UDC 591.5+591.95+598.2 https://doi.org/10.31548/biologiya2021.02.001

THE ANALYTICAL APPROACH TO ORNITHOLOGICAL COLLISION RISK ASSESSMENT (THE EXAMPLE OF THE «BORYSPIL» INTERNATIONAL AIRPORT)

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Abstract. *The paper considers issues of interaction between aviation and avifauna, relevant in terms of flight safety and safety of habitats for birds living in the impact area of airports. A number of parameters of aircraft and air traffic flow significantly affect the behavior and diversity of birds living in the respective areas. The analysis showed that species composition of avifauna at airports includes very few fully synanthropic species, while semi-synanthropes, such as members of the family Corvidae, are often found in airport areas and, due to their size and behavior, are of major hazard to aircrafts. A variety of methods for assessing the level of ornithological hazard are proposed by researchers and used in some countries. The authors presented a matrix method for assessing the risk of collisions between birds and aircraft, adapted to the conditions of Ukrainian airports. In particular, this method takes into account the peculiarities of avifauna monitoring carried out at the airports of Ukraine and the range of data on birds that may be available at these enterprises. The proposed analytical approach to ornithological risk assessment and ornithological management was tested on the example of Boryspil Airport, for which the attractiveness of the territory for birds, focal species of birds that need the most attention during ornithological observations by the airport staff, and the risk level were determined. It is necessary to expand the list of indicators according to which data should be collected during routine ornithological monitoring of airports.*

Keywords: *avifauna, aviation, airports, matrix, risk assessment, hazard, habitat attractiveness, species composition.*

Introduction.

The history of interrelations between aviation and avifauna is long, rich and complicated. The first collision of bird flock with an aircraft, that marked the start of these relationships, occurred in 1905-1908; at the same time of the first controlled test flight by Orwell Wright. In course of that flight one bird died. The first human death as a result of bird strike occurred in 1912, when pilot Cal Rodgers collided with a seagull and drowned as a result of fall (Hedayati, 2015; Thrope, 2003).

Thus, the risk of people dying as a result of meeting with a bird have initiated extensive research work on the ways to reduce this risk as well as drawn attention to the possible implications aviation development may have on the environment. Many latest studies deal with questions of impact of different variables brought by airports into natural environments (such as noise, perceived risk factor, nesting and resting spots, additional forage opportunities etc.) and populations' response to those factors. One of the earliest strong instances of such studies is by German scientists N. Kempf & O. Hüppop (1998). In their study they reviewed 161 publications and expert reports on avifauna's reaction to flying aircraft, described a wide range of reactions birds can express upon meeting a plane (from outwardly non-visible physiological reactions to protection, ducking, increased calling activity, restless pacing back and forth, running away, flying off and returning to the same place or a place close by, flying off and leaving the area, pseudo-attack and actual attacks on aircraft, right through to panic-like flight reactions), as well as outlined potential long-term implications of birds' interaction with aircraft (first of all, increase in heart rate and stress hormones production, significant changes in energy conversion with increase up to 20 times from base levels, alteration of food intake time slots, and subsequent energy loss, shifts in nutrition balance, reduced survivability, life quality and expectancy, reproduction capacity and success).

While the results of this work are supported by other studies (Hoang, 2013; Summers, Simpson, & Gebauer, 1993; Якоби, 2019), and it provides additional insight as to species, which react to airplanes, dependencies of reactions on aircraft type, size, speed and other parameters – it still gives little to no answer as to why these reactions and impacts occur, as well as does not consider the ground aviation infrastructure and airports. Most of the studies on this topic once again focuses on disturbances and noise impacts on wildlife populations, which results in cortisol levels increase and voice call pitches adjustment for proper communication, that in turn could entail changes in physiology (e.g., bigger beaks) (Shochat, Lerman, & Fernбndez-Juricic, 2010; Alquezar & Macedo, 2019).

A study from Russian Scientist V. Jacoby (2019) suggests a more comprehensive overview. Having studied avifauna reactions to absolutely or relatively immobile (moving at a rate lower than that typical for birds' flight) equipment and structures, he concluded that birds were indifferent, up to the point of worst conditions, when birds use immobile structures as nesting substrate or if those structures are perceived as direct threat. He also emphasized, that nesting stereotypes (such as height of nesting, width of holes, type and sizes of materials etc.) are of high significance and that those interactions are realized via trial-and-error type of behavior, i.e., primarily through learning and not heredity.

As for fast-moving technical means (primarily, aircraft) – Jacobi argues, that the velocity of its movement plays the major part in strike events, alongside the noise levels, which give preemptive warning to birds. Along with other researches, Jacobi underlines the importance of learning in behavioral adaptation of birds to living near airports and planes, especially when so called "orientation reflex" comes into play, which causes young birds, newly introduced to irritators, to move towards the source of irritation (e.g., planes, noise sources) to investigate. As birds learn, they become aware more quickly as of how to treat these sources and what reactions to exhibit. Yet another interesting observation is that some adaptations to fast-moving transport may yield positive outcomes for birds, such as newly created foraging opportunities (e.g., alongside runway strip with uncovered insects or small rodents).

All these findings show considerable knowledge gap about interaction between wildlife and objects of technosphere, as well as emphasize the need for transition into biocentric and ecologically oriented management practices for such objects (in our case – for airports and aviation industry) (Soldatini, Georgalas, Andreon, Torricelli, & Albores-Barajas, 2011).

Problem statement.

According to the Annex 14 «Aerodromes» to the Convention on International Civil Aviation, ICAO Guidelines for Airport Services, Part 3 «Danger Posed by Birds and Methods for Reducing It» (ICAO, Doc 9137), and ICAO Bird Strike Information System (IBIS) Guidelines (ICAO, Doc 9332), all airports (especially ones, which want to be a part of international air traffic) are expected to have bird activity and population monitoring and control systems established.

To date, Ukrainian legislation on ornithological management in airports is mostly advisory in nature, allowing free choice of management practices in domestic airports, while also omitting any strict requirements regarding data collection and the levels of data specification and orientation. This leads to predominately "factual analysis" in Ukrainian ornithological collision risk assessment and management practices, which is a simple collection and review of data with subsequent drawing conclusions as to the situation, based on scientists' or managers' expertise.

The most important is that there is a lack of consistent approach to the collection of information about the ornithological situation at the airports both from the point of flight safety and biota well-being. This problem prevents getting reliable integral assessments due to the fact, that they are incomparable, because they are often presented using different parameters and attributes, and at the same time expert opinion about the risk levels is a subject for considerable uncertainty.

Materials and methods.

In order to improve both the efficiency of birds control and preservation of avifauna from direct damage and negative impacts of airports there is a need to add more scrutiny and coherence in the collection of data to characterize the situation in airports. Thus, in order to perform comprehensive assessment of the ornithological collision risks in the airport area, we consider the following sequence of questions necessary to be answered by collection and analysis of the relevant information:

- location and distance of bird populations in relation to aerodrome area and take-off and landing trajectories;
- the number of birds present as well as extrapolated numbers of birds in nearby populations (for forecast and management decision-making);
- data on species of birds (including size, behavior, habits, food base etc.);
- account of locations within 15 km impact area which are potentially attractive to birds (food and water sources, nesting areas);
- migration routes and habits of populations, that are present or nearby as well as possible intersections of those routes with take-off, landing and flight trajectories;
- data on daily and seasonal activities of present or nearby populations (activity peaks, mating, breeding and nurturing seasons etc.);
- account and data on all and any management and control activities at the airport or nearby.

Having obtained those data one can move on to the formal risk assessment with output comparable data. One of the best formal methods, applied in various airports over the world, is matrix risk assessment and mathematical modeling.

An example from the Copenhagen (CPH) airport (Bradbeer et al, 2017) shows the simplest way to assess ornithological collision risk using previous airport experience with bird strikes, and make following management decisions via matrices. Risk here is a product of bird strike frequency (calculated as an average number of strikes involving certain species over the last 5 years) and severity (which is, in other words, a hazard posed by different bird species, and highly depends on their weight). As a result of defining those two parameters, a special valuation is assigned to them in relation to each species of interest, which then translates to matrix of risk assessment (fig. 1). This approach is very attractive due to its simplicity, but has a considerable limitation of being reactive, instead of predictive.

More comprehensive option was proposed by Chinese (Hu et al., 2020) and Spanish (Lopez-Lago et al., 2017) scientists. In the first case, more detailed and varied data is incorporated (such as accounting birds' flight height, number of individuals, clustering coefficient as well as activity of birds at the territory of airport), with the following calculation of likelihood and severity of strikes. After that, the similar valuation and matrix approach is taken. In the second case, the strong emphasis is made on simulation modelling and use of new technologies (e.g., radar) for the real-time risk assessment. Both those options have an essential advantage of predictive risk evaluation and management as opposed to reactive one, based on previous strike experiences, yet both of them are fairly complicated, require expanded data sequences and concentrate primarily on social and technological flight safety and not on environmental well-being.

Finally, a methodology implemented in Italy (Montemaggiori et al., 2012) focuses solely on numerical computation, while also integrating very diverse data into the process. The main benefit coming from this approach is the possibility of its standardization and application to compare situations in different airports, while considering their site-specific features and discrepancies in data availability. Yet, to implement it, you need a quite detailed data on both ornithological situation and operation of airports, which is not always accessible.

It appears that matrices are the most simple, fast and convenient method for application in decision-making for airports. Another important advantage of such approach is its flexibility regarding the type

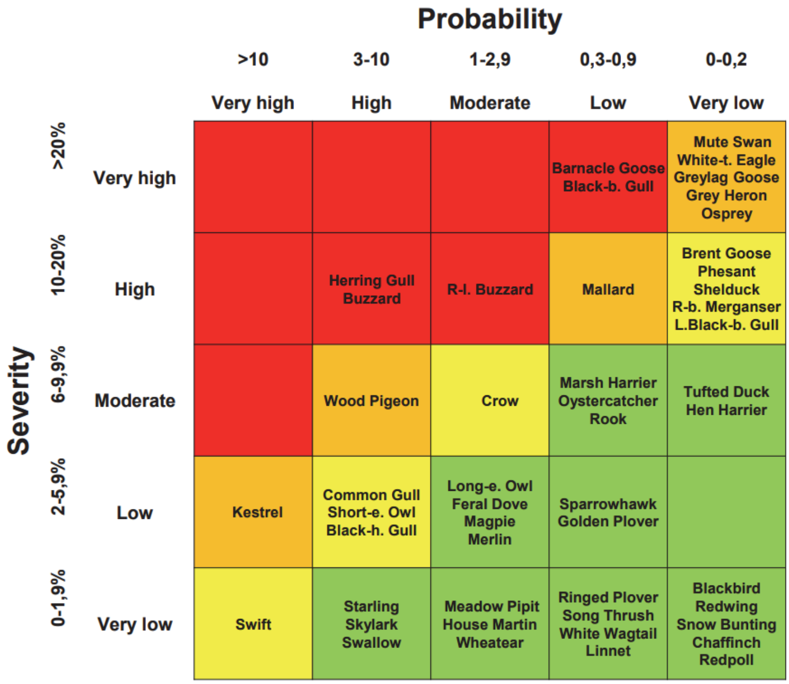

Fig. 1. Example of CPH ornithological collision risk assessment using matrix (Bradbeer et al, 2017)

and amounts of input data. Therefore, in our work we decided to take the example of Danish airport and modify it so that we could make it more applicable to airports in Ukraine, adding dependence of strikes on birds' numbers and clustering ability. For this, we tied the Frequency / Probability variable with number of bird sightings, instead of number of recorded bird strikes. In its turn, Severity / Collision risk parameter is found according with the formula: Severity / Collision risk = 0,014 x standard weight of the species. The valuation for both parameters is presented in Table 1.

1. Valuation of Probability and Severity / Risk categories

Probability (% of total bird number)	<1 %	1…5 %	6…10 %	10…30 %	>30 %
Severity / Risk (average % of strikes leading to aircraft damage)	0 – 1,9 %	2 – 5,9 %	6 – 9,9 %	10 – 20 %	>20 %
Valuation	Very Low	Low	Moderate	High	Very High

2. Risk categories as a result of matrix analysis

Risk category	Low (green)	Moderate (yellow)	High (orange)	Very high (red)
Transcript	No further action required beyond the risk management measures currently in place.	Current risk management for this species should be reviewed and additional steps taken if appropriate.	Additional management actions should be implemented for this species as soon as possible if appropriate.	Additional management actions should be implemented for this species as soon as possible.

The risk categories and their transcriptions as a result of matrix analysis are presented in Table 2.

Results and discussion.

The offered technique (data collection sequence and matrix for risk assessment) was applied to evaluate the data collected by ornithological service of Boryspil airport in terms of their sufficiency for analytical needs, ornithological collision risk assessment and proper fulfillment of environmental management goals. Boryspil International Airport (KBP) – is an international airport located in the northern part of Ukraine. In terms of natural conditions, KBP area is placed on Dnipro Lowland in Ukrainian Polissya or mixed forests zone, with temperate-continental climate. Distinctive feature of this zone is the high density of forest areas, with considerable amounts of wetlands and water bodies.

Separately, the airport should be also characterized in terms of potential level of impacts on birds, in particular, its attractiveness for them.

Characteristics of the site attractiveness.

The territory of the airport is mostly surrounded with agricultural fields with the exception of Boryspil city, which lies to the east. In terms of ornithological management, proximity to agricultural fields has both its advantages and disadvantages. On the one hand, considering that all fields are managed semi-artificial landscapes, which are constantly monitored – it may be beneficial for preemptive measures efficiency enhancement by joint bird control measures. On the other hand, depending on the types of crops being cultivated, fields may prove to be spots of the higher interest either for seed-eating species or for predatory birds who hunt small rodents, frequently present in or nearby the fields. In any case, the airports under such conditions are required to cooperate with landowners, as the airport strategies, suggestions and needs on dealing with birds are not always in line with the locals' view of the problem.

Taking into account the agricultural fields and urban spaces surrounding KBP, the vegetation in the vicinity of the airport is mostly low to medium in height and closely controlled, which significantly reduces the possibility of undesirable nesting. However, there are separate isolated trees at the airport territory, which may serve as temporary resting spots, as well as small forest adjacent from the south, with approximate area of ~90 ha. At a distance of ~3 km to the west there is also a bigger forest with area of ~412,5 ha, followed by a vast Darnytskyi forest, located 6 to 7 km away from KBP, which is a proven nesting spot for many species.

Another group of objects, which are always of interest for avifauna and other wildlife, are water bodies. At the territory of KBP there is a small technical pond, as well as group of adjacent artificial water bodies in the southeastern direction, with the area ~60 ha. Technical and artificial water bodies are especially favored by birds in cold periods, due to their heat regimes. The biggest nearby water objects are Dnipro river and Osokorky lakes, with adjacent system of smaller ponds and channels, at ~10-12 km east of the airport. The potential issue lies in the fact that such big and branched rivers and their surrounding landscapes often serve as migratory corridors (e.g., Dnipro migratory corridor) and resting spots for various species. They also provide shelter and nesting for waterfowls, who are often big enough to pose an actual threat to aircraft.

Last, but not least – at a distance less then 2 km southeast of the airport located a mixed solid waste (MSW) landfill ("Eco-Service" LLC). Such facilities always pose a heightened risk of avifaunal clustering attracting a huge array of species, since they provide additional foraging opportunities similar to urban territories, without the excessive human presence and containment provided via nesting opportunities (thus, it is not obligatory for birds to have strong synanthropic alignment, contrary to cities). Landfills also create additional danger in cold months, as they generate heat

3. Species diversity and numbers distribution by months in 2018-19 (Source: KBP wildlife monitoring reports for 2018-19)

Month	Year 2018	Year 2019
January	Partridge (15), rook (10), magpie (10), buzzard (8), rough-legged buzzard (4)	Partridge (20), rook (10), rough-legged buzzard (5), buzzard (3)
	Total – 47	Total – 38
February	Rook (30), partridge (20), buzzard (7)	Partridge (20), buzzard (8), rough-legged buzzard (2)
	Total – 57	Total – 30
March	Rook (62), starling (50), magpie (10), buzzard (5)	Rook (105), starling (50), buzzard (6)
	Total – 127	Total – 161
April	Starling (90), rook (70), buzzard (5)	Rook (510), starling (100)
	Total – 165	Total – 610
May	Rook (240), starling (100), gulls (20), buzzard (4), kestrel (2), harrier (1)	Rook (550), starling (100), gulls (60), raven (5), buzzard (2)
	Total – 367	Total – 717
June	Rook (110), kestrel (2), buzzard (1)	Rook (340), gulls (40), buzzard (4), stork (2)
	Total – 113	Total – 386
July	Rook (560), starling (80), kestrel (4), heron (1)	Rook (350), dove (50), kestrel (11), buzzard (9), stork (1)
	Total – 645	Total – 421
August	Starling (250), rook (80), stork (8), kestrel (4), buzzard (2)	Starling (600), rook (170), kestrel (6), buzzard (4), stork (1)
	Total – 344	Total – 781
September	Rook (538), starling (400)	Rook (80), dove (10), buzzard (3), kestrel (3)
	Total – 938	Total – 96
October	Rook (150), partridge (15), buzzard (4), kestrel (2)	Rook (520), kestrel (5), buzzard (2), magpie (2)
	Total – 171	Total – 529
November	Rook (80), partridge (30), buzzard (6), rough-legged buzzard (2)	Rook (115), dove (12), buzzard (2)
	Total – 118	Total – 129
December	Rook (85), partridge (50), rough-legged buzzard (14), kestrel (4), buzzard (1)	Rook (15), buzzard (8), rough-legged buzzard (1)
	Total – 154	Total – 24

from organic decomposition, which also attracts birds. All of those above-mentioned locations have to be carefully monitored as well as considered and incorporated into risk assessment and ornithological management plans of the airport.

Species of prior interest.

The city is a gathering place for synanthropic or semi-synanthropic species, who seek to profit from living near or in human settlements by using artificial structures for nesting and feeding off on leftovers and wastes. Full synanthropes, such as *Columba livia* or *Passer domesticus* rarely leave their urban habitats and as such present little threat to the airport area. More dangerous are semi-synanthropes, such as *Corvidae*, who are commuting between cities and suburbia for different reasons – they live in and feed out of cities or vice versa. Populations of such species require additional attention.

According to ornithological monitoring data acquired from KBP, 69 species of birds were sighted for the entire observation period, of which 29 were migratory and 40 were resident or sedentary. Of those 69 species:

- Singing and flocking birds – 34 species;
- Waterfowl birds – 13 species;
- Predatory birds – 7 species;
- Woodpeckers – 6 species;
- Herons and storks, owls and hens – 3 species each (9 species total).

In last 5 years of observation 20 species were sighted at or near the territory of airport, of which 10 are singing or flocking, 5 are predatory, 3 are waterfowl and 1 of stork and 1 of hen species.

Of the 29 species of migratory birds, 6 usually fly over the airport in transit, without stopping for rest or feeding. Those are: graylag goose (*Anser anser*), great white-fronted goose (*Anser albifrons*), bean goose (*Anser fabalis*), shoveler (*Spatula clypeata*), wigeon (*Mareca penelope*), common crane (*Grus grus*). These species are characterized by migration along the Dnipro river along the Dnipro migration corridor. Birds fly in the dark and early morning hours. The peak of the flight occurs from 22:00 to 2:00. The usual height of flight is 200-400 meters. The greatest concentration of migratory flocks is noted in the Dnipro river-side corridor, about 15 km wide. Migration occurs with a favorable north or north-east wind – this is a prerequisite for migration. The remaining 23 species of migrant birds make resting and feeding stops at or near the airport. Technical ponds of the airport reportedly attract at least 6 species: common kingfisher (*Alcedo atthis*), redshank (*Tringa totanus*), waterhen (*Gallinula chloropus*), garganey (*Spatula querquedula*), grey heron (*Ardea cinerea*), great egret (*Ardea alba*).

Ornithological hazard assessment.

Based on the data presented in the Table 3 the distribution patterns can be defined and ornithological hazard peaks can be isolated. Thus, the months April through October, with the peaks in May, July-September, are of highest concern, which generally corresponds to reporting patterns on bird collisions. The assignment of risk to separate species performed in accordance with methodology for different years is presented in Tables 4 and 5. Considering the distribution of risk by species, we can see the clear and overwhelming hazard coming from rooks (*Corvus frugilegus*), due to their size and flocking patterns. This species requires decisive actions in terms of their presence control, as they are sighted almost all year and in big quantities.

Comparatively frequent and regular sightings of big predatory birds, such as buzzards (*Buteo buteo*) and rough-legged buzzards (*Buteo lagopus*), as well as herons and storks (*Ciconia ciconia*), all of who pose significant flight hazard, also indicate the need for specific management strategies development with regard to those species. Although sightings of herons and storks are isolated cases, considering their size, they are less mobile than smaller birds and pose greater threat of significant damage, thus it is best to eliminate the possibility of their being at the airport's territory completely.

Finally, the conditionally high risk also comes from starlings (*Sturnus vulgaris*) and ravens (*Corvus corax*). Starlings are on the smaller side, yet tend to gather in large flocks during certain periods of the year, overwhelming the airport, creating almost inevitable risk of minor collisions. In turn, ravens vary greatly in terms of weight, which means they also vary greatly in Severity / Risk category. They are also more social, than big waterfowl or predatory birds, and may gather in big groups, which may result in quick and unexpected escalation of a hazardous situation. Both of those species need to be observed closely, and measures on their management have to be taken where it is possible and appropriate.

It is also important to emphasize, that the data from the bird census presented in Table 3 and used as a basis for analysis in Tables 4 and 5 come directly from ornithological management service of the airport, and their monitoring covers specifically the airport territory and runway strips. While this information is of primary importance during ornithological

4. Ornithological collision risk matrix for Boryspil airport for 2018

		Probability				
		Very high	High	Moderate	Low	Very low
Severity / Risk	Very high					Heron, stork
	High				Buzzard	Rough-legged buzzard
	Moderate	Rook			Partridge	
	Low					Magpie, gull, kestrel, harrier
	Very low		Starling*			

5. Ornithological collision risk matrix for Boryspil airport for 2019

		Probability				
		Very high	High	Moderate	Low	Very low
Severity / Risk	Very high					Raven**, stork
	High				Buzzard	Rough-legged buzzard, raven**
	Moderate	Rook			Partridge	
	Low				Gull	Magpie, kestrel, dove
	Very low		Starling*			

Notes: * – although starlings are in the "low risk" category in this yearly assessment, during separate months they can come up to the "very high" risk due to seasonal activities in airport;

** – raven vary greatly in terms of weight, which places them in different risk categories depending of severity / risk factor.

Fig. 2. Satellite photo of KBP and surrounding territory point of observation

safety management, the airport impact area stretches far outside the sole boundaries of the facility (at the very least for 3-4 km around), especially, considering that taking-off planes are gaining altitude for some time, therefore are particularly susceptible to collisions until they reach certain heights. Our own census for another Kyiv airport – Zhuliany or IEV – showed, that within this impact area outside the airport the diversity can be at least three times of that inside the territory of runways, while the numbers can increase in even greater proportions (for instance, magpies' numbers differ by the factor of 5) depending on the landscape types. Thus, while this analysis remains valid and useful in terms of airport immediate management, its expansion with more data from impact area would be an important addition. Thus, we offer to include points 1-10 (Fig. 2) into the monitoring plan around the airport in order to cover the issues related to biodiversity and density / number of birds population in the impact area of the facility. This will be important for both safety enhancement and understanding the interactions between technogenic objects and components of biocenosis.

Conclusions:

Airports are important sources of both disturbance and benefits for birds, which raises concerns about the conservation of species due to collision risks and concerns about the safety of flights. Airports turn to be those factors, which may alter the species structure of the local ecosystems, affect their behavior and health. As such, they should be considered as local focal points for conservation efforts in response to inevitable negative impacts of the airport facilities and ornithological control activity.

The absence of clear and imperative nationally approved methodologies for those tasks apparently only adds an unnecessary layer of difficulty to it, resulting in considerable incompleteness of data being collected. Therefore, national level methodology for ornithological management and control needs to be developed and approved. Additionally, ornithological data should be collected not only inside the airport territory, but also in the nearby impact area (up to 5 km around airport depending on its capacity), as this is still territories of increased risk and they often present much higher population numbers and diversity.

The quantification of risk associated with avifauna is proved to be necessary, as it can place necessary emphasis and define vectors of improvement for the airport ornithological safety, as well as uncover some overlooked and hidden risks (such as the one with starlings and ravens in Boryspil airport).

Overall ornithological picture of the KBP airport includes 69 species, of which: 20 were sighted in last 5 years, 29 are migratory (6 are transitory and 23 are making resting and feeding stops) and 40 are resident or sedentary. Species composition includes 34 singing and flocking species, 13 waterfowl species, 7 predatory species, 6 woodpecker species, 3 species each of herons and storks, owls and hens.

The ornithological collision risk analysis for KBP airport for 2018 and 2019 shows, that rooks are the species, which require most attention in terms of management, with predatory buzzards, herons and storks following. This is further emphasized their continual sighting within airports.

A biocentric and ecologically oriented management practices instead of economic ones need to be introduced in Ukrainian airports in order to learn and preserve wildlife at the level, corresponding to the modern standards.

References

1. Hedayati R., Sadighi M. (2015). Bird Strike: An Experimental, Theoretical and Numerical Investigation. Sawston, Cambridge: Woodhead Publishing. 258.
2. Ahmed F. El-Sayed. (2019). Bird Strike in Aviation: Statistics, Analysis and Management. New York: John Wiley & Sons. 398.
3. Mulero-Pázmány M., Jenni-Eiermann S., Strebel N., Sattler T., Negro J.J. (2017). Unmanned aircraft systems as a new source of disturbance for wildlife: A systematic review. PLOS ONE 12(6): e0178448. https://doi.org/10.1371/journal.pone.0178448
4. Hoang T. (2013). A literature review of the effects of aircraft disturbances on seabirds, shorebirds and marine mammals. San Francisco, California: NOAA, The Seabird Protection Network. 12.
5. Romero-Bautista, Y.A., Moreno-Calles, A.I., Alvarado-Ramos, F. (2020). Environmental interactions between people and birds in semiarid lands of the Zapotitlán Valley, Central Mexico. J Ethnobiology Ethnomedicine 16: 32. https://doi.org/10.1186/s13002-020-00385-1
6. Jacoby V. E. (2019). Povedenie ptits i tehnika. The Russian Journal of Ornithology 28(1809): 3807-3823 (in Russian).
7. Shochat E., Lerman S., Fernandez-Juricic E. (2010). Birds in urban ecosystems: population dynamics, community structure, biodiversity, and conservation. In J. Aitkenhead-Petersons and A. Volders (Ed.) Urban Ecosystem Ecology: Agronomy monograph (pp. 75-86). Madison: ASA-CSSA-SSSA. https://doi.org/10.2134/agronmonogr55.c4
8. Alquezar R. D., Macedo R. H. (2019). Airport noise and wildlife conservation: What are we missing? Perspectives in ecology and conservation 17(4): 163-220. https://doi.org/10.1016/j.pecon.2019.08.003

9. Soldatini C., Georgalas V., Torricelli P., Albores-Barajas Y. (2010). An ecological approach to birdstrike risk analysis. European Journal of Wildlife Research 56(4): 623-632. https://doi.org/10.1007/s10344-009-0359-z
10. Bradbeer, D. R., Rosenquist, C., Christensen, T. K., Fox, A. D. (2017). Crowded skies: Conflicts between expanding goose populations and aviation safety. Ambio, 46(2): 290–300. https://doi.org/10.1007/s10344-009-0359-z
11. Hu Y., Xing P., Yang F., et. al. (2020). A birdstrike risk assessment model and its application at Ordos Airport, China. Scientific Reports 10(1): 19627. https://doi.org/10.1038/s41598-020-76275-z
12. Lopez-Lago M., Casado R., Bermudez A., Serna J. (2017). A predictive model for risk assessment on imminent bird strikes on airport areas. Aerospace Science and Technology 62: 19-30. https://doi.org/10.1016/j.ast.2016.11.020
13. Soldatini C., Albores-Barajas Y.V., Lovato T., Andreon A., Torricelli P., et al. (2011). Wildlife Strike Risk Assessment in Several Italian Airports: Lessons from BRI and a New Methodology Implementation. PLOS ONE 6(12): e28920.. https://doi.org/10.1371/journal.pone.0028920

М.М. Радомська, Л.М. Черняк, І.В. Горобцов, (2021). АНАЛІТИЧНИЙ ПІДХІД ДО ОЦІНКИ ОРНІТОЛОГІЧНОГО РИЗИКУ (НА ПРИКЛАДІ МІЖНАРОДНОГО АЕРОПОРТУ «БОРИСПІЛЬ»). BIOLOGICAL SYSTEMS: THEORY AND INNOVATION, 12(2): 5-16. *http://journals.nubip.edu.ua/index.php/Biologiya/editor/submission/15092 https://doi.org/10.31548/biologiya2021.02.001.*

Анотація. *У статті розглядаються аспекти взаємодії авіації та орнітофауни,актуальні з точки зору безпеки польотів та безпечності ареалів для птахів, що проживають в зоні впливу аеропортів. Показано, що ряд параметрів повітряних суден та транспортного потоку у повітрі загалом суттєво впливають на життєдіяльність, поведінку та різноманіття птахів, що проживають на відповідних територіях. Розглянуто видовий склад орнітофауни на території аеропортів та виявлено низьке представлення повністю синантропних видів, натомість напів-синантропи, такі як представники родини Corvidae, часто зустрічаються в зоні аеропортів і, зважаючи на свої розміри та поведінку, можуть становити основну небезпеку для польотів літаків. Проаналізовано методи оцінки рівня орнітологічної небезпеки, що пропонуються дослідниками і застосовуються у ряді країн світу. Представлено матричний метод оцінки ризику зіткнень між птахами та повітряними суднами, адаптований до умов українських аеропортів. Зокрема, даний метод враховує особливості моніторингу орнітофауни, що здійснюється в аеропортах України, та спектр даних про птахів, що можуть бути наявні на цих підприємствах. Запропонований аналітичний підхід до оцінки орнітологічного ризику та орнітологічного менеджменту апробовано на прикладі аеропорту «Бориспіль», для якого оцінено привабливість території для птахів, виділено фокусні види птахів, які потребують найбільшої уваги під час проведення орнітологічних спостережень персоналом аеропорту, а також визначено рівень ризику зіткнень. Встановлено необхідність розширення переліку показників, за якими слід збирати дані під час рутинного орнітомоніторингу аеропортів.*

Ключові слова: *орнітофауна, авіація, аеропорти, матриця, оцінка ризиків,загроза, привабливість ареалів, видовий склад.*