Capabilities of the WEBBIRDS system in the process of assessing the impact of wind farms on seasonal bird complexes on the example of spring migrants at the Botiieve wind farm in 2013-2021

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Abstract. This paper contains the analysed results of field observations of the spring migration of birds on the territory of the Botiieve wind farm in 2013-2021. The work was carried out as part of the planned monitoring of the ornithological situation in the area of the Botiieve wind farm (Pryazovskyi district, Zaporizhzhia region) and also covered the Tubal Estuary formed by the confluence of the Velyka and Mala Domuzla and Akchokrak Rivers and in the mouth of the Korsak River. During each trip, up to 70% of the wind farm area was covered. There were given characteristics of the taxonomic composition of the ornithocomplex, flight phenology, height and direction of migration by seasons and months. In the spring period of 2013-2021, 156,910 individuals of 125 species were recorded in the project area. 52,575 individuals of 92 species of these birds (33.5%) were observed directly within the Botiieve wind farm and buffer zones and there were recorded 104,335 individuals of 99 species (66.5%) at the adjacent wetlands - the Botiieve Ponds and the Tubal Estuary. New methods for collecting, storing and processing information, including mapping, server storage and data processing using two web applications, have been proposed. In order to describe in detail the migration processes in the local area, methods of vector mathematics, as well as computer vision algorithms, were used. The result of the analysis was a gradient map of seasonal bird migration concentration, which allows a differentiated approach to assessing the threats to birds from operating wind turbines. The impact of the Botiieve wind farm on birds during the period of seasonal migrations is estimated to be low.

1. Introduction
The need to adapt traditional methods of ornithological observations is due to the peculiarities of the behaviour of birds and their reactions in different phases of the annual cycle to the infrastructure of wind farms at the stages of planning, construction and operation of wind farms [1]. The ambiguous attitude to the development of wind energy, which is especially discussed among ornithologists [2–20], makes it necessary to critically study the versatile aspects of the interaction between operating wind turbines and birds [21]. The research, the result of which should be a conclusion obtained on the basis of personal experience, is improved by using software systems for statistical data processing. This requires taking into account
modern analysis tools, such as multivariate correlation and regression analyses, construction and analysis of OLAP models, automatic expert systems, systems based on heuristic analysis algorithms, etc. [22–24]. Therefore, an independent software system was developed, which not only provides the user with the opportunity to receive versatile monitoring data, both in tabular and cartographic formats, but also contains tools for assessing the impact of the construction and operation of wind farms on birds.

The idea of creating a mechanism for automatic assessment of possible negative impact of wind turbine generators (WTGs) on birds with the developed author’s method became the basis of the WEBBIRDS Computer Programme with the multithreaded Web-portal, which provides the process of transmission, storage, multilevel access and processing of information on the state of the seasonal ornithocomplexes on the research territories [25–27].

The WEBBIRDS system is designed as a web application that creates a single information network for all participants in the study of ornithological complexes, and which can be used simultaneously with a browser by several users using a mobile device with GPS capable to automatically determine the coordinates of observations. The system allows to quickly obtain up-to-date information about observations, both new and those recorded in the programme earlier, to work with data on bird species, changes in their numbers, flight altitude, types of migrations.

The main purpose of the study is to assess the impact of wind farms on the ornithological situation of a given territory through the element of the WEBBIRDS system called concentration gradient.

2. Materials and methods
Monitoring studies of the ornithological situation were carried out at the Botiieve wind farm in 2013-2021 according to generally accepted methods by carrying out special expeditionary trips using vehicle and pedestrian methods of bird census. During each trip, up to 70% of the wind farm territory was covered. Studies were also carried out on the Tubal Estuary, formed by the confluence of the Velyka and Mala Domuzla and Akhokrak Rivers and in the mouth of the Korsak River (figure 1). Until recently, ornithological research in the area between the Domuzla and Korsak Rivers was practically absent. The first report on the birds of the Korsak River was published by Chernichko I. and Falko A. [28]. In connection with the plans to build the Botiieve wind farm, the authors organize preliminary studies since 2010, and after the start of construction and commissioning of the wind farm (2012-2013), seasonal ornithological observations.

The research paper is based on the results of observations of spring migration as the most massive movement of birds against the background of maximum species diversity.

Using the tools of the WEBBIRDS mobile WEB-application with the saved data based on the results of field studies, tables and maps were generated to conduct a detailed analysis of the seasonal migrations at the Botiieve wind farm. The analysis of the presented results was carried out for certain seasons, using the necessary filters in the date format. The numerical, altitude and rhumb characteristics of the behaviour of the species recorded in the study area were obtained by choosing a specific species from the proposed list of birds from the wind farm site.

Data on migrations were entered into the WEBBIRDS application using the Birds Fly programme (author’s development, certificate APS/9126-18122018 [25, 26]) through the active page, which made it possible to obtain in addition to distribution maps of recorded migrations, tables and graphs with migration directions, the ratio of the number of individuals to heights, as well as to analyze the impact of wind farms on migratory birds using a concentration gradient.

Data obtained during monitoring studies in 2013-2021 at the Botiieve wind farm were entered into the programme database and processed by the WEBBIRDS using the concentration gradient
analysis method. The method of analysis used in the work can be presented as a study of the concentration gradients of migration flows to assess their safety, which was done by the authors in previous studies [27].

Migration studies, assessment of their intensity, safety and impact on them, were carried out using the basic methods of vector mathematics, as well as algorithms used in computer vision. Since the migration process is directly related to the map data and is also being explored in a certain geographic area, computer vision tools such as image convolution, image filtering, and gradient delimitation allow analysis of critical areas of the map. If we define the geometric content of the vector, then this is a straight line segment for which limit points and a direction corresponding to the concept of bird migration are given. Vector analysis provides tools for the study of vectors, their features and allows you to perform operations on them.

Based on the results of research on the monitoring site of the Botiieve wind farm, included in the programme, a map is generated with vectors (figure 2) indicating the direction of the nearest migration in relation to a certain point on the ground, taking into account the influence of other, less numerous migrations. If the vector field showing the direction of growth of a certain value $\phi$ – gradient, then this is a concentration gradient, and having a map of the gradients of each field (figure 3), it is possible to determine the concentration gradients, which allow us to assess the impact of various factors on the migration flow.

Statistical processing of the material was carried out in Microsoft Office Excel 2007.

In addition, we adapted the generally accepted methods for specific areas of the wind farm, where studies are necessary to assess the degree of impact of operating wind turbines on birds [27,29].

The accumulation and storage of the field data was carried out in a specially designed database of a server created for this purpose [30].

The algorithm of the model, designed as a web application, can be defined as follows:

(i) Representation of a set of observations of a bird or a flock migration as a set of vectors.

(ii) The calculation of the bases of the obtained vectors and determination of the weight coefficients.

(iii) The construction of concentration gradients for each vector.

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**Figure 1.** Area of research (1 – the Tubal Estuary; 2 – the Botiieve wind farm; 3 – the mouth of the Korsak River; ○17 – wind turbines; △ – a meteorological mast).
(iv) The convolution of a geographical map.
(v) Overlaying the obtained gradients on the map with subsequent accumulation of values.
(vi) Filtering out insignificant gradient values.
(vii) Determination of areas of increased concentration of vector gradients.
(viii) Carrying out a differential analysis of each zone to identify its weight characteristics.
(ix) Interpretation of the weight characteristics on bird migrations passing in this zone.

Thus, the combination of classical field observations and server accumulation of long-term ornithological monitoring data in a specific area with the capabilities of two web applications not only characterize in detail the state of birds during migration periods, but also objectively assess the impact of the wind farm on ornithocomplexes [30].

3. Results and discussion
To compare the ornithological situation at the Botiieve wind farm, its buffer zones and adjacent areas of increased biodiversity (the Botiieve Ponds and the Tubal Estuary) during 2013-2021 (wind farm operation period), the spring period was chosen because in this region it is more significant than the period of autumn migration.

In general, the picture is clear: most of the birds, both sitting on the ground and flying in the air, were observed outside the territory of the wind farm. This trend is observed throughout all 9 monitoring years, with slight modifications, as shown in figures 4-7.
In 2013, the main concentrations of birds were observed on the Tubal Estuary, the Botiieve Ponds were in second place. Migrations were recorded mainly over the Azov Sea, at a distance of up to 2-2.5 km.

In 2014, the number of birds was significantly less (10,572 individuals against 19,741 individuals in 2013), and due to the fact that the period of existence of the water surface on the Tubal Estuary was much shorter and at the end of spring there was almost no water in most of the estuary, significant gatherings of birds were not formed here (unlike the Botiieve Ponds). However, we observe the growth of number of birds in the northern part of the wind farm site, near the WTG No 50. In spring 2014, 2 colonies of *Corvus frugilegus* were formed here, which in May consisted of 420 and 120 nests. Migratory movements of birds were carried out mainly outside the wind farm site, along the coastline of the sea, as well as in the area of the mouth of the Korsak River and the lower Botiieve Pond.

The weather conditions in spring 2015 led to the fact that the water level in the adjacent wetlands increased, and was the highest for the previous 3 monitoring years, which led to an increase in the total number of birds (24,862 individuals). Among the migratory birds, the most numerous was *Phalacrocorax carbo*, 7,625 individuals (or 63.1% of the migrants), which was noted southeast of the village of Prymorskiy Posad. In the second place among the migratory birds was *Corvus frugilegus*, 2,238 individuals, 18.5%. It is interesting that one flock of this species numbering 1,250 individuals flew in transit to the northeast at altitudes of more than 200 m along the coast of the Sea of Azov.

The following year, the number of birds was even greater (39,724 individuals), also due to the adjacent areas. On the territory of the wind farm birds did not form significant gatherings at all. 3,000 individuals of *Phalacrocorax carbo* were recorded in the sea on March 11, 2016 at a distance of up to 1.5 km from the wind farm site. On this day, *Phalacrocorax carbo* dominated among the migratory birds: 3 flocks with a total number of 1,104 individuals headed to the
colony on the Obytichna Spit in the eastern direction.

In 2017, a total of 18,472 individuals were registered (15,879 individuals of them, 86.0%, were observed outside the wind farm site and buffer zones). As in 2016, no numerous concentrations of birds were observed on the territory of the wind farm, migratory movements were not intensive (1,075 individuals, 5.8% of the total number of birds).

In 2018, the picture was similar, although the number of birds decreased to 7,097 individuals. And only 873 of them (12.3%) were recorded in flight. We observe several places where the number of flying birds was higher. One of them was noted in the southern part of the wind farm, in the area of the WTGs No 53, 54, 60 and 61, and coincides with the registration of flocks of *Sturnus vulgaris*, which made forage and transit flights at altitudes outside the zone of risk collision with wind turbines. Another situation is observed in the northeastern part of the wind farm near the WTGs No 9 and 10 and is explained by the foraging flights of *Corvus frugilegus* from the colony located in the forest near the Botiieve Ponds to neighboring agrocenoses.

Observations in 2019 showed a continuation of the trend in the last 3 years. In total, 6,928 individuals were recorded, 1,034 individuals of them (14.9%) were registered as migrants. Gatherings of perched birds, except for the adjacent wetlands, were observed only in the waters of the Sea of Azov southeast of WTG No 37 (these were waterfowl birds - *Podiceps cristatus*, *Larus cachinnans*, *Anas querquedula*, *Aythya marila*), and also partially, in the area of the WTGs No 9 and 10 (*Corvus frugilegus*). Among the migrants, the most numerous were *Larus melanoccephalus*, the flight of which was observed on April 24, 2019 east of the WTG No 37 over the coastline of the Sea of Azov, as well as the *Corvus frugilegus* and *Sturnus vulgaris* (in total, these 3 species accounted for 41.8% of migratory birds in spring 2019).

In 2020, the trend of previous years continued. In general, 14,638 individuals were recorded, only 8.7% (1,277 individuals) of them made flights. Traditionally, gatherings of mainly waterfowl birds were recorded in adjacent wetlands (mainly on the Botiieve Ponds), including the lower part of the Tubal Estuary, which is located between the villages of Prymorskyi Posad and Novokonstantynivka, and a small number of them were observed in the the Sea of Azov near the WTGs No 37 and 21. *Corvus frugilegus*, *Larus ridibundus* and *Oenanthe isabellina* dominated among migrants, subdominants were *Hirundo rustica*, *Phalacrocorax carbo* and *Sturnus vulgaris* (these 6 species accounted for 73.9% of the total spring migratory birds). The most intensive flights were in the area of artificial afforestation at the Botiieve Ponds, as well as in the southern part of the wind farm.

And, finally, in 2021, 14,876 individuals were registered, a quarter of them 25.6% (3,808 individuals) were observed during flights. The vast majority of birds, 12,264 individuals, 82.4%, were recorded outside the territory of the wind farm (at the same time, the role of the adjacent territories was not the same - about 60% of birds were recorded on the Tubal Estuary, and only 40% on the Botiieve Ponds; unlike last year when the situation was the opposite). Among the migrants, *Anser albofrons* dominated, and the subdominant was *Philomachus pugnax* (these 2 species accounted for 64.8% of the total number of spring migrants). The most intensive flights were in the southern and eastern parts of the wind farm.

Thus, in the spring period of 2013-2021, 156,910 individuals of 125 species were recorded in the project area. Of these, 52,575 individuals of 92 species (33.5%) were observed directly within the Botiieve wind farm and buffer zones. 104,335 individuals of 99 species (66.5%) were recorded on the adjacent wetlands, the Botiieve Ponds and the Tubal Estuary.

The role of different functional zones was not the same, although in almost all years (except 2014-2015) the adjacent territories dominated in terms of the number of birds recorded there (figures 4-7).

Migration movements were carried out by 34,297 individuals of birds (or 21.86% of the total number of recorded birds). At the same time, the number of migrants varied over the years (figures 4-7). In the first 3 monitoring years, the number of migrants was growing (30.3, 35.1
Figure 4. Ornithological situation at the Botieve wind farm and adjacent territories in the spring period of 2013-2016. On the left are recorded birds (not in flight), on the right are migratory movements.
Figure 5. Ornithological situation at the Botieve wind farm and adjacent territories in the spring period of 2017-2020. On the left are recorded birds (not in flight), on the right are migratory movements.
and 48.6% of migrants against 69.7, 64.9 and 51.4% of the recorded perched birds), but starting from 2016 it was decreasing. However, in 2021, the number of migrants increased again and accounted for almost a quarter (25.6%) of all birds, while the number of recorded perched birds, on the contrary, decreased (74.4%).

If we extrapolate the obtained data for the whole spring period, we can expect about 380 thousand birds to fly through the project area in 9 years (2 months of spring migration per year). However, it should be noted that migration is divided into transit and forage. The peculiarity of bird transit flight is the massive process involving a large number of birds and species, purposeful active type of flight (swinging and soaring) in the appropriate direction, long single flight distance (over 500-600 km), with no delays and stops on the migration route.

At the same time, foraging migrants reveal a slightly different type of behaviour, characterized by a long stay of birds within the region, daily foraging flights from roosting places to feeding places, the entire spectrum of migration directions determined only by the search for food, the formation of gatherings of various sizes, and short distances of flights.

The number of forage and transit migrants was almost the same (16,422 individuals, or 47.88% of forage migrants and 17,875 individuals, or 52.12% of transit migrants). But if we exclude 2015 from the calculations (when there was a massive anomalous transit passage of
Figure 8. Distribution of birds recorded in 2013-2021 on the territory of the Botiieve wind farm and buffer zones (red column) and adjacent territories (blue column).

*Phalacrocorax carbo* across the project area to the colony of the species on the Obitochna Spit, which accounted for 63.1% of all recorded migrants in spring 2015), then the situation will be different (65.82% of forage migrants vs. 34.18% of transit ones).

Landscape and biotope conditions have a significant impact on the abundance and species composition of the ornithocomplex in the project area. If within the Botiieve wind farm the state of biotopes (which are mainly represented by an anthropogenic landscape - farmland and artificial forest plantations-forest belts) remained more or less stable for 9 monitoring years, then in the adjacent areas of increased biodiversity, the Tubal Estuary and the Botiieve Ponds, it can vary dramatically over the years. For example, in 2014 the water level was the lowest compared to previous years, and the gatherings of waterfowl birds there were few. A completely opposite picture was observed in 2016 when the high water level remained throughout the spring and almost the entire summer, which led to an increase in both the number and species diversity of birds. Another significant factor influencing birds in adjacent areas is hunting, primarily for game birds, which lasts from early August to late December (although a greater impact from hunting as a disturbance factor is observed in the post-breeding and autumn phenological periods).

In 2018-2019 the lowest number of birds was observed in the project area, approximately the same situation was in 2014, which is not related to the operation of the wind farm. The most probable reason for this phenomenon is periodic fluctuations in the abundance in the populations of recorded bird species, as well as less favourable conditions in adjacent areas. However, today (2020-2021) the situation has changed somewhat, and bird numbers have begun to grow again. But if we consider only the territory of the Botiieve wind farm, then over the past 5 years (2017-2021), the number of birds here has been consistently low.

The presence of areas of increased biodiversity near the Botiieve wind farm leads to a relatively high total number of birds in the project area. 66.49% of the total number of birds in the spring period have been recorded in the Tubal Estuary and the Botiieve Ponds in 9 years. In 7 years, out of 9, the part of the adjacent territories was larger (59.88% in 2013, 76.02% in 2016, 85.96% in 2017, 65.06% in 2018, 71.55% in 2019, 83.59% in 2020 and 82.44% in 2021). Only in 2014 and 2015, the wind farm site and buffer zones dominated, and part of the adjacent territories accounted for only a third of the total (35.94 and 34.45%, respectively).

Observations showed that only 21.86% of the total number of birds carried out forage and transit movements through the project area (34,297 individuals). If we extrapolate the obtained
data for the whole spring period, we can expect about 380 thousand birds to fly through the project area. At the same time, the number of transit migrants is smaller than the number of foraging migrants, as most of the recorded birds that moved through the project area flew during feeding (*Sturnus vulgaris*, *Corvus frugilegus*, *Larus cachinnans*, etc.).

Of all migrants registered during 9 years, only a small part moved in the potentially dangerous altitude range of 51-150 m. There were less than 1% of such birds (285 individuals). If a part of migrants is at risk zone, the number of individuals and frequency of such cases is small. The bulk of migrants is accounted for either under the rotor-swept area (85.88%) or above the rotor-swept area (13.28%). Since a significant part of migrants were *Passeriformes*, more than 40% of migrants were observed at ground altitudes up to 10 m.

For migratory birds, a significant factor of disturbance is the anthropogenic factor - agricultural work during the year. However, it can affect birds that are long-term associated with the project area, i. e. forage migrants and those birds that remain breeding at the end of the spring migration. For transit migrants, the territory of the Botiieve wind farm is not a place for them to stop due to the unattractiveness of its habitats. On the other hand, recently there has been a change in transcontinental migrations, when most geese and Eurasian Cranes and others fly through the territory of Ukraine in transit. The disturbance factors existing at the wind farm, such as the presence of wind turbines and routine work on the territory of the wind farm, do not practically impact on these birds.

4. Conclusions
As a result of the work performed with the help of the BirdsFly programme and the WEBBIRDS web application, there were created maps (figures 4-7), which reflect the ornithological situation at the Botiieve wind farm and adjacent areas in the spring period in 2013-2021. Thanks to the “concentration gradient” tool, the maps clearly trace the functional areas with the largest bird concentration. These areas all lie outside the wind farm. We note the low theoretical and no real negative impact of the Botiieve wind farm on bird populations during the spring migrations in 2013-2021, both in the short and long term.

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