Development of the information system for forecasting collision between birds and wind farms

Article *in* Eastern-European Journal of Enterprise Technologies · August 2019

DOI: 10.15587/1729-4061.2019.174398

Viacheslav Osadchyi
Borys Grinchenko Kyiv University

Petro Gorlov
Biodiversity Research Institute, Ukraine, Melitopol

Kateryna Osadcha
Bogdan Khmelnitsky Melitopol State Pedagogical University

UDC 004.42:[621.311.245:598.2.526](477.64)
DOI: 10.15587/1729-4061.2019.174398

DEVELOPMENT OF THE INFORMATION SYSTEM FOR FORECASTING COLLISION BETWEEN BIRDS AND WIND FARMS

Створена інформаційна система для обробки результатів спостереження птахів на території вітропарку. Інформаційна система забезпечує зберігання і обробку результатів моніторингу, проведення статистичного аналізу даних і отримання прогнозу можливості зіткнення птахів з лопатями вітрових електроустановок. Математична модель прогнозування дозволяє проводити розрахунки в разі неповної інформації про параметри вітроколеса. Як приклад розглянуто екологічну ситуацію на території вітропарку "Приморськ-1", який розташований на узбережжі Азовського моря. Опрацьовано інформацію по 5923 зареєстрованим птахам 45 видів. У небезпечній зоні зіткнення птахів з лопатями ротора на висотах між 48 м і 182 м виявлено 72 особини чотирьох видів: Larus ridibundus (43 птаха), Merops apiaster (15 птахів), Buteo buteo і Circus aeruginosus, відповідно, 5 і 9 птахів. Оцінювання ризиків зіткнень здійснено для одного року експлуатації вітрового парку з урахуванням поведінки птахів у різні сезони річного циклу (зимівля, міграції, гніздування). На підставі отриманих даних проведено аналіз можливості загибелі птахів за рахунок їх зіткнення з лопатями роторів. Розрахунки проводилися за допомогою моделі, яка побудована відповідно до рекомендацій Фонду «Шотландська природна спадщина». Ймовірність зіткнення птиці при знаходженні в просторі ротора слабо залежить від її геометричних розмірів і знаходиться в межах 11–14 %. Прогнозування загального числа зіткнень у розрахунку на одну турбіну за один рік перебуває на рівні 0,07–0,25 птаха. З цієї кількості майже половина відноситься до Larus ridibundus. Сумарна кількість зіткнень усіх птахів протягом одного року експлуатації вітропарку з 26 турбінами складе майже 1,7–6,5 особин. Отримані дані узгоджуються з результатами робіт європейських дослідників

Ключові слова: вітрова електростанція, інформаційна система прогнозування загибелі птахів, математична модель прогнозування

V. Osadchyi
Doctor of Pedagogical Sciences, Professor, Head of Department*
E-mail: osadchyi@mdpu.org.ua
V. Siokhin
PhD, Associate Professor, Director**
E-mail: siokhinvd@gmail.com
P. Gorlov
PhD, Associate Professor**
E-mail: petrgorlow@gmail.com
V. Yeremieiev
Doctor of Technical Sciences, Professor*
E-mail: evs1938@gmail.com
K. Osadcha
PhD, Associate Professor*
E-mail: okp@mdpu.org.ua
*Department of Informatics and Cybernetics
Bogdan Khmelnitsky Melitopol
State Pedagogical University
Hetmanska str., 20, Melitopol, Ukraine, 72312
**Scientific and Training Center "Biodiversity"
Hetmanska str., 20, Melitopol, Ukraine, 72312

Received date 25.03.2019
Accepted date 10.07.2019
Published date 23.08.2019

1. Introduction

The development of wind power engineering is a priority direction in the general term of creating energy-saving resources in many countries. Current projects and developments in this area pose a certain threat to birds. At the UN Climate Conference in Bonn, a number of researchers noted that wind turbines and electric power lines are becoming a particular problem for migratory birds. Low and fast rotating wind power plants (WPP), which were developed in the late twentieth century, were the cause of death of a large number of birds [1]. Only at one wind power farm (WPF) in San Francisco, from 800 to 1,300 birds of prey died each year [2]. Annual mortality at all wind farms of the United States caused by collisions with turbines is 140,000–328,000 birds [3] and 500,000–1,600,000 bats [4]. The number of birds that died on wind generators Enercon E-82 for 8.5 months is estimated at 14.3–29.6 recalculated per one turbine [5].

The reaction of environmentalists to such inadmissible development of the power market was extremely negative. The main factor responsible for the death of birds is the proximity of a farm to areas with a high density of birds (migration routes, concentration areas, wintering areas) [6]. According to the authors of paper [6], extended research in this direction ensured obtaining additional information that will help mitigate the adverse impact of the development of wind power engineering on ornitocomplexes.

The advisability of creating new capacities is solved taking into consideration the specific environmental conditions. The death of birds on the territory of a WPF is determined by many factors. Analysis of the causes of deaths of birds on the WPF territory was performed in review paper [7]. The degree of their manifestation depends on the type and the number of birds, landscape-biotopic characteristics of the territory, the weather, flock's migration direction, technical parameters of a WPP etc. That is why the development of methods for studying the behavior of birds on the territory of wind farms and prediction of their interaction with wind plants is a relevant task.

2. Literature review and problem statement

The results of the study of environmental problems and, in particular, the prediction of collision between birds and WPP turbines is largely dependent on the methodology of information collecting and processing. According to paper [8], for the past 30 years, intensive ornithology research has led to a decrease in the threat of the WPF for birds. This is related to the technical improvement of the WPP, taking into consideration scientifically grounded recommendations during designing, construction and operation of wind farms.

Currently, there are two approaches to the solution of the problem: a theoretical and empirical [9]. The theoretical approach is based on using the formula for calculating the number of collisions of n_j birds of the j-th species with WPP turbines

$$n_j = R_{fj} n_{jDang}, \qquad (1)$$

where R_{fj} is the risk of a collision of one bird with turbine blades; n_{jDang} is the number of birds flying in the direction to a wind wheel.

It is known that in the WPP zone birds change the flight trajectory and, thereby, avoid collisions with turbine blades. In connection with this circumstance, we will represent magnitude R_{fj} in the form of product of evasion coefficient f_j on the probability of a bird collision with blades P_j in case of its passing through the space occupied by a wind wheel, that is:

$$R_{fj} = f_j P_j. \qquad (2)$$

The probability of a collision can be determined using the integral

$$P_j = \iint_S p_j(r, \varphi) r \mathrm{d}r \mathrm{d}\varphi / \pi R_v^2, \qquad (3)$$

where $p_j(r, \varphi)$ is the density of probability of a collision of a bird with turbine blade, and integrating is performed on the whole surface of a wind wheel.

As shown by formulas (1) to (3), a mathematical model of the general form is determined by three parameters. One of them n_{jDang} characterizes the number of birds flying towards a wind wheel. Parameter f_j determines the possibility of changing the flight trajectory when encountering the WPP. The third parameter P_j characterizes the probability of a bird collision with blades when getting into the space occupied by a wind wheel.

Correct implementation of the model is possible if there is reliable original information. The value of n_{jDang} is determined according to the data of monitoring birds on the areas belonging to a wind farm. Databases of the MySQL, Microsoft Access type and the others are applied to store information. Observation data are processed using statistical packages of the Excel, Statistica, Mathematica, Maple type. Many researchers prefer their own software development, which better meet the specificity of conditions for monitoring. Thus, in paper [10], the original program in the form of the Web-application was created for computer support of accounting and analysis of monitoring results. It was effectively used in the study of seasonal ornitocomplexes of birds on the coast of the Sea of Azov [11]. An improved version of this program allows representing the registration material in the form of tables, drawings and graphs [12].

The value of the second parameter f_j in formula (2) is determined in the empirical way. Its magnitude depends on weather conditions and the type of birds. Its most probable value is found in the range of 0.05–0.005 [13].

The third parameter refers to the probability of the collision of a bird with blades of turbines. The probability was first assessed in paper [14]. The author of this work proceeded from the assumption that a bird has a cruciform shape, its flight trajectory is perpendicular to the surface of a wind wheel, the WPP is operated in a continuous mode, etc.

The mathematical aspect of the calculation of P_j does not have any fundamental difficulties. Modern numerical methods make it possible to determine the integral (3) with any precision. The main source of errors is the original information necessary for calculation. Calculation results in paper [14] contain a large number of assumptions, which is they are qualitative rather than quantitative in nature. However, this method is widely used in a number of studies, for example, in articles [10, 15–17].

According to the international standards, performance of the ornithological expert analysis on the territory of a wind farm is a compulsory condition for making decision on the construction of a wind farm. In many cases, it is considered in the absence of any information on many issues relating to the elements of the WPP structure, where the application of the mathematical model (1) to (3) turns out to be impossible. Article [18] contains the analysis of statistical material on bird mortality on 109 wind farms in Europe and North America. The authors of this study concluded that the average number of dead birds is about 0.5–1.0 per one WPP within one-year operation. That is why, at the stage of preliminary analysis of the ecological situation on the territory of a wind farm to estimate the number of bird collisions with turbines in calculation per one WPP, instead of formula (1), we can use the value of

$$n = (0{,}5 \ldots 1{,}0), \text{Birds per one turbine.} \qquad (4)$$

The method of prediction of the possibility of birds' deaths with the help of assessment (4) was called "empirical model". Naturally, such an approach reflects an averaged situation and implies ornithological studies on the territory of a wind farm. It is known that in some cases the number of collisions of birds with turbines differs from values (4). For example, the death of birds on the territory of a wind farm in study [6] was not detected, while in paper [5], on the contrary, it is reported that the value of n reaches 10 and more on some farms. Assessment (4) can be trusted in the case of the WPP with the turbines located high in the absence of intense migration paths. Low-power WPP with low-lying wind wheels pose a much greater danger to birds. Thus, 10,017 birds and bats of 170 species died on the territory of the WPP in Spain within the period from 1993 to 2016 [19].

Correctness of the mathematical forecasting models using formulas (1) to (3) is beyond doubt. The problem of its use is in the choice of the original data. One of the main causes of calculation inaccuracy is related to obtaining and processing the results of monitoring. Another reason stems from the extrapolation of data, obtained on separate sections of a wind farm within a relatively short period, on the entire territory of a farm taking into consideration real time resources of its operation. The study of the influence of these factors on prediction results and assessment of the adequacy of the used model under specific conditions is of great practical significance.

3. The aim and objectives of the study

The aim of the study is to create IS enabling processing the results of the study of birds' ornitocomplexes and anticipating the possibility of their death on the territory of a wind farm with an assessment of accuracy of the data obtained.

To accomplish the set aim, the following tasks were set:

– to develop an algorithm for calculating the number of collisions of birds with the WPP turbines based on the mathematical model (1) to (3);

– to create software shell for IS functioning;

– to explore the adequacy of the mathematical prediction model;

– to assess the accuracy of the obtained calculation results;

– to test the use of the IS based on the analysis of the possibility of collisions of birds with WPP under real conditions.

4. Source data for a mathematical model

Interaction of birds with turbines is determined by the technical characteristics of the WPP, geometrical parameters of birds, speed, direction and height of their flight, as well as weather conditions (wind velocity, state of the atmosphere, etc.). We will divide the source data for calculations into three groups: technical parameters of the WPP, results of monitoring the birds on the territory of a wind farm and flight characteristics of birds.

4. 1. Technical parameters of a wind farm

High-power WPF contain up to 20 and more WPP. Wind wheels of modern WPP have three blades that are mounted on the hub. Introduce the following designations: R_v is the blade length, R_0 is the radius of the hub, N is the number of turbines on the farm territory, d_v is the width of the wind wheel blade, γ is the angle of wedging between its chord and the plane of wind wheel rotation. Interaction of a bird with the WPP occurs in the case of its being in a dangerous zone of a wind farm (DZ). By the DZ, we will imply the part of the wind farm space, occupied by all rotating wind wheels.

The main characteristics of a bird, determining the possibility of its collision with a turbine, are flight speed v_j, length L_1 and wingspan L_2. If the linear size of a bird is much less than the wind wheel depth, equal to $d_v\sin(\gamma)$, the DZ volume is approximately equal to $V_{Dang} = N\pi R_v^2 d_v \sin(\gamma)$. In case of a big bird, the DZ depth should be counted down from the point of its beak appearing in the wind wheel plane to the point of a bird' tail location when its flies out of the DZ. The DZ volume is equal to

$$V_{Dang} = N\pi R_v^2\left(d_v \sin(\gamma)+L_1\right). \quad (5)$$

To predict the number of collisions of birds with turbines, we require information on angular velocity of the wind wheel rotation, geometric parameters of the WPP and the magnitude of the DZ volume.

4. 2. Monitoring birds on the wind farm territory

Bird-watching sites on the territory of the designed farm are chosen in such a way that takes into consideration its landscape-biotropic features and possible ways of birds' flights from the surrounding buffer zones. Special attention is paid to observations at altitudes in a risk zone (RZ) of a collision with WPP turbines. The RZ occupies some space on bird-watching sites in the interval of altitudes δH between the lower H_1 and the upper H_2 levels of the WPP wind wheel edges: $\delta H = H_2 - H_1$. Its volume is equal to

$$V_{Risk} = \delta H S_{Risk}, \quad (6)$$

where S_{Risk} is the area of bird-watching sites.

It is assumed that the primary information about birds obtained on the territory of a wind farm is consistent with the recommendations from Fund "Scottish nature heritage" [20]. Table 1 shows the example of accounting the monitoring results in spring on 25.03.2017 on site 1 during monitoring in the morning hours from 8.00 to 11.00 and in the evening hours from 13.30 to 16.30 by the research results in [11]. When compiling Table 1, the following abbreviations were used:

– The number of birds registered in the morning (M) or evening (E) time – N.

– Flight type: transit – T, feed – F, demonstration – D.

– Direction of migrants' flight: north – N, north-east – NE, east – E, south-east – SE, south – S, south-west – SW, west – W, north-west – NW.

– Height H and length L of the flight on the given observation site.

– Time of a bird being on the site on the assigned interval of altitudes: t_1 is the total time, t_2 *is* at the height up to the lower level of a wind wheel, t_3 – in the interval of heights, corresponding to a wind wheel, t_4 – at the height higher than a wind wheel.

Table 1

Results of monitoring birds in spring of 25.03.2017 on the observation site 1 in the morning (M) and evening (E) time, N is the number of registered birds [11]

No.	Bird species	M/E	N	Direction	Type	H, m	L, m	t_1, s	t_2, s	t_3, s	t_4, s
1	Circus aeruginosus	M	1	NE	T	60	530	29	10	19	0
2	Circus cyaneus	M	1	N	F	30	660	37	37	0	0
3	Acanthis cannabina	M	22	SE	T	5	250	14	14	0	0
4	Pica pica	M	2	E	F	10	250	14	14	0	0
5	Fringilla coelebs	M	30	N	T	7	300	17	17	0	0
6	Corvus frugilegus	M	7	SW	F	15	350	19	19	0	0
7	Falco tinnunculus	M	1	E	F	20	850	47	47	0	0
8	Passerinae spp.	M	9	N	T	5	660	37	37	0	0
9	Sturnus vulgaris	M	25	NW	T	5	700	39	39	0	0
10	Falco tinnunculus	M	2	S	D	15	900	50	50	0	0
11	Corvus cornix	E	3	W	F	10	300	17	17	0	0
12	Larus ridibundus	E	7	SE	T	15	700	39	39	0	0
13	Fringilla coelebs	E	21	NW	T	7	380	21	21	0	0
14	Fringilla coelebs	E	8	NW	T	7	380	21	21	0	0
15	Accipiter nisus	E	1	S	F	20	530	29	29	0	0
16	Larus ridibundus	E	9	E	T	10	800	44	44	0	0
17	Pica pica	E	1	NW	F	7	400	22	22	0	0
18	Circus aeruginosus	E	1	SE	F	30	600	33	33	0	0

Primary information presented by monitoring results is entered in the database, which is used for statistical analysis and prediction of birds' collisions with turbines.

4. 3. Flight characteristics of birds

Flight characteristics of birds are determined by geometrical sizes, their flight speed and the ability to change a flight trajectory in the presence of obstacles. The bird's shape can be represented using a cruciform or a rectangular model. In the first case, a bird is considered in the shape of a cross with wings location midway between the beak and tip of the tail. The use of the cruciform shape understates the calculated probability of a collision. In a rectangular model when one of the sides of the rectangle is taken equal to the length of a bird L_1 and another – to wingspan L_2, calculation value of probability is slightly overestimated.

Exactness of assigning flight speed v_j for a bird of the j-th species largely determines the reliability of predicting the number of collision victims on wind power plants. In paper [21], it is shown that value of v_j for one and the same species may vary widely. Thus, the maximum magnitude v_j during the flight of a sandwich tern, adjusted for individual variations and the flight type is (12.2±3.3) m/s. The lowest speed was observed during the search for food and was equal to (8.3±3.0) m/s.

Flight characteristics of birds used in the present work are presented in Table 2.

Table 2

Dimensions and flight speed of birds [22]

Bird species	Length of bird, L_{1j}, m	Wingspan L_{2j}, m	Flight speed, m/s
Buteo buteo	0.54	1.2	11.6
Circus aeruginosus	0.55	1.25	11.2
Larus ridibundus	0.37	0.93	11.9
Merops apiaster	0.28	0.47	19.7

Table 2 shows that large species (*Buteo buteo, Circus aeruginosus, Larus ridibundus*) have lower speed compared to smaller species (*Merops apiaster*).

In paper [23], extensive information on the ability of birds to shy away from an obstacle on its path was collected for 62 species of marine and 19 species of waterfowl. When performing calculations in this study, the magnitude of evasion coefficient f_j in formula (2) was accepted equal to (0.05–0.1), which corresponds to the most unfavorable situation.

5. Algorithm of calculations for prediction of interaction between birds and turbines

5. 1. Calculation of the number of birds' collisions with turbines

According to formula (1), the number n of collisions of birds of the j-th species with the WPP depends on the number of birds n_{jDang} flying toward a wind wheel and the risk of their collision with turbine blades R_{fj}. The value of n_{jDang} is determined by processing monitoring results of birds' behavior on bird-watching sites. Let us introduce the following designations:

– T_{Risk} is the interval of time within which the monitoring is performed;

– n_{ij} is the number of birds of the j-th species in the i-th group, flying at the same speed;

– t_{ij} is the time of a bird of the j-th species from the i-th group being in the RZ;

– T_{jOper} is the duration of a life cycle of a bird of the j-th species on the territory of a wind farm for one year of the WPP operation.

Activity of behavior of birds in the RZ will be determined using coefficient

$$K_{jRisk}=\sum_i n_{ij}t_{ij}. \quad (7)$$

Magnitude T_{jOper} depends on migration routes and natural conditions of where the station is. For example, according to the data of paper [11], the value of T_{jOper} for birds of the Azov coast is determined, basically, by duration of migration processes in spring and autumn seasons. Let us assume that the number of birds and the duration of their stay in the RZ is known from observations and coefficient of their activity K_{jRisk} is calculated from equation (7). Participants of monitoring are selected on the wind farm site, so behavior of birds in the dangerous zone and in the risk zone will be the same. It can be proven that in this case coefficient of activity of birds T_{jDang} in the DZ will be determined from formula

$$K_{jDang}=f_jK_{jRisk}V_{Dang}T_{Oper}/\left(V_{Risk}T_{Risk}\right), \quad (8)$$

where V_{Dang} and V_{Risk} are the volumes of DZ and RZ, respectively.

The number of birds' collisions with the WPP blades at quite long observation time will be the same in all cases that satisfy condition K_{JRisk}=const. For example, the number of collisions when 100 birds stay in the DZ for 10 seconds will be the same as in the case when 10 birds are in the same zone within 100 seconds.

Suppose that the birds that get to the DZ cross the wind wheel surface at right angle to it. Denote the time of flight of a bird of the j-th species through the wind wheel as τ_j. Then the total number of birds flying through the DZ is determined from formula

$$n_{jDang}=K_{jDang}/\tau_j, \quad (9)$$

and the expression to calculate the number of collisions (1) taking into consideration formula (8) takes the form of

$$n_j=\frac{fV_{Dang}T_{Oper}P_j}{\tau_jT_{\mathrm{Risk}}V_{Risk}}\sum_i n_{ij}t_{ij}. \quad (10)$$

The time of a bird flying through a wind wheel is equal to

$$t_j=\left(d_v\sin(\gamma)+L_{1j}\right)/v_j, \quad (11)$$

where v_j is the speed of a bird; L_{1j} is the length of a bird of the j-th species.

Substituting formula (11) in expression (10), we will obtain

$$n_j=\frac{fN\pi R_v^2v_jT_{Oper}P_j}{T_{Risk}\delta HS_{Risk}}\sum_i n_{ij}t_{ij}. \quad (12)$$

Expression (12) is the basic formula when calculating the number of bird collisions with turbines. To use it, it is necessary to determine the probability of a collision of one bird with wind wheel blades P_j. The other parameters of the formula contain information on technical characteristics of the WPP, the flight speed of a bird and the results of monitoring of birds' behavior on observation sites.

5. 2. Determining the probability of a bird collision with turbines

The risk of an injury to a bird flying through the rotor space is associated with rotating blades and the wind wheel central zone. The solution to the set problem can be obtained in three ways:

1. General problem statement is formulated in paper [14], where formula (3) was applied for calculation of the probability of a collision of one bird with the WPP blades. Since the implementation of this formula in exact statement is impossible, the following assumptions were used when carrying out the calculations [14]:

– blade thickness is equal to zero;

– angle of the direction of a bird's flight to the wind wheel surface is equal to 90°;

– geometrical characteristics of a bird are determined by length L_1 and wingspan L_2.

2. The appropriateness of the WPF operation is usually considered before power capacities are put in operation, when some technical parameters of a farm can be unknown. In particular, function $d(r)$ may be unknown. In this case, one can use the approximated solution obtained in research [17]. Suppose that the blade width retains its constant value along its length and is equal to d_v. Within the flight time of a bird t_j through the rotor, which is determined from formula (11), a wind wheel will be rotated at angle ωt_j, where ω is the angular velocity of rotation, resulting in a blade moving to position B (Fig. 1).

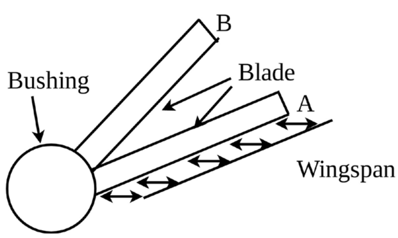


Fig. 1. Schematic of a wind wheel part at moving of blade *A* to position *B*

Paper [17] provides a simple expression to compute the frontal area of one wind wheel blade S_{1j} responsible for its interaction with a bird:

$$S_{1j} = \pi R_0^2 + \frac{2(R_v - R_0)L_{2j}}{\pi} + (R_v - R_0)d_v\cos(\gamma) + \frac{(R_v - R_0)^2 t_j\omega}{2}. \quad (13)$$

Similar expressions can be found for the other two blades S_{2j} and S_{3j}. The probability of a collision of one bird with a wind wheel is equal to

$$P_j = \frac{S_{1j} + S_{2j} + S_{31j}}{\pi R_v^2}. \quad (14)$$

Formula (14), taking into consideration (13), after insignificant simplifications is converted to the form of

$$P_j = \frac{\left[\pi R_0^2 + \frac{6(R_v - R_0)L_{2j}}{\pi} + 3(R_v - R_0)d_v\cos(\gamma) + \frac{3(R_v - R_0)^2 t_j\omega}{2}\right]}{\pi R_m^2}. \quad (15)$$

3. Rough estimation. Modern WPP are characterized by large dimensions and low rate of turbines rotation. In this case, large birds face the greatest risk of collision with turbines. In paper [17], it was found that for the length of birds in the interval of (0.28–0.54) m at the change of angular velocity from 7 to 14 rpm and the blade width from 3.0 m to 4.1 m, the value of P_j is in the interval of 0.1...0.2. These results are consistent with the predictions in paper [14], where the calculation magnitude of probability for approximately the same parameters of birds and the WPP are within 0.093–0.17. Thus, in the case of the lack of data on dependence $d(r)$, it is possible to use rough estimation during analysis of the interaction of large birds to determine the probability of a collision of a bird flying through one wind wheel

$$P_j = 0.15. \quad (16)$$

Note that in empirical methods, the probability of a collision is accepted as equal to the constant [24]. Compare the accepted value of probability (16) with the data of observations of birds' death on the territories of different wind farms. In paper [25], the facts of birds' collision with the WPP of the new generation of high power (1.65 MW), which are characterized by a large blade area, were collected and analyzed. According to data obtained, the risk of birds' collision with turbines is equal to R_{fj}=0.0014. If we accept that f_j=0.01, then according to formula (2) and empirical data on the mortality of birds (4), the probability of their collision with the WPP will prove to be equal to 0.14. The resulting value almost coincides with rough estimation of probability (16).

6. Description of functioning of the information system

The developed IS consists of three modules "Read", "Forecasting", "Write", which ensure, respectively, entering the original information, a mathematical model output of the analysis results on a display or a printer (Fig. 2).

The first submodule "Read.Wind.Fime" of module "Read" is intended for entering and storage of data on characteristics of WPF, determining the possibility of birds' collision with turbines. The second submodule "Read.Monitoring" ensures entering and storage of the data on monitoring the wind farm territory. In fact, it is a database containing the monitoring results. The third submodule "Read.Wind.Birds" contains all parameters for individuals of various species that are required to calculate the interactions of birds with turbines (geometrical characteristics, flight speed, etc.).

The first submodule "Forecasting, Zone" in the second module "Forecasting" ensures determining the parameters of activity of the birds that find themselves in the zone of a risk of the possible interaction with the WPP turbines. The Second Submodule "Forecasting.Probability" is intended to calculate the probability of a collision of birds with wind wheel blades. The third submodule "Forecasting.Statistics" ensures statistical treatment of the source information in database "Read.Monitoring".

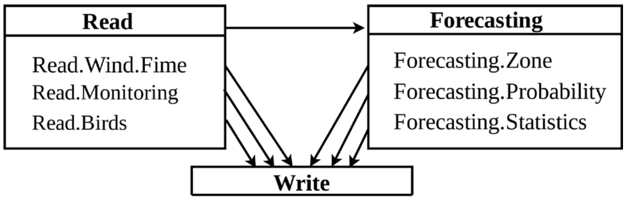


Fig. 2. Structure of IS

Software code is compiled based on the Windows Forms technology in the environment of software development Microsoft Visual Studio Community 2017. When implementing the code, the following elements were used: *dataGridView, tabControl, comboBox, groupBox, button, label, checkListBox*. The program is run by initiation of the executed file "*Birds.exe*". The main window which shows the content of tab "DB1", displaying the results of monitoring the wind farm territory, appears on the display. Fig. 3 shows the part of accounting data from observation protocols of the type of Table 1.

Table scan is performed by moving the slider in the vertical direction in the right part of the window or scrolling the mouse wheel. The data in *dataGridView1* are only available to display information. It is impossible to change them by a user. Primary information is contained in the database file of Microsoft Access 2003 *"base_m.mdb"*, found in the folder with executed file "*Birds.exe*". The latter is automatically uploaded into the table by command

this.таблица1TableAdapter.Fill (this.base_mDataSet1.Таблица1).

All the examples in this section refer to the results of monitoring on the territory of wind farm "Primorsk-1" [11], where 5,923 birds of 45 species were accounted on three sections in 2017. By default, at the start of the program, all the information is uploaded into the table from the database file.

The "Calculate" button is located under the table in the main window. Its pressing initiates the process of calculating coefficients $k1$, $k2$, $k3$, $k4$ from formula (5), as as result of which the number of birds and the magnitude of coefficients $k1$, $k2$, $k3$, $k4$ is displayed, Fig. 4. The values of the coefficients are required to calculate the number of collisions of birds with turbines from formulas (10) to (15).

The second tab named "DB2" contains the second table with the results of processing the records found in the first table in tab "DB1". Fig. 5 shows the part of these data referring to all monitoring sites PS1, PS2, PS3. In this case, the information on all 5,923 birds available in the database will be processed. This table contains the data on the type, flight direction, flight altitude, as well as the values of parameters $\Sigma k1$, $\Sigma k2$, $\Sigma k3$, $\Sigma k4$. The major part of the birds (3,795 birds or 65 %) flew by transit. The feed group consisted of 2,113 birds (35 %), the share of the demonstration flights was 15 (less than 0.3 %).

Birds S

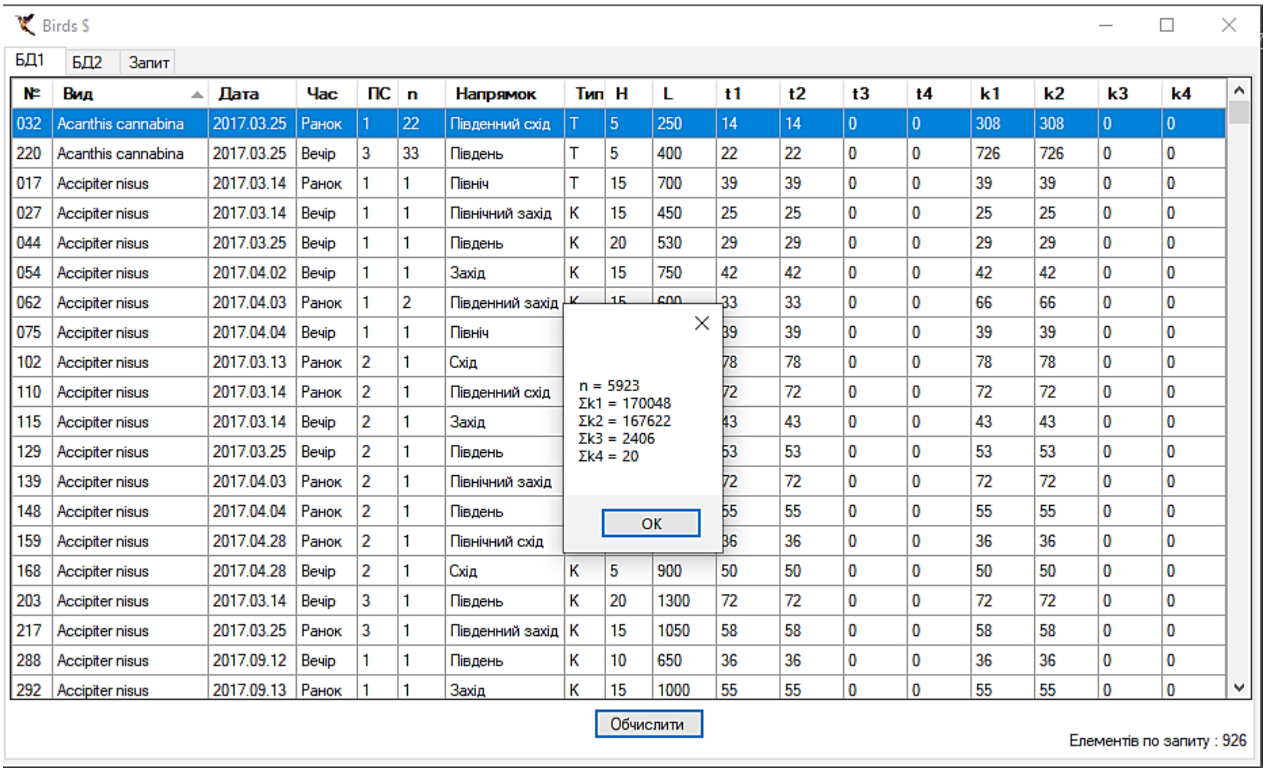
БД1 БД2 Запит

№	Вид	Дата	Час	ПС	n	Напрямок	Тип	H	L	t1	t2	t3	t4	k1	k2	k3	k4
032	Acanthis cannabina	2017.03.25	Ранок	1	22	Південний схід	T	5	250	14	14	0	0	308	308	0	0
220	Acanthis cannabina	2017.03.25	Вечір	3	33	Південь	T	5	400	22	22	0	0	726	726	0	0
017	Accipiter nisus	2017.03.14	Ранок	1	1	Північ	T	15	700	39	39	0	0	39	39	0	0
027	Accipiter nisus	2017.03.14	Вечір	1	1	Північний захід	K	15	450	25	25	0	0	25	25	0	0
044	Accipiter nisus	2017.03.25	Вечір	1	1	Південь	K	20	530	29	29	0	0	29	29	0	0
054	Accipiter nisus	2017.04.02	Вечір	1	1	Захід	K	15	750	42	42	0	0	42	42	0	0
062	Accipiter nisus	2017.04.03	Ранок	1	2	Південний захід	K	15	600	33	33	0	0	66	66	0	0
075	Accipiter nisus	2017.04.04	Вечір	1	1	Північ	T	15	700	39	39	0	0	39	39	0	0
102	Accipiter nisus	2017.03.13	Ранок	2	1	Схід	K	15	1400	78	78	0	0	78	78	0	0
110	Accipiter nisus	2017.03.14	Ранок	2	1	Південний схід	K	15	1300	72	72	0	0	72	72	0	0
115	Accipiter nisus	2017.03.14	Вечір	2	1	Захід	T	15	780	43	43	0	0	43	43	0	0
129	Accipiter nisus	2017.03.25	Вечір	2	1	Південь	T	15	950	53	53	0	0	53	53	0	0
139	Accipiter nisus	2017.04.03	Ранок	2	1	Північний захід	K	10	1300	72	72	0	0	72	72	0	0
148	Accipiter nisus	2017.04.04	Ранок	2	1	Південь	T	15	1000	55	55	0	0	55	55	0	0
159	Accipiter nisus	2017.04.28	Ранок	2	1	Північний схід	K	15	650	36	36	0	0	36	36	0	0
168	Accipiter nisus	2017.04.28	Вечір	2	1	Схід	K	5	900	50	50	0	0	50	50	0	0
203	Accipiter nisus	2017.03.14	Вечір	3	1	Південь	K	20	1300	72	72	0	0	72	72	0	0
217	Accipiter nisus	2017.03.25	Ранок	3	1	Південний захід	K	15	1050	58	58	0	0	58	58	0	0
288	Accipiter nisus	2017.09.12	Вечір	1	1	Південь	K	10	650	36	36	0	0	36	36	0	0
292	Accipiter nisus	2017.09.13	Ранок	1	1	Захід	K	15	1000	55	55	0	0	55	55	0	0

Обчислити

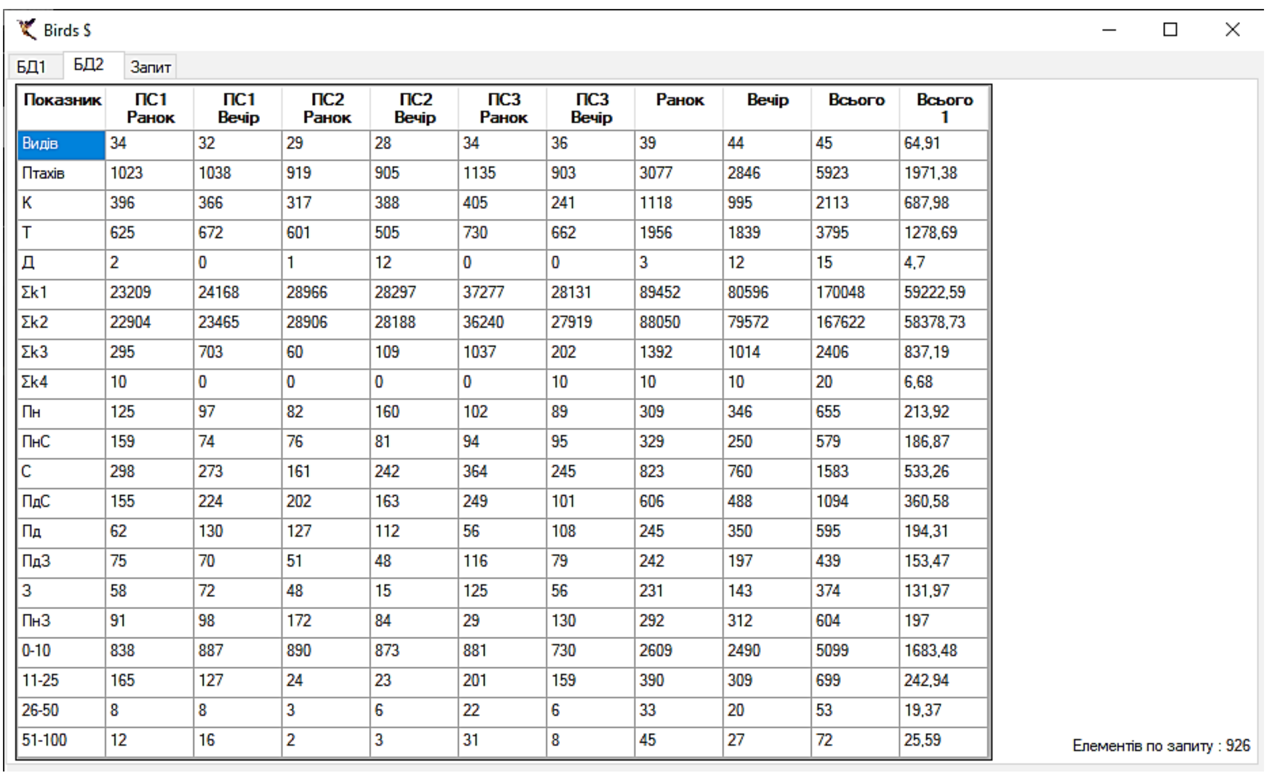
Елементів по запиту : 926

Fig. 3. Example of output of the tables with original data



№	Вид	Дата	Час	ПС	n	Напрямок	Тип	H	L	t1	t2	t3	t4	k1	k2	k3	k4
032	Acanthis cannabina	2017.03.25	Ранок	1	22	Південний схід	T	5	250	14	14	0	0	308	308	0	0
220	Acanthis cannabina	2017.03.25	Вечір	3	33	Південь	T	5	400	22	22	0	0	726	726	0	0
017	Accipiter nisus	2017.03.14	Ранок	1	1	Північ	T	15	700	39	39	0	0	39	39	0	0
027	Accipiter nisus	2017.03.14	Вечір	1	1	Північний захід	K	15	450	25	25	0	0	25	25	0	0
044	Accipiter nisus	2017.03.25	Вечір	1	1	Південь	K	20	530	29	29	0	0	29	29	0	0
054	Accipiter nisus	2017.04.02	Вечір	1	1	Захід	K	15	750	42	42	0	0	42	42	0	0
062	Accipiter nisus	2017.04.03	Ранок	1	2	Південний захід	K	15	600	33	33	0	0	66	66	0	0
075	Accipiter nisus	2017.04.04	Вечір	1	1	Північ				39	39	0	0	39	39	0	0
102	Accipiter nisus	2017.03.13	Ранок	2	1	Схід				78	78	0	0	78	78	0	0
110	Accipiter nisus	2017.03.14	Ранок	2	1	Південний схід				72	72	0	0	72	72	0	0
115	Accipiter nisus	2017.03.14	Вечір	2	1	Захід				43	43	0	0	43	43	0	0
129	Accipiter nisus	2017.03.25	Вечір	2	1	Південь				53	53	0	0	53	53	0	0
139	Accipiter nisus	2017.04.03	Ранок	2	1	Північний захід				72	72	0	0	72	72	0	0
148	Accipiter nisus	2017.04.04	Ранок	2	1	Південь				55	55	0	0	55	55	0	0
159	Accipiter nisus	2017.04.28	Ранок	2	1	Північний схід				36	36	0	0	36	36	0	0
168	Accipiter nisus	2017.04.28	Вечір	2	1	Схід	K	5	900	50	50	0	0	50	50	0	0
203	Accipiter nisus	2017.03.14	Вечір	3	1	Південь	K	20	1300	72	72	0	0	72	72	0	0
217	Accipiter nisus	2017.03.25	Ранок	3	1	Південний захід	K	15	1050	58	58	0	0	58	58	0	0
288	Accipiter nisus	2017.09.12	Вечір	1	1	Південь	K	10	650	36	36	0	0	36	36	0	0
292	Accipiter nisus	2017.09.13	Ранок	1	1	Захід	K	15	1000	55	55	0	0	55	55	0	0

Fig. 4. Results of calculating coefficients $k1$, $k2$, $k3$, $k4$



Показник	ПС1 Ранок	ПС1 Вечір	ПС2 Ранок	ПС2 Вечір	ПС3 Ранок	ПС3 Вечір	Ранок	Вечір	Всього	Всього 1
Видів	34	32	29	28	34	36	39	44	45	64,91
Птахів	1023	1038	919	905	1135	903	3077	2846	5923	1971,38
К	396	366	317	388	405	241	1118	995	2113	687,98
Т	625	672	601	505	730	662	1956	1839	3795	1278,69
Д	2	0	1	12	0	0	3	12	15	4,7
Σk1	23209	24168	28966	28297	37277	28131	89452	80596	170048	59222,59
Σk2	22904	23465	28906	28188	36240	27919	88050	79572	167622	58378,73
Σk3	295	703	60	109	1037	202	1392	1014	2406	837,19
Σk4	10	0	0	0	0	10	10	10	20	6,68
Пн	125	97	82	160	102	89	309	346	655	213,92
ПнС	159	74	76	81	94	95	329	250	579	186,87
С	298	273	161	242	364	245	823	760	1583	533,26
ПдС	155	224	202	163	249	101	606	488	1094	360,58
Пд	62	130	127	112	56	108	245	350	595	194,31
ПдЗ	75	70	51	48	116	79	242	197	439	153,47
З	58	72	48	15	125	56	231	143	374	131,97
ПнЗ	91	98	172	84	29	130	292	312	604	197
0-10	838	887	890	873	881	730	2609	2490	5099	1683,48
11-25	165	127	24	23	201	159	390	309	699	242,94
26-50	8	8	3	6	22	6	33	20	53	19,37
51-100	12	16	2	3	31	8	45	27	72	25,59

Fig. 5. Results of computing the parameters characterizing behavior of birds on observation sites

The third tab “Query” contains the forms that ensure the formation of a sample from the general database. An example of sample data is shown in Fig. 6.

In this case, the sample contained four species of birds (*Buteo buteo, Buteo lagopus, Carduelis carduelis, Chloris chloris*), which were accounted on the first site in the morning of 13, 14 and 25, March, 2017. Subsequently, calculation of the number of collisions will be performed from this sample for the group of birds that are found in the zone of risk of collisions with the WPP turbines.

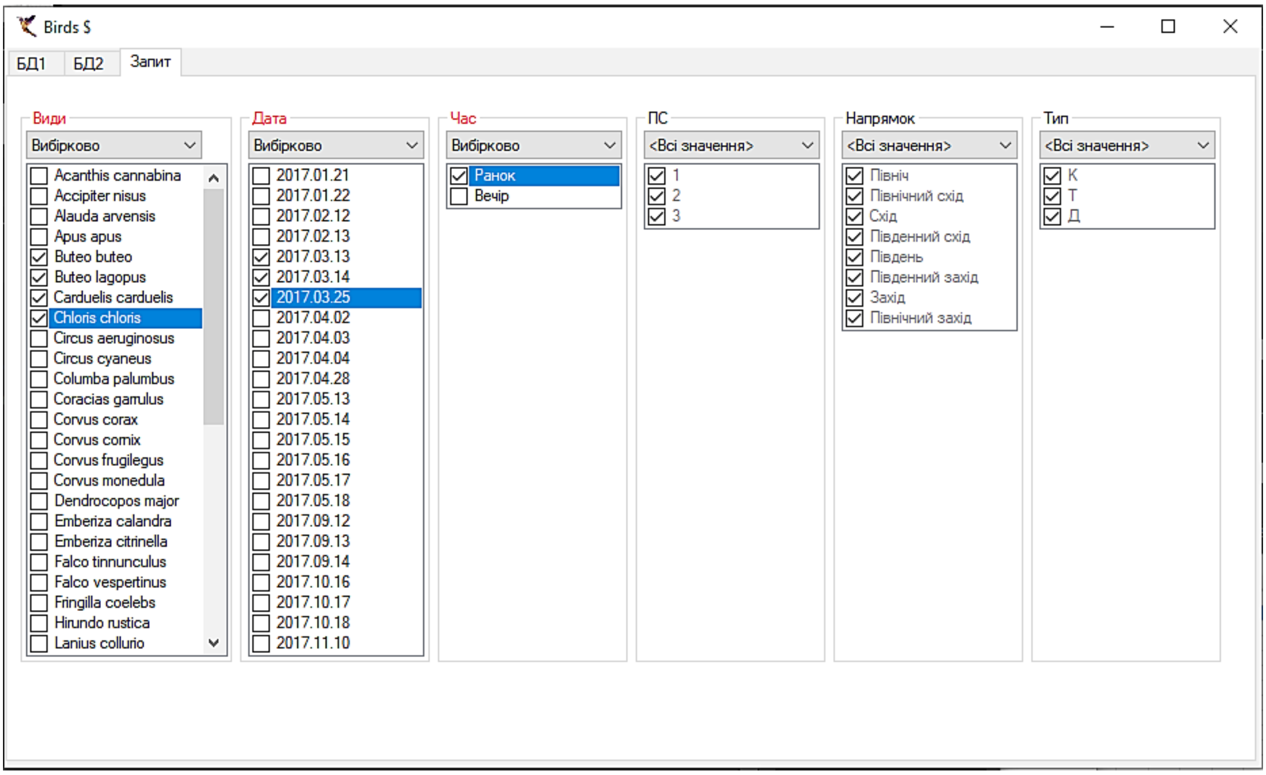


Fig. 6. Selection of birds by assigned parameters

7. Analysis of adequacy of the mathematical model for forecasting the death of birds on the wind farm territory

7. 1. Comparison of forecasting results with data from the scientific literature

Validation of the IS operation was carried out by comparing the obtained information with the results of paper [17]. The results of birds' migration observations on the territory of the wind farm "Primorsk-1" served as source data in calculations [11]. Computations were provided by submodules "Forecasting.Probability" and "Forecasting. Statistics" of the information system. The WPP parameters for calculations were consistent with the operation conditions of wind farm "Primorsk–1" with 26 WPP, which is located on the shore of the Sea of Azov. The rate of rotation of the blades was accepted equal to 14 rpm, the turbine bushings radius was 3 m, the blade length was 67 m, the blade width was 4.1 m. The angle between the chord of the blade cross-section and the wind wheel plane was 30°, the total area of the observation sites was 2.59 km^2. The dimensions and the flight speed of birds are shown in Table 2.

72 birds of four species were accounted in the zone of risk of birds' collision with the rotor blades at the altitudes between 48 m and 182 m: *Larus ridibundus* (43), *Merops apiaster* (15), *Buteo buteo* (5) и *Circus aeruginosus* (9). All they were registered in the periods of spring and autumn migration. The sum of products of the number of birds of every species by the time of their stay in the RZ in seconds was equal to 1440 s for *Larus ridibundus,* 495 s for *Merops apiaster,* 329 s for *Circus aeruginosus and* 142 s for *Buteo buteo*. Observations were held in the periods of spring and autumn migrations within 7 days for 6 hour a day for each of the migration period. Therefore, temporal parameters T_{Risk} in formula (12) for different seasons were equal and made up

$$T_{Risk}(\text{spring migration})=T_{Risk}(\text{autumn migration})=42 \text{ hours.}$$

Spring migration of birds in the coastal area of the Sea of Azov is in the period from the beginning of March until the end of May and lasts approximately 85 days. The first flocks of migratory birds in autumn appear at the end of August. At the end of November, that is, after about 100 days, the migration is over. If we accept that the duration of the light part of the day is equal to 12:00, the magnitude T_{Oper}(spring migration) will turn out to be equal to 1,020 hours and T_{Oper}(autumn migration) – 1,200 hours. The forecasted probabilities of crossing the birds' flight trajectory birds with the turbine blade surface and the numbers of collisions with the WPP corresponding to them are shown in Table 3. Calculations were carried out using formulas (12), (15).

The results of program testing, presented in Table 3, fully coincided with predictions in paper [17].

Table 4 shows the computations using the empirical model of the probability of collision of one bird with the WPP. In this case, the probability was calculated from formula: (16) and the number of collisions – from formula (12).

According to the data of Table 3, 4, parameters of interaction of birds with the WPP, found by various models, differ within 30 %. Parameters f_j and T_{Oper} have a stronger impact on forecast accuracy compared to the influence of probability of birds' collision with a turbine.

The obtained data are on the whole consistent with literary sources, in particular, with the data of the empirical model (4), according to which the average number of collisions of birds on 109 wind farms in Europe and North

America is estimated by magnitude of 0.5–1.0 birds per one WPP [18]. Similar results are also presented in paper [26]. It is reported that the number of deaths of birds on the WPF territory in the United States and Canada in calculation per one turbine varies from 0 to 0.81.

Table 3

Forecast of probability of collision of one bird P_i with WPP and the number of collisions of n_i birds at T_{Oper}(spring)=1020 hours and T_{Oper}(autumn)=1200 hours. Calculations were made from formulas (12), (15)

Bird species	Forecasted probabilities of crossing the birds' flight trajectory with turbine blade surface (P_i) and numbers of collisions with WPP (n_i) corresponding to them	
	P_i	n_i
Buteo buteo	0.19	0.82
Circus aeruginosus	0.19	1.37
Larus ridibundus	0.17	3.44
Merops apiaster	0.11	0.84
All birds		6.47
All birds in calculation per one WPP		0.25

Table 4

Forecast of probability of collision of one bird P_i with the WPP and the number of of collisions of n_i birds at T_{Oper}(spring)=1020 hours and T_{Oper}(autumn)=1,200 hours with the use of the empirical model for probability (16)

Species of bird	Forecasted probabilities of crossing the birds' flight trajectory with the turbine blade plane (P_i) and numbers of collisions with WPP (n_i) corresponding to them	
	P_i	n_i
Buteo buteo	0.15	0.67
Circus aeruginosus	0.15	1.07
Larus ridibundus	0.15	3.55
Merops apiaster	0.15	1.16
All birds		6.45
All birds in calculation per one WPP		0.25

7. 2. Assessment of accuracy of forecasting results

Reliability of forecasting the interaction of birds with rotors is determined by accuracy of assigning three parameters of the mathematical model: P_j, f_j and n_{jDang}. The probability of a bird collision P_j depends on technical and operational characteristics of the WPP, flight properties of a bird and weather conditions. Dimensions and average rotation rate of the blades of modern WPP are comparable with each other. In this paper, we studied the influence of the rate of wind wheel rotation and blade dimensions on the probability of collision for birds having the length in the interval of (0.28–0.54) m. It turned out that at a change of angular velocity from 7 to 14 revolutions per minute and the blade width from 3.0 m to 4.1 m, the value of probability is in the range of 0.1...0.2.

High-power wind plant turbines are located at the altitude of about 50 meters and above. Flights at these altitudes are typical for large species. According to the data of paper [11], their share is around 1–2 % of the total number of birds. As Table 2 shows, the dimensions and flight speeds of birds for species *Larus ridibundus*, *Merops apiaster*, *Buteo buteo* and *Circus aeruginosus* are comparable with each other. That is why the computed probabilities of their collision with turbines are close and are in the range of 0.11–0.19.

Observation results depend on season, weather conditions and time of day of monitoring. For example, the total number of individuals for species *Larus ridibundus, Merops apiaster, Buteo buteo, Circus aeruginosus*, recorded in spring and autumn, 2017 on all sites and at all altitudes was 493 and 412, respectively, (total 905 birds). Out of this number, only 72 birds were recorded in the zone of risk of collision with turbines. Computations use not this number, but rather coefficient K_{jRisk}, equal to the product of the number of birds by the time of their stay in the risk zone. Magnitude K_{jRisk} for the studied group at different seasons varies widely. For example, it was 1,851 birds in spring and 55 birds in autumn. The value of K_{jRisk} in the morning measurements amounted to 1,392, and at evening measurements – 1,014. Weather conditions also affected the results of measurements – there were fewer birds on rainy and windy days and more birds in clear and dry weather. Such fluctuations are of a statistical nature, on the background of which it is possible to obtain reliable averaged data. It should be noted that a rather large sample of 5,923 birds of 45 species was processed in this study.

The flight speed of a particular bird depends on wind direction. However, the impact of wind direction on its speed is partially mitigated by the fact that the number of birds flying downwind and upwind is equal. In the first case, the speed increases, in second case it decreases, but on average the time of bird flight through the wind wheel, determined from formula (11), remains.

Thus, despite certain difficulties associated with using the source data, on the whole, the studied models give similar results. A more complex situation is related to the identification of the evasion coefficient f_j. Its magnitude depends on weather conditions and type of birds. The value of f_j is apparently in the range of 0.05–0.005 [13, 27]. If we accept magnitude f_j equal to 0.05–0.01, as it was done in this work, the results obtained by us are in good agreement with literature data and empirical model (4). That is why it is logical to assume that the most probable magnitude f_j is in the interval 0.05–0.01.

Consider the role of parameter T_{Oper}. Bird migration is not uniform. Thus, according to the data in work [11], in 2017, the great majority of birds flew for over 46 days from March, 13 to April, 28 and in autumn in the period from September, 12 to November, 10 for 62 days. It is precisely these parameters that were used when performing calculations, which are shown in Tables 3, 4. The greatest bird activity is known to be manifested during 3 hours the morning and 3 hours in the evening. That is why, to assess the duration of the life cycle of birds T_{Oper}, it is possible to consider another option of selecting parameter T_{Oper}: T_{Oper} (spring migration)=276 hours, T_{Oper} (autumn migration)=372 hours. In this case, the forecasted data decrease approximately by three times, at that, the total number of collisions per WPP will be 1.72 or 0.07 in calculation per one turbine for one year of operation. These values are much lower than the admissible number of birds' deaths on the wind farm territory.

The conducted analysis of the role of different factors when performing calculations shows that the main reason for inaccuracy is related to the choice of evasion coefficient and determining the duration of a life cycle of birds. Weather conditions also affect the forecasted parameters. The use a large amount of sample data eliminates this effect and makes it possible to obtain satisfactory results.

8. Discussion of effectiveness of the application of an information system for forecasting the death of birds on a wind farm territory

The developed information system uses various mathematical methods for assessment of the possibility of birds' death under actual conditions of WPF operation. The use of the most accurate model, formulas (3), (12) is possible if there is enough complete information on the technical characteristics of the WPP. The approximated model, formulas (12), (15), is limited by the assumption of the permanence of the width of a WPP blade along its length. The last most inaccurate model, formulas (12), (16), is based on the results of analysis of literature data on the probability of collision of birds with the wind wheel blade. Here, as a rough approximation, it was accepted that the value of P_j does not depend on the characteristics of birds and the WPP structure and is equal to 0.15.

Reliability of forecasting is determined not so much by the correctness of using the mathematical methods as by assigning the source data by the technical parameters of the WPF, characteristics of birds and the data on their motion on the wind park territory. Calculation results showed that in the case of large birds and the high-power WPP, assigning the parameters of turbines, flight speed and dimensions of birds causes a relatively small error (less than 30 %). A higher margin of error is associated with the establishment of evasion coefficient and determining the duration of the vital cycle of birds on the wind farm territory.

Comparison of the obtained results of calculation within the mathematical model of the IS with the literary data [17, 18, 26] attests to the reliability of the proposed Statistical treatment of the data of monitoring the wind farm "Primorsk-1", which accounted for 5,923 birds of 45 species, showed that less than 1.3 % of the birds are in the risk group. This group consists of 72 individuals of four species: *Larus ridibundus* (43 birds), *Merops apiaster* (15 birds), *Buteo buteo* (5 birds) and *Circus aeruginosus* (9 birds). The most probable number of collisions of these birds with the farm turbines within one year of its operation is in the range of 1.7–6.5.

Thus, the IS ensures storage, processing the results of birds monitoring on the territory of the wind farm and prediction of the probability of their collision with turbines. The accuracy of the prediction is determined, to a large extent, by the adequacy of monitoring results and setting the WPF operating mode.

To enhance the reliability of forecasting, it is necessary to foresee empirical research in the following directions:

– accumulation of information on the territory of the wind farm and beyond it in line with methodical recommendation from Fund "Scottish natural heritage";

– increase in the observation duration during the periods of spring and autumn migration;

– development and the use of new monitoring methods, providing a more precise definition of coefficient of birds' activity K_{jRisk} on the territory of the wind farm, in particular, the route method of ornithological examination.

Acquisition and accumulation of new data will make it possible to refine the mathematical model and solve the problem under conditions of less rigid restrictions. In particular, it seems interesting to analyze the impact of the wind-rose on birds' collision with turbines and abandon the limiting assumption that birds' trajectories cross the wind wheel surface at right angle.

9. Conclusions

1. Different ways of using the mathematical model for forecasting the number of collisions of birds with the WPP turbines were proposed. The model implies the possibility of obtaining a prediction for various variants of information on the source data. Calculations show that the results of computations by various models differ by not more than 30 %. Consideration of the possibility of the wind farm construction is often carried out in conditions of incomplete information on technical and environmental issues. If the dimensions of birds and characteristics of a wind wheel are unknown, it is possible to be limited only by approximated calculation methods for the WPP with large dimensions and low rate of turbines' rotation. At complete absence of the source data, it is advisable to apply the results of the statistical analysis of bird mortality at 109 wind farms in Europe and North America, where about 0.5...1.0 collisions with turbines were recorded for one year of the WPF operation.

2. The program shell, ensuring the functioning of the IS was created. The developed IS contains the database for birds' monitoring, tool sets for statistical analysis of observation results and different variants of mathematical models for predicting the interactions of birds from turbines. The software product enables assessment of the birds of the time a bird flies through the WPF, find the probability of a bird's collision with a wind wheel and calculate the number of collisions of birds with turbines. The calculated data take into consideration the role of the main factors identified based on the analysis of literary sources. The main parameters that determine the interaction of birds with turbines are characteristics of the WPP, dimensions of birds, their flight speed, the number of the birds recorded in the risk zone and the duration of their stay in this zone.

3. Operability of the IS was tested on the example of studying the behavior of birds on the territory of the wind farm "Primorsk-1", located on the shore of the Sea of Azov. According to the data of monitoring, less than 1.3 % out of 5,923 birds of 45 species, registered on the territory of the farm within 2017, were in the zone of the risk of birds' collisions with rotor blades. This group of birds included 72 birds of four species: *Larus ridibundus* (43 birds), *Merops apiaster* (15 birds), *Buteo buteo* (5 birds) and *Circus aeruginosus* (9 birds). The predicted number of collisions is within 1.7–6.5 or 0.07–0.25 in calculation per one turbine, which is consistent with literature data.

References

1. Smallwood, K., Thelander, C. (2005). Bird Mortality at the Altamont Pass Wind Resource Area. Golden, Colorado, USA: National Renewable Energy Laboratory. Available at: http://www.nrel.gov/docs/fy05osti/36973.pdf
2. Fact Sheet on Altamont Pass Bird Kills (2005). San Francisco, CA, USA: Center for Biological Diversity. Available at: https://www.biologicaldiversity.org/campaigns/protecting_birds_of_prey_at_altamont_pass/pdfs/factsheet.pdf

3. Loss, S. R., Will, T., Marra, P. P. (2013). Estimates of bird collision mortality at wind facilities in the contiguous United States. Biological Conservation, 168, 201–209. doi: https://doi.org/10.1016/j.biocon.2013.10.007
4. Arnett, E. B., Baerwald, E. F. (2013). Impacts of Wind Energy Development on Bats: Implications for Conservation. Bat Evolution, Ecology, and Conservation, 435–456. doi: https://doi.org/10.1007/978-1-4614-7397-8_21
5. Aschwanden, J., Stark, H., Peter, D., Steuri, T., Schmid, B., Liechti, F. (2018). Bird collisions at wind turbines in a mountainous area related to bird movement intensities measured by radar. Biological Conservation, 220, 228–236. doi: https://doi.org/10.1016/j.biocon.2018.01.005
6. Powlesland, R. G. (2009). Impacts of wind farms on birds: a review. Science for Conservation 289. Wellington, New Zealand: Department of Conservation, 51. Available at: https://www.doc.govt.nz/Documents/science-and-technical/sfc289entire.pdf
7. Wang, S., Wang, S., Smith, P. (2015). Ecological impacts of wind farms on birds: Questions, hypotheses, and research needs. Renewable and Sustainable Energy Reviews, 44, 599–607. doi: https://doi.org/10.1016/j.rser.2015.01.031
8. Gorlov, P. I., Siokhin, V. D. (2012). Study of influence of wind-power stations on birds: analysis of international practices. Biolohichnyi Visnyk Melitopolskoho derzhavnoho pedahohichnoho universytetu imeni Bohdana Khmelnytskoho, 1, 37–47.
9. Masden, E. A., Cook, A. S. C. P. (2016). Avian collision risk models for wind energy impact assessments. Environmental Impact Assessment Review, 56, 43–49. doi: https://doi.org/10.1016/j.eiar.2015.09.001
10. Annenkov, O. B., Horlov, P. I., Siokhin, V. D., Salnikova-Budenko, I. B., Siokhin, Ye. V. (2014). Metodyka vykorystannia Veb dodatku «WebBirds» dlia monitorynhu sezonnykh ornitokompleksiv i kompiuternoho modeliuvannia otsinky vplyvu VES. Naukovo-metodychni osnovy okhorony ta otsinky vplyvu na navkolyshnie pryrodne seredovyshche pid chas proektuvannia, budivnytstva, ekspluatatsiyi vitrovykh ta soniachnykh elektrostantsiy, liniy elektromerezh. Melitopol: MDPU imeni B. Khmelnytskoho, 93–107.
11. Siokhin, V. D., Horlov, P. I., Polishchuk, I. K., Podorozhnyi, S. M., Dolynna, O. M., Salnykova-Budenko, I. B. et. al. (2018). Naukovyi zvit ta ekspertnyi vysnovok z otsinky vplyvu budivnytstva ta ekspluatatsii ploshchadky Prymorskoi VES na ornitolohichni kompleksy za rekomendatsiyamy Shotlandskoho Fondu Pryrodnoi Spadshchyny. Melitopol: Naukovo-vyrobnyche pidpryiemstvo «Ekoresurs i monitorynh», 149.
12. Siokhin, V. D., Horlov, P. I., Chernychko, Y. I, Volokh, A. M., Podorozhnyi, S. M., Dolynna, O. M. et. al. (2019). Naukovyi zvit z monitorynhu sezonnykh kompleksiv ptakhiv ta kazhaniv, yikh mihratsiinoi ta kormovoi aktyvnosti, otsinka roslynnosti ta roslynnykh uhrupovan na diliankakh ekspluatatsiyi ta budivnytstva VEU, vyznachennia na osnovi suchasnoho obladnannia ta novitnikh tekhnolohiyi otsinky vplyvu VES na ptakhiv u mezhakh ploshchadky Overianivskoi ta Novotroitskoi VES ta bufernykh zon u Novotroitskomu raioni Khersonskoi oblasti. Melitopol: Naukovo-vyrobnyche pidpryiemstvo «Ekoresurs i monitorynh», 320.
13. May, R., Hoel, P. L., Langston, R., Dahl, E. L., Bevanger, K., Reitan, O. et. al. (2010). Collision risk in white-tailed eagles. Modelling collision risk using vantage point observations in Smøla wind-power plant. NINA Report 639, 25.
14. Band, W. (2012). Using a collision risk model to assess bird collision risks for offshore wind farms, 62. Available at: https://www.bto.org/sites/default/files/u28/downloads/Projects/Final_Report_SOSS02_Band1ModelGuidance.pdf
15. Jervis, L., McGovern, S., Sweeney, S., Buisson, R. (2017). Offshore Ornithology – Collision Risk Modelling Report, 4, Annex 4-2. London: Vattenfall Wind Power Ltd.
16. Morinha, F., Travassos, P., Seixas, F., Martins, A., Bastos, R., Carvalho, D. et. al. (2014). Differential mortality of birds killed at wind farms in Northern Portugal. Bird Study, 61 (2), 255–259. doi: https://doi.org/10.1080/00063657.2014.883357
17. Osadchyi, V., Yeremieiev, V., Osadcha, K. (2018). Software for analyzing the probability of collisions of birds with rotors of wind electrical installations. Ukrainian Journal of Educational Studies and Information Technology, 6 (4), 1–18. doi: https://doi.org/10.32919/uesit.2018.04.01
18. Chylarecki, P., Kajzer, K., Polakowski, M., Wysocki, D., Tryjanowski, P., Wuczyński, A. (2011). Wytyczne dotyczące ocen oddziaływania elektrowni wiatrowych na ptaki. Warszawa: Generalna Dyrekcja Ochrony Środowiska. Available at: https://www.researchgate.net/profile/Michal_Polakowski/publication/260436975_Wytyczne_dotyczace_ocen_oddzialywania_elektrowni_wiatrowych_na_ptaki/links/00b495314e67e289ff000000/Wytyczne-dotyczace-ocen-oddzialywania-elektrowni-wiatrowych-na-ptaki.pdf
19. Sebastián-González, E., Pérez-García, J. M., Carrete, M., Donázar, J. A., Sánchez-Zapata, J. A. (2018). Using network analysis to identify indicator species and reduce collision fatalities at wind farms. Biological Conservation, 224, 209–212. doi: https://doi.org/10.1016/j.biocon.2018.06.003
20. Recommended bird survey methods to inform impact assessment of onshore wind farms (2014). Guidance. Scottish Natural Heritage. Available at: https://www.nature.scot/sites/default/files/2017-09/Guidance%20note%20-%20Recommended%20bird%20survey%20methods%20to%20inform%20impact%20assessment%20of%20onshore%20windfarms.pdf
21. Fijn, R. C., Gyimesi, A. (2018). Behaviour related flight speeds of Sandwich Terns and their implications for wind farm collision rate modelling and impact assessment. Environmental Impact Assessment Review, 71, 12–16. doi: https://doi.org/10.1016/j.eiar.2018.03.007

22. Alerstam, T., Rosén, M., Bäckman, J., Ericson, P. G. P., Hellgren, O. (2007). Flight Speeds among Bird Species: Allometric and Phylogenetic Effects. PLoS Biology, 5 (8), e197. doi: https://doi.org/10.1371/journal.pbio.0050197
23. Kelsey, E. C., Felis, J. J., Czapanskiy, M., Pereksta, D. M., Adams, J. (2018). Collision and displacement vulnerability to offshore wind energy infrastructure among marine birds of the Pacific Outer Continental Shelf. Journal of Environmental Management, 227, 229–247. doi: https://doi.org/10.1016/j.jenvman.2018.08.051
24. Kleyheeg-Hartman, J. C., Krijgsveld, K. L., Collier, M. P., Poot, M. J. M., Boon, A. R., Troost, T. A., Dirksen, S. (2018). Predicting bird collisions with wind turbines: Comparison of the new empirical Flux Collision Model with the SOSS Band model. Ecological Modelling, 387, 144–153. doi: https://doi.org/10.1016/j.ecolmodel.2018.06.025
25. Winkelman, J. E. (1992). De invloed van de Sep-proefwindcentrale te Oosterbierum (Fr.) op vogels, 1: aanvaringsslachtoffers. RIN-rapport 92/2. DLO-Instituut voor Bos– en Natuuronderzoek, Arnhem, Netherlands, 71.
26. Krijgsveld, K. L., Akershoek, K., Schenk, F., Dijk, F., Dirksen, S. (2009). Collision Risk of Birds with Modern Large Wind Turbines. Ardea, 97 (3), 357–366. doi: https://doi.org/10.5253/078.097.0311
27. Furness, R. W. (2015). A review of red-throated diver and great skua avoidance rates at onshore wind farms in Scotland. Scottish Natural Heritage Commissioned Report, No. 885.