Assessment of the impact of technogenic monitoring sites on seasonal migration ornithocomplexes

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Abstract. Today, the Azov-Black Sea coast of Ukraine is one of the most important migration routes in Europe, which is used by up to 15 million birds every season. The development of a scientific and information system for monitoring, assessing and predicting the state of biodiversity on the territories of wind power plants (WPP) in the Azov-Black Sea region is extremely important, and the study of seasonal ornithocomplexes is a key moment in the creation of wind farm sites. Assessment of the impact on them is paramount in the development of management plans and risk minimization. The studies were carried out in the Azov-Black Sea region of Ukraine at 12 monitoring sites in the period from 2010 to 2021 using modern international methods adopted in the European Community, used for these technogenic territories, as well as author’s developments. The studies that were carried out using the WEBBIRDS WEB-application for monitoring seasonal ornithocomplexes and computer modeling of assessing the impact of the wind farm site based on the server accumulation of monitoring data (an author’s development), software for calculating the risk assessment of bird collisions with wind turbines (CRM), assessing the potential biological removals (PBR) showed no significant adverse impact of wind farms on birds observed at all 12 sites. These monitoring studies make it possible to assert that the main impact on the stability of migratory bird complexes in the project area is exerted by various biotic and abiotic factors such as landscape-biotopic, forage, weather factors, and the impact of wind farms is minimal.

1. Introduction

The Azov-Black Sea coast of Ukraine is recognized as one of the most important migration routes in Europe. The most intense transcontinental migration corridor passes here, through which 8 – 15 million birds fly every season. At the same time, the Azov-Black Sea region of Ukraine has the largest wind potential in the country, which leads to the development of a large number of wind farms here.

The development of a scientific and information system for monitoring, assessing and forecasting the state of biodiversity in the territories of wind farms in the region is very important. This is due to the presence of natural areas on the Azov-Black Sea coast of Ukraine, which are not only reserves of unique biodiversity, but they also support numerous populations of migratory birds across Eurasia. This fact provides significant responsibilities for determining qualitative assessments of complex changes in controlled ecosystems, protection, monitoring and management of components of natural complexes both on natural and technogenic territories. The study of seasonal ornithocomplexes is a key moment in the creation of wind farm sites, and
the assessment of the impact on them is paramount in the development of management plans and risk minimization.

To achieve this goal, old research methods are not enough. Therefore, there is a need for new technologies. At the initial stage, we used the recommendations of the Scottish Natural Heritage Foundation (SNH), which since 2016 have been generally accepted methods for carrying out research on the territories of wind parks and power transmission lines (PTL) in the European Union. On their basis, a team of authors developed the “WEBBIRDS” - “BirdsFly” - “EasyBirds” complex, designed to adapt the SNH recommendations to domestic realities. The material presented below is based on a number of methodological developments [1–8].

2. Material and methods

The studies were carried out in the Azov-Black Sea region of Ukraine at 14 monitoring sites with a total area of 462.42 km² in the period from 2010 to 2021 (figure 1). At the same time, the total number of projects for the justification of wind farms in the region for a given period of time, prepared by the team of authors, was 25 projects. 13 of them have been put into operation today.

Most of the expedition work was carried out using the methods of fixed vehicle and pedestrian census on transects, as well as using stationary vantage points (VP). For a more complete characterization of the species composition and abundance of ornithocomplexes, expedition trips to the study area were carried out during massive migration waves. In total, 14-17 expedition trips were made every year lasting 3-6 days each.

Surveys were made with Etherna binoculars (10x) and Nikon ACULON A211 10x50 and VIXEN Geoma telescope (20 – 60x80). To determine the species, sex and age of birds, as well as the characteristics of seasonal outfits, we used the European bird guide (Collins Bird guide / Second edition, 2009) [9]. Mapping of bird gathering places and spatial characteristics of routes were made using a GARMIN GPSMAP 78s navigator. Biotopes and birds were photographed with Canon EOS 450D and Nikon D700 cameras. The photographs were exported to the FastStone Image Viewer programme, which together with the camera software in the Exif metadata mode made it possible to control the geolocation data of the photographs taken, the date and conditions of shooting. Linear dimensions between objects and object heights were measured using a Nicon Forestry 550 laser altimeter. Statistical processing of the obtained data was carried out in Microsoft Excel 2010 and Statistica Release 8 (Basic Statistic module) programmes.

In addition to the methods of collecting and processing field data and the methods of analysis (statistical, mathematical, graphical) described above, methods for assessing the impact on ornithocomplexes were also used using the author’s complex of “WEBBIRDS” – “BirdsFly” – “EasyBirds” web platforms.

The data, the possibility of entering which exists at all stages of functioning of the wind farm during planning, construction and operation, fall into a special Online Storage. The calculation of risk coefficients is based on the developed mathematical algorithms and international collision risk assessment models (CRM). The modular system uses both foreign modern models for analyzing the impact of wind farms and predicting the risk of collisions, as well as its own models based on Big-Data Algorithms, Regression analysis methods, Clustering, Artificial intelligence and Computer vision. Each of the Web Platform applications works according to its own data processing algorithm, but uses a common data storage for analysis:

- “WEBBIRDS” assesses the risk of bird collisions with wind turbines based on surveys of movement across the territory [10];
- “BirdsFly” analyzes migration processes, calculates risk ratios for migratory birds and identifies zones of dangerous bird concentration during migrations [11];
Figure 1. The territory of monitoring work at wind farms in the Azov-Black Sea region in 2010-2021.

- “EasyBirds” makes analysis based on CRM (Collision Risk Model is carried out according to the recommendations of the Scottish Natural Heritage Foundation) and PBR (Potential Biological Removal) calculations [12].

This development is an important point for the unification of methods for monitoring and assessing the impact on ornithocomplexes.

At the moment, there is the main international approach, the recommendations of the Scottish Natural Heritage Foundation (SNH) [7] based on observations at special sites (vantage points, VP), on the basis of which mathematical calculations are carried out:

(i) Intensity of airspace use.
(ii) Distribution of birds in three altitude intervals (below the rotor-swept area or outside the risk zone, at the height of the rotor-swept area or the risk zone, above the rotor-swept area or also outside the risk zone).
(iii) Probability of bird collisions with wind turbines, etc.

The most important aspect of performing work according to the methodology of the Scottish Natural Heritage Foundation is the assessment of the impact on mortality rates, the calculation of the probability of bird collisions with wind turbines (Collision Risk Model, CRM) and potential biological removal (Potential Biological Removal, PBR).

The authors of the project have developed a web application that includes 3 software products: the “WEBBIRDS” – “BirdsFly” – “EasyBirds” complex (hereinafter referred to as the WEBBIRDS complex), which models and makes a mathematical assessment of the impact on birds. The system of the computer programme includes the route census of birds and short-term surveys at the places of the highest concentration of birds. In addition, the WEBBIRDS complex also has a mathematical model for calculating PBR and CRM indicators.

The purpose of our research was the unification of these methods, ensuring the availability of their implementation and the unity of methodological approaches. In our opinion, the “WEBBIRDS” – “BirdsFly” – “EasyBirds” software complex has a number of advantages:

(i) Coverage area of the WPP territory and buffer zones by monitoring studies of seasonal ornithocomplexes. According to the Scottish Natural Heritage (SNH) methodology, the
coverage area of the study territory due to control VPs is approximately no more than 30% (in general, from 8.8 to 24.3%), while the area of each VP is on average 100-300 ha, and these studies are clearly limited by the boundaries of the WPP site. The WEBBIRDS complex mainly includes a route survey of various biotope complexes and places of the highest concentration of birds (water (wetland) areas), as well as buffer zones (BZ) of 500 m, which is not less than 50% (mainly 65-80%) according to studies carried out at 10 wind farm sites in 2015-2021. This area is formed due to 100% reliability of census in the 200 m zone on both sides of the route (the distribution of bird census zones on the transect occurs in gradations of 0 – 25 m, 26 – 100 m and 101 – 200 m);

(ii) The SNH method preferentially takes into account migratory birds, and less attention is paid to perched birds, since the observer is sitting at one point. The WEBBIRDS complex takes into account almost all the migrants seen and perched ones, as well as all the bird voices heard.

(iii) The time aspect of surveys: morning and evening surveys according to the SNH method in total amount to approximately 6 hours, and according to this method, they are not summed up, but will be 6 hours a day for both a WPP with three VPs and a WPP with 12 VPs. When using the WEBBIRDS complex, the number of hours for carrying out research depends on the area of the WPP and averages 5 – 7 hours. But it should be noted that the number of observation days for seasonal ornithocomplexes both for the SNH method and when using the WEBBIRDS complex is approximately the same, and is maximum 12 days (with the established minimum number of observations at a VP 72 hours per year) for census at vantage points and minimum 12 days for census on fixed transects (route census);

(iv) Coverage by monitoring studies of nearby areas of high biodiversity (objects of the Nature Reserve Fund, the Emerald Network). According to the SNH method, in these areas the studies are carried out only in relation to certain species and groups of birds (gatherings of diurnal birds of prey, wintering and migratory waterfowl, especially geese and swans, coastal species, including breeding gulls, etc.). When using the WEBBIRDS complex, a detailed accounting of all biotope complexes with the corresponding seasonal species composition of birds is carried out. The latter makes it possible to determine the movement of birds from buffer zones to the WPP site during periods of seasonal and foraging migrations, covering a larger number of species. The composition of the seasonal ornithocomplex can be presented in dynamics, based on the databases in the WEBBIRDS programme at different stages of the existence of wind farm sites (design, construction, operation);

(v) The SNH method focuses on target species, while the WEBBIRDS complex includes a larger list of species (88 species and 4 taxonomic groups of birds) that are characterized as “vulnerable due to the operation of wind farms” and are included in the “EU Guidance on wind energy development in accordance with the EU nature legislation” [13];

(vi) The budget for monitoring time in the SNH method depends on the number of VPs. When using the WEBBIRDS complex, 1-2 vehicles with 3 researchers can be involved in a small WPP area. At the same time, when using the SNH method, additional time is incurred for placing observers at the VP: in the morning, the expeditionary vehicle transports the observers (one for each VP), takes them after 3-hour observations, and also transports and takes the observers in the afternoon after the similar 3-hour observations.

(vii) Mobility in the processing of census results. The use of the WEBBIRDS complex allows you in the field to enter the information about birds on tablets or electronic media, and online data is generated on GIS maps of the given territory. When using the SNH method, this process is in a more primitive state (in the field, the observer enters the results of observations on a paper form and the corresponding paper chart, then there is mandatory cameral processing of the material, followed by entering the information obtained into an
(viii) PBR calculations both in the case of the SNH method and in the case of calculations of the WEBBIRDS complex are made using the same set of indicators (\(a\) – is the age of the first breeding year; \(s\) – is the probability of survival of an adult; \(f\) – is the protection coefficient; \(N_{\text{min}}\) – is the minimum estimated number of individuals in the subregional abundance), but the WEBBIRDS complex uses the \(N_{\text{min}}\) indicator directly for the WPP territory, while the SNH method takes into account the regional territory. CRM calculations take into account 25 criteria, as opposed to 5 criteria in similar calculations of the SNH method;

(ix) Special parameters and indicators taken into account only in WEBBIRDS calculations, for example, flight intensity (ind./h) and average flock size (ind.) separately in the morning and evening hours, etc.;

(x) Complementarity of WEBBIRDS databases with ArcGIS software tools. When using the SNH method for the formation of GIS maps, additional steps are taken to create databases. When using the “WEBBIRDS” complex, databases are automatically created and available for the formation of a variety of GIS formats.

Thus, the use of the WEBBIRDS complex makes it possible to reduce labour costs with a greater coverage of the territory and a functional assessment of seasonal ornithocomplexes, and allows characterizing the degree or level of wind farm impact on ornithocomplexes.

3. Results and their discussion

Ornithological research at wind farm sites is based on generally accepted methods, but at the same time includes important specific features. The implementation of the latest scientific and practical developments, that allow assessing the impact of the construction and operation of wind farms on natural components, occurs during monitoring work.

Due to the use of a mobile WEB-application based on the server accumulation of monitoring data collected during the periods of monitoring studies, maps are automatically created in linear and three-dimensional format based on Google Earth. This is a new approach in the cartographic presentation of bird census results. At different scales, it is possible to obtain data on bird gatherings in a general form for the wind farm site and buffer zones, as well as with significant detail information on individual sites, taking into account the name of the bird species, abundance, dates of research and their location. Of particular importance are voluminous cartographic formats for presenting monitoring information with significant detail information on individual sites, taking into account the names of birds, abundance, dates of research and their location.

But this is not the whole range of tasks that this programme can perform. Let us look at an example of a summary table generated using the functions of the WEBBIRDS web application and the tools of the Birds Fly programme, which, based on the analysis of a number of parameters, displays the risk coefficient for bird species. As an example, let us consider ornithological surveys during monitoring studies of migrations at the site of the Overianivka and Novotroitsk wind farms in March 2019 – February 2020. This summary table consists of 36 columns, the principle of which is described below.

The mechanism for creating a summary table. Column 1. Data on migratory birds were taken in the WEBBIRDS web application by: enter the Programme - menu “Reports” - select “Migrations” (viewing recorded migrations), in the “Site” column, using the arrow, and select from the drop-down list the site we need – the Overianivka and Novotroitsk wind farms. The filter selected the WPP data, including data from all studies in this area in the table. Using the filter in the “Date” column, select the “between” function, set the values: 03.01.2019 and 02.29.2020. The generated table provides data on bird migration at the Overianivka and Novotroitsk wind farms during the monitoring period. If you go to the drop-down list in the “Species” column,
you can see a list of bird species recorded during migration studies in March 2019 – February 2020, and listed in the Programme in the “Migrations” section (figure 2).

Figure 2. A fragment of the list of bird species recorded during migratory movements at the Overianivka and Novotroitsk wind farms in March 2019 – February 2020, which appears in the menu of the “Species” column when generating the Migration Report in the “WEBBIRDS” Programme.

The mechanism for creating a summary table. Column 2. Data for column 2 “Population abundance”, received in the “WEBBIRDS” Web application where it, in turn, was listed in the line “Population abundance” (Programme menu: “Settings”, “Bird Species” window at the figure 3) based on data provided by BirdLife International, 2015 (http://datazone.birdlife.org/species/search)

As a result, we have obtained a list of 45 species and 7 taxonomic groups that have not been identified as a species (Passerinae spp., Alauda spp., Anatidae spp., Anas spp., Chlidonias spp., Larus spp., Calidris spp.), which made migratory movements in March 2019 – February 2020 on the territory of the Overianivka and Novotroitsk wind farms, and were recorded during the research.

The mechanism for creating a summary table. Column 3. Data on the survey period (“Period” column) – a year, spring migratory, breeding, post-breeding, autumn migratory – is automatically generated by the Programme based on the time frames previously set by the User (for example, spring migratory: 01.03 – 30.04; breeding: 01.05 – 30.06, etc.).

The mechanism for creating a summary table. Columns 4-9. Data on the number of censuses (columns 4 and 7), the number of birds maximum and per day (columns 5 and 8), the average size of a flock (columns 6 and 9) are generated based on data previously entered into the programme by the User. These 2 blocks (“Census” and “Census on the territory”) contain data on recorded “immovable” birds of species, which also had migratory movements. Although these data are not included in risk coefficient calculations, as well as PBR and CRM calculations, they can be used by an expert in assessing the impact on a particular species at risk.

The mechanism for creating a summary table. Columns 10-21. Data on the number of migrations (columns 10 and 16), the number of birds (columns 11 and 17), the average and maximum number of birds per day (columns 12 and 18; 13 and 19), the average size of a flock...
Figure 3. Page of the “WEBBIRDS” programme for entering data on bird species.

(columns 14 and 20), the average height of migration (columns 15 and 21) are generated by
the Programme on the basis of the data entered by the User on the number and distribution of
recorded migrants with the delimitation of birds that flew across the territory of the WPP and
outside it.

The mechanism for creating a summary table. Columns 22-23. The average migration length
of the species across the territory of the wind farm (column 22) and the area of the passage
corridor (column 23) are calculated by the Programme based on the data entered into the
WEBBIRDS or Birds Fly web application during surveys. You can track a specific species on
the page of the analysis generated in the WEBBIRDS web application. For example: *Sturnus
vulgaris* is the most massive migrant in March 2019 – February 2020, which accounted for 53.57%
of all migrants per year: the length of the path over the wind farm site averaged from 818 to
1005 m per season (figure 4).

The mechanism for creating a summary table. Columns 24-33. These columns (included in
the blocks “Migrations across the territory taking into account the height” and “Number of birds
for a period”) are created by the programme based on the available data on migratory birds.
Information about birds recorded in potentially dangerous altitude intervals is displayed here.
If representatives of the species were not recorded at dangerous heights, then the programme
puts a dash for the given season in the columns mentioned above. There is no information in
columns 24-33 in March 2019 – February 2020 (since not a single bird was recorded at dangerous
heights directly on the territory of the wind farm).

The mechanism for creating a summary table. Column 34. The next column is Filtration
Figure 4. Analysis of the abundance, flight height and migration length of *Sturnus vulgaris* during surveys at the Overianivka and Novotroitsk wind farm site.

The abundance coefficient, which reflects the design parameters of the WPP territory and is calculated using the following formula:

\[ K_{filtration} = |V| \times \rho_{WPP} \times |\sin(\Delta \alpha)| \]

*|V|* - The length of the path vector across the WPP territory. It is set depending on the size of the WPP and the interaction scenario.

\( \rho_{WPP} \) is the location density of WTGs in the studied area of the WPP, which is calculated as \( \rho_{WPP} = 2L_{WPP}/R_{WPP} \), where \( L_{WPP} \) is the size of the wind turbine blade (indicated in the “Settings” menu, through the “WPP” window), \( R_{WPP} \) is the distance between the WTGs, \( |\sin(\Delta \alpha)| \) is the sine of the difference between the path vector angle \( |V| \) and the WTG direction angle.

The mechanism for creating a summary table. Column 35. After the formation of the previous columns, the abundance coefficient is calculated. The abundance coefficient (AC) is the main parameter that should reflect the assessment of the species abundance, calculated after the formation of the previous columns. The WPP area is formed by the User in the software environment, where the vector of movement and bird gathering is plotted.

The mechanism for creating a summary table. Column 36. On the generated page, you can also see an indicator from the average heights at which migratory birds were recorded. These indicators are needed to derive the height coefficient.

The height coefficient plays a very significant role in calculating the loss of migratory species. In the event that the range of bird flight heights does not coincide with the height interval determined by the dimensional characteristics of the blades, taking into account their length, the wind turbine is not a factor impacting the analyzed species.

The sigmoid function is used for the calculation of \( \delta_{heights} \). The sigmoid is a smooth, monotonically increasing, non-linear S-shaped function that is often used to smooth out jump values in some quantity. That is, when the flight altitude of the species differs by more than a meter from the danger zone, the height coefficient is 0. As soon as this value approaches 0, or falls into the danger zone, then the coefficient is equal to one.
The most important for assessing the impact of wind farms is the model of the migration process. This is a multi-criteria model based on parameters of the scenario, the species composition of birds, technological parameters of the WPP and WTG territory. As a result, when using this model, it is possible to obtain a value that, when compared with an expert’s assessment, gives the final results for the analysis of the migration process and can be the basis for managing the operation of individual wind turbines in certain seasons of the year.

For all wind farm sites, the results of studies that are included in the programme, tables similar to the summary table described above with the calculation of the Risk coefficient are generated by the “BirdsFly” tool as part of the summary general table with the calculation of PBR and CRM, and, if necessary, they are filtered.

In March 2019 – February 2020, 45 species of birds and 7 taxonomic groups were recorded at the Overianivka and Novotroitsk wind farm site (Passerinae spp., Alauda spp., Anatidae spp., Anas spp. and Calidris spp.), which made migratory movements. The calculation of the probable number of collisions was made for all 5 seasons – spring migration, breeding, autumn migration, wintering and total for the whole year.

From the data of 52 species and taxonomic groups of birds that moved through the project area, for 10 species and 1 taxonomic group (Passer montanus, Passerinae spp., Corvus cornix, Galerida cristata, Riparia riparia, Hirundo rustica, Emberiza calandra, Pica pica, Motacilla alba, Motacilla flava and Upupa epops) there is no threat of collision. The explanation for this fact lies in the peculiarities of the biology of the above-mentioned species, which move at safe ground heights up to 25 m (and more often up to 10 m), and the probability of finding them in a potentially dangerous altitudinal range is extremely low.

For the other 35 species and 6 taxonomic groups, there is a theoretical threat of collisions. Such species, according to common European practice, are designated as those that may be “threatened due to the operation of wind farms” (European Commission recommendations, 2010). But for all of them, collisions are not expected in all 5 seasons, either due to the absence of a threat of collision (i.e., ground flight heights), or due to the fact that the migration process on the territory of the wind farm is insignificant (a small total number of representatives of a species, or the main bird movements took place outside the wind farm site, and only a small percentage flew across the wind farm territory).

In general, the following can be stated. The territory of the Overianivka and Novotroitsk wind farm sites is not a place of significant concentrations and migratory movements of birds; the species that we observed within the wind farm are mainly characterized by the heights of flights under the rotor-swept area, the main part of which is the common starling. Species that may feel the impact of the wind farm make regular forage and transit flights mainly within the nearby wetlands (Larus spp., anseriformes), or they are not numerous (falconiformes). The most “intense” are the periods of seasonal migrations, when the number of birds and the intensity of their flights increase (149 records of 3720 individuals in spring and 108 records of 6056 individuals in autumn versus 41 records of 1283 individuals in winter and 32 records of 423 individuals in summer).

Among the migratory birds there were only 3 representatives of the Red Data Book of Ukraine (Circus cyaneus, Grus grus and Larus ichthyaeetus), but they were recorded at safe heights and did not feel the impact of the WPP.

It should also be noted that according to the reference data [6], there is mortality of 1 bird individual per 10 MW of electricity produced at the wind farm. This empirically confirmed relationship was determined based on many years of research on 109 operating wind farms in Europe and North America. That is, with a total capacity of the Overianivka and Novotroitsk wind farm of approximately 140 MW, 14 bird individuals should die. According to our calculations, based on the available data on the number of birds at the height of the rotor-swept area and the directions of their movement, the probability of bird collision with the wind
turbines was extremely low.

The same work carried out in 2018-2021 on the territory of the Botiieve wind farm showed similar results.

Thus, in 2018, 64 species and 2 groups of birds that were not identified to species were recorded at the Botiieve wind farm site. For 34 species and 1 group of birds (53.0%), collisions are not expected in all seasons either because there is no threat of collision or because the migration process on the territory of the wind farm is insignificant. For 6 species (9.1%), *Corvus cornix*, *Alauda arvensis*, *Chloris chloris*, *Hirundo rustica*, *Sturnus vulgaris* and *Carduelis carduelis*, the threat of collisions is insignificant in all seasons. For 16 species and 1 group of birds (25.8%), *Passer montanus*, *Passer spp.*, *Columba palumbus*, *Turdus pilaris*, *Turdus merula*, *Fringilla coelebs*, *Falco vespertinus*, *Riparia riparia*, *Tadorna tadorna*, *Emberiza calandra*, *Parus major*, *Pica pica*, *Apus apus*, *Motacilla alba*, *Motacilla flava*, *Philomachus pugnax* and *Larus minutus*, the threat of collisions is not significant in 2 seasons. At the same time, for all of them, it is generally not significant throughout the year.

In 2018, 8 species fell into the potential risk group: *Falco tinnunculus*, *Columba livia*, *Corvus frugilegus*, *Buteo buteo*, *Circus aeruginosus*, *Larus cachinnans*, *Larus ridibundus* and *Larus melanocephalus*. For *Falco tinnunculus* and *Corvus frugilegus*, the threat is significant in one season, but it is insignificant throughout the year (the death rate is predicted to be no more than 2 individuals for *Falco tinnunculus* and 30 individuals for *Corvus frugilegus* - 50.0% and 33.0% of the “permitted” PBR calculations). For *Columba livia*, *Buteo buteo*, *Circus aeruginosus* and *Larus melanocephalus* the collision threat is defined by the programme as significant in one season, and significant throughout the year. The predicted mortality is 100% of the “permitted” PBR calculations for *Columba livia*, *Buteo buteo* and *Circus aeruginosus*, and 150% for *Larus melanocephalus*. And only for Larus cachinnans and Larus ridibundus the threat is significant throughout the year (the predicted assessment of mortality is 112.5% and 100% of the “permitted” PBR calculations respectively, or 9 and 4 individuals).

According to the results of research in 2019, we can state the following: the vast majority of migratory birds of the Botiieve wind farm ornithocomplex – 45 out of 46 species and one taxonomic group have a risk coefficient of 0. The reason for this is the absence of bird migrations recorded during the research at altitudes of the dangerous range (from 51 up to 150 m), so their height coefficient is 0 this year, and respectively, the value of the risk coefficient of the species indicated in the table is 0%. The exception is *Larus ridibundus*, which has a height coefficient of 0.9991% and a risk coefficient of 3.41%. The explanation for the conclusion of the programme, which determined the result “Threat: NOT SIGNIFICANT” by calculating the risk coefficient, is that 45 individuals of this species were recorded in spring at a height of 90 metres, their route ran along the coast of the Sea of Azov and was partly reflected within the study area, which gave the programme grounds to pay attention to these processes.

For 45 out of 46 recorded species and 1 group of birds, there is no threat of collisions in all periods of the year. And for *Larus ridibundus*, the annual number of which is 195 individuals, 45 of which were recorded in the danger zone, the programme predicts 8 collisions per year and therefore gives a conclusion about a significant threat (8 is bigger than 3, where 3 are PBR individuals) in the spring, when dangerous heights used by birds of this species were just recorded; the result obtained is 3, the conclusion gives (3 is smaller than or equal to 3) “the threat is not significant, monitoring is necessary.”

In 2020, out of 30 species for which there was a theoretical threat of collisions with wind turbines (out of 47 species and 2 taxonomic groups registered in the project area during the year), 24 species of them are not expected to have collisions in all 5 seasons, either due to the absence of a threat of collision (i.e., ground flight heights), or because the migration process through the wind farm is insignificant (a small total number of representatives of the species, or the main movements of birds took place outside the site, and only a small percentage flew across
the wind farm). For 3 species *Falco tinnunculus, Corvus frugilegus* and *Larus cachinnans*, which were recorded at dangerous heights directly on the territory of the WPP, the Programme found no impact (risk coefficient is 0%) due to small numbers and a small percentage of the time. Another 2 species *Corvus corax* and *Larus ridibundus* were identified as endangered, but the impact of the Botiieve wind farm on them was determined by the Programme as not significant. For *Corvus corax* as a whole, a loss of 1 individual is predicted for the year, for *Larus ridibundus* – 12 individuals. And only for *Buteo buteo* the programme concludes that there is a significant threat, since the loss of 2 individuals is predicted for the year, although this scenario is quite unlikely.

And, finally, in 2021, according to the results of research, almost all species of the Botiieve wind farm ornithocomplex, 45 out of 46 species and one taxonomic group (*Tringa spp.*), have a risk coefficient of 0. This result was facilitated by the absence of representatives of these species registered during bird migration studies at heights of the dangerous range (from 51 m to 150 m) above the territory of the wind farm, therefore, their height coefficient is 0 this year, hence the value of the risk coefficient will be 0. As an exception, one species *Pandion haliaetus* has the risk coefficient of 0.94%. The comment of the programme regarding the threat is as follows: “the threat is not significant”. For the entire period of research, only one individual of this species was recorded on September 14, 2021 at 10:00 a.m. on a forage flight 50 meters high. This height is close to the range of dangerous heights. The average number of birds of this species, both for the season and for the year, respectively, was 1 individual, hence the average height of migration is 50 metres, therefore, the height coefficient is 1. Considering these values, calculations were made for the flow filtration coefficient and the population coefficient, which affected the value of the risk coefficient.

It should be noted that *Pandion haliaetus* is not the only species recorded during research at a height of 50 m, which is close to dangerous ones (51 – 150 m). *Merops apiaster*, 20 individuals, and *Circus aeruginosus*, 1 individual, were at such height. The average number of birds, both of the first and second species, and the average flock size are bigger than 1 and, accordingly, the average flight height for all records of these species will be already below the risky one. But an important criterion for concluding that there is no risk for these two species is the fact that flights at an altitude close to dangerous were made off the site.

4. Conclusions
Thus, the assessment of the impact of wind farms on the ornithological component of the territory is a complex functionally dependent model characterized by a number of factors.

Factors can be divided into the following features:

- factors relating to the scenario of behaviour (depending on the phase of the life cycle);
- factors of species composition of birds;
- WPP territory factors;
- factors of expert assessment.

To measure the quantitative changes in the species composition of birds, a population coefficient was proposed, calculated on the basis of the total abundance of the recorded species within the project area of the WPP site and the European abundance of the species.

The most important for assessing the impact of wind farms is the model of the migration process. This is a multi-criteria model based on parameters of the scenario, species composition and technological parameters of the WPP territory. As a result, when using this model, you can get a value that, when compared with the expert’s assessment, gives the final results for the analysis of the migration process.
The implemented mathematical model and the WEBBIRDS programme, based on it, allows you to analyze the impact of wind farms on the ornithological component within the WPP site and for the region as a whole.

The developed “WEBBIRDS” web application is a multifunctional solution that supports the use of mobile devices, GPS systems to determine the current coordinates during surveys and the ability to generate reports.

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