Identification of “Primorsk-1” wind power plant impact on the ecological situation connected with the behavior of ornithofauna on the Azov Sea coast

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Abstract. The results of ornithocomplexes monitoring in the territory of the wind power plant (WPP) “Primorsk-1” in 2017 and 2018 are presented. The research was conducted by two methods: observations made according to the recommendations of the Scottish Natural Heritage Fund (SNH) and route accounting method (RAM). The distribution of birds by seasons, direction of migration and flight altitudes has been identified. The number of birds, registered in 2017 by the SNH method, was 5923 specimens of 45 species: 3795 specimens of 33 species were flying in transit, 2,113 specimens of 40 species belonged to the forage group, 15 birds of four species belonged to the demonstration type. Most of the birds (64.2%) were flying in transit. The greatest activity of birds was observed in spring (36.3%) and autumn (35.0%) seasons of migration, when the share of the transit group accounted for 75.5% of all annual transit flights. At an altitude of up to 10 m 5086 (86.2%) birds were registered, in the range of altitudes (11 ÷ 25) m – 697 (11.8%), in the range of altitudes (26 ÷ 50) m – 53 (0.7%). No birds were found at an altitude above 180 m. In the risk zone of interaction with turbines, there were 72 birds of four species: Larus ridibundus, Merops apiaster, Circus aeruginosus, Buteo buteo. The total number of birds, registered by the RAM method in 2018, was 8927 specimens of 72 species: 802 specimens of 11 species were flying in transit, 2511 specimens of 32 species belonged to the forage group, 5614 specimens of 60 species belonged to the terrestrial group. The greatest activity of birds was registered in autumn (70.0%) and spring (15.2%) seasons of migration, and the share of the transit group in these seasons accounted for 93.4% of all annual transit flights. The predominant directions of migration were western, north-eastern and south-western. At an altitude of up to 10 m – 2369 (71.5%) birds were registered, in the range of altitudes (11 ÷ 25) m – 371 (11.2%), in the range of altitudes (26 ÷ 50) m – 367 (11.2%). At an altitude above 51 m – 202 birds (6.1%) were registered. Comparison of the results, obtained by different monitoring methods, was carried out by bringing the number of birds to 1 hour of observation in an area of 1 km². The total bird density in the case of the RAM method was 3.3 times higher. The density of transit type birds according to different methods was within the admissible statistical dispersion of 10.2 ÷ 12.7 specimens/hour-km². However, the density of forage type birds, registered by the RAM method, was 7.1 times higher than the density, identified by the SNH method. The average number of all the birds flying over the wind park territory at each moment of time according to various counting methods was within the statistical scatter (1.15 ÷ 1.28) specimen/(hour-km²). The size of the transit group in the case of the SNH method use was 3 times larger than that calculated by the RAM method, while the size of the forage group, on the contrary, was 2.5 times less. The anticipated number of collisions during one year of the wind power plant functioning, calculated by the SNH and RAM methods, was in the range of 5.6 ÷ 6.7 (about 0.6 specimens per turbine for one year of its functioning, or 0.2 specimen/1 MW/year). The number of collisions was about 6.9 ± 4% of the
total number of transit and forage type birds in the wind park territory, 3.3-3% of the number of the considered species specimens present at all altitudes, and 0.25% of all birds in a risk zone. The data obtained indicate an insignificant impact of the “Primorsk-1” wind power plant on the ornithofauna of the Azov sea coast.

1. Introduction

Research of the wind power plants (WPPs) impact on the environmental situation is becoming especially urgent. The issue of bird interaction with turbines is particularly relevant one [1–4] and it is also important to take measures to minimize the consequences of their collisions with turbines [5–7].

The energy strategy of Ukraine envisages producing at least 30% of renewable energy sources from all generated electricity by 2030 [8–10]. A significant part of wind power plants (WPPs) will be located on the Azov Sea coast. The natural territories of the Azov and Black Sea coasts of Ukraine are the reserves of unique biodiversity. They contain steppe plant communities and support numerous populations of birds migrating across Eurasia. This fact imposes significant responsibilities on the specialists responsible for anticipating environmental changes. Therefore, the formation of a system for monitoring, assessing and anticipating the state of bird communities in this region is extremely important.

The algorithm of a systematic approach to predictive assessment of the wind energy impact on birds is described in a number of scientific works [11]. It allows the researchers to choose the most optimal observation methods. The bird complexes monitoring in the territory of wind parks and adjacent zones is usually carried out in two ways. One of them, proposed by the Scottish Natural Heritage Foundation [12], is based on the study of individual sites belonging to the wind park. The Foundation Method (SNH) has gained widespread acceptance in the scientific community and has practically become a reference method. Another method uses the results of observations made by the route accounting method (RAM), adapted to the monitoring conditions of the wind power plant [11]. Each of these methods of obtaining necessary information has its own advantages and disadvantages. The SNH method provides data on the birds’ activity parameter \( k_j = n_j t_j \) in the risk zone (RZ) of their interaction with the rotors, where \( k_j = n_j t_j \) is the number of birds of the \( j \)-species registered in RZ, \( t_j \) is the time of their stay in this zone. The value \( k_j = n_j t_j \) is used in mathematical models to estimate the number of bird collisions with turbines [13]. The disadvantage of this method is a need to extrapolate the data obtained from the observation sites (the area which, as a rule, does not exceed 20% of the total area of the wind power park) to the territory of the entire park. The RAM method covers the study of the area occupied by 70÷80% of the wind power plant territory. In addition, the implementation of route accounting method is more convenient from the point of view of organizing observations and is more profitable in terms of economy and time. One of the RAM method disadvantages is its inaccuracy in identifying the birds’ activity parameter \( k_j \).

There appears a question – which of the considered methods of studying the wind turbines impact on the ecological situation connected with the behavior of ornithofauna in the territory of wind parks and adjacent areas is better. So, this question remains unanswered. In this work, both methods are used to study the interaction of birds with turbines, which allows obtaining more reliable information. The work was performed on the basis of observations of the “Primorsk-1” wind park territory. This WPP is a typical representative of a series of wind turbines that are functioning on the Azov Sea coast or are being designed to bring new capacities into operation in the coming years.
2. Research aim and objectives

The aim of the research work was to analyze the results of ornithofauna monitoring in the wind power plant territory, obtained in two ways – by the route accounting method (RAM) and using the recommendations of the Scottish Natural Heritage Fund (SNH). To achieve the aim, it was necessary to organize seasonal observations of bird complexes in the “Primorsk-1” wind park territory and accomplish the following objectives:

• to identify the distribution of birds in different seasons, as well as according to different directions of migration and altitude flight characteristics,
• to choose a method for anticipating the possibility of bird interactions with turbines and, based on the results of monitoring the “Primorsk-1” wind park territory by the RAM and SNH methods, estimate the number of their collisions with turbines,
• to carry out a comparative analysis of data on the behavior of birds in the wind park territory, obtained by means of various observation methods.

In accordance with accumulated experience of studying ornithocomplexes on the Azov Sea coast, migration processes monitoring should be carried out in different seasons at least 4 times a year for up to three or four days of observations at counting sites or route sections. An important moment is the measurement and processing of data using modern equipment and appropriate software, which largely determines the reliability of the results.

Ornithological monitoring should cover the main periods of the bird life cycle, namely: spring migration period, nesting period, autumn migration period, wintering. The results of long-term studies [11] indicate that the nesting period falls on the first and third decades of March, as well as the first ten days of April. The first nesting counting usually takes place at the end of April, from 25.04 to 28.04, and the second – at the end of May, from 25.05 to 28.05. The exact observation terms may vary slightly. The correct terms of observations allow researchers to take into account early and late nesting bird species. Autumn monitoring should cover the second decade of September, the first and second decades of October and the first decade of November. It is advisable to carry out additional counting in November. The terms of registration the winter season should be divided into two stages: during the prevailing wintering periods (usually the second decade of January) and during the end of wintering periods (usually the second decade of February).

2.1. Bird monitoring methods in the “Primorsk-1” wind power plant territory

2.1.1. General foundations of the observation organization. The research was carried out in accordance with the requirements of national legislation. The coordinates of the registered birds, observation sites and wind park territory were linked to a Google map, which made it possible to identify the direction of flight and a number of parameters necessary to describe the behavior of birds in the wind park territory. The mapping of flora and fauna was carried out using previously developed AutoCAD program, which facilitated the discussion of the results obtained, taking into account the design layout of the integrated planning infrastructure of the wind park site [11].

During the observations, the following equipment was used: NIVA 2121 car, Etherna, Bushnell binoculars, optical tubes OPTOLYTH 20-60x80, VIXEN 20-60x100-1, VIXEN Geoma 20-60x80, NICON Forestry 550 laser device for altitude identification, GARMIN GPS MAP 78s device for identifying coordinates. Identification of species, sex, age of birds, as well as characteristics of winter and transitional outfits was carried out using the identifier of birds of Europe (Collins Bird guide/Second edition, 2009). The mapping of the places of birds’ accumulation, as well as the spatial characteristics of movements along the route, was carried out using the GARMIN GPS MAP 78s navigator. The linear dimensions between the objects
and the flight altitude of the birds were measured using a NICON Forestry 550 laser altimeter. Meteorological data were recorded using a compact LeCrosse 1700 weather station.

Observation sites were selected in accordance with the recommendations of the SNH Foundation [12]. In particular, the following requirements were taken into account:

- monitoring sites corresponded to natural areas of the wind park and buffer zones,
- a number of monitoring sites did not exceed the possibility of their examination within 1-2 days,
- observer’s field of view at the observation point (OP) did not exceed 180° for each section.

Using the route accounting method of observation (RAM), observer was moving on foot or by car. The mapping, available for bird registration, was about 0.5±0.1 km along the route, as well as to the left and right of its direction. The observation area was approximately 1 km². The size of the area, covered by the route accounting method, was about 75% of the entire wind power plant territory.

2.1.2. Conducting observations at stationary sites by the SNH method. Monitoring of seasonal ornithological situation at three observation points (OP) belonging to the “Primorsk-1” WPP territory was carried out during 2017. The sizes of the OP1, OP2 and PO3 sites were 0.50 km², 0.86 km² and 1.23 km² respectively with a total area of 2.59 km². It is represented in figure 1.

In terms of their landscape and biotopic parameters, the OPs were close to those of the entire WPP territory with an area of 10.1 km². The OPs were chosen in such a way that not a single point belonging to the wind park was at a distance of more than 2 km from the OP borders. Experience shows that in this case the impact of the observer on the behavior of birds will be a minimal one. Physical characteristics of OP within the study area are presented in table 1 and figures 1-4.

![Figure 1. Layout of observation points within the project area of the WPP site.](image)

| OP  | Coordinates N   | Coordinates E   | A, km | B, km | C, km | D, km | S, km² |
|-----|-----------------|-----------------|-------|-------|-------|-------|--------|
| 1   | 46.733790       | 36.424918       | 0.69  | 0.71  | 0.74  | 0.69  | 0.50   |
| 2   | 46.759229       | 36.469566       | 0.65  | 1.4   | 0.7   | 1.19  | 0.86   |
| 3   | 46.758907       | 36.509302       | 0.92  | 1.3   | 0.9   | 1.4   | 1.23   |
| Total|                 |                 |       |       |       |       | 2.59   |
Figure 2. Characteristics of observation point OP1 (1 – Physical-geographical situational plan, 2 – Geomorphological profile in the line A-C, 3 – Physical-geographical situational plan, 4 – Geomorphological profile in the line A-C).

Figure 3. Characteristics of observation point OP2 and the layout of its central part.

The accounting scheme was as follows. The expedition car transported three observers, one to each point, to carry out morning measurements during the period of three hours. The duration of evening observations was also three hours at each site. The observations were made in a clear weather with a visibility on the ground of at least 2 km. In rare cases, if the rains were not too frequent and prolonged, observations were allowed on rainy days. The bird’s trajectory was tracked until it stopped flying or disappeared from the sight. The flight altitude was identified at the first moment of bird registration and then repeated with 15 seconds intervals. The altitude value was classified according to five zones: below 10 m, in the range of 11÷25 m, in the range of 26÷50 m, in the risk zone of interaction with turbines from 51 m to 174 m and more than 174 m. Sitting birds (terrestrial type of stay in the territory site) were registered only once at the beginning of observation. The observation results were entered into forms, samples are shown in tables 2-4.

Observations were carried out in the morning and in the evening for 3 hours each. The
Figure 4. Layout of south-eastern part of OP3.

Table 2. Summary table of observation results at OP in 2017, T1 and T2 – time of start and end of observations, ∆T – duration of observations in hours, coordinates: SW – south-east, SE – south-east, E – east.

| Date   | Observer | OP | T1   | T2   | ∆T | Weather                                      |
|--------|----------|----|------|------|-----|----------------------------------------------|
| 20.09  | Serdiuk  | 1  | 08:00| 11:00| 3   | Partly cloudy, south-western wind, good visibility |
| 21.09  | Petrik   | 2  | 09:00| 12:00| 3   | Partly cloudy, south-western wind, good visibility |
| 10.10  | Kosach   | 1  | 08:00| 11:00| 3   | Dry, sunny, eastern wind                      |

Table 3. Observation results: n – number of birds, t – time of stay at the site, nt - reproduction of the number of birds n by the time of their stay t at the observation site of OP (The flight of the birds of target species at observation sites in 2017).

| Species     | Date       | OP | n   | Type and direction of flight, age of a bird | t, sec | nt, sec |
|-------------|------------|----|-----|--------------------------------------------|-------|--------|
| Sandpiper   | 12.03.131  | 1  | 1   | Demonstrational flight                      | 30    | 30     |
| Sandpiper   | 14.04.132  | 30 |     | Direction: north-western                    | 15    | 450    |
| Circus cyaneus | 15.04.131 | 1  |     | Adult specimen. Demonstrational flight       | 25    | 25     |

Monitoring time was chosen in such a way as to cover all periods of bird life. In 2017, observations were carried out for 24 days: winter periods: 2017.01.21, 2017.01.22, 2017.02.12, 2017.02.13; spring migration periods: 2017.03.13, 2017.03.14, 2017.03.25, 2017.04.02, 2017.04.03, 2017.04.04, 2017.04.25; nesting periods: 2017.05.13, 2017.05.14, 2017.05.15, 2017.05.16, 2017.05.17, 2017.05.18; autumn migration season: 2017.09.12, 2017.09.13, 2017.09.14, 2017.10.16, 2017.10.17, 2017.10.18, 2017.11.10.

The dependence of the observation duration T and the length of life cycle phases $T_{lcp}$ of birds on the registration season as applied to the annual cycle of the “Primorsk-1” wind park functioning is given in table 5. The $T_{lc}$ value is calculated on the basis of conditionally light 12.5
**Table 4.** Displaying the migration pattern at the OP for each hour of observation in the AutoCAD program: \( n \) – number of birds, \( h \) – flight altitude, coordinates: \( NE \) – north-east, \( S \) – south, \( N \) – north.

| Layer 1 |  |  |  |  |  |
|---------|---|---|---|---|---|
| 1       | 9:00 | Anser albifrons | 22 | Transit | 400 | NE |
| 2       |  | Turdus merula | 3 | Transit | 5 | S |
| 3       |  | Sturnus vulgaris | 18 | Forage | 10 | N |
| 4       |  | Emberiza calandra | 22 | Transit | 5 | N |

| Layer 2 |  |  |  |  |  |
|---------|---|---|---|---|---|
| 5       |  |  |  |  |  |

| Total species | 12 | 258 |

hours per day in spring and summer periods, 10 hours – in autumn and 8 hours – in winter.

**Table 5.** Duration of observations \( T \) by the SNH method in 2017 and the phase of the annual life cycle of birds \( T_{lcp} \).

| Cycle of observation | Duration of observation \( T \) (OP1), hours | Duration of observation \( T \) (OP2), hours | Duration of observation \( T \) (OP3), hours | \( \sum T \) | \( T_{lcp} \), days | \( T_{lcp} \), hours |
|----------------------|-------------------------------------------|-------------------------------------------|-------------------------------------------|-----------|----------------|----------------|
| Spring migration     | 36                                        | 36                                        | 36                                        | 72        | 85             | 1062.5        |
| Nesting              | 42                                        | 42                                        | 42                                        | 126       | 90             | 1125          |
| Autumn migration     | 42                                        | 42                                        | 42                                        | 126       | 100            | 1000          |
| Winter period        | 24                                        | 24                                        | 24                                        | 72        | 90             | 720           |
| Total                | 144                                       | 144                                       | 144                                       | 432       | 365            | 3907.5        |

2.1.3. **Route accounting method (RAM).** During the monitoring process, all bird species that were observed along the route were registered. The accounting was carried out in 2018 in the morning and evening hours, lasting approximately 3 hours. The observation days were chosen in such a way as to cover all periods of bird life: winter season: 2018.01.25, 2018.02.16, spring migration season: 2018.03.10, 2018.03.20, 2018.04.11, nesting period: 2018.05.05, 2018.05.23, autumn migration season: 2018.09.15, 2018.09.29, 2018.10.13. The duration of observations was 63 hours: 13 hours in winter, 22 hours in the spring migration season, 15 hours during the nesting period, 13 hours in the autumn migration season.
During the period of seasonal migrations, almost the same route was used with minor changes. The accounting width was differentiated depending on the following conditions:

- features of movement (on foot, by car),
- ability to view the biotope (open biotopes, wood line),
- features of species biology (secretive, living in open biotopes),
- size of specimens,
- lighting (clear, cloudy),
- season (nesting, migration, winter).

During the territory monitoring, the observation date, time of the day, bird coordinates, type of registration (on foot, by car), impact of weather on the quality of registration (interferes, does not interfere), route length in each biotope, and total number of each species were registered. The compulsory parameters of the data taken into account included the following characteristics of ornithocomplexes:

- number and species characteristics of birds,
- altitude and direction of flight,
- behavioral characteristics of birds during migration period in the wind power plant territory,
- trophic migrations and the degree of use of biotopes as forage sites,
- impact of anthropogenic and natural factors on the state of birds of seasonal ornithocomplexes.

Cartographic work was carried out using the AutoCAD program in accordance with the tables of records and registration of migrants. Each route had its own schematic map, where the layer-by-layer (hourly) results of registration and migration of transit and forage groups birds were registered separately. The results of the route observation were entered into the tables of registration (table 6) and migration movements (table 7). Based on these tables, two maps were created in the AutoCAD program.

**Table 6.** Sample route accounting of birds in the wind park territory on September 25, 2018:

| No. | Time  | Species         | Type of biotope | n  |
|-----|-------|-----------------|-----------------|----|
| 1   | 08.00 | *Turdus merula* | Wood line       | 6  |
| 2   |       | *Buteo buteo*   | Field           | 2  |
| 3   | 09.00 | *Accipiter nisus* | Field       | 3  |
| ... | ...   | ...             | ...             | ...|
| Total|       | 29 species      |                 | 208|

2.1.4. Methods for processing the results of bird observation in the territory of wind park. The primary processing of the results of bird monitoring at three observation points by the SNH method was carried out using the “BIRDS1” database [3]. This program is designed to obtain information on the dependence of the number of registered birds on the time and season of observation, direction of flight, type of migration, flight altitude at various sites. To ensure the analysis of information based on the results of monitoring the wind park territory by the RAM
Table 7. Results of registration of migratory movements of birds in the wind park territory on September 25, 2017, $n$ – a number of birds, coordinates: NE – north-east, S – south, N – north.

| No | Time | Species              | $n$ | Type of migration | Altitude, m | Coordinates |
|----|------|----------------------|-----|-------------------|-------------|-------------|
| 1  | 09.00| *Anser albifrons*    | 22  | Transit           | 400         | NE          |
| 2  |      | *Turdus merula*      | 3   | Transit           | 5           | S           |
| 3  |      | *Sturnus vulgaris*   | 18  | Forage            | 10          | N           |

... ... ... ... ... ...

Total 12 species 258

method, the information system “BIRDS2” was used, which provided storage and processing of the initial data. In response to a user’s request, the program makes it possible to receive information on the following parameters: an identifier that binds the coordinates of a registered bird to a point on a Google map, time of the day, month of registration, duration of observation, altitude and flight speed, average number of birds in flight over the wind power plant territory at a given time and other data.

Comparison of quantitative parameters that characterize the behavior of birds in the territories with different areas $S$ during an unequal time interval $T$ is incorrect; therefore, in a number of cases, normalized data were used. Some of them ($n_s$) referred to an area of 1 km$^2$, others ($n_{ST}$) – to an area of 1 km$^2$ per 1 hour of observation:

$$n_s = \frac{N}{S}, n_{ST} = \frac{N}{ST}. \quad (1)$$

For example, the average number of birds, which corresponds to the results of registration at three observation points by the SNH method per 1 km$^2$, was calculated by the formula:

$$n_s = \frac{N_1 + N_2 + N_3}{S_{sum}}, \quad (2)$$

where $N_1, N_2, N_3$ are the numbers of birds registered, respectively, at three observation points with an area of $S_1, S_2, S_3$, $S_{sum} = (S_1 + S_2 + S_3)$ – total area of observation sites.

When using the RAM method, the average value was calculated by the formula

$$n_{S0} = \frac{N}{S_0}, \quad (3)$$

where $N$ is a number of counted birds on this route, $S_0$, – available view area for bird registration, which is approximately equal to 1 km$^2$.

In the research work, the parameter $N_0$, was introduced, which identifies the number of flying birds over the territory of the wind park at each moment of time. The $N_0$ value can be obtained by photographing the wind park territory from a flying vehicle. Based on the results of photographing, $m$, images were obtained, where $M_0$, of flying birds were registered. In this case, the parameter $N_0$, is equal to

$$N_0 = \frac{M_0}{m}, \quad (4)$$

The information obtained during the wind park monitoring contains data on the time $t_{ij}^{(k)}$ of the stay of birds of $k$-species in the number $n_{ij}^{(k)}$ at each of three observation sites ($i=1,2,3$). In
In this case, the value of $N_0^{(k)}$ can be calculated by the formula

$$N_0^{(k)} = \frac{S \sum \left( \sum K^{(k)}_{ij} \right)}{S_{sum} T},$$

(5)

where $S$ – area of the wind park, $S_{sum}$ – total area of observation sites, $T$ – observation time, during which $n_{ij}^{(k)}$ birds were registered in the $j$-group, which have flown through the given area during time $t_{ij}^{(k)}$, $K^{(k)}_{ij}$ – parameter that determines the activity of birds of $k$-species at $i$-observation site in $j$-group, $n_{ij}^{(k)}$ – a number of specimens in $j$-group of birds that have flown through $i$-section during time $t_{ij}$. The activity coefficient of birds for one $j$-group in the number of $n_{ij}$, that have flown through the $i$-segment during time $t_{ij}^{(k)}$ is calculated by the formula

$$K_{ij}^{(k)} = n_{ij}^{(k)} \cdot t_{ij}^{(k)},$$

(6)

When using the RAM method, the observers have at their disposal only one section with the area $S_0$. In its center there is an observer. If the SNH method provides for the registration of the flight time and the number of registered birds over each observation point, but the results of the territory monitoring by the RAM method provide information only about the altitude and direction of flight. In this case to estimate the activity coefficient, we represent the shape of the observation site as a circle with radius $r$ with area $S_0 = \pi r^2$, in the center of which the observer is located. The value of $S_0$ is about 1.0 km$^2$, which corresponds to the viewing radius $r = \sqrt{S_0}/\pi = 560$ m. It can be shown that the average statistical length of the flight path for birds flying over a similar area is approximately equal to $l \approx 880$ m. According to the RAM method coefficient of activity of several groups of birds, each of which consists of $n_{ij}^{(k)}$ of $j$-specimens of $k$-species, which have flown by with a speed $v_{ij}^{(k)}$ during the entire observation time, will be equal to

$$K_{0}^{(k)} = l \sum \frac{n_{ij}^{(k)}}{v_{ij}^{(k)}}.$$  

(7)

Using formulas (6) and (7) makes it possible to transform formula (5) to a form that can be used to identify the average number of birds flying over the territory of the wind park at each moment of time based on the results of monitoring by the RAM method

$$N_0^{(k)} = lS \sum \frac{n_{ij}^{(k)}}{v_{ij}^{(k)}} = \frac{SK_{0}^{(k)}}{TS_{RAM}},$$

(8)

where $S_{RAM}$ is the total area along the route where birds are registered during one day of observation. The calculation of the probability of a bird collision $p_j$ with the blades of a wind wheel when it is in the danger zone of a wind park (DZ) was first proposed in [13,14]. DZ refers to the portion of the territory above the wind power plant occupied by rotating turbines. Let’s consider the possibility of a bird collision with turbines in the territory of the “Primorsk-1” wind power plant. The amount of the danger zone DZ is

$$VDZ = M \pi R^2 \text{dcos}(\gamma),$$

(9)

where $M = 26$ – a number of turbines in the territory of WPP, $R = 68$ m – radius of the wind wheel, $d = 4.1$ m – width of the wind wheel blade, $\gamma = 300$ – blade wedge angle between its chord and the plane of rotation of the propeller.
The value of probability $P_j$ is calculated by the formula [3]

$$P_j = \left[ \pi R_0 + 6(R - R_0)L^{(k)} - 2/\pi + 3(R - R_0)d + 3(R - R_0)2\varphi t^{(k)}/2 \right]/(\pi R_2), \quad (10)$$

where $L^{(k)}$ – wingspan of the bird, $\varphi = 14$ rpm – angular speed of turbine rotation, $r_0$ – radius of the rotor sleeve on which the blade is attached, $t^{(k)}$ – time of bird’s flight of $k$-species through the rotor with a speed $v^{(k)}$.

The time of flight is calculated by the formula

$$t^{(k)} = \frac{d \sin(\gamma) + L^{(k)}_i}{v^{(k)}}, \quad (11)$$

where $L^{(k)}_i$ – length of a bird.

Following the research work [14], let’s introduce the concept of a risk zone of possible collision of birds with turbines $RZ$. It refers to the part of the space in the altitude interval $\delta H = H_2 - H_1$ between the lower $H_1$ and upper $H_2$ levels of the turbine wind wheel above the observation sites of the area $S$. Distance from the ground to the lower part of the rotor $H_1 = 48$ m, to the upper part – $H_2 = 182$ m. The amount $RZ$ is

$$V_{RZ} = \delta H S, \quad (12)$$

The number of collisions of birds of $k$-species with turbine blades in $i$-section in one of $m$-seasons ($m=1÷4$) is calculated by the formula [3]

$$n^{(k)}_{im} = \frac{M \pi R^2 \cos(\gamma) v^{(k)}_{im} f T_L c f P^{(k)}_{im}}{R_i \delta H S_i K^{(k)}_{im}}, \quad (13)$$

where $f$ is the coefficient of evasion, which determines the bird’s ability to change the direction of flight near the wind wheel and, thus, avoid collision with it. The most probable value of the coefficient $f$ is in the range of 0.05÷0.005 [6, 15], $T_L$ – duration of the life cycle of birds for one year of wind park functioning for one year, $K^{(k)}_{im}$ – activity coefficient of birds of $k$-species registered in the RZ at $i$-site with an area of $S^{(k)}$ during the monitoring period $T$ in $m$-season, $T_{im}$ – duration of observations at $i$-site with an area of $S_i$ in $m$-season.

Formula (13) was derived to anticipate the interaction of birds with turbines based on the results of monitoring the observation sites by the SNH method. It can be shown that when using information on the behavior of birds in the territory of a wind park using the RAM method, it is necessary to use the same formula after replacing the activity coefficient $K^{(k)}_{im}$ in it by the parameter $K^{(k)}_0$ calculated by formula (7), and the value $S$ by an area $S_0$, which is available for registration of birds by the route counting method.

3. Results of work

3.1. General analysis of the number of birds in the “Primorsk-1” wind park territory

Ornithocomplexes at the observation points OP1, OP2 and OP3 were monitored using SNH recommendations in 2017. The total number of registered birds was 5923 specimens of 45 species: 3795 specimens of 33 species have flown in transit, 2113 specimens of 40 species belonged to the forage type, 15 birds of four species – to the demonstration type. The number of demonstration group did not exceed 0.3% of the total number of registered birds, therefore, in the future, the analysis will be carried out only for the birds of the transit and forage groups in the amount of 5908 specimens.

In 2008 in the process of monitoring the territory by the RAM method, birds sitting on the ground, wires, trees and bushes were additionally registered and included in the group called
“terrestrial”. The total number of registered birds on the routes was 8927 specimens of 72 species: 802 specimens of 11 species have flown in transit, 2511 specimens of 32 species belonged to the forage type, 5614 specimens of 60 species – to the terrestrial type.

Quantitative characteristics of transit and forage type birds in different seasons are given in table 8.

Table 8. Distribution of birds by season, registered by the SNH method in 2017 (1) and by the RAM method in 2018 (2).

| Type of migration | Winter season | Spring migration | Nesting season | Autumn migration | Total according to the type |
|------------------|---------------|------------------|----------------|------------------|-----------------------------|
| Transit          | 547(1)        | 1237(1)          | 381(1)         | 1630(1)          | 3795(1)                     |
|                  | 0(2)          | 128(2)           | 53(2)          | 621(2)           | 802(2)                      |
| Forage           | 345(1)        | 907(1)           | 420(1)         | 441(1)           | 2113(1)                     |
|                  | 277(2)        | 375(2)           | 162(2)         | 1697(2)          | 2511(2)                     |
| Total            | 892(1)        | 2144(1)          | 801(1)         | 2071(1)          | 5908(1)                     |
|                  | 277(2)        | 503(2)           | 215(2)         | 2318(2)          | 3313(2)                     |

According to monitoring data, in 2017 (64%) birds have flown in transit. The greatest bird activity was observed in spring (36%) and autumn (35%) seasons of migration, when the transit group accounted for 76% of all annual transit flights. The predominant directions of migration were east (27%) and southeast (19%). At an altitude of up to 10 m, 5086 (86%) birds were registered, in the range of altitudes (11±25) m – 697 (12%), in the range of altitudes (26±50) m – 53 (0.7%). No birds were observed at an altitude above 180 m. In the RZ zone there were 72 (1.3%) birds of four species:

(i) *Larus ridibundus* in the amount of 43 specimens of the transit group: 30 birds have flown during the spring migration, 13 – during the autumn migration. 1011 birds of this species were registered at all altitudes: 978 birds have flown in transit, 33 belonged to the forage group.

(ii) *Merops apiaster* in the amount of 15 specimens have flown in transit during the spring migration. At all altitudes, 45 birds of this species were registered: 39 birds belonged to the transit group, 6 – to the forage group.

(iii) *Circus aeruginosus* in the amount of 9 specimens (7 – of transit group, 2 – of forage group). Six birds were registered during the spring migration and three during the autumn migration. At all altitudes, 45 birds of this species were registered: 25 birds have flown in transit, 20 belonged to the forage group.

(iv) *Buteo buteo* in the amount of 5 specimens have flown in transit in autumn. 26 birds of this species were registered at all altitudes: 13 birds have flown in transit, 13 belonged to the forage group.

The results of monitoring by the RAM method in 2018 also showed that the greatest migration activity of birds is observed in autumn (70%) and spring (15%), and the share of the transit group in these seasons accounted for 93% of all annual transit flights. The predominant directions of flight were west and north-east. At an altitude of up to 10 m, 2369 (72%) birds were calculated,
in the altitude interval \((11 \div 25)\) m – 371 (11%), in the altitude interval \((26 \div 50)\) m – 367 (11%). At an altitude of over 51 m, 202 birds (6%) were registered. The RZ contained 4 specimens of the species \textit{Buteo buteo} (less than 1%): two birds of forage type were registered in the spring migration period at an altitude of 100 m, two birds have flown in autumn at an altitude of 150 m.

Observation by the RAM method more fully reveals the forage group, the number of which is 3.1 times higher than the number of transit birds. In addition, the RAM method makes it possible to register terrestrial birds, the number of which was 1.7 times higher than the total number of transit and forage birds. It is recommended to carry out the comparison of data on other parameters after bringing the monitoring results to one hour of registration per 1 km² of the observation site area using formulas \((1) \div (4)\).

### 3.2. Distribution of birds by observation seasons, flight altitude and direction of migration

The number of birds and their species largely depend on the season. The total number of birds registered in the winter season: 2017.01.21, 2017.01.22, 2017.02.12, 2017.02.13 by the SNH method was 892 specimens of 14 species: 547 (61%) specimens of twelve species have flown in transit, 345 (39%) specimens of thirteen species belonged to the forage group. Using the RAM method in the period of 2018.01.25, 2018.02.16, 277 specimens of seven species were identified. All of them belonged only to the forage group. The distribution of birds by direction is presented in table 9.

#### Table 9. Distribution of migratory birds by directions in winter: N – north, NE – north-east, E – east, SE – south-east, S – south, SW – south-west, W – west, NW – north-west, (1) – SNH method, (2) – RAM method.

| Direction | N  | NE  | E   | SE  | S   | SW  | W   | NW  |
|-----------|----|-----|-----|-----|-----|-----|-----|-----|
| Transit   | 1%(1) | 1%(1) | 41%(1) | 28%(1) | 13%(1) | 2%(1) | 8%(1) | 7%(1) |
|           | 0%(2) | 0%(2) | 0%(2) | 0%(2) | 0%(2) | 0%(2) | 0%(2) | 0%(2) |
| Forage    | 7%(1) | 23%(1) | 26%(1) | 19%(1) | 13%(1) | 6.4(1) | 4.2(1) | 1.4(1) |
|           | 1%(2) | 47%(2) | 0%(2) | 1%(2) | 1%(2) | 52%(2) | 0%(2) | 0%(2) |

**SNH method.** In winter period of 2017 the main directions of flight for the transit group were eastern (41%), southeastern (28%) and southern (13%), and for the forage group – eastern (26%), north-eastern (23%) and southeastern (19%). All birds were registered at an altitude up to 51 m: 89% of them at altitude up to 10 m, 10% in the range of altitudes \((11 \div 25)\) m, 1% in the range of altitudes \((26 \div 50)\) m.

**RAM method.** A completely different distribution was observed in 2018. The birds did not fly by in transit. Half of the birds from the prey group (52%) moved south-westward, and the other half (47%) moved north-eastward. All birds were registered at an altitude up to 51 m: 66% up to 10 m, 32% – in the range of altitudes \((11 \div 25)\) m, 2% – in the range of altitudes \((26 \div 50)\) m.

The spring migration period was characterized by a higher diversity of species. The total number of birds registered in the periods of 2017.03.13, 2017.03.14, 2017.03.25, 2017.04.02, 2017.04.03, 2017.04.04, 2017.04.25 by the SNH method was 2144 specimens of 20 species: 1237 (60%) specimens of 16 species have flown in transit, 907 (40%) specimens of 14 species belonged to the forage type. 51 (2.4%) bird was found in the RZ zone. In the range of altitudes \((26 \div 50)\) m 17 birds (<2%) were observed, in the range of altitudes \((11 \div 25)\) m – 250 (12%) birds, the remaining 1822 (85%) specimens were at an altitude of up to 10 m.
Observations by the RAM method, carried out in the periods of 2018.03.10, 2018.03.22, 2018.04.11 have identified 503 specimens of 26 species. In the forage group 375 birds (75%) were counted, in the transit group – 128 birds (25%). In RZ, at an altitude of 100 m, two forage-type Buteo buteo birds were observed. Most of the birds were registered at an altitude of up to 10 m. In the range of altitudes (26÷50) m one bird was observed, in the range of altitudes (11÷25) m – 40 (8%) birds.

Distribution of birds by direction during the spring migration is presented in table 10.

Table 10. Distribution of birds by direction in spring migration season: N – north, NE – north-east, E – east, SE – south-east, S – south, SW – south-west, W – west, NW – north-west, (1) – 2017, (2) – 2018.

| Direction | Transit | Forage |
|-----------|---------|--------|
|           | N   | NE  | E   | SE  | S   | SW  | W   | NW  |
| Transit   | 13%(1)| 12%(1)| 20%(1)| 14%(1)| 7%(1)| 7%(1)| 8%(1)| 19%(1)|
|           | 0%(2)| 75%(2)| 0.8%(2)| 21%(2)| 3.2%(2)| 0%(2)| 0%(2)| 0%(2)|
| Forage    | 22%(1)| 6%(1)| 24%(1)| 6%(1)| 11%(1)| 7(1)| 7(1)| 17(1)|
|           | 32%(2)| 45%(2)| 8%(2)| 15%(2)| 1%(2)| 22%(2)| 5%(2)| 1%(2)|

SNH method. During the spring migration in 2017, the predominant transit routes were eastern (20%) and northwestern (19%). In the northern, north-eastern and southeastern directions, 12% to 14% of the specimens have flown. The main directions of flight of forage type birds were eastern (24%), northern (22%) and south-western (17%).

RAM method. The main directions of birds in transit during spring migration were north-eastern (75%) and southeastern (21%). Most of them (98%) were registered at an altitude of up to 10 m, two birds (about 2%) have flown in the range of altitudes (11÷25) m. There were no birds at an altitude above 26 m.

By the nesting period, the activity of birds sharply decreased. The total number of birds registered in the periods of 2017.05.13, 2017.05.14, 2017.05.15, 2017.05.16, 2017.05.03, 2017.05.17, 2017.05.18 by the SNH method was 801 specimen of 37 species: 381 (48%) specimen of 20 species have flown in transit, 420 (52%) specimens of 30 species belonged to the forage type. In the range of altitudes (11÷25) m 55 (8%) birds were found, the remaining 746 (62%) specimens were at an altitude of up to 10 m. No birds were observed at an altitude above 26 m.

In the periods of 2018.05.05, 2018.05.23, 215 specimens of 11 species were identified by the RAM method (162 birds have flown in transit, 53 birds belonged to the forage group). At an altitude of up to 10 m there were 134 (62%) birds, 40 (8%) specimens were observed in an altitude interval (11÷25) m, 11 (32.5%) birds were registered in the altitude interval (26÷50) m. In RZ and above it the birds were not observed.

Distribution of birds by direction is presented in table 11.

SNH method. The main directions of transit flights during the nesting period in 2017 were: south-western (28%), north-eastern (26%) and northern (15%). At an altitude of up to 10 m, 85% of birds were registered, in the range of altitudes (11÷25) m – 15%. The main directions of flight of forage type birds were northern (26%), north-eastern (21%) and south-western (16%). At an altitude of up to 10 m, 97% of birds were observed, in the range of altitudes (11÷25) m – 3%. No birds were found at an altitude over 26 m.

RAM method. In 2018 the main direction of transit migration during the nesting period was north-eastern – 70%. About 15% have flown in the eastern and south-western directions each. At an altitude of up to 10 m, 7.5% were registered, in the interval (11÷25) m 75.5% of specimens were observed, in the interval (26÷50) – 17%. The main directions of flight of forage type birds
Table 11. Distribution of migratory birds by direction in the autumn season: N – north, NE – north-east, E – east, SE – southeast, S – south, SW – south-west, W – west, NW – north-west, (1) – 2017, (2) – 2018.

| Direction | N    | NE   | E    | SE   | S    | SW   | W    | NW   |
|-----------|------|------|------|------|------|------|------|------|
| Transit   | 15%(1)| 26%(1)| 13%(1)| 7%(1)| 3%(1)| 28%(1)| 3%(1)| 5%(1) |
|           | 0%(2)| 70%(2)| 13%(2)| 0%(2)| 0%(2)| 17%(2)| 0%(2)| 0%(2) |
| Forage    | 26%(1)| 21%(1)| 13%(1)| 14%(1)| 1%(1)| 16(1) | 5(1) | 5(1)  |
|           | 2%(2)| 62%(2)| 4%(2) | 0%(2) | 2%(2)| 27%(2)| 2%(2) | 1%(2) |

were north-eastern (62%) and south-western (27%). In the range of altitudes (26–50) m one bird was registered, in the range of altitudes (11–25) m – 40 (8%) birds, the remaining 460 (91%) specimens were observed at an altitude of up to 10 m. There were no birds at an altitude above 50 m.

Monitoring during the autumn migration periods of 2017.09.12, 2017.09.13, 2017.09.14, 2017.10.16, 2017.10.17, 2017.10.18, 2017.11.10 by the SNH method has identified 2071 bird of sixteen species. Most of them (1630 specimens) have flown in transit, the rest (441 specimens) belonged to the forage group.

The use of the RAM method in the periods of 2018.09.15, 2018.09.25, 2018.10.13 made it possible to register 2318 birds of 26 species, of which 621 have flown in transit, and 1691 belonged to the forage group.

Distribution of birds in the autumn season by direction is given in table 12.

Table 12. Distribution of migratory birds by direction in the autumn season: N – north, NE – north-east, E – east, SE – southeast, S – south, SW – south-west, W – west, NW – north-west, (1) – 2017, (2) – 2018.

| Direction | N    | NE   | E    | SE   | S    | SW   | W    | NW   |
|-----------|------|------|------|------|------|------|------|------|
| Transit   | 1%(1)| 5%(1)| 37%(1)| 32%(1)| 12%(1)| 3%(1)| 6%(1)| 5%(1) |
|           | 0%(2)| 8%(2)| 4%(2) | 0%(2) | 44%(2)| 2%(2)| 34%(2)| 8%(2) |
| Forage    | 21%(1)| 5%(1)| 23%(1)| 8%(1) | 29%(1)| 8(1) | 6(1) | 9(1)  |
|           | 1%(2)| 10%(2)| 1%(2) | 3%(2) | 1%(2)| 7%(2) | 75%(2)| 2%(2) |

SNH method. Most of the birds in the autumn season of 2017 have flown in transit in the eastern (37%) and southeastern (32%) directions. The main directions of flight of forage type birds were southern (29%), eastern (23%) and northern (21%). At an altitude of up to 10 m, 1723 (82%) birds were registered, in the range of altitudes (11–25) m – 297 (15%), in the range of altitudes (26–50) m – 30 (2%) specimens. 21 (1%) bird was observed in the risk zone of interaction with turbines.

RAM method. Birds of only one species, Larus Cachinaris, in the amount of (45%) specimens have flown in the southern direction. In the western direction (34%) specimens of two species Merops apiaster and Motacilla alba were observed. 10% of birds were registered at an altitude of up to 10 m. In the range of altitudes (11–25) m there was 4% of birds, in the range of altitudes (26–50) m – 54% of birds, 32% of birds have flown above 150 m.
The main direction of flight of forage type birds was western – 75%. The north-eastern and south-western directions accounted for 10% and 7%, respectively. At an altitude of up to 10 m, 90% of specimens were registered, 9% of birds were observed in the range of altitudes (10÷25) m. In the range of altitudes (25÷50) m – 1% of birds was observed. Two forage type *Buteo buteo* birds were found in the risk zone at an altitude of 100 m.

### 3.3. Identification of the number of birds in the wind park territory and the number of their collisions with turbines

The calculation of the number of bird collisions with turbines was carried by the formula (13) using the results of monitoring of the wind park territory by the RAM method in 2018. In the risk zone of interaction with turbines (RZ), 4 specimens belonging to the species *Buteo buteo* were observed. Two birds, demonstrating feeding behavior, were registered at an altitude of 100 m in the spring migration period, two birds have flown in transit in autumn at an altitude of 150 m. The length of the bird’s flight path at the observation site was 880 m, the flight speed was 11.6 m/s [16], period of each bird’s stay was 75.9 s.

In the calculations, the following values of WPP parameters and flight characteristics of birds were used: maximum blade width \(d=4.1\) m, maximum angular rotation speed of the wind wheel \(\varphi=14\) rpm, radius of the wind wheel \(R=67\) m, radius of the wind wheel hub \(R_0=3\) m, angle between the chord of the section of the blade and the plane of the wind wheel \(\gamma=300\), length of the bird \(m\), wingspan of its wings \(L_{2j}=1.2\) m. The probability of collision, calculated by the formula (10) for a bird flying perpendicular to the plane in which the wind wheel is located, is equal to 0.19.

To anticipate the interaction of birds with turbines, there are two calculation schemes.

First case. In the RZ zone birds were observed only in the spring and autumn seasons. The value of the phase of the life cycle \(T_{Lc}\) in different seasons in relation to one year of the wind park “Primorsk-1” functioning is presented in table 13. When calculating \(T_{Lc}\), the duration of a conditionally light day per day \(\Delta T\) was taken equal to 12.5 hours for the spring migration and autumn migration seasons, 10 hours in the autumn period and 8 hours in the winter period.

| Cycle of observation | \(T\), hour | \(\Delta T\), hour | \(T_{Lc}\), days | \(T_{Lc}\), hour |
|---------------------|------------|-------------------|----------------|--------------|
| Spring migration    | 13         | 12.5              | 85             | 1062.5       |
| Nesting             | 22         | 12.5              | 90             | 1125         |
| Autumn migration    | 15         | 10                | 100            | 1000         |
| Winter period       | 13         | 8                 | 90             | 720          |
| Total               | 63         | 43                | 365            | 3907.5       |

The number of collisions during one year of the WPP functioning, calculated by the formula (13) for the collision probability \(P_j=0.19\), taking into account the data in table 14 is equal to 3.7 for the spring and 3.0 for the autumn migration season. The total number of collisions was 6.7 specimens per year.

Second case. The total number of *Buteo buteo* birds that were observed in the territory of the wind park at all altitudes was 16. One bird was registered outside the RZ in winter, seven – during the spring migration period (2 in the RZ and 5 outside it), three – during the nesting season and five – in autumn (2 in RZ and 3 outside it). It can be assumed that, theoretically,
birds could appear in the risk zone not only in spring or autumn, but also in winter and during nesting periods. Therefore, the registered number of birds can be equally attributed to any season. In this case, the same formula (13) is valid, but due to different duration of the life cycle of birds $P_j$ and duration of monitoring time $T$, the results will not be the same. The calculated number of collisions during one year of WPP functioning turned out to be 5.6 specimens, which practically coincides with the calculated value in the first case.

Combining the latest data with the previously obtained results and taking into account seasonal differences, it can be assumed that the valid anticipation of a number of collisions is the range of values 5.6÷6.7. It is interesting to compare the obtained data on the interaction of birds with turbines with the research done on the basis of monitoring the “Primorsk-1” wind park territory in 2017 [3]. In this research work, 72 birds of four species were registered at stationary observation sites of a larger size (2.59 km$^2$) in the RZ: Larus ridibundus (43 specimens), Merops apiaster (15 specimens), Buteo buteo and Circus aeruginosus, respectively, 5 and 9 specimens. In this research work, birds of the species Circus aeruginosus were not found in the WPP territory. Two species Larus ridibundus (29 specimens) and Merops apiaster (246 specimens) represented a fairly large group, but were observed outside zone of interaction with wind wheels. Some of them belonged to the forage group and were at an altitude of 50 m, while the others were flying above the turbines. The anticipated number of collisions during one year of WPP functioning, according to the cited work, was about 6.5 birds.

The results of the analysis of the observation sites monitoring using the recommendations of the Scottish Natural Heritage Fund in 2017 and the route accounting method in 2018 are shown in table 15. The first value with index (1) in each cell of the table characterizes information about birds of the transit and forage groups obtained by the SNH method in 2017 at all observation sites, the second value with index (2) corresponds to the results of route accounting method in 2018. The parameters of the first line of the table refer to birds of all species registered at the WPP in all seasons:

- $N$ – total number of birds of all species registered at the observation sites,
- $n_0$ – number of birds registered during one hour in an area of 1 km$^2$,
- $K$ – coefficient of bird activity in the observation area,
- $K_0$ – coefficient of bird activity in the area calculated by formulas (6), (7), and reduced to one hour of observation per 1 km$^2$,
- $N_0$ – number of birds in the wind park territory in a state of flight at each moment of time, calculated by formulas (5) and (8). The speed of birds of various species was in the range (11÷19) m/s. When calculating the activity coefficient $K$, the speed value was taken equal to 15 m/s. The flight speed of each bird species registered in the RZ was taken from the literary sources,
- $N_1$ – extrapolated value of the total number of transit and forage birds that have flown over the wind park territory during one year.

Similar information on transit and forage groups of birds is separately presented in the second and third lines. The fourth line contains data only for birds that were found in the RZ zone at an altitude from 51 m to 174 m: 72 birds of the four species Larus ridibundus, Merops apiaster, Buteo buteo and Circus aeruginosus in 2017 and 4 birds of the same species Buteo buteo in 2018. The listed species constitute a risk group that was observed at all altitudes.

The last line of the table 14 contains information on the risk group of birds. Four species from this group (Larus ridibundus, Merops apiaster, Buteo buteo, and Circus aeruginosus) were registered at all altitudes in 2017, and three species (Larus ridibundus, Merops apiaster, Buteo buteo) – in 2018.

Comparative analysis of observations carried out by two different methods using the information given in the first column of Table 14 would not be correct for two reasons. Firstly, according to SNH method the area of three points is 2.6 times larger than the area of the site that
Table 14. Results of the analysis of the ornithocomplexes observations in the “Primorsk-1” wind park territory by the SNH monitoring method in 2017 (1) and the RAM method in 2018 (2): \( N \) – number of birds counted, \( n_0 \) – number of birds registered for 1 hour per 1 km\(^2\), \( K \) – coefficient of bird activity, \( K_0 \) – coefficient of bird activity per hour per 1 km\(^2\), \( N_0 \) – number of birds in the WPP territory in a state of flight at each moment of time, \( N_1 \) – number of birds that have flown through the WPP during 1 year.

|                | \( N \)  | \( n_0, \text{hour} \cdot \text{km}^2\)\(^{-1} \) | \( K \)  | \( K_0, \text{s/hour} \cdot \text{km}^{-2} \) | \( N_0 \)     | \( N_1 \)    |
|----------------|---------|---------------------------------|---------|---------------------------------|--------------|--------------|
| All birds      | 5908(1) | 15.8(1)                         | 170000(1)| 460(1)                          | 1.28(1)      | 620000(1)    |
|                | 3313(2) | 52.6(2)                         | 190000(2)| 3100(2)                         | 1.15(2)      | 2080000(2)   |
| Transit        | 3795(1) | 10.2(1)                         | 110000(1)| 300(1)                          | 0.83(1)      | 400000(1)    |
|                | 802(2)  | 12.7(2)                         | 47000(2) | 750(2)                          | 0.28(2)      | 500000(2)    |
| Forage         | 2113(1) | 5.6(1)                          | 59000(1) | 160(1)                          | 0.44(1)      | 220000(1)    |
|                | 2511(2) | 39.9(2)                         | 150000(2)| 2300(2)                         | 1.11(2)      | 1580000(2)   |
| Birds in the risk zone RZ | 72(1) | 0.19(1)                         | 2400(1) | 6.5(1)                          | 0.018(1)     | 7500(1)      |
|                | 4(2)    | 0.06(2)                         | 240(2)  | 4.8(2)                          | 0.0018(2)    | 2400(2)      |
| Birds of risk group | 1127(1) | 3.0(1)                          | 40000(1)| 110(1)                          | 0.30(1)      | 120000(1)    |
|                | 291(2)  | 4.6(2)                          | 17000(2)| 270(2)                          | 0.13(2)      | 180000(2)    |

...
the size of the transit group in the case of the SNH method is 3 times higher compared to the RAM method, while the size of the forage group, on the contrary, is 2.5 times less. The number of birds *Larus ridibundus, Merops apiaster, Circus aeruginosus, Buteo buteo* in the risk zone of interaction with turbines and the total number of birds of the listed species at all altitudes, identified by the SNH method, are also several times higher than that done by the RAM method.

The last column of \( N_1 \) of table 14 contains extrapolation values of parameters characterizing the behavior of birds in the WPP territory as a whole. The total number of birds of transit and forage types, registered by different observation methods, is within \((0.62 \pm 2.08) \times 10^6\). The transit group of specimens that have flown over the territory of the wind park was about \((4.0 \div 5.0) \times 10^5\) birds. There were about \((2.4 \div 7.5) \times 10^3\) specimens of four species *Larus ridibundus, Merops apiaster, Circus aeruginosus, Buteo buteo* in the risk zone of collisions with rotors. Representatives of these species are present at all altitudes in the amount of \((1.2 \div 1.8) \times 10^5\) birds.

In conclusion, let us compare the parameters of all birds from the risk group *Larus ridibundus, Merops apiaster, Circus aeruginosus, Buteo buteo*, which were found in the area of possible collision with turbines. According to our research and research work [3], the anticipated number of collisions is in the range \((5.6 \div 6.7)\), i.e., about 0.6 specimens per turbine during one year of its functioning or 0.2 specimen/1 MW/year. Thus, the number of collisions is:

6.9-4% of the total number of transit and forage type birds in the territory of wind park,
3.3-3% of the number of specimens of the considered species present at all altitudes,
0.25% of all birds of the specified species that are in a risk zone.

The data obtained in order of magnitude correlate with the literature sources known to us. For example, the mortality rate of forage type birds in the wind park territory in Andalusia (Spain) was 0.03 specimens per year per turbine [17]. At another station with 256 turbines, the figure was 0.4 [18]. In the research work by Polish scientists [19], they analyzed data on the registered deaths of birds at 109 functioning wind parks in Europe and North America. It turned out that the average number of dead birds is at the level of 0.1 specimen/1 MW/year.

The main error in the calculated data is associated with the choice of the coefficient \( f \) in the formula (13). This factor takes into account the ability of the bird to change direction of flight near the wind wheel and, thus, avoid collision with it. In this research work, the value of \( f \) is equal to 0.05. There is every reason to believe that \( f \) value is actually much lower [15, 20]. Therefore, it can be assumed that high-power turbines are dangerous, mainly in poor visibility, as well as for sick or weakened birds after a long flight.

### 4. Conclusions
The article presents the results of the ornithofauna monitoring in the “Primorsk-1” wind park territory by the SNH method in 2017 and the RAM method in 2018. The distribution of birds by season, direction of migration and flight altitude has been identified. An algorithm for calculating the number of birds in the wind power plant territory and their death due to collisions with turbines has been described. A comparative analysis of the data obtained by various methods has been carried out.

The total number of birds for 24 days of observation by the SNH method was 5923 specimens of 45 species: 3,795 specimens of 33 species have flown in transit, 2,113 specimens of 40 species belonged to the forage type, 15 birds of four species – to the demonstration type. Most of the birds (64.2%) have flown in transit. The greatest activity of birds was observed in spring (36.3%) and autumn (35.0%) seasons of migration, when the transit group accounted for 75.5% of all annual transit flights. The predominant directions of migration were northern, north-east, eastern, western and northwestern. At an altitude of up to 10 m there were 5086 (86.2%) birds, in the range of altitudes \((11 \div 25)\) m – 697 (11.8%), in the range of altitudes \((26 \div 50)\) m – 53 (0.7%). No birds were found at an altitude above 180 m. In the risk zone of interaction with
turbines, 72 birds of four species were observed: *Larus ridibundus*, *Merops apiaster*, *Circus aeruginosus*, *Buteo buteo*.

When monitoring the territory by the RAM method in 2018, birds of the terrestrial group, sitting on the ground, wires, trees and bushes, were additionally registered. The total number of registered birds was 8927 specimens of 72 species: 802 specimens of 11 species have flown in transit, 2511 specimens of 32 species belonged to the forage type, 5614 specimens of 60 species belonged to the terrestrial type. The greatest activity of birds was observed in autumn (70.0%) and spring (15.2%) seasons of migration, and the share of the transit group in these seasons accounted for 93.4% of all annual transit flights. The predominant directions of migration were western, north-eastern and south-western. At an altitude of up to 10 m, 2369 (71.5%) birds were observed, in the range of altitudes \(11 \div 25\) m \(= 371\) (11.2%), in the range of altitudes \(26 \div 50\) m \(= 367\) (11.2%). There were 202 birds (6.1%) above 50 m. There were 4 specimens of the species *Buteo buteo* in the RZ zone. Monitoring of the territory by the route accounting method more fully reveals the forage group, the number of which was 3.1 times higher than the number of transit birds.

Comparison of the results was carried out on the basis of data reduced to 1 hour of observation over an area of 1 km\(^2\). The number of birds of the transit group, identified by different monitoring methods, was within the admissible statistical spread of 10.2 \(\div\) 12.7 specimens/(hour-km\(^2\)). However, the density of birds registered by the RAM method is 7.1 times higher than the density found by the SNH method. Such a difference cannot be caused by statistical scatter, and is more likely related to the specifics of monitoring. It can be assumed that the movement of the observer along the route leads to frightening of the sitting birds and, thereby, to an increase in the number of forage group birds.

The average number of all birds in the wind park territory in a state of flight at each moment of time, calculated by various methods, was within the statistical scatter (1.15 \(\div\) 1.28) specimens/(hour-km\(^2\)). However, the size of the transit group in the case of the SNH method is 3 times higher compared to the RAM method, while the size of the forage group, on the contrary, is 2.5 times less. The number of birds *Larus ridibundus*, *Merops apiaster*, *Circus aeruginosus*, *Buteo buteo* in the risk zone of interaction with turbines and the total number of birds of the listed species at all altitudes, identified by the SNH method, are also several times higher than that done by the RAM method.

The total anticipated number of transit and forage type birds in the wind park territory during one year of its functioning, according to different methods, is (0.62 \(\div\) 2.08) 106. The number of birds that will be flying in transit over the wind power plant territory during this time is (4.0 \(\div\) 5.0) 105. The number of birds in the risk zone of collisions with rotors is estimated at (2.4 \(\div\) 7.5) 103 specimens of four species *Larus ridibundus*, *Merops apiaster*, *Circus aeruginosus*, *Buteo buteo*. It is anticipated that representatives of these species will be present at all altitudes.

The calculated number of bird collisions with turbines during one year is in the range of 5.6 \(\div\) 6.7 (about 0.6 specimens per turbine during one year of its functioning, or 0.2 specimens/1 MW/year). Such a frequency of collisions can be considered rather low and quite acceptable during the “Primorsk-1” wind park functioning. It is about 6.9-4% of the total number of birds of the transit and forage type in the wind power plant territory, 3.3-3% of the number of specimens of the considered species present at all altitudes, and 0.25% of all birds in the risk zone of interaction with turbines. The data obtained agree in order of magnitude with the literature sources known to us. For example, in accordance with the analysis of the bird interaction with turbines at 109 functioning wind power plants in Europe and North America, the average number of dead birds is 0.1 bird/1 MW/year [19].

In our opinion, the study of the wind power plant impact on birds should not be limited to assessing the possibility of bird collisions with turbines. The development of the wind energy
component in providing modern civilization with new energy sources might have a significant impact on the environmental situation in general. In particular, the construction of a large number of wind power plants can lead to a redistribution of the existing balance between predators and victims in the ornithofauna, a change in the habitats and feeding of birds, a change in the direction of migration flows and other negative phenomena. The statistical data, accumulated in many countries, makes it possible to approach the understanding of the wind energy impact on the ecological situation in a broader aspect. Research in this direction is of theoretical and practical interest.

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