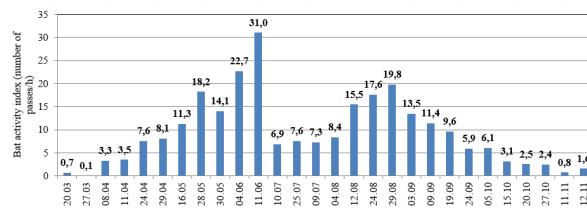


Figure 6. Dynamics of bat voice activity calculated as an activity index in 2019 on the territory of the Zaporizhia wind park (average for three methods).

An analysis of the bat behaviour in different periods of the life cycle is shown in table 3. As you can see, the maximum activity of animals was recorded in the period of disintegration of colonies, the beginning of autumn migrations and grouping in flocks (the second half of August), which confirms our long-term surveys. Such results will enable us to assess the wind park impact on bat populations and develop measures to minimize the negative impact.

8. Static detector surveys at height

Research carried out in 2017 showed the following:

- bats also hunt (migrate) at a height of 42 m and above;
- in total, 22 signals were recorded by detectors;
- the proportion of bats using these altitude intervals in different periods of the year ranged from 1.7 to 3.4% of the total number of recorded signals.

The technical complexity of installing and maintaining the detector on the meteorological mast did not allow us to collect more extensive data, but such work is very relevant and it is mandatory for wind parks.

Table 3. Bat activity index during different periods of the life cycle.

Life cycle	Life cycle	N	T	I_x
Leaving winter roosts by animals	15.03-30.03	12	1970	0,37
Spring migration and the formation of breeding colonies	01.04-20.04	115	2028	3,40
Reproduction and the peak activity of local bat populations	21.04-31.05	862	4462	11,59
Summer flight	01.06-10.08	1154	5040	13,74
Disintegration of colonies, the beginning of autumn migrations and grouping in flocks	11.08-30.08	865	2938	17,67
Autumn migrations and grouping in flocks	01.09-20.10	929	7630	7,31
Last flights between roosts and the beginning of hibernation	21.10-30.11	93	3546	1,57
Total	15.03-30.11	4030	27614	
General mean				8,76

Notes*: N – number of passes (signals), T – total duration of the analyzed registration in minutes, I_x – number of passes/h.

9. Species diversity of bats

6928 signals were analyzed for 5 seasons in 2010-2019, 6636 signals of them were identified to the species (genus). As we can see from the detailed characteristics of the species diversity in table 4, representatives of the *Pipistrellus* genus dominated in the territory of the Zaporizhia wind park. In total, 4 species of *Pipistrellus* were recorded, which in total amounted to 3852 signals (55.6%). Such a picture is typical for the entire Azov and Sivash areas, which is confirmed by our preliminary studies in the Azov-Black Sea region. The subdominants were *Nyctalus noctula* (1108 signals, 15.99%) and *Vespertilio murinus* (1064 signals, 15.36%). According to our data, these 2 species retain their positions throughout the region. However, they can change places depending on the season of the year and the place of research.

10. Discussion

Given the rather large area of the Zaporizhia wind park, it is expected that bats will use it unevenly. Thus, there is a need for zoning the entire territory and identifying places of animal concentration. To do this, we used the “Kernel Density” method. Thanks to the technical capabilities of the LunaBat DFR-1 Pro detector, each recorded signal of a bat had its own geographical coordinate. A total of 694 signals were documented. In more detail, by seasons, we gave such a characteristic in a previous article [10]. Figure 7 shows the results of such zoning for 2019.

Taking into account the numerical values and the 2-kilometer radius of influence of individual points, we divided the obtained indicators into 6 gradations, which were respectively characterized by low, medium and high signal density (two gradations each).

The northern sites of the wind park fell into the high-density zone, where according to the plan, the wind turbines No. 155, 157, 158, 163, 164, 165, 166 were installed. The Plantage forest

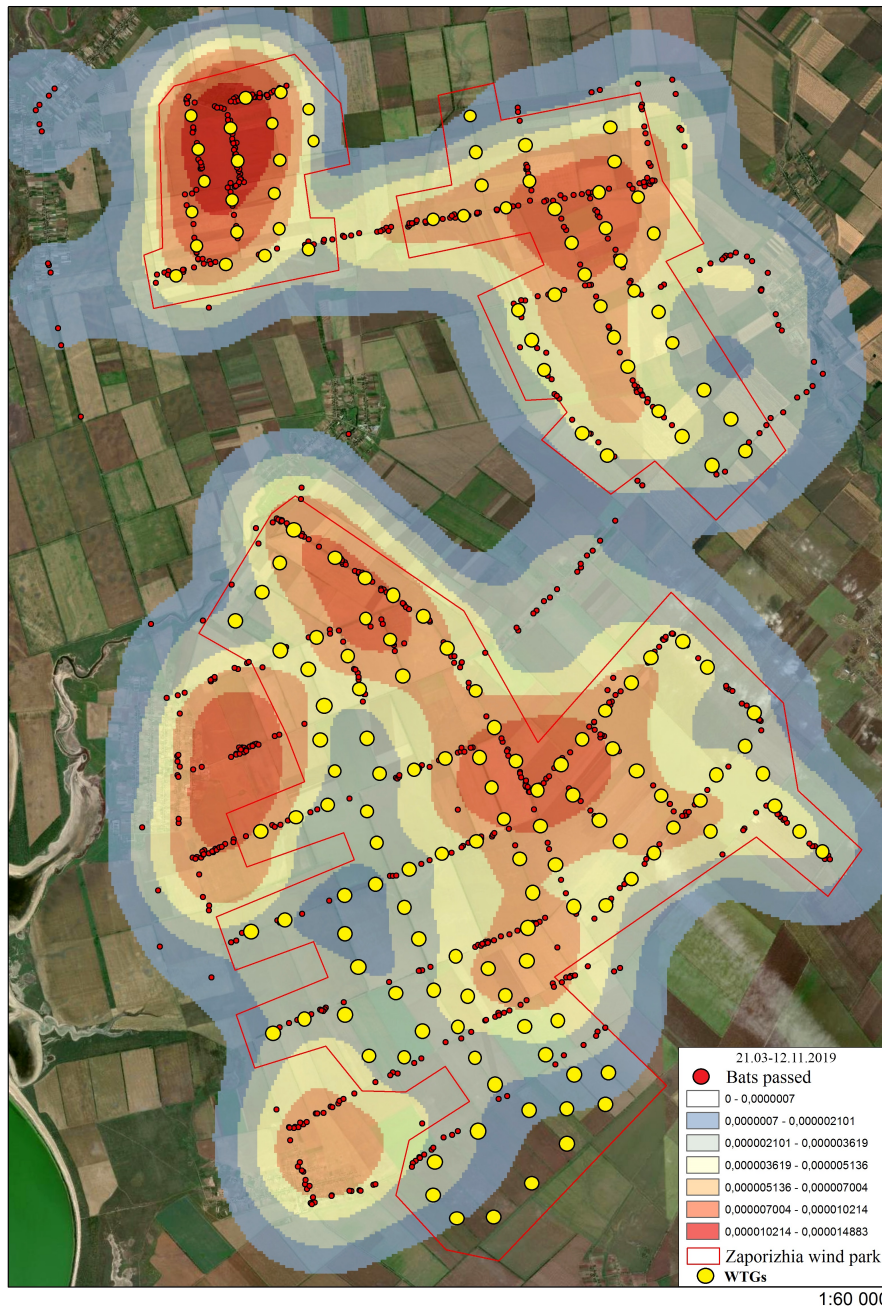


Figure 7. Kernel Density of count points of bats within the Zaporizhia wind park in 2019 (28 expedition trips, 694 signals).

Table 4. Species diversity of bats within the project area of the Zaporizhia wind park.

No	Species	2010, abs.	2010, %	2014, abs.	2014, %	2016, abs.	2016, %	2017, abs.	2017, %	2019, abs.	2019, %	2010-2019, abs.	2010-2019, %
1	<i>Plecotus sp.</i>	1	0,28			5	0,5			11	0,26	17	0,25
2	<i>Nyctalus noctula</i>	8	2,23	146	24,25	149	15,8	104	12,24	701	16,78	1108	15,99
3	<i>Pipistrellus kuhlii</i>	291	81,28	299	49,67	415	44,1	465	54,71	2061	49,34	3531	50,97
4	<i>Pipistrellus nathusii</i>	291	81,28	299	49,67	130	13,8	465	54,71	2061	49,34	130	1,88
5	<i>Pipistrellus pipistrellus</i>	4	1,12	17	2,82	27	2,9	12	1,41	32	0,77	92	1,33
6	<i>Pipistrellus pygmaeus</i>					42	4,5			9	0,22	51	0,74
	<i>Pipistrellus sp.</i>			15	2,49	11	1,2	22	2,59			48	0,69
7	<i>Vespertilio murinus</i>			42	6,98	62	6,6	73	8,59	887	21,24	1064	15,36
8	<i>Eptesicus serotinus</i>	51	14,25	33	5,48	49	5,2	39	4,59	255	6,1	427	6,19
9	<i>Hypsugo savii</i>							4	0,47			4	0,06
10	<i>Myotis mystacinus</i>	3	0,84					38	4,47	58	1,39	99	1,43
	<i>Myotis sp.</i>			4	0,66	9	0,9	47	5,53	5	0,12	65	0,94
	Not identified			46	7,65	42	4,5	46	5,41	158	3,78	292	4,21
	Total	358	100,0	602	100,0	941	100,0	850	100,0	4177	100,0	6928	100,0

area and the best-preserved forest belts of high bonitet are located here. For such locations, there is a high probability of bat collisions with towers and blades of WGTs, PTL, as well as receiving barotrauma [13].

Medium signal density levels were found in the following four zones.

- (i) Installation locations of the wind turbines No. 126, 127, 130, 131, 132, 133, 134, 135, 140, 144.
- (ii) Location area of the wind turbines 5, 6, 7, 11, 12.
- (iii) Southeast part of the wind park. The wind turbines No. 20, 21, 41, 42, 73A, 99, 105, 106, 107 got into this zone.

- (iv) Eastern outskirts of the village of Hirsovka and nearby areas where it is not planned to install wind turbines. The wind turbines No. 26, 27 are the closest to this zone with average values of density indicators. However, calculations show that they are installed in a low hazard zone.

The other areas of the Zaporizhia wind park are unattractive for bats, since the level of signal density is characterized by the lowest indicators. Thus, by applying the Kernel Density method, we were able to identify zones and compile a list of the wind turbines for which seasonal environmental management efforts are needed to minimize the possible negative impact on bat populations.

11. Dynamics of the bat species diversity

Indirect evidence of the stability of local bat populations is the dynamics of their species composition. Table 4 shows the ratio of bat species for 5 seasons in the period 2010-2019. In all years, representatives of the *Pipistrellus* genus occupied a dominant position. Their total part has always been more than 50% of the number of all other species. Understanding the complexity of identification to a species in the *Pipistrellus kuhlii* + *Pipistrellus nathusii* complex, we still tend to believe that *Pipistrellus kuhlii* is the most numerous. In the period 2014-2017, the subdominant was *Nyctalus noctula*, the share of which was 12.2-24.3%. In 2010, the second most important species was *Eptesicus serotinus* (14.3%), and in 2019, *Vespertilio murinus* (21.2%). Thus, over the entire period of research, the species diversity of the Zaporizhia wind park chiropterocomplex is represented by at least 10 species. According to the Eurobat commission, [14] *Pipistrellus kuhlii* is in the group with a low risk of collisions with wind turbine generators, while *Nyctalus noctula* (16% of the whole bat complex), has a high risk of falling under a moving rotor. A fairly effective method to reduce fatality is to change the rotation speed of wind turbines [15,16].

Most species of bats marked by the detector within the wind farm and adjacent areas are widespread and with a stable population status (table 4).

In the project area of the wind farm there are no natural formations that could be used by bats for daytime, breeding and wintering. The main places of concentration of bats are the settlements, the population of which depends on the presence of hollow trees, convenient structures for habitation, in particular, high-rise buildings, and fresh water bodies [6,10,11].

The species composition of bats in the study area is poorer than in other natural areas. Analysis of literature data and recording of signals with the help of an ultrasound detector suggests that the fauna of bats here is close to that in the North Priazovia, where *Pipistrellus* dominate, in particular, *Pipistrellus kuhlii*) [12,17].

The species spectrum of bats is represented by widespread species that have a fairly wide area of existence. No endemic species have been registered. There are no territories unique for bats too.

12. Environmental management of the Zaporizhia wind park

In accordance with the calculations of the activity index of bats, we state that the most dangerous period for them is August and the first half of September (tables 2 and 3). It is during this period that measures are needed to minimize the negative impact of wind turbines on bats, as also pointed out by L Rodrigues et al. [18].

As an environmental management of the Zaporizhia wind park area, we suggest using the experience of colleagues when the start-up rotor speed (define a threshold wind speed, at which the rotors start to operate) was increased from 3.5 to 5-6 m/s [19,20]. This recommendation is based on the foraging behaviour of bats, which typically prey in wind speeds up to 3.5 m/s. At these speeds, bats are very sensitive to collisions and barotrauma (figure 8; [21]). The financial

losses of wind farms when the start-up speed increases to 5 m/s are minimal and are in balance with the task of conserving bats [22].

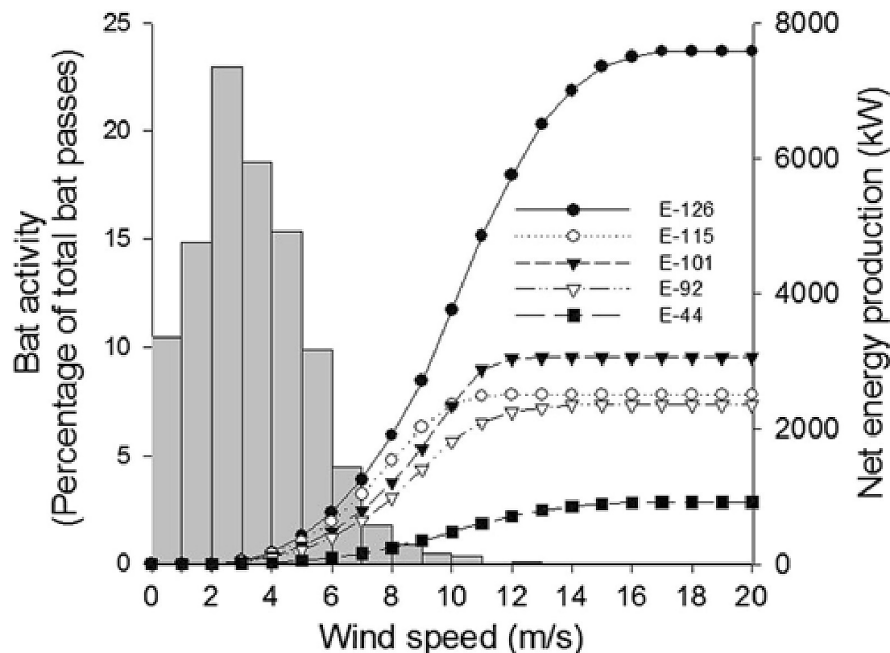


Figure 8. Bat and net energy production in relation to wind speed [21] (E - rotor diameter).

Active methods to deter bats from wind turbines may also be applicable. The Ultrasonic Acoustic Bat Deterrent System for the Wind Industry, developed by the NRG Systems Company, has shown a 32-67% reduction in bat fatality from 15 wind turbines in Illinois (USA) [23].

13. Conclusions

Thus, a comparison of the data obtained in 2010-2021 concerning the study of foraging behaviour and vocal activity of bats allows us to draw the following conclusions:

- (i) The total number of registered voices is 43938 signals, 4177 of which were recorded in 2019.
- (ii) Index of bat activity depending on the research methodology ranged in the interval 4.62 (on transects) – 10.81 (at a stationary vantage point), and was in average 8.76 signals per hour (for comparison: the Myrne wind farm (the Kherson region) – 7.14 signals per hour; the Kalanchak wind farm (the Kherson region) – 6.62 signals per hour; the Overianivka and the Novotroitsk wind farms (the Kherson region) – 10.53 signals per hour; the Prymorsk wind farm (the Zaporizhzhia region) – 7.07 signals per hour; the Prymorsk wind farm-2 (the Zaporizhzhia region) – 8.10 signals per hour; the Botiievo wind farm (the Zaporizhzhia region) – 6.70 signals per hour).
- (iii) Forage and migratory behaviour of bats, calculated by determining the index of their activity, shows the average values.
- (iv) The distribution of bats in the project area, defined as the difference between the number of recorded signals in individual habitats, indicates the attraction of animals to settlements and open waters, while the wind farm area is less attractive to them.
- (v) The species composition of bats, identified for 6928 signals recorded in the territory of the projected wind farm, is stable and represented by widespread at least 10 species belonging

to 7 taxonomic ranks. The undisputed dominants were *Pipistrellus kuhlii*+ *Pipistrellus nathusii*, the part of which was more than 50% of the whole complex.

- (vi) There are no species of the category “endangered” among the identified bats. The distribution areas of all species of the project area are quite wide. Within the Zaporizhia wind park there are no endemic species or unique habitats of their existence.
- (vii) Analysis of the bat distribution, carried out by the Kernel Density method, revealed several areas of the increased activity of animals. Most bats were attracted to the settlements and to open waters. There were revealed some wind turbine generators near which the implementation of minimization measures is required. In total, according to forecasts, there are 7 such wind turbine generators within the Zaporizhia wind park. Another 24 turbines are in the zone of average negative impact on bats.
- (viii) August and September are the most dangerous for bats. Methods for changing the start-up speed and ultrasonic bat deterrence are effective and can be recommended as environmental management.

Monitoring the state of bats in the project area both during the construction of the wind farm and its operation is mandatory for the development and implementation of measures to minimize the possible negative impact on bats.

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