

Vulnerable bird species and avian mortality due to predation by domestic cat (*Felis catus*) in anthropogenically transformed landscapes of the Bukovynian Carpathians

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Abstract The domestic cat (*Felis catus*) poses a significant threat to bird fauna, particularly in the urbanised, anthropogenically transformed landscapes of the Bukovynian Carpathians, Ukraine. This study aimed to determine the annual bird mortality rate due to cat predation and identify vulnerable species to this threat. Using the Monte Carlo method with 10,000 iterations, mortality rates were calculated. Data were gathered from sociological surveys, field observations, and scientific publications. The methodology included estimating the number of rural pets and feral cats across 877.9 km², calculating population density, and assessing bird predation. Annually, an average of 509,000 birds are killed, with a 95% mortality estimate range between 188.6 thousand and 1,008.6 thousand, which highlights the cats' impact on local bird populations. Linear regression models were developed to predict bird mortality based on cat population size. The regression formulae are $nBFC = 44.10 * nFC$ for feral cats and $nBRP = 32.92 * nRP$ for rural pets. A total of 62 vulnerable bird species were identified in these landscapes of the Bukovynian Carpathians.

Keywords: Ukrainian Carpathians, cat predation, Monte Carlo simulation, cat population density, bird species conservation.

Összefoglalás A házimacska (*Felis catus*) jelentős veszélytető tényező a madárvilágra nézve, különösen a Bukovinai-Kárpátok (Ukrajna) urbanizált, ember által módosított tájain. Jelen tanulmány célja a házimacska okozta éves madárpusztulási arány meghatározása és az e veszélynek kitett fajok azonosítása volt. A 10 000 iterációval végzett Monte Carlo-módszerrel számoltuk ki a mortalitási rátákat. Az adatokat szociológiai felmérésekből, terepi megfigyelésekből és tudományos publikációkból gyűjtöttük. A módszertan magában foglalta a vidéki háziállatok és elvadult macskák számának becslését 877,9 km²-es területen, a populációsűrűség kiszámítását és a madár zsákmányolás értékelését. Évente átlagosan 509 000 madarat pusztítanak el a macskák, a 95%-os becsült mortalitás 188 600 és 1 008 600 közé esik, ami rávilágít a macskák helyi madárpopulációra gyakorolt jelentős hatására. Lineáris regressziót használtunk a madárpusztulás előrejelzésére a macskapopuláció nagysága alapján. A regressziós képletek a következők: $nBFC = 44,10 * nFC$ az elvadult macskák esetében és $nBRP = 32,92 * nRP$ a háziállatok esetében. A Bukovinai-Kárpátok tájain összesen 62 veszélyeztetett madárfajt azonosítottunk.

Kulcsszavak: Ukrán Kárpátok, macskák predációja, Monte Carlo szimuláció, macskák populációsűrűsége, madárfajok védelme

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Introduction

Since the 1600s, at least 33 bird species have gone extinct due to predation by domestic cat (Winter & Wallace 2006). Cats pose a serious threat, and research from various countries indicates significant bird mortality due to predation. In the United States, between 1 and 4 billion birds die annually (Loss *et al.* 2013), in Canada between 105 and 348 million per year (Blancher 2013), 27 million annually during the spring-summer period in the United Kingdom (Woods *et al.* 2003), and between 100,000 and 300,000 during the spring each year in Switzerland (Tschanz *et al.* 2011). Cat predation is one of the most significant factors in bird mortality resulting from human activity (Loss *et al.* 2013), surpassing mortality from collisions with glass surfaces and other engineering structures (Erikson *et al.* 2005), industrial solar power stations (Walston *et al.* 2016, Visser *et al.* 2019, Kosciuch *et al.* 2020), wind power stations, or traditional sources of electrical energy (Sovacool 2009). Domestic cats rank second in the number of birds preyed upon (29% of the total) after the Northern Goshawk (*Accipiter gentilis*) in the US and Southern Canada (Dunn & Tessaglia 1994). In several countries, the domestic cat is classified as an invasive alien species (Winter & Wallace 2006). The number of domestic cats in Western Europe has increased since the 1970s, resulting in up to 26.3% of birds being killed due to predation (Pavisse *et al.* 2019).

To more accurately estimate the prey hunted by domestic cat, researchers distinguish between owned cats and stray cats based on their conditions and behavioral characteristics. A stray cat is an animal without care or an owner, living on its own and foraging for food independently. P. Baker and colleagues use the term «semiferal/feral cats» to describe this group of animals (Baker *et al.* 2010), while other definitions include «un-owned cats» (Loss *et al.* 2013) or «free-ranging cats» (Winter & Wallace 2006). Owned cats, in turn, are divided into urban (urban pet) and rural (rural pet) categories (Blancher 2013).

It is known that accurately counting instances of domestic cat predation is challenging due to the difficulty in documenting such events. Only a certain percentage of prey is brought to the homes by cats and can be identified, while the rest of the prey is consumed in natural conditions (Toner 1956, Barratt 1998, Woods *et al.* 2003, Tschanz *et al.* 2011, Thomas *et al.* 2012, Blancher 2013). Therefore, adjustment factors are introduced for a more accurate estimation of bird mortality (George 1974, Kays & DeWan 2004, Thomas *et al.* 2012). Recent studies using cameras on collars have found that only 23% of prey is brought to homes by domestic cats (Lloyd *et al.* 2013). Analysis of stomach contents has shown that the ratio of consumed to brought prey is 11.4 (Krauze-Gryz *et al.* 2012).

Currently, research on domestic cat predation has been conducted in the following countries: Australia (Barratt 1998), Canada (Blancher 2013), USA (Loss *et al.* 2013), United Kingdom (Churcher & Lawton 1987, Woods *et al.* 2003, Thomas *et al.* 2012), Sweden (Liberg 1984), Switzerland (Tschanz *et al.* 2011), Poland (Krauze-Gryz *et al.* 2012, 2018), France, and Belgium (Pavisse *et al.* 2019), Croatia (Lanszki *et al.* 2016), Hungary (Biró *et al.* 2005). A comparative analysis of the diet of feral and house cats, and wildcat in Europe, was the focus of a recent study (Széles *et al.* 2018). A global synthesis and assessment of free-ranging domestic cat diet was made by Lepczyk *et al.* (2023).

As of 2013, in Canada, the number of urban and rural cats was 8.5 million, while the number of feral cats ranged from 1.4 to 4.2 million (Blancher 2013). Thus, the percentage of feral cats in Canada varied from 14% to 33% of the total number. In the USA, there are approximately 70 million feral cats, and nearly 25% of their diet consists of birds (Web1), with the total number of pet cats in the USA reaching up to 82 million (Web2). Thus, feral cats constitute over 46% of the total number in the USA. In Western Europe, the number of feral cats remains completely unknown as of 2019 (Pavisse *et al.* 2019).

In Ukraine, data on bird mortality due to domestic cat predation is currently unavailable, and thorough studies have not been conducted, except for some individual reports (Merzlikin 1998, Koshelev & Osytkovska 2017).

The aim of this study is to establish the probable annual range of bird mortality due to domestic cat predation in the anthropogenically transformed landscapes (ATL) of the southwestern Bukovynian Carpathians, within the former Putyla district, now encompassing the Konyatyn, Putyla, Selyatyn, and Ust-Putyla territorial communities (TC) of the Vyzhnytsia district in the Chernivtsi region, Ukraine. This is the first time that a preliminary assessment of mortality and identification of the most affected species are being conducted. The results of the study will help understand the scale of the problem and identify the most vulnerable species in need of protection. The ultimate goal is to identify bird species vulnerable to domestic cat predation, based on research from other countries and criteria for species vulnerability developed as a result. Data analysis will provide recommendations for mitigating the negative impact of domestic cats on bird populations and will contribute to the conservation of biodiversity in these areas.

Material and Methods

Calculation of bird mortality due to domestic cat predation

In this study, all cats owned by people are considered rural pets, while animals without owners that live independently are referred to as feral cats. The approach used to calculate bird mortality due to domestic cat predation in the ATL of the southwestern Bukovynian Carpathians involved estimating the number of rural pets and feral cats in the area and the average number of birds hunted by one cat per year (Blancher 2013). The total number of bird fatalities was calculated using the formula:

$nB = nBRP + nBFC$, where $nBRP$ is the number of birds hunted by the rural pet population per year, and $nBFC$ is the number of birds hunted by the feral cat population per year.

$nBRP = nRP * BpRP * koefRP$, where nRP is the population size of rural pets in the ATL of the southwestern Bukovynian Carpathians; $BpRP$ is the average number of birds hunted by one rural pet per year; and $koefRP$ is the correction coefficient for rural pet.

$nBFC = nFC * BpFC$, where nFC is the population size of feral cats in the ATL of the southwestern Bukovynian Carpathians; $BpFC$ is the average number of birds hunted by one feral cat per year.

The above formulas are similar to Blancher's equations (2013), but we did not use the proportion of rural pets that are allowed outdoors. All surveyed owners reported that their cats are not kept isolated indoors but have free access to the surrounding environment, which poses a threat to small mammals and birds. Therefore, the proportion of rural domestic cats with access to the outdoors is considered to be 1.

Estimation of the rural pet population

Given that there is no official census of rural or urban pets in Ukraine, the author had to employ a sociological approach to estimate rural pets population. This approach was based on a survey of residents of private households and apartments in multi-story buildings, primarily in Putyla township and in nearby villages, to determine the presence and number of cats in each household. Similar surveys, though on a much larger scale, have been conducted by colleagues in Poland (Krauze-Gryz *et al.* 2018) and in the USA (APPA 2019). The number of private households in the southwestern Bukovynian Carpathians was determined by the number of household consumers recorded by the Putyla Central Operations Centre of Chernivtsi Regional Energy Supply Company LLC («CRESC» LLC). Based on the survey results, a statistical calculation was made of the number of rural pets per household in Putyla township and in the aforementioned TC. The average number of rural pets per household in Putyla township and in the southwestern Bukovynian Carpathians was taken as the mean value of the survey sample for these areas. The obtained values were extrapolated to the entire study area by multiplying the average number of pets per household by the number of households in Putyla township or in the specified TC according to the formula:

$nRP = nH * nRPPH$, where nRP is the total number of rural pets in the study area; nH is the number of households; and $nRPPH$ is the number of rural pets per household.

To ensure the representativeness of households, a stratified sample was used that included households from different socio-economic groups and settlements. Such an approach allowed us to reduce the error and maintain the representativeness of the results.

Statistical analysis of the obtained results

Samples formed through monitoring and surveys were analyzed using statistical methods. The calculation of the minimum sample size for Putyla township and the southwestern Bukovynian Carpathians was performed using the online calculator from the Laboratory of Sociological Research at Vinnytsia National Technical University, Ukraine (<https://socio-lab.vntu.edu.ua/calculator/>). The following criteria were set to obtain the result: confidence level – 99%; margin of error – $\pm 10\%$.

The mean value of the sample obtained from the study was determined using the formula $\bar{X} = \sum x_i n_i / n$, where x_i represents the variant values (individual values in the sample), n_i is the frequency of the variant (the number of times the value x_i appears in the sample), and n is the total number of values in the sample (the sum of all frequencies).

The deviation was calculated using the formula $d_i = a_i - \bar{X}$, where d_i is the difference between the current and mean values; a_i is the current value in the sample; $\bar{X}$ is the mean value.

The mean deviation was calculated using the formula $\sigma_a = \sqrt{\frac{1}{N-1} \sum_1^N d_i^2}$, where N is the number of sample elements, and d_i is the deviation.

The standard deviation was calculated using the formula $\sigma_a = \sigma_a / \sqrt{N}$, where σ_a is the mean deviation and N is the number of sample elements.

The relative error was calculated using the formula $\Delta a = \frac{\sigma_a}{\bar{X}} 100\%$, where Δa is the relative error ($\pm\%$), σ_a is the standard deviation, and $\bar{X}$ is the sample mean (Ploskonos 2012).

To automate the calculation processes, these formulas were interpreted according to the syntax of the R programming language, using the free software RGui (R Console) version R-4.4.1 as the environment for statistical computations.

Estimation of the average identified number of birds hunted by rural pets per year

This parameter is crucial for a reliable assessment of bird mortality due to cat predation. Considering that no thorough studies have been conducted in Ukraine, it is reasonable to rely on data from other temperate climate countries where such information is available.

Studies on birds hunted by rural pets are usually based on the number of prey detected by owners, but this method is not accurate since some prey is consumed by the cat without being brought home. The average number of identified birds killed per year in Canada ranges from 2.8 to 14 birds per year for rural pets, while feral cats kill between 24 and 64 birds per year (Blancher 2013). These ranges were used for the research in this study.

Given the lack of data from Ukraine, especially from the mountainous areas of the Ukrainian Carpathians, the author applied the method of extrapolating results from countries with a temperate climate where such studies have been conducted. The extrapolation method involves transferring known patterns to areas where such patterns are unknown.

Blancher's (2013) research, specifically the establishment of ranges for identified bird fatalities per year, was based on an analysis of research from various countries. Of course, this method has certain drawbacks, as there may be climatic differences and other local factors. The diet of rural pets and feral cats can also include small mammals, which can sometimes be more significant than birds. Therefore, this may reduce the proportion of birds killed by cats in different territories or countries.

Assuming that the diet of cats in the Bukovynian Carpathians is different and may somewhat vary from the data of our Canadian colleagues, these inaccuracies are mitigated by the application of the Monte Carlo method, which accounts for uncertainty and variations in the data. The Monte Carlo method employs random modeling to estimate the probability of different outcomes, allowing for a wide range of possible scenarios and variations in the data to be considered.

Thus, even if the diet of cats in the Bukovynian Carpathians differs from that in Canada (Blancher 2013), the Monte Carlo method helps ensure the accuracy of our estimates by reducing the impact of potential inaccuracies in the data and providing a clearer understanding of the actual impact of cats on bird populations in this region.

Determining the value of the correction factor for calculating instances of successful hunting by rural pets (koefRP)

Findings of rural pet prey near private residences do not provide a complete picture of their numbers because it is difficult to investigate all instances of successful hunting, as cats bring only a small percentage of their prey (Krauze-Gryz *et al.* 2012, Loyd *et al.* 2013). G. Toner reports that observations of 4 cats on a farm in Canada produced the following results: one cat brought all the prey, another about half, and the other two did not bring their prey but consumed it in close proximity to the hunting site (Toner 1956). Various authors estimate the value of the correction factor for counting bird mortality due to rural pet predation, ranging from 2 to 5.8 (George 1974, Krauze-Gryz *et al.* 2012), with most leaning towards a value of 3.3 (Baker *et al.* 2005, 2008, Maclean *et al.* 2008, Thomas *et al.* 2012). Studies using video cameras embedded in cat collars yielded a result of 4.34 (23%) (Loyd *et al.* 2013). In analyzing bird mortality due to rural pet predation in Canada, the correction factor was chosen in the range of 2 to 5.8 (Blancher 2013). Considering that the studied area of the Bukovynian Carpathians is mountainous, like much of Canada, and the fact that the upper limit of the correction factor (5.8) is based on stomach content analysis (Krauze-Gryz *et al.* 2012), which is considered the most accurate method, a correction factor range for rural pets (koefRP) from 2 to 5.8 was chosen.

Estimation of the feral cat population

Determining the population of feral cats is scientifically challenging, but this estimate is crucial for assessing mortality, as these animals are the primary predators of birds. This study used personal observations and local surveys to estimate the feral cat population in the specified area.

Extrapolation and spatial modeling methods were employed to assess the feral cat population. A representative model area in the center of Putyla township, with an area of 1.0 km², was selected. This area included all potential habitats for feral cats, such as residential buildings (private homes and apartment blocks), commercial infrastructure (shops, eateries), administrative buildings, a park predominantly consisting of deciduous trees, a stadium and sports ground, coniferous forest and riverbank areas. Feral cats are known to prefer locations with access to resources, particularly food (Tennent & Downs 2008). Based on this criteria, potential gathering spots for feral cats within the model area were identified (places where food waste is generated, apartment buildings, high-traffic areas, such as shops). Observations and local surveys were conducted to determine the number of feral cats at these locations (*Table 1*). The population density of feral cats in the control area was calculated using the formula:

$D_{FCCP} = N_{FCI} / S_{CP}$, where: D_{FCCP} – feral cat population density in the control area; N_{FCI} – total identified number of feral cats in the control area; S_{CP} – area of the control area (1.0 km²). This value was extrapolated to the total area of Putyla township using the formula:

$N_{FCP} = D_{FCCP} * S_{PUT}$, where: N_{FCP} – total number of feral cats in Putyla township; S_{PUT} – area of the settlement.

Table 1. Results of the study on the population size and density of rural pet and feral cat in the southwestern Bukovynian Carpathians

1. táblázat A háziállatként tartott és elvadult macskák populációmérete és denzitása a Délnyugat-Bukovinai-Kárpátok különböző területein

Settlement, community	Area, km ²	Number of house-holds	Number of rural pets, ind.	Density of rural pets, ind. /km ²	Number of feral cats, ind.	Density of feral cats ind. /km ²	Number of domestic cats, indiv.	Density of domestic cats ind. /km ²
Putyla town-ship (Putyla TC)	13.7	2,192	2,234±357	163±26.08	343±19	25±1.38	2,577±554	188±40.42
Konyatyn TC	122.0	Not examined in terms of communities.						
Putyla TC	231.6							
Selyatyn TC	367.7							
Ust-Putyla TC	156.6							
Together across communities:	877.9	9,539	13,599±1,904	15.49±2.17	1,493±82	1.70±0.09	15,092±3,245	17.19±3.70

To determine the number of feral cats per dwelling in Putyla township, the formula was used: $N_{FCPH} = N_{FCP} / nH_p$, where: N_{FCPH} – number of feral cats per dwelling; nH_p – total number of dwellings in Putyla township. To extrapolate the number of stray cats to the scale of ATL in the southwestern Bukovynian Carpathians, the formula used was:

$nFC = N_{FCPH} * nH$, where: nFC – feral cat population size in ATL of the southwestern Bukovynian Carpathians; nH – number of dwellings in the ATL of the specified areas.

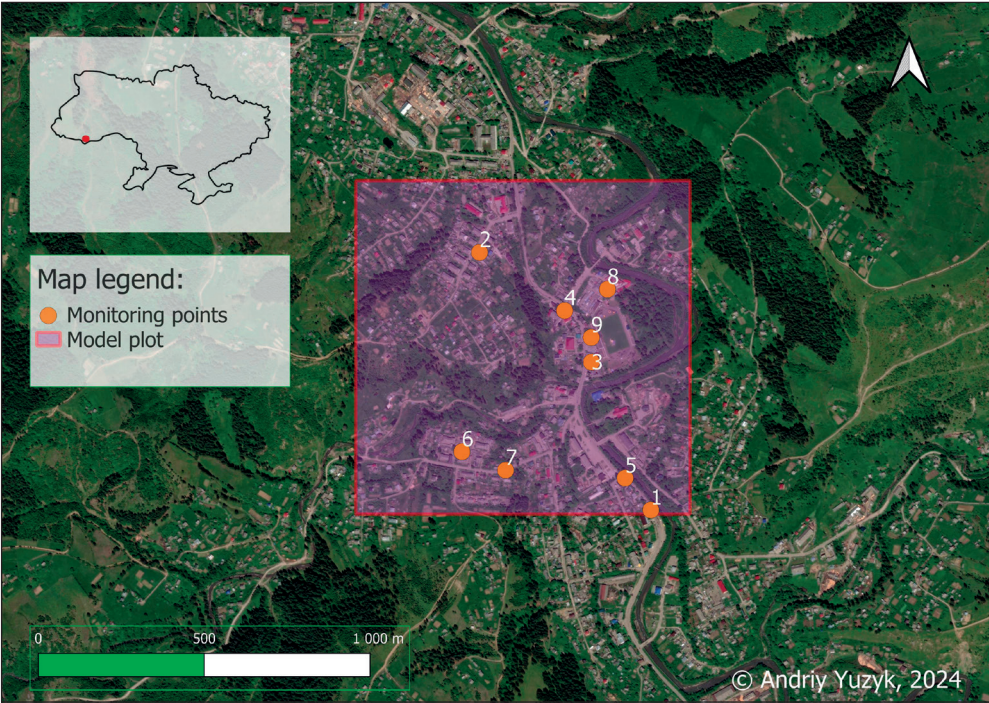


Figure 1. Map-scheme of the model area for feral cat monitoring in Putyla township
1. ábra Az elvadult macskák mintaterülete Putyla körzetében

For mapping the model area and monitoring points, the free software QGIS ver. 3.18.1 Zürich, QuickMapServices plugin, and Bing Satellite raster data were used. Coordinates of the vertices of the model area: 25.08920738, 47.99324544; 25.08920738, 48.00225444; 25.07570438, 47.99324544; 25.07570438, 48.00225444 (*Figure 1*).

To prevent the same individuals of feral cats from being counted multiple times in the study area, the author focused on the physical characteristics of the cats, such as size, fur color, and the presence or absence of certain features (e.g. spots, stripes). Additionally, traits like the absence of a collar and the overall health condition of the cats (e.g. scars, injuries) were taken into account for the identification of stray cats. Whenever possible, staff members of the institutions were surveyed to determine whether the cat was stray or had an owner and was simply roaming the streets.

The counts were conducted using a route method at least 4 times a month. Each time, the number of animals at the monitoring point was recorded, after which the average value for the month was calculated as the sum of all detections divided by the number of observations.

In the case of using information from third-party observers, the author attempted to independently verify the data. In the event of discrepancies, preference was given to personal observations.

Table 2. Encounters of feral cat from January to June 2024 at the model site in Putyla township
2. táblázat Az elvadult macskák megfigyelései 2024 január-június időszakában Putyla területén

Monitoring point number	Location	Monthly abundance, ind.						Source of information
		1	2	3	4	5	6	
1.	Ukrains'ka Street, "Norma" Store	2	1	1	2	1	1	Personal observation
2.	Meshkova Street, Building 4, 8, 12	12	11	10	12	12	16	Balan, S., oral pres.
3.	Ukrains'ka Street, Library	2	2	2	2	2	2	Boychuk, S., oral pres.
4.	Ukrains'ka Street, "Horyanka" Restaurant	6	3	4	5	4	4	Matsenko, M., oral pres., personal observation
5.	Corner of Ukrains'ka Street and Alekseev Street, Pizzeria	1	2	1	1	2	1	Personal observation
6.	Franko Street (Apartment Buildings)	0	0	0	0	0	0	Mykyrtuchyan, L., oral pres.
7.	Franko Street, Grocery Store	0	0	0	0	0	0	Personal observation
8.	Ukrains'ka Street, Market	2	1	1	2	2	2	Personal observation
9.	Ukrains'ka Street, "Classic" Store (near the stadium)	5	4	2	0	0	2	Personal observation
Total by months:		30	24	21	24	23	28	
Average number for the period:		25 ± 1.38						

The basis for estimating the population of feral cats in the specified areas was settlements. The presence of feral cats in forests is unlikely, as these animals tend to search resources, particularly food (Tennent & Downs 2008), and rarely venture deep into the forests (Kays & DeWan 2004), unless it is an isolated area where there are human dwellings.

Coniferous or mixed coniferous-deciduous forests that cover the Bukovynian Carpathians are poorly suited for the permanent presence of feral cats for several reasons. There are no anthropogenic food sources here, which often consist of garbage dumps or feeding by humans. In the forests, there are significantly fewer places for shelter, in contrast to populated areas where animals can stay in abandoned buildings, basements, attics, agricultural structures, etc., which provide protection from predators and adverse environmental conditions. Forests are habitats for predatory mammals capable of preying on feral cats, such as the Brown Bear (*Ursus arctos*), Grey Wolf (*Canis lupus*), domestic dog (*Canis familiaris*) (mostly feral individuals), European Wildcat (*Felis silvestris*), and Eurasian Lynx (*Lynx lynx*), among others. Small mammals, particularly rodents, tend to be more numerous in human settlements, which in turn attract cats. These assertions are supported by the author's personal observations, as he has not encountered feral cats in the forests of the Bukovynian Carpathians during extensive expeditions.

Determining the population density of rural pets

The population density of rural pets was assessed for the largest settlement, which is Putyla township. The area of this settlement was determined according to the official source (letter from the State Geocadastr of the Chernivtsi Region No. III-72/0-68/0/63-20 dated October 16, 2020) and for the southwestern Bukovynian Carpathians as a whole. The area of the settlements in these mountainous regions was determined as the total sum of the areas of Koniatyn, Putyla, Selyatyn, and Ust-Putyla TC (<https://decentralization.ua>).

The population density of rural pets in these areas was calculated using the formula: $D_{RP} = n_{RP} / S$, where: D_{RP} – population density (number of rural pets per unit area, km²); S – area of the studied territory.

Similarly, the population density for feral cats (D_{FC}) and the overall population density (D_{TOTAL}) were calculated.

Application of the Monte Carlo method for the overall assessment of bird mortality and the construction of linear regression models

To achieve a more accurate estimation of the annual bird mortality rate due to domestic cat predation in the ATL of the southwestern Bukovynian Carpathians, the Monte Carlo method was applied. For this purpose, a random value of a specific parameter was selected from the range of probable values listed in *Table 3*. These random parameters were then multiplied according to the formulas mentioned above, and all the multiplication results were recorded. A total of 10,000 iterations were performed, followed by calculations of the average value and relative error of the obtained samples for rural pets and feral cats, frequency distribution of all iterations, and the construction of regression models. To achieve this, the bird mortality

Table 3. Parameters and value ranges used for calculating bird mortality due to domestic cat predation in the anthropogenically transformed landscapes of the southwestern Bukovynian Carpathians

3. táblázat A házimacska okozta madárpusztulás kiszámításához használt paraméterek és értéktartományok a Délnyugat-Bukovinai-Kárpátok területén

Parameters	Acronym	value ranges	Data source
Number of rural pets, ind.	nRP	11695–15503	Original research
Percentage of rural pets with access to the outdoors	pORP	100% (all surveyed owners, was not considered)	Original research
Number of feral cats, ind.	nFC	1411–1575	Original research
Average identified number of birds preyed upon by rural pets per year	BpRP	2.8–14.0	Blancher 2013
Correction factor for calculating successful hunting incidents by rural pets	koefRP	2.0–5.8	Krauze-Gryz <i>et al.</i> 2012, Blancher 2013
Average number of birds preyed upon by feral cats per year	BpFC	24–64	Blancher 2013

Table 4. Preliminary assessment of annual bird mortality in the ATL of the southwestern Bukovynian Carpathians based on values from Table 3 and using the Monte Carlo method (10,000 iterations)

4. táblázat Az éves madárpusztulás előzetes becslése a Délnyugat-Bukovinai-Kárpátok területén a 3. táblázat értékei alapján Monte Carlo-módszerrel (10 000 iteráció) számolva

	Total	Rural pet	Feral cat
Cat population, thousands	15.1±21.5%	13.6±14.0%	1.5±5.5%
Bird mortality, thousands	509,0 (188.6–1008.6)	443,0 (127.0–942.5)	66,0 (37.6–95.1)

calculation formulas for domestic and stray cats were interpreted according to the syntax of the R programming language, and the code was executed in the aforementioned software environment. The results are presented in Table 4 and Figures 2–4. The specialized ggplot2 library for RGui was used to create the graphs.

As is known, the general formula for linear regression is: $y = \beta_0 + \beta_1 x$. In this formula, y is the dependent variable (annual number of birds killed by feral cats or rural pets), x is the independent variable (population size of feral cats or rural pets), β_0 is the intercept, representing the value of y when $x=0$, β_1 is the slope coefficient, which indicates how much y changes with a one-unit change in x . In predicting the number of bird killings based on cat population size, it is logically assumed that if the predator population size x is 0, the number of victims would also be 0, as there would be no cats to kill birds. Therefore, in our linear regression models for estimating bird mortality due to feral cats and rural pets, the intercept β_0 should be 0 (or simply absent), making the general equation $y = \beta_1 x$.

The next step in deriving the linear regression formula is to estimate the relationship between mortality values and cat population size based on predicted data (β_1 based on the analysis of 10,000 Monte Carlo simulations). This can be done using the least squares method, which was used to build the linear regression model without an intercept, seeking

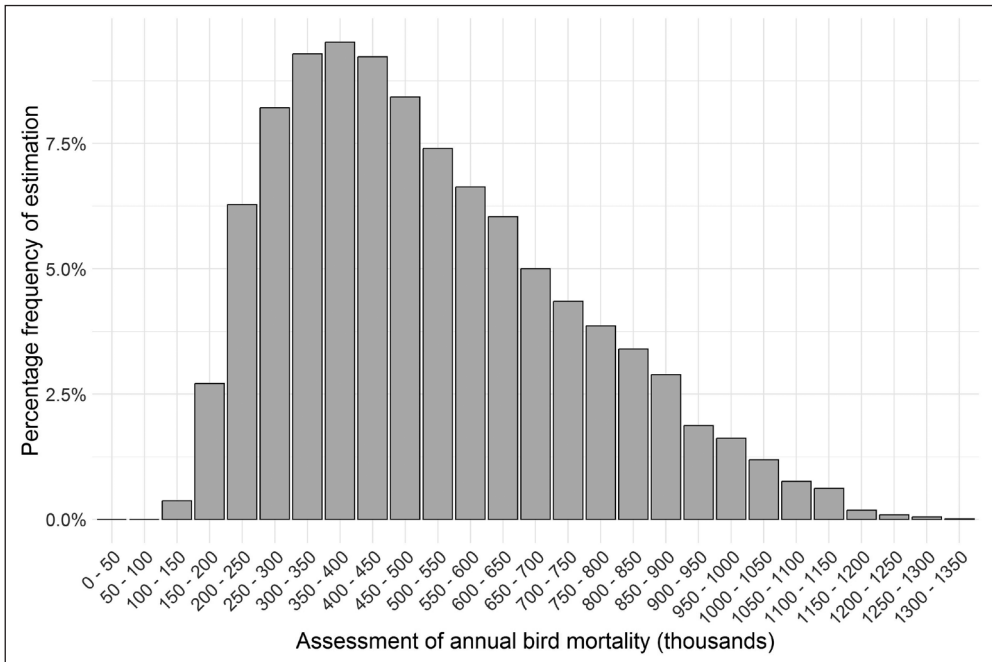


Figure 2. Distribution of the percentage frequency of annual bird mortality estimation due to cat predation in the ATL of the southwestern Bukovynian Carpathians

2. ábra A macskák által okozott éves madárpusztulás becsült százalékos gyakoriságának megoszlása a Délnyugat-Bukovinai-Kárpátok területén

the line that best describes the relationship between cat population and bird mortality. The quality of the model was assessed by the coefficient of determination R^2 , which indicates the proportion of variation in the dependent variable explained by the model. The closer R^2 is to 1, the better the linear regression model explains the variation in the dependent variable (in this case, annual bird mortality) based on the independent variable (cat population). Thus, a coefficient of determination R^2 close to 1 indicates that the linear model well describes the dependency of mortality on population size.

The use of Artificial Intelligence (AI) for working in the R programming environment

To make efficient use of time, the author employed the AI software product ChatGPT 4.0 by OpenAI for syntax analysis and self-learning in R programming, selecting appropriate commands according to the calculation methodology, interpreting statistical formulas in R, and working with the ggplot2 library. The R scripts, created using AI and used in this study, are provided as appendices at the end of the article. The author formulated queries, composed code blocks, identified incorrect responses of AI, and set the code according to the tasks set within this study.

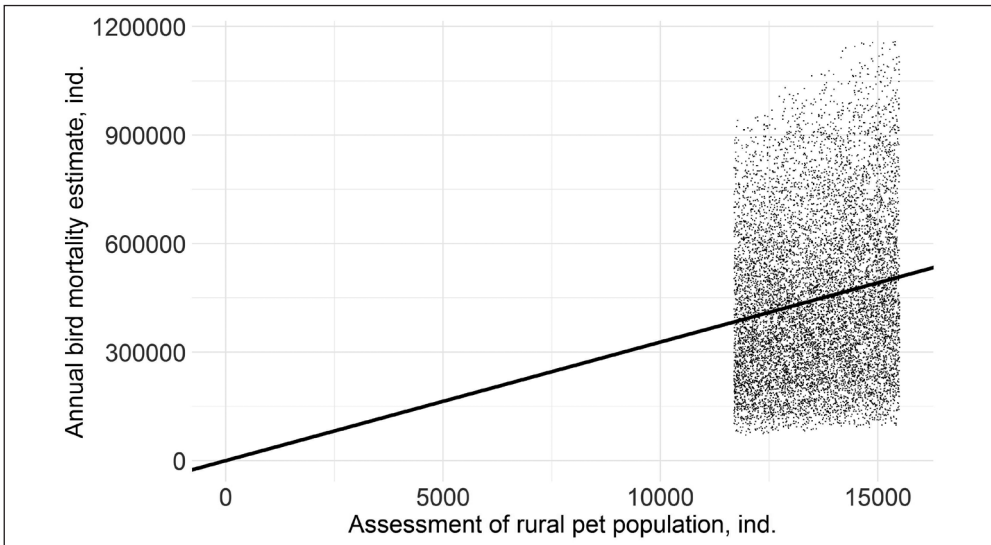


Figure 3. The relationship between the estimated annual number of birds killed by rural pet and the size of the cat population. The shaded area on the graph represents the range of results from multiplying the parameters over 10,000 iterations

3. ábra A vidéki háziállatok által elpusztított madarak becsült éves száma és a macskapopuláció nagysága közötti kapcsolat. Az árnyékolt terület a paraméterek 10 000 iteráción keresztüli szorzásából származó eredmények tartományát jelöli

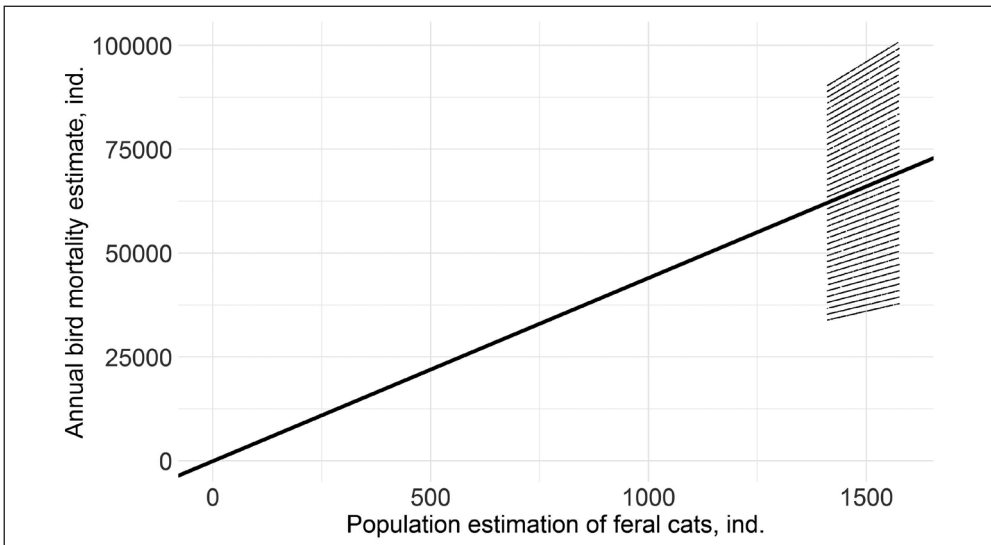


Figure 4. The relationship between the estimated annual number of birds killed by feral cat and the size of the cat population. The shaded area on the graph represents the range of results from multiplying the parameters over 10,000 iterations

4. ábra Az elvadult macskák által elpusztított madarak becsült éves száma és a macskapopuláció nagysága közötti kapcsolat. Az árnyékolt terület a paraméterek 10 000 iteráción keresztül történő szorzásából származó eredmények tartományát jelöli

Criteria for identifying vulnerable bird species

It is evident that not all bird species identified in the Bukovynian Carpathians can be hunted by cats. Forest species face a significantly lower threat from predators, as cats rarely venture deep into forests (Kays & DeWan 2004). Observations of the Wood Thrush (*Hylocichla mustelina*) nests in Ontario, Canada, which were located in forests near human settlements and farms, recorded 12 predator species, but domestic cats were not among them (Blancher 2013). Wetlands also serve as a natural barrier to cat predation, making birds that nest there much less vulnerable, except for species that nest on the edges of wetlands (Winter & Wallace 2006). The body mass of a bird is a significant factor. Studies at bird feeders have shown that domestic cats prefer smaller birds weighing between 14 and 42 grams, but a few larger birds, such as Mourning Doves (*Zenaida macroura*) weighing over 100 grams, were also hunted (Dunn & Tessaglia 1994). The nesting location is also crucial to a cat's hunting success. Species that nest or feed on the ground are more vulnerable (Winter & Wallace 2006) than those that nest in tree canopies or anthropogenic environments (artificial nests, roofs of buildings and structures, power line poles, etc.) and forage in the air. Another important criterion is the food base. Species whose diet includes berries and fruits of trees, terrestrial molluscs and invertebrates, earthworms, etc., are more vulnerable due to their proximity to the ground during foraging, which makes them easy prey for predators (Churcher & Lawton 1987, Crooks & Soulé 1999, Hawkins *et al.* 2004, Baker *et al.* 2005, 2008, van Heezik *et al.* 2010, Balogh *et al.* 2011). In Western Europe, vulnerable bird species are those frequently found on the ground or visiting feeders in winter (Pavisse *et al.* 2019).

Thus, the following criteria were selected to identify potentially vulnerable species due to cat predation in the anthropogenically transformed landscapes of the Bukovynian Carpathians:

1. Established presence of the species in these areas (Yuzyk & Yuzyk 2016, 2022, 2024, Yuzyk 2021).
2. Bird body mass between 10 and 150 g (Blancher 2013).
3. Ground-nesting habits or nesting in locations potentially accessible to cats.
4. Foraging behavior associated with obtaining food on the ground or in bushes or shrubs.

Result

Determining the population of rural pets in the study areas

The number of households is crucial for estimating the population of cats kept by owners. Upon the author's request, information was obtained on the number of household consumers from the Putyla Central Operations Centre «CRESC» LLC within the former Putyla district and in Putyla township (*Table 1*). According to the aforementioned calculation criteria (see Methods), the minimum sample size for the town of Putyla was 155, and

for the southwestern Bukovynian Carpathians, it was 164. In this study, residents from the following settlements were surveyed: Putyla township, the villages of Dykhtynets, Kyselytsi, Malyi Dykhtynets, Ploska, Ploshchi, Serhiyi, Sokoli, Stebni, Toraky, and the hamlet of Khrabusna.

In total, 158 residents from different addresses in Putyla township and nearby hamlets were surveyed, while 195 were surveyed in the southwestern Bukovynian Carpathians. The extrapolated estimates of the rural pet population in the town of Putyla and across the entire study area are presented in *Table 1*.

The average number of rural pets per household in Putyla township is 1.02 ± 0.163 , whereas for the ATL of the southwestern Bukovynian Carpathians, this value is higher (1.43 ± 0.2).

A survey of rural pet owners revealed that none of the animals are kept exclusively indoors; all (or 100%) have free access to the outside world, and therefore pose a threat to birds.

Estimating the population of feral cats in the studied areas

The population of feral cats significantly affects bird mortality, as these animals hunt more frequently to survive (see Methods).

The results of the monitoring of feral cats in the model area in Putyla township are presented in *Table 2*, with the monitoring points shown in *Figure 1*. Data on the estimated population size and density of feral cats in Putyla township and in the ATL of the southwestern Bukovynian Carpathians are presented in *Table 1*.

From the results obtained (*Tables 1, 4*), it can be established that the population of feral cats constitutes about 10% of the total population, yet these cats kill over 14% of all birds, which is related to their higher food requirements.

Bird mortality due to domestic cats predation

Anthropogenically transformed landscapes create new ecological conditions for the local fauna. One of the most influential anthropogenic factors is the presence of domestic cats, which, due to their hunting instincts, significantly impact local bird populations. The Bukovynian Carpathians, as a biodiversity hotspot, are an important area for studying this impact.

To accurately calculate the number of birds killed by cats in these areas annually, the Monte Carlo method with 10,000 iterations was used (see methods). This method provides a more accurate estimate and accounts for the high variability in cat behavior and ecological living conditions. The raw data and ranges for calculating 10,000 probable annual bird mortality values due to cat predation are presented in *Table 3*.

The analysis of the results from each iteration allowed for the distribution of the percentage frequency of the estimated annual bird mortality due to cat predation in the southwestern Bukovynian Carpathians (*Figure 2*) and shows a wide range of possible impacts on the bird fauna. *Table 4* presents the median values for the obtained sample and the 95% ranges of mortality estimates due to predation by feral cats, rural pets, and the total number of birds killed per year (values are given in parentheses).

Determination of linear regression models for estimating bird mortality due to predation by rural pets and feral cats

The relationships between the estimated total number of birds killed annually by rural pets and feral cats and their population sizes are shown in *Figures 3, 4*. The points on the graph represent the distribution of random values resulting from 10,000 iterations within the specified ranges. The line represents the computed linear regression model.

The computed linear regression model for feral cats is: $nBFC = 44.10 * nFC$ (acronyms as defined above, see methods). Thus, with a one-unit increase in the feral cat population, the annual bird mortality in the southwestern Bukovynian Carpathians will change approximately by 44 birds. $R^2 = 0.9325$. The linear regression model for rural pets is: $nBRP = 32.92 * nRP$. With a one-unit increase in the rural pet population, the annual bird mortality in the specified areas will change approximately by 33 birds. $R^2 = 0.8063$.

Based on the slope coefficients of the linear regressions, it is possible to determine how many more birds are killed by feral cats compared to rural pets. Calculation: $((44.1 / 32.9) - 1) * 100\% = 34\%$. Thus, feral cats kill 34% more birds compared to rural pets.

Bird species vulnerable to domestic cat predation

In accordance with the selection criteria (see Methods), a list of bird species vulnerable to domestic cat predation in the ATL of the Bukovynian Carpathians has been compiled (*Table 5*).

Discussion

Cats are opportunistic carnivores that consume a wide variety of animals, including mammals, birds, reptiles, amphibians, and insects. The study identifies 2,084 species consumed by cats, of which 347 species are of conservation concern. Notably, islands have a higher proportion of species affected by cat predation compared to continents. Cats prey on approximately 9% of bird species, 6% of mammal species, and 4% of reptile species globally. These findings underscore the ecological threat that free-ranging domestic cats pose, as they prey on vulnerable and endangered species across a wide geographical range (Lepczyk *et al.* 2023).

This study found that the average number of cats per household in villages and remote homesteads is higher compared to Putyla township. According to the author, this is related to the larger number of cats kept in homesteads and remote villages, where almost every private household keeps livestock and poultry, and cats help control small mammals, particularly rodents. Such cats potentially kill more birds, as Polish colleagues note that domestic cats on Polish farms are mainly kept to control mice and are poorly fed, which intensifies their impact on biodiversity and birds (Krauze-Gryz *et al.* 2018).

In the village of Vakalivshchyna, Sumy region, Ukraine in 1992, there were 18 rural pets in 10 households, and by 1996, there were 25 rural pets in 18 households. Between 1989 and 1996, 72 cases of bird mortality (22 species) due to cat predation were recorded

Table 5. Vulnerable bird species to domestic cat predation in the Bukovynian Carpathians

5. táblázat A házimacska zsákmányolás által veszélyeztetett madárfajok listája a Bukovinai-Kárpátokban

Species ¹	Criteria of vulnerability			Conservation status
	Body mass up to 150 g	Ground nesting	Feeding on the ground or in shrubs (bushes)	
<i>Coturnix coturnix</i>	+	+	+	Annex II of the EU Birds Directive, Annex II of the Bonn Convention, Annex III of the Bern Convention, IUCN, LC
<i>Cuculus canorus</i>	+	-	+	EU Birds Directive (Article 1), Annex III of the Bern Convention, IUCN, LC
<i>Columba oenas</i>	+	-	+	RDBU ² , Annex II of the EU Birds Directive, Annex III of the Bern Convention, IUCN, LC
<i>Streptopelia decaocto</i>	+	-	+	Annex II of the EU Birds Directive, Annex III of the Bern Convention, IUCN, LC
<i>Charadrius hiaticula</i>	+	+	+	RDBU, EU Birds Directive (Article 1), Annex II of the Bern Convention, Annex II of the Bonn Convention, Annex II of the AEWA, IUCN, LC
<i>Charadrius dubius</i>	+	+	+	EU Birds Directive (Article 1), Annex II of the Bern Convention, Annex II of the Bonn Convention, Annex II of the AEWA, IUCN, LC
<i>Actitis hypoleucos</i>	+	+	+	EU Birds Directive (Article 1), Annex II of the Bern Convention, Annex II of the Bonn Convention, Annex II of the AEWA, Helsinki Convention, IUCN, LC
<i>Tringa totanus</i>	+	+	+	Annex II of the EU Birds Directive, Annex III of the Bern Convention, Annex II of the Bonn Convention, Annex II of the AEWA, IUCN, LC
<i>Upupa epops</i>	+	-	+	EU Birds Directive (Article 1), Annex II of the Bern Convention, IUCN, LC
<i>Dryobates minor</i>	+	-	+	EU Birds Directive (Article 1), Annex II of the Bern Convention, IUCN, LC
<i>Dendrocopos major</i>	+	-	+	EU Birds Directive (Article 1), Annex II of the Bern Convention, IUCN, LC
<i>Picus canus</i>	+	-	+	Annex I of the EU Birds Directive, Annex II of the Bern Convention, IUCN, LC
<i>Oriolus oriolus</i>	+	-	+	EU Birds Directive (Article 1), Annex II of the Bern Convention, IUCN, LC
<i>Lanius collurio</i>	+	+	+	Annex I of the EU Birds Directive, Annex II of the Bern Convention, IUCN, LC

Species ¹	Criteria of vulnerability			Conservation status
	Body mass up to 150 g	Ground nesting	Feeding on the ground or in shrubs (bushes)	
<i>Poecile montanus</i>	+	+	+	EU Birds Directive (Article 1), Annex II of the Bern Convention, IUCN, LC
<i>Coloeus monedula</i>	+	-	+	Annex II of the EU Birds Directive, IUCN, LC
<i>Bombycilla garrulus</i>	+	-	+	EU Birds Directive (Article 1), Annex II of the Bern Convention, IUCN, LC
<i>Periparus ater</i>	+	-	+	EU Birds Directive (Article 1), Annex II of the Bern Convention, IUCN, LC
<i>Poecile palustris</i>	+	+	+	EU Birds Directive (Article 1), Annex II of the Bern Convention, IUCN, LC
<i>Cyanistes caeruleus</i>	+	-	+	EU Birds Directive (Article 1), Annex II of the Bern Convention, IUCN, LC
<i>Parus major</i>	+	-	+	EU Birds Directive (Article 1), Annex II of the Bern Convention, IUCN, LC
<i>Remiz pendulinus</i>	+	-	+	EU Birds Directive (Article 1), Annex III of the Bern Convention, IUCN, LC
<i>Lullula arborea</i>	+	+	+	Annex I of the EU Birds Directive, Annex III of the Bern Convention, IUCN, LC
<i>Hirundo rustica</i>	+	-	+	EU Birds Directive (Article 1), Annex II of the Bern Convention, IUCN, LC
<i>Phylloscopus sibilatrix</i>	+	+	+	EU Birds Directive (Article 1), Annex II of the Bern Convention, Annex II of the Bonn Convention, IUCN, LC
<i>Phylloscopus trochilus</i>	+	+	+	EU Birds Directive (Article 1), Annex II of the Bern Convention, Annex II of the Bonn Convention, IUCN, LC
<i>Phylloscopus collybita</i>	+	+	+	EU Birds Directive (Article 1), Annex II of the Bern Convention, Annex II of the Bonn Convention, IUCN, LC
<i>Hippolais icterina</i>	+	-	+	EU Birds Directive (Article 1), Annex II of the Bern Convention, Annex II of the Bonn Convention, IUCN, LC
<i>Sylvia atricapilla</i>	+	+	+	EU Birds Directive (Article 1), Annex II of the Bern Convention, Annex II of the Bonn Convention, IUCN, LC
<i>Sylvia borin</i>	+	-	+	EU Birds Directive (Article 1), Annex II of the Bern Convention, Annex II of the Bonn Convention, IUCN, LC

Species ¹	Criteria of vulnerability			Conservation status
	Body mass up to 150 g	Ground nesting	Feeding on the ground or in shrubs (bushes)	
<i>Curruca curruca</i>	+	+	+	EU Birds Directive (Article 1), Annex II of the Bern Convention, Annex II of the Bonn Convention, IUCN, LC
<i>Regulus regulus</i>	+	-	+	EU Birds Directive (Article 1), Annex II of the Bern Convention, Annex II of the Bonn Convention, IUCN, LC
<i>Troglodytes troglodytes</i>	+	+	+	EU Birds Directive (Article 1), Annex II of the Bern Convention, IUCN, LC
<i>Sitta europaea</i>	+	-	+	EU Birds Directive (Article 1), Annex II of the Bern Convention, IUCN, LC
<i>Sturnus vulgaris</i>	+	-	+	IUCN, LC
<i>Turdus philomelos</i>	+	-	+	Annex II of the EU Birds Convention, Annex III of the Bern Convention, IUCN, LC
<i>Turdus viscivorus</i>	+	-	+	Annex II of the EU Birds Convention, Annex III of the Bern Convention, IUCN, LC
<i>Turdus merula</i>	+	+	+	Annex II of the EU Birds Convention, Annex III of the Bern Convention, IUCN, LC
<i>Turdus pilaris</i>	+	-	+	Annex II of the EU Birds Convention, Annex III of the Bern Convention, IUCN, LC
<i>Erithacus rubecula</i>	+	+	+	EU Birds Directive (Article 1), Annex II of the Bern Convention, Annex II of the Bonn Convention, IUCN, LC
<i>Luscinia svecica</i>	+	+	+	EU Birds Directive (Article 1), Annex II of the Bern Convention, Annex II of the Bonn Convention, IUCN, LC
<i>Ficedula parva</i>	+	-	+	Annex I of the EU Birds Directive, Annex II of the Bern Convention, Annex II of the Bonn Convention, IUCN, LC
<i>Ficedula albicollis</i>	+	-	+	Annex I of the EU Birds Directive, Annex II of the Bern Convention, Annex II of the Bonn Convention, IUCN, LC
<i>Phoenicurus ochruros</i>	+	-	+	EU Birds Directive (Article 1), Annex II of the Bern Convention, Annex II of the Bonn Convention, IUCN, LC

Species ¹	Criteria of vulnerability			Conservation status
	Body mass up to 150 g	Ground nesting	Feeding on the ground or in shrubs (bushes)	
<i>Phoenicurus phoenicurus</i>	+	-	+	EU Birds Directive (Article 1), Annex II of the Bern Convention, Anex II of the Bonn Convention, IUCN, LC
<i>Cinclus cinclus</i>	+	-	+	EU Birds Directive (Article 1), Annex II of the Bern Convention, IUCN, LC
<i>Passer montanus</i>	+	-	+	EU Birds Directive (Article 1), Annex III of the Bern Convention, IUCN, LC
<i>Passer domesticus</i>	+	-	+	EU Birds Directive (Article 1), IUCN, LC
<i>Motacilla cinerea</i>	+	+	+	EU Birds Directive (Article 1), Annex II of the Bern Convention, IUCN, LC
<i>Motacilla alba</i>	+	-	+	EU Birds Directive (Article 1), Annex II of the Bern Convention, IUCN, LC
<i>Anthus pratensis</i>	+	+	+	EU Birds Directive (Article 1), Annex II of the Bern Convention, IUCN, LC
<i>Anthus trivialis</i>	+	+	+	EU Birds Directive (Article 1), Annex II of the Bern Convention, IUCN, LC
<i>Anthus spinoletta</i>	+	+	+	EU Birds Directive (Article 1), Annex II of the Bern Convention, IUCN, LC
<i>Fringilla coelebs</i>	+	-	+	EU Birds Directive (Article 1), Annex III of the Bern Convention, IUCN, LC
<i>Coccothraustes coccothraustes</i>	+	-	+	EU Birds Directive (Article 1), Annex II of the Bern Convention, IUCN, LC
<i>Pyrrhula pyrrhula</i>	+	-	+	EU Birds Directive (Article 1), Annex III of the Bern Convention, IUCN, LC
<i>Chloris chloris</i>	+	-	+	EU Birds Directive (Article 1), Annex II of the Bern Convention, IUCN, LC

Species ¹	Criteria of vulnerability			Conservation status
	Body mass up to 150 g	Ground nesting	Feeding on the ground or in shrubs (bushes)	
<i>Linaria cannabina</i>	+	-	+	EU Birds Directive (Article 1), Annex II of the Bern Convention, IUCN, LC
<i>Carduelis carduelis</i>	+	-	+	EU Birds Directive (Article 1), Annex II of the Bern Convention, IUCN, LC
<i>Serinus serinus</i>	+	-	+	EU Birds Directive (Article 1), Annex II of the Bern Convention, IUCN, LC
<i>Spinus spinus</i>	+	-	+	EU Birds Directive (Article 1), Annex II of the Bern Convention, IUCN, LC
<i>Emberiza citrinella</i>	+	+	+	EU Birds Directive (Article 1), Annex II of the Bern Convention, IUCN, LC

Note. ¹ Classification and scientific species names of birds according to the IOC World Bird List (version 14.1) (<https://www.worldbirdnames.org/new/>).

² RDBU – the Red Data Book of Ukraine, according to the Order of the Ministry of Environmental Protection and Natural Resources of Ukraine No. 29 dated January 19, 2021.

(Merzlikin 1998). However, annual data is not provided, making it impossible to estimate the average number of birds hunted per year by rural pets in this area. Additionally, data on the number and hunting cases of feral cats in the mentioned locality is not provided. According to O. Koshelev and O. Osytkovska, in 2017, Ukraine ranked 9th in the world in terms of cat population (7.5 million individuals) and second in the number of cats per 100 residents (17 cats per 100 people). On average, one cat kills 30–47 birds per year (Koshelev & Osytkovska 2017). However, it was not specified whether this figure applies to urban, rural pets, or feral cats, nor the source or calculation method were not provided.

The population of feral cats varies significantly over time and is difficult to accurately estimate, as these animals reproduce uncontrollably, which can lead to a sharp increase in their numbers. At the same time, they die from diseases, malnutrition, traffic, and other factors, which has the opposite effect. Therefore, the population changes dynamically.

The number of feral cats in the study area is significantly influenced by the fact that feral animals have much larger home ranges compared to rural pets. The home range of feral cats greatly exceeds that of cats kept by owners, due to the constant need to search for food. Studies from various countries support this view. Recent research on feral cats in New Zealand found that the home range of males varies from 22.1 to 3,232 hectares, while for females, it ranges

from 9.6 to 2,078 hectares (Nottingham *et al.* 2022). Research conducted in winter 2005 in New South Wales, Australia, indicates that the average home range of feral cats was 248 hectares (Molsher *et al.* 2005). Data from the Mauna Kea Forest Reserve (Hawaii, USA) show significant home ranges for local feral cats. For females, the area was 772 hectares, while for males, it ranged from 1,418 to 2,050 hectares, making it one of the highest recorded figures (Goltz *et al.* 2008). A two-year study from central Illinois (USA) demonstrated that feral cats have much larger home ranges than rural pets. The largest home range for a male was 547 hectares, while for rural pets, it was around 2 hectares. Additionally, rural pets were active only 3% of the time, while ferals were active 14% of the time (Horn *et al.* 2011). Researchers in Europe, particularly in Croatia, distinguish between rural pets and feral cats based on their dependency on human settlements. Accordingly, rural pets are dependent on human homes, while feral cats are independent of them (Lanszki *et al.* 2016). In the Bukovynian Carpathians, it is currently difficult (or nearly impossible) to draw such a parallel, as feral cats are associated with settlements. Prolonged stay of a domestic cat in forests seems unlikely, as under such conditions, the cat would transform from predator to prey, given that forests have a greater number of natural enemies compared to areas near human dwellings (see methods). To either confirm or refute this idea, it is worth conducting a study of the home ranges of feral cats in the Bukovynian Carpathians using high-tech equipment.

With the increase in the proportion of feral cats, overall bird mortality will rise. Therefore, effective measures are necessary to control the feral cat populations.

The coefficients of determination R^2 , which are 0.9325 and 0.8063 for feral cat and rural pet respectively, indicate that approximately 93.25% and 80.63% of the annual bird mortality variations can be explained by domestic cat population size variations, suggesting a fairly high level of model accuracy. However, 6.75% and 19.37% of the variations remain unexplained by the models, pointing to the presence of other factors and random variables influencing bird mortality. One such factor is that a cat may catch a bird weakened by the use of pesticides, or a bird poisoned from feeding at a landfill, or injured by collisions with glass surfaces of windows (Erickson *et al.* 2005), solar panels (Visser *et al.* 2019, Kosciuch *et al.* 2020, Yuzyk 2024), or vehicles. Another factor is the need for more precise investigation of the koefRP value for these areas. Therefore, further research is needed, including the use of advanced technologies (collars with cameras, GPS trackers, etc.) (Lloyd *et al.* 2013, Nottingham *et al.* 2022), to shed more light on domestic cat predation and its home range in the specified areas.

Among bird species vulnerable to predation by domestic cat, 2 species are listed in the Red Data Book of Ukraine, the Stock Pigeon (*Columba oenas*) and Common Ringed Plover (*Charadrius hiaticula*). 44 species are listed in Annex II, 15 in Annex III of the Convention on the Conservation of European Wildlife and Natural Habitats (the Bern Convention). 18 species are listed in Annex II of the Convention on the Conservation of Migratory Species of Wild Animals (the Bonn Convention). 5 species are listed in Annex I, 9 in Annex II, and 47 in Article 1 of the EU Birds Directive. 4 species are listed in Annex II of the Agreement on the Conservation of African-Eurasian Migratory Waterbirds (the AEWA). 1 species is listed in the Helsinki Convention. The data from this study align with the results of a comparative analysis of the diet of feral and house cats, and wildcat in Europe, where rural pets, feral cats, and wildcats hunted the following number of bird species: 71, 42, and 23

species, respectively (Széles *et al.* 2018). Small mammals were the main prey for all cat groups (including feral domestic cats, wild cats, and their hybrids), with birds constituting the second most important prey in Hungary (Biró *et al.* 2005).

To more accurately assess species vulnerability, detailed studies of parameters such as the total population size and the proportion of individuals falling victim to cat predation are required. These data allow for evaluating the impact of domestic cats on various bird species and developing strategies for biodiversity conservation in the future.

Conclusion

The population of feral cats and rural pets in the ATL of the southwestern Bukovynian Carpathians was estimated at $1,493 \pm 82$ and $13,599 \pm 1,904$ individuals, respectively. The total population of domestic cats was determined to be $15,092 \pm 3,245$ individuals. Annually, feral cats (smaller population compared to rural cats) kill an average of 66.0 thousand birds, with a 95% mortality estimate range from 37.6 thousand to 95.1 thousand, while rural pets kill an average of 443.0 thousand birds annually (ranging from 127.0 thousand to 942.5 thousand). The total bird mortality rate due to domestic cat predation in the ATL of the southwestern Bukovynian Carpathians is 509.0 thousand (ranging from 188.6 thousand to 1,008.6 thousand).

Linear regression models were developed for feral cats and rural pets, described by the formulas: $nBFC = 44.10 * nFC$; $nBRP = 32.92 * nRP$. Thus, with a change in the feral cat population by 1 individual, the annual bird mortality in the ATL of the southwestern Bukovynian Carpathians would change by approximately 44 birds, $R^2 = 0.9325$. With a change in the rural pet cat population by 1 individual, the annual bird mortality would change by approximately 33 birds, $R^2 = 0.8063$.

It was found that feral cats in the southwestern Bukovynian Carpathians kill 34% more birds compared to rural pets. A total of 62 bird species vulnerable to domestic cat predation were identified.

Research indicates the need to develop comprehensive strategies for protecting birds from domestic cat predation in anthropogenically transformed landscapes. This includes not only population control measures for cats but also environmental education for the public and the promotion of responsible pet ownership. Further research and monitoring are necessary to understand the dynamics of this process and to develop effective biodiversity conservation measures.

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Appendix 1. R Script for Monte Carlo simulation of bird mortality due to domestic cats predation, data analysis and visualization

1. függelék R Script a házimacsák okozta madárpusztulás Monte Carlo szimulációjához, adatelemzéshez és vizualizációhoz

```
# Setting the number of iterations
n <- 10000

# Generating random numbers within specified ranges
range1 <- runif(n, 1411, 1575)
range2 <- runif(n, 24, 64)
range3 <- runif(n, 11695, 15503)
range4 <- runif(n, 2.8, 14.0)
range5 <- runif(n, 2.0, 5.8)

# Setting the total number of bird mortality
results <- (range1 * range2) + (range3 * range4 * range5)

# Rounding the sorted multiplication results to whole numbers
rounded_results <- round(results)

# Outputting the sorted multiplication results as a single line, separated by spaces
cat(paste(rounded_results, collapse = " ", "\n"))

# Mean value
mean_value <- mean(results)

# Deviations
deviations <- results - mean_value

# Mean deviation
mean_deviation <- sqrt(sum(deviations^2) / (length(results) - 1))

# Standard deviation
standard_deviation <- mean_deviation / sqrt(length(results))

# Relative error
relative_error <- (standard_deviation / mean_value) * 100

# Outputting results
cat("Mean value of the sample:", mean_value, "\n")
cat("Mean deviation:", mean_deviation, "\n")
cat("Standard deviation:", standard_deviation, "\n")
cat("Relative error (%):", relative_error, "\n")
```

```

# Calculating the percentage distribution of values across ranges
bins <- seq(0, 1300000, by = 50000)
percentage <- sapply(bins, function(b) {
  sum(results >= b & results < b + 50000) / length(results) * 100
})

# Outputting percentage distribution
cat("Percentage distribution of values across ranges:\n")
for (i in seq_along(bins)) {
  cat(sprintf("From %d to %d thousands: %.2f%%\n", bins[i], bins[i] + 50000,
percentage[i]))
}

# Creating a bar chart of the ranges against percentages
library(ggplot2)

# Creating a dataframe for the chart
distribution_data <- data.frame(
  Range = paste(bins / 1000, "-", (bins + 50000) / 1000),
  Percentage = percentage
)

# Building the chart
p <- ggplot(distribution_data, aes(x = factor(Range, levels = Range), y = Percentage))
+
  geom_bar(stat = "identity", fill = "gray", color = "black") +
  labs(x = "Assessment of annual bird mortality (thousands)", y = "Percentage
frequency of estimation") +
  theme_minimal() +
  scale_y_continuous(labels = scales::percent_format(scale = 1)) +
  theme(axis.text.x = element_text(angle = 45, hjust = 1, size = 16),
        axis.text.y = element_text(size = 16),
        axis.title.x = element_text(size = 20),
        axis.title.y = element_text(size = 20),
        plot.title = element_text(size = 20))

# Saving the chart to a JPEG file
ggsave("D:/percentage_distribution.jpg", plot = p, width = 12, height = 8, dpi = 300)

# Opening the saved file in Windows
shell.exec("percentage_distribution.jpg")

```

```
# Calculating quantiles for the interval covering 95% of values
```

```
lower_bound <- quantile(results, 0.025)
```

```
upper_bound <- quantile(results, 0.975)
```

```
# Outputting the minimum and maximum values for the interval
```

```
cat("95% of values are within the range from", lower_bound, "to", upper_bound,  
    "\n")
```

Appendix 2. R Script for Monte Carlo simulation of bird mortality due to feral cats predation, data analysis, visualization and linear regression model

2. függelék R Script az elvadult macskák okozta madárpusztulás Monte Carlo szimulációjához, adat-elemzéshez, vizualizációhoz és lineáris regressziós modellhez

```
# Loading the necessary library
```

```
library(ggplot2)
```

```
# Setting the number of iterations
```

```
n <- 10000
```

```
# Generating random integers within specified ranges
```

```
set.seed(123) # Fixing seed for reproducibility of results
```

```
range1 <- sample(1411:1575, n, replace = TRUE)
```

```
range2 <- sample(24:64, n, replace = TRUE)
```

```
# Multiplying random numbers
```

```
results <- range1 * range2
```

```
# Creating a dataframe for plotting
```

```
data <- data.frame(  
  range1 = range1,
```

```
  range2 = results
```

```
)
```

```
# Creating a linear regression model without an intercept
```

```
model_no_intercept <- lm(range2 ~ range1 + 0, data = data)
```

```
summary(model_no_intercept)
```

```
# Outputting the R-squared value to the console for the model without an intercept
```

```
r_squared_no_intercept <- summary(model_no_intercept)$r.squared
```

```
cat("R-squared value for the model without an intercept:", r_squared_no_intercept,  
    "\n")
```

```
# Regression formula without an intercept
```

```

coefficients_no_intercept <- summary(model_no_intercept)$coefficients
slope_no_intercept <- coefficients_no_intercept[1, 1]

cat("Linear regression formula without an intercept: range2 =", slope_no_intercept,
    "* range1\n")

# Creating a scatter plot with a thicker regression line without an intercept
p <- ggplot(data, aes(x = range1, y = range2)) +
  geom_point(color = "black", size = 0.1) +
  geom_abline(intercept = 0, slope = slope_no_intercept, color = "black", size = 1.5)
+ # Regression line without an intercept
  labs(x = "Population estimation of feral cats, ind.", y = "Annual bird mortality
estimate, ind.") +
  theme_minimal() +
  theme(
    axis.text = element_text(size = 20), # Font size for axis labels
    axis.title = element_text(size = 20) # Font size for axis titles
  ) +
  coord_cartesian(xlim = c(0, max(data$range1)), ylim = c(0, max(data$range2)))

# Saving the plot to a JPEG file
ggsave("D:/ENG_FC_R2_no_intercept.jpg", plot = p, width = 10, height = 6, dpi =
300)

# Opening the saved file in Windows
shell.exec("D:/ENG_FC_R2_no_intercept.jpg")

```

Appendix 3. R Script for Monte Carlo simulation of bird mortality due to rural pets predation, data analysis, visualization and linear regression model

3. függelék R script a vidéki háziállatok által okozott madárpusztulás Monte Carlo szimulációjához, adatelemzéshez, vizualizációhoz és lineáris regressziós modellhez

```

# Loading necessary libraries
library(ggplot2)

# Setting the number of iterations
n <- 10000

# Generating random integers in specified ranges
range1 <- sample(11695:15503, n, replace = TRUE)
range2 <- runif(n, min = 2.8, max = 14.0)
range3 <- runif(n, min = 2.0, max = 5.8)

```

```
# Calculating the result for variable2
variable2 <- range1 * range2 * range3

# Creating a dataframe for plotting
data <- data.frame(
  variable1 = range1,
  variable2 = variable2
)

# Creating a linear regression model without an intercept to obtain R squared
model <- lm(variable2 ~ variable1 + 0, data = data)
r_squared <- summary(model)$r.squared

# Building a scatter plot
p <- ggplot(data, aes(x = variable1, y = variable2)) +
  geom_point(color = "black", size = 0.1) +
  geom_abline(intercept = 0, slope = summary(model)$coefficients[1, 1], color =
    "black", size = 1.5) +
  labs(x = "Assessment of rural pet population, ind.", y = "Annual bird mortality
estimate, ind.") +
  theme_minimal() +
  theme(
    axis.text = element_text(size = 20), # Font size for axis labels
    axis.title = element_text(size = 20) # Font size for axis titles
  ) +
  coord_cartesian(xlim = c(0, max(data$variable1)), ylim = c(0, max(data$variable2)))

# Saving the plot to a JPEG file
ggsave("D:/ENG_scatter_plot.jpg", plot = p, width = 10, height = 6, dpi = 300)

# Opening the saved file in Windows
shell.exec("D:/ENG_scatter_plot.jpg")

# Printing the value of R squared to the console
cat("R squared value:", r_squared, "\n")

# Printing the linear regression formula to the console
slope <- summary(model)$coefficients[1, 1]
cat("Linear regression formula without intercept: variable2 =", slope, "* variable1\n")
```