MORTALITY OF BIRDS AS A RESULT OF COLLISIONS WITH GLAZING ON THE EXAMPLE OF BUILDING STRUCTURES IN WARSAW

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Abstract

Collisions between birds and buildings are a common phenomenon given the increasing anthropogenisation of the environment and the emergence of human settlements along traveling routes of species' migration. Glass surfaces, which are increasingly frequently used in modern construction engineering, appear to be particularly dangerous in this aspect, as birds may not recognise them as obstacles even during the day. In this paper, the results of a study of collisions between birds and different types of buildings in the urban zones with low, medium and high proportions of green areas in buildings were analysed.
The highest number of collisions was observed for buildings located near enclaves of vegetation, characterised by high biological diversity. The presence of distractors on the glazing had a significant impact on reducing the number of collisions.

Keywords: bird mortality, urban areas, collisions, facades, external wall coverings, glass surfaces, glazing

1. Introduction

The use of glass elements in architecture can be traced back to the first half of the 1st century, when it was first used as a structural element of windows in ancient Rome. Fitting window openings with glass tiles was for a long time an unpopular solution (Chopinet, 2019) – as late as the 13th century it was only available to the wealthy (Butera, 2005). The significant development of the glass industry took place during the First Industrial Revolution (Górski, 2005), so that the fitting of windows with glazing in most European homes did not become common until the 19th century (Butera, 2005). Thanks to improvements in glass production

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technology, the trend towards larger glass surfaces soon became apparent, resulting in the appearance of the first shopfronts or the creation of the Crystal Palace in London (Krajewska, 2019).

As a result of the drive to create fully glazed building facades, the curtain wall concept was developed in 1925 and was first put into practice on the Bauhaus school building in Dessau (Górski, 2005). The curtain wall is a self-supporting element of the building envelope, attached to its substructure (Jakimowicz, Borek, 2018). The wall is most often constructed with a metal or wooden frame, where the open spaces are filled with glass panes (Sędłak, 2014). This structure performs all the standard functions of a building external wall, but does not affect its load-bearing capacity or stability (Jakimowicz, Borek, 2018) – as a result, it offers the possibility of creating a building with quite a fancy facade.

Curtain walling is a solution nowadays frequently used in buildings under construction, especially those in large cities. The technique is commonly associated with modernity since glass adds a dynamic character to the urban landscape (Jakimowicz, Borek, 2018). However, the advantages of glazed facades are not limited to high aesthetics. Glass allows a large amount of daylight to pass through, making significant energy savings possible, and it is also easy to maintain and provides good fire protection. There is a reason why it is so common to see glass facades for high-rise buildings – according to the Decree of the Minister of Infrastructure of 7 June 2019 "in a building, at a height above 25 m from ground level, the facade cladding and its mechanical fixing, as well as the thermal insulation of the external wall, should be made of non-combustible materials", and glass being a non-combustible material meets these requirements (Kopciński, 2010). Glass balcony glazing is also an increasingly common solution. Balcony glazing allows high energy cost savings for the building by reducing heat loss through the walls, so this method is widely used in many countries, including northern Spain and Portugal as a passive heating strategy (Fernandez et al., 2020). The installation of a glass balcony enclosure makes it possible to raise the air temperature on the surface of the loggia by an average of 3°C to 6°C (Hilliaho et al., 2016). According to research carried out on the example of a building in Bialystok (Eastern Poland), the loss of thermal energy through the external wall of an unglazed balcony loggia is 26% higher than when glazing is used (Turecki, 2011). However, stylish glazing comes with certain disadvantages – one of which is the high collision rate with birds. While all anthropogenic vertical structures pose a threat to these animals by creating difficult conditions for aerial manoeuvring, glass elements are the most significant problem in this respect (Erickson et al., 2002). Despite their good eyesight, birds do not recognise transparent planes as barriers, so numerous collisions with them are observed (Klem 1989, 1990, 1990a, 2009; Szurlej-Kielańska et al., 2020), which are all the more frequent the larger the area of the object in question (Klem 1989). Collisions are most often observed during the periods of the most intensive bird movements, i.e. during seasonal migration and breeding dispersion (Szurlej-Kielańska et al., 2020; Pilacka, 2019), when young birds that have gained their independence seek new territories (Grzywaczewski, Szczepaniak, 2007). The collision with a glass surface most often occurs through one of the following mechanisms: mirror effect, transparency effect or lighthouse effect. The mirror effect occurs in a significant percentage of modern office buildings, where highly reflective glass curtain walls have been used. Such surfaces reflect the surrounding landscape, giving birds the false impression of a continuous open space. The effect of transparency can be particularly dangerous when objects that are potentially attractive to birds, such as high vegetation, are located behind transparent panes (Szurlej-Kielańska et al., 2020). The lighthouse effect, on the other hand, poses a greatest threat to species characterised by a nocturnal lifestyle – artificial lighting visible through building glass disorientates birds, and collisions occur as a result of their loss of orientation in the area (Szurlej-Kielańska et al., 2020; Schmid et al., 2013; Korner et al., 2022).

Collisions with buildings pose a serious risk to birds, with severe injuries resulting in imminent death in about a half of all cases (Klem 1990, 1990a). It is estimated that for every building in the United States, there are between 1 and 10 fatal bird collisions per year, totalling to between 98 and 976 million of these incidents nationwide (Klem 1990). Bird collisions with transparent surfaces represent the second (after intentional nest destruction by humans) greatest threat to wild birds (Klem, 2009; Korwel-Lejkowska, Zawadzka, 2015).

The aim of this study was to assess the frequency of fatal bird collisions with glazing used on buildings and to verify the following hypotheses:

1) The number of collisions between birds and buildings increases in direct proportion to the area of glazing used.
2) The highest number of collisions between different bird species and glazing occurs in areas characterised by a high percentage of green space and, consequently, greater biodiversity.

2. Methodology

Between 2019 and 2021, surveys were carried out for seven buildings located in Warsaw. The research included: one commercial building (hereafter: CM), four office buildings (hereafter: OB1, OB2, OB3, OB4) and two residential buildings (hereafter: RB1, RB2). The buildings were characterised by their different heights (H), total surface area (TSA), type of glazing used, area of glazing (GA), presence of elements that increase the visibility of glazing (EIV) and type of development and proportion of green areas in the immediate vicinity. The characteristic features of individual buildings are shown in Table 1. In order to obtain information on the dimensions of the surveyed buildings, measurements were taken with the use of a laser rangefinder. The landscaping around the building was determined for an area up to 100m from the building walls. The proportion of green areas (hereafter: PGA) was determined according to the following scheme: < 30% – low proportion of green areas; 30–60% – medium proportion of green areas; > 60% – significant proportion of green areas.

Table 1. Characteristics of the studied facilities

Object	TSA [m²]	H [m]	Application of glazing	GA [m²]	EIV	Land use
CB	64 000	20	Glass facade	3380	Graphic markers (partly)	Sparse urban development; significant proportion of green space
OB1	12 000	25	Glass facade	3875	None	Sparse urban development; average proportion of green space
OB2	16 800	21	Glass facade	7350	Aluminium profiles	Dense urban development; significant proportion of green space
OB3	76 500	30	Glass facade	12 300	Graphic markers	Dense urban development; average proportion of green space
OB4	41 400	30	Glass facade	7200	None	Dense urban development; small proportion of green space
RB1	71 000	92	Fixed balcony development	15 126	None	Dense urban development; small proportion of green space
RB2	31200	42	Fixed balcony development	4487	None	Dense urban development; small proportion of green space

Abbreviations: CB – commercial building; OB - office building; RB – residential building; TSA – total surface area; H – building height; GA – glazed area; EIV–visibility elements.

The research consisted of direct observations of the ground surface up to 10m from the walls of the buildings to identify birds that died in collisions with glass panes. A combined mapping method was adopted as the survey method (Szurlej-Kielańska et al., 2020). Counts of individual species of dead birds whose injuries were indicative of a collision, i.e. visible mechanical injuries to the head and/or cervical spine, were recorded during the inspection (Klem, 2009). If the cause of death of an observed bird was uncertain, the glass of the building was viewed with binoculars in search of a mark indicating that the individual bird had collided with it. Specimens whose death could not be unequivocally attributed to a collision with the surveyed buildings were not considered in the study. The surveys were carried out during the spring-summer period, i.e. at the time when the breeding dispersal of most bird species takes place. Four inspections were carried out for each site on the following dates:

- CB – 13.05, 16.05, 20.05, 02.06 2019
- OB1 – 14.04, 02.06, 07.07, 11.08 2020
- OB2 – 18.04, 31.05, 20.06, 15.07 2020
- OB3 – 01.05, 30.05, 29.06, 01.08 2020
- OB4 – 07.05, 12.06, 15.07, 05.08 2020

- RB1 – 11.04, 03.05, 05.06, 01.07 2021
- RB2 – 22.04, 19.05, 22.06, 30.07 2021.

Based on the results, the average daily number of fatal collisions per 1,000 m^2 of glazing was calculated for each building (DCN). The following formula developed by the authors was used:

$$DCN_i = \frac{\frac{c_i}{in_i}}{GA_i \cdot 1000}$$

where:

c_i – total number of observed fatal collisions for the i-th building
in_i – number of inspections carried out for the i-th building
GA_i – glazed area of the i-th building [m^2].

The species structure of birds involved in fatal collisions with the surveyed buildings was further determined by calculating the Shannon-Wiener index:

$$H' = -\sum_{i=1}^{S} p_i \log p_i$$

where:

S – species richness
p_i – ratio of the number of individuals of a given species to the number of all individuals of all species

$$p_i = \frac{n_i}{N}$$

where:

n_i – number of individuals of the i-th species,
N – number of all individuals of all species.

3. Results

The results of the study were characterised by wide variability depending on the object observed. A total of 13 bird species were recorded in fatal collisions with building glazing. The species observed included representatives of the Passeridae, Paridae, Muscicapidae, Turdidae, Sturnidae, Apodidae, Scolopacidae, Laridae, Corvidae and Columbidae families.

The only commercial building (CB) surveyed had the highest number of fatal bird collisions. A total of 56 representatives of 12 different species have been recorded. Both the species richness and the biodiversity of animals killed in collisions with glazing appeared to be highest for this building from among all the study sites. By far the most frequently observed species was the sparrow (15 quotations out of 56), but the CB nevertheless proved to be the site with the highest Shannon-Wienner coefficient (0.93). Detailed observation results for CB are presented in Table 2.

Table 2. The results of the field survey for the CB facility

Object		**CB**						
Exposition		**N**	**E**	**S**	**W**		total	$p_i \log p_i$
EIV		**yes**	**no**	**no**	**yes**	**no**		
Species	**great tit** ***Parus major***		1	1	1	1	4	-0.07
	feral pigeon ***Columba livia f. urbana***		2	2		4	8	-0.13
	swift ***Apus apus***	1	1			1	3	-0.07
	jackdaw ***Corvus monedula***			1	1	1	3	-0.06
	black redstart ***Phoenicurus ochruros***		1			1	2	-0.06
	blackbird ***Turdus merula***	1					1	-0.03
	fieldfare ***Turdus pilaris***	1	2	1			4	-0.09
	tree sparrow ***Passer montanus***		2		1	1	4	-0.07
	common redstart ***Phoenicurus phoenicurus***		1				1	-0.03
	woodcock ***Scolopax rusticola***							
	starling ***Sturnus vulgaris***	2		3	1	2	8	-0.12
	black-headed gull ***Chroicocephalus ridibundus***	1					1	-0.03
	house sparrow ***Passer domesticus***	5	4	4	2	2	17	-0.16
TOTAL		11	14	12	6	13	56	-0.93
S		12						
H'		0.93						
K		4.14						

Facility OB1, despite the smallest area of glazing used, proved to be the office building with the highest incidence of bird collisions. During the inspection, 42 fatal collisions were recorded and representatives of eight different species were identified among the birds observed. The survey results for OB1 are presented in Table 3.

Table 3. Field survey results for OB1 facility

Object		**OB1**					
Exposition		**N**	**E**	**S**	**W**	total	$p_i \log p_i$
EIV		**no**	**no**	**no**	**no**		
Species	**great tit** *Parus major*	2		2		4	-0.10
	feral pigeon *Columba livia f. urbana*	2	4	1	2	9	-0.14
	swift *Apus apus*	2	2		3	7	-0.13
	jackdaw *Corvus monedula*						
	black redstart *Phoenicurus ochruros*					0	
	blackbird *Turdus merula*					0	
	fieldfare *Turdus pilaris*	1				1	-0.04
	tree sparrow *Passer montanus*	2				2	-0.06
	common redstart *Phoenicurus phoenicurus*					0	
	woodcock *Scolopax rusticola*						
	starling *Sturnus vulgaris*	2	2	4		8	-0.14
	black-headed gull *Chroicocephalus ridibundus*		1		1	2	-0.06
	house sparrow *Passer domesticus*	4	2	2	1	9	-0.14
TOTAL		15	11	9	7	42	-0.82
S		8					
H’		0.82					
K		2.71					

OB2 was the only building whose façade was fitted with aluminium profiles. For this building, 13 fatal bird collisions were recorded, with a significant predominance on the western exposure. OB2 was one of the two buildings surveyed whose glazing was collided with by a woodcock, a bird of the snipe family (Scolopacidae). The results of the observations for OB2 can be seen in Table 4.

Table 4. Results of field surveys for OB2 facility

Object		**OB2**					
Exposition		**N**	**E**	**S**	**W**	total	$p_i \log p_i$
EIV		**yes**	**yes**	**yes**	**yes**		
Species	**great tit** *Parus major*			1	3	4	-0.15
	feral pigeon *Columba livia f. urbana*		1		2	3	-0.15
	swift *Apus apus*	1		1		2	-0.13
	jackdaw *Corvus monedula*					0	
	black redstart *Phoenicurus ochruros*					0	
	blackbird *Turdus merula*					0	
	fieldfare *Turdus pilaris*					0	
	tree sparrow *Passer montanus*				2	2	-0.13
	common redstart *Phoenicurus phoenicurus*					0	
	woodcock *Scolopax rusticola*				1	1	-0.09
	starling *Sturnus vulgaris*					0	
	black-headed gull *Chroicocephalus ridibundus*					0	
	house sparrow *Passer domesticus*		2	1	2	5	-0.16
TOTAL		1	3	3	10	17	-0.73
S		6					
H'		0.73					
K		0.58					

OB4 was found to have the lowest number of fatal bird collisions on all sites for which such observations were made. Despite the lack of EIV applied on the building façade, a total of only 7 fatal collisions of birds of 5 different species were recorded.

Table 5. Results of the field survey for the OB4 facility

Object		**OB4**					
Exposition		**N**	**E**	**S**	**W**	total	$p_i \log p_i$
EIV		**no**	**no**	**no**	**no**		
Species	**great tit** *Parus major*		2			2	-0.16
	feral pigeon *Columba livia f. urbana*					0	
	swift *Apus apus*				1	1	-0.12
	jackdaw *Corvus monedula*	1		1		2	-0.16
	black redstart *Phoenicurus ochruros*					0	
	blackbird *Turdus merula*					0	
	fieldfare *Turdus pilaris*					0	
	tree sparrow *Passer montanus*					0	
	common redstart *Phoenicurus phoenicurus*					0	
	woodcock *Scolopax rusticola*			1		1	-0.12
	starling *Sturnus vulgaris*					0	
	black-headed gull *Chroicocephalus ridibundus*					0	
	house sparrow *Passer domesticus*			1		1	-0.12
TOTAL		1	2	3	1	7	-0.67
S		5					
H'		0.67					
K		0.24					

Abbreviations: CB – commercial building; OB – office building; RB – residential building; EIV – visibility elements; pi – ratio of the number of individuals of a species to the number of all individuals of all species; S – species richness; H' – Shannon-Wienner index, K – the average number of collisions per day per 1000 m^2 of the glazing. No fatal bird collisions were observed at sites OB3, RB1 and RB2.

Depending on the area of glazing used, individual buildings showed different average daily numbers of bird collisions. The highest number of collisions was recorded for buildings with the smallest area of glazing, while no collisions at all were observed for those with the largest area of glazing. The results are presented graphically in Figure 1.

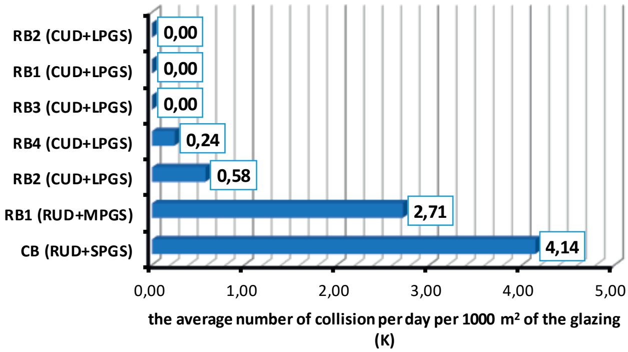

Figure 1. Effect of the area of glazing used on the number of bird collisions

Abbreviations: RB – residential building, CB – commercial building, CUD – compact urban development, RUD – sparse urban development, LPGS – low proportion of green space, MPGS – medium proportion of green space, SPGS – significant proportion of green space.

The study showed the impact of the land use around the building on the average daily number of crashes. The highest number of fatal collisions was observed for buildings located in an area with sparse urban development and a significant or medium PGA. The observations are shown in Fig. 2. For these buildings, the study also showed the highest S and H' values, as presented in Fig. 3.

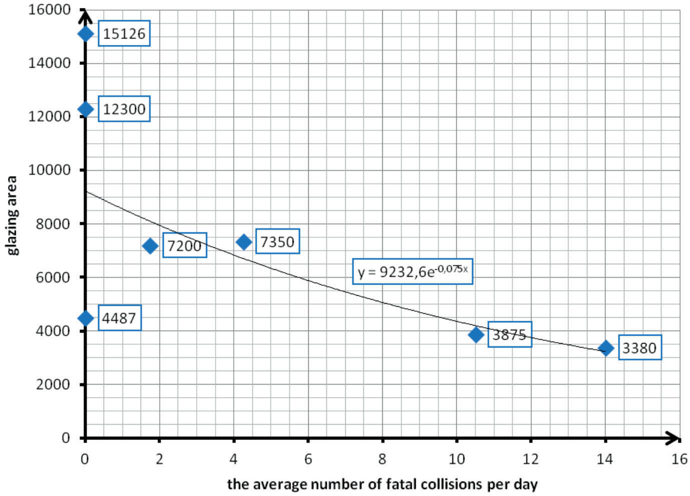

Figure 2. Average daily number of fatal collisions per 1,000 m^2 of glazing depending on the landscaping around the building

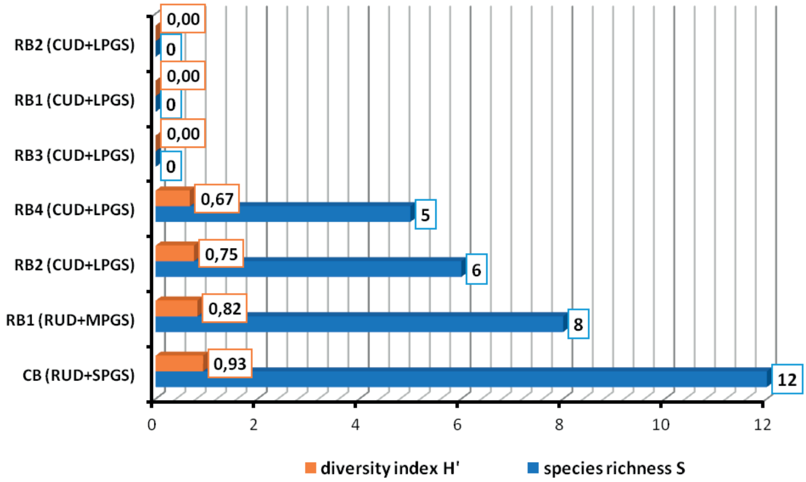

Figure 3. Species richness (S) and species diversity index (H') of birds suffering fatal collisions in relation to land use around the building

Abbreviations: RB – residential building, CB – commercial building, CUD – compact urban development; SUD – sparse urban development; LPGS – low proportion of green space; MPGS – medium proportion of green space, SPGS – significant proportion of green space.

4. Discussion

Both the highest species richness of birds crashing into the glazing with fatal consequences and the highest biological diversity were recorded in the CB building, which initially seemed to be a very surprising result due to the smallest area of glazing of all the buildings studied and the use of graphic markers on part of the facade, which are considered to be an effective glazing protection solution (Szurlej-Kielańska et al., 2020; De Groot et al., 2022). The CB showed the highest daily average number of collisions per 1,000 m^2 of glazing – 4.14. A slightly lower result, although also unexpectedly high, was recorded for building OB1, the building with the second lowest area of glazing. On average, 2.71 birds per 1 000 m^2 of glazing collided with fatalities per day. The opposite situation was encountered in the case of the buildings with the largest area of glazing, i.e. RB2 and OB3 – the checks carried out for these buildings did not reveal a single fatal bird collision. These results proved to be a refutation of hypothesis (1) – prior to the study, it was expected that a directly proportional increase in the number of fatal collisions to the area of glazing of the building in question would be detected, yet the observations indicate the exact opposite. This may be explained by the fact that most collisions occur close to the ground (Klem, 2009). The considerable height of the building, which has a significant impact on the final area of glazing, does not seem to have much influence on the number of bird collisions in this situation.

The results of the study point to a positive correlation between the number of bird collisions with glazing and land use, confirming hypothesis (2). The highest number of collisions in areas with sparse urban development and low PGA, and the lowest with compact urban development and significant PGA, arises from a dissimilar abundance of birds in the areas mentioned (Klem, 2009; Gómez-Martínez et al., 2019). Urban greenery, especially tall greenery, provides a key habitat for many bird species (Stagoll et al., 2012; Threlfall et al., 2016). Green areas allow birds to shelter and breed (Dymitryszyn, Urban, 2015; Arévalo et al., 2022), as well as provide a valuable food base (Dymitryszyn, Urban, 2015), so these areas are generally characterised by a significant concentration of these animals (Gómez-Martínez et al., 2019), as confirmed by the species richness of birds roosting on the individual buildings in this study. The highest abundance of species, as well as the highest biological diversity of birds that suffered fatal collisions, was found for the CB, the only site around which a significant PGA was recorded.

The interesting result is the lack of observed collisions with RB1 and RB2. While these observations may be due to the small PGA in the immediate vicinity, they may have been influenced by quite a different factor. The two mentioned buildings are the only residential buildings included in the study, and the glazing used in them differed from that found on the other buildings – in the case of RB1 and RB2, there was no glazed facade, but instead a fixed balcony enclosure. Based on the results obtained, a hypothesis may be made that birds are able to observe the building wall standing 1.2 m behind the glazing. This hypothesis needs to be confirmed in further studies. Indeed, the lack of recorded collisions for RB1 and RB2 may also arise from other reasons – the medium greenery planted along the wall provided with glazing may have made it difficult to find birds that died as a result of collisions with the building. The lack of evidence of collision may also have been dictated by chance – it is likely that four inspections were too few to observe collisions between birds and some of the buildings.

The third and final building for which not a single collision was recorded was RB3. In this case, in addition to the landscaping favouring a high density of birds, the graphic markers used throughout the building were most likely to be a factor for the lack of collisions. Graphic markers are one of the most recognised ways of minimising collisions with birds (Szurlej-Kielańska et al., 2020; De Groot et al., 2022), so there is a real chance that in the case of the site in question they fulfilled their role. This solution was also applied to parts of the CB elevation, and although collisions were nevertheless observed on that building, the graphic markers seem to have reduced them to some extent. The north elevation was the only one glazed almost entirely and had fewer collisions than the much less glazed south elevation.

The OB2 site used atypical EIV – no reported effect of aluminium panels on bird collisions was found in the literature. The study determined that despite the use of profiles, the glazed facade poses a danger to birds. An interesting observation is that 10 of the 17 collisions recorded took place on the western exposure – the presence of a small patio with several trees and shrubs located on this side of the building is considered to be the reason for this. As previously mentioned, green areas increase the number of birds in an area (Klem, 2009; Gómez-Martínez et al., 2019; Dymitryszyn, Urban, 2015; Arévalo et al., 2022), resulting in a natural rise in the number of collisions (Klem, 2009; Gómez-Martínez et al., 2019). OB2 was one of two buildings whose neighbourhood was characterised by dense urban development and low PGA, and where bird collisions were observed. The other building was OB4, which, despite not having any EIV installed of the glazed façade, showed a lower collision count than OB2.

An interesting observation is the collision of woodcock (*Scolopax rusticola*) for both buildings mentioned above. Woodcock is a species of the snipe family and is associated with aquatic habitats, so such a densely built-up area is not its regular habitat, however, this recording may be due to the species' high sensitivity to changing weather. The numerous collisions of moving woodcocks depend to a large extent on phenomena such as strong winds and low cloud (Loss et al., 2022). Within a radius of approximately 3 kilometres from both buildings there are two parks supplied with water bodies – it is likely that the birds observed colliding with OB2 and OB4 originated from these areas.

5. Conclusions

1) The highest number of bird collisions with buildings occurs in areas characterised by a high proportion of green space, especially tall trees;
2) Significant threats to birds are constituted by large glazed windows with no distractions, as well as the glazing facades;
3) The highest number of collisions of birds with buildings takes place on the western side of the buildings;
4) Even birds not associated with the urban environment, such as woodcock, are observed colliding with buildings.

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ŚMIERTELNOŚĆ PTAKÓW W WYNIKU KOLIZJI Z PRZESZKLENIAMI NA PRZYKŁADZIE OBIEKTÓW BUDOWLANYCH W WARSZAWIE

Abstrakt

Kolizje ptaków z budynkami są zjawiskiem powszechnym ze względu na postępującą antropogenizację środowiska i powstawanie osiedli ludzkich wzdłuż tras migracji gatunków wędrownych. Szczególnie niebezpieczne w tym aspekcie wydają się być powierzchnie szklane, coraz częściej stosowane w nowoczesnym budownictwie, gdyż ptaki mogą nie rozpoznawać ich jako przeszkód nawet w ciągu dnia. W niniejszej pracy przeanalizowano wyniki badań kolizji ptaków z różnymi typami budynków w strefach miejskich o niskim, średnim i wysokim udziale terenów zielonych w zabudowie. Największą liczbę kolizji zaobserwowano dla budynków zlokalizowanych w pobliżu enklaw zielonej roślinności, charakteryzujących się dużą różnorodnością biologiczną. Obecność elementów rozpraszających na szybach istotnie wpływała na spadek liczby kolizji.

Słowa kluczowe: śmiertelność ptaków, obszary miejskie, kolizje, fasady, zewnętrzne pokrycia ścian, powierzchnie szklane, przeszklenia