The Thesis of the Doctoral (Ph.D.) Dissertation

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Gödöllő

2025

Hungarian University of Agriculture and Life Sciences

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TRANSBOUNDARY CONSERVATION FOR SMALL FELIDS: ASSESSING THREATS AND DISTRIBUTION OF PALLAS'S CAT AND EUROPEAN WILDCAT IN RELATION TO CONSERVATION BEHAVIOR

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DOI: 10.54598/007190

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1. BACKGROUND OF THE WORK AND ITS AIMS

1.1. Conservation needs and challenges to small felids

Smaller-bodied, highly threatened, and elusive wild felids are often overlooked in conservation and research efforts compared to their larger, more charismatic counterparts (Brodie, 2009; Dickman et al., 2015). The Pallas's cat (*Otocolobus manul* Pallas, 1776) and European wildcat (*Felis silvestris* Schreber, 1777), hence "wildcat", are examples of species that remain severely understudied, with significant gaps in knowledge concerning their ecology and conservation status. Furthermore, studying felines in their natural habitat is notoriously difficult due to their low population density, large home range, nocturnal lifestyle, and elusive behavior (Brodie, 2009; Ross et al., 2020), notably small felids whose small size make them especially difficult to detect. This poses a significant challenge for conservation biologists, as effective conservation efforts rely on extensive knowledge of a species' ecology (Macdonald et al., 2010; Ross et al., 2019b).

The Pallas's cat is among the most threatened felids in the cat family and population is declining due to anthropogenic activities (Ross et al., 2020; Chimed et al., 2021). Likewise, the wildcat was once widespread throughout Europe but is now one of the most at-risk species (Nowell & Jackson, 1996; Macdonald et al., 2010). Due to increasing human pressures over the last two centuries, wildcat populations have gradually declined, leading to a largely fragmented distribution across both local and regional scales (Nowell & Jackson, 1996; Pierpaoli et al., 2003). The study background highlights the urgent conservation needs of small felids, with a focus on Pallas's cats in Mongolia and wildcats in Hungary. This research aims to provide detailed insights into their distribution, habitat use, and the local and regional threats they face.

By assessing threats and distribution in key habitats, the research provides valuable insights into the ecological needs and conservation challenges of these majestic felids.

1.2. Aim and objectives

The main aim of the study is to investigate the distribution patterns of the Pallas's cat in Mongolia and wildcats in Hungary, and to identify the key threats facing the species within their ranges, using a consistent methodology in different countries. Specifically, this study aims to a) conduct and evaluate the existing and potential global threats to the small felids in Asia, and Europe, ranking these threats according to their severity; b) assess local knowledge of Pallas's cats and wildcat within their respective natural ranges; c) use local knowledge to understand and evaluate perceived threats to both species in Mongolia and Hungary; d) investigate the distribution of Pallas's cats in Mongolia and examine important habitat variables that influence the species' occurrence; e) investigate current distribution of wildcats, changes in their distribution, and examine land cover influences on species distribution in Hungary; f) study temporal activity patterns of Pallas's cats in Mongolia.

2. MATERIALS AND METHODS

2.1. Literature survey: Threats to wildcats and Pallas's cats

2.1.1. Literature search and paper selection

The study was carried out using publications that reported threats to wildcats and Pallas's cats, sourced from Web of Science, Scopus, and Google Scholar in January 2025. We identified 49 threats for Pallas's cats from 21 articles and 2 thesis, while we obtained 88 articles for wildcats and analyzed 93 distinct threats. Due to the limited number of publications, we did not filter or specify publication years for further analysis.

2.1.2. Threat classification and rankings

Based on the analyzed threats from the literature search, we identified 12 categories of threats to Pallas's cats, which were coded into 7 classes, while 13 categories of threats to wildcats were grouped into 6 classes (Table 1). Due to the variety of threat categories, we used the IUCN Threats Classification Scheme (IUCN, Threats Classification Scheme) to categorize threats and code them into groups.

Table 1: The number of recorded threats for each species, classified according to the IUCN threat classification system.

IUCN Category	Threat	Pallas's cat		Wildcat	
		Frequency	(%)	Frequency	(%)
Biological Resource Use	Overgrazing by livestock	7	14	-	-
	Traps/snares	1	2	1	1
	Illegal hunting & trade	5	10	-	-
	Hunting	-	-	2	2
	Ungulate pressure	-	-	2	2
	Decrease of prey	-	-	2	2
	Population declining	2	4	1	1
	Predator control	-	-	3	3
Invasive & Other Problematic Species	Predation by herding dogs	13	27	-	-
	Competition with other species	3	6	1	1
	Disease	2	4	21	23
	Hybridization	-	-	38	41

Climate Change & Severe Weather	Climate change	2	4	-	-
Transportation & Service Corridors	Roadkill	2	4	9	10
Human Intrusions & Disturbance	Human disturbance	2	4	3	3
Pollution	Secondary poisoning	9	19	-	-
	Primary poisoning	-	-	3	3
Residential & Commercial Development	Habitat fragmentation/loss	1	2	7	8

Documented threats were differentiated as either existing or potential. Among the collected publications, confirmed existing threats were reported in 13 papers on Pallas's cats and 73 papers on wildcats, while the remaining papers referred to potential threats that were not yet confirmed or studied. To develop a ranked list of threats to each species, we classified them based on the proportion of total threats documented in the literature survey as follows: 'Serious' (over 21%), 'Medium' (11–20%), and 'Minor' (1–10%).

2.2. Field-based research

We established an integrated field-based research method to achieve our objectives (a – f).

2.2.1. Study area

This study was carried out in Hustai National Park (HNP) in Central Mongolia. The park was established in 1992, covering approximately 60,000 of small mountains, meadows, and river valleys. The altitude ranges between 1100 m and 1842 m. The region is dominated by grassland and shrubland steppe. The climate is continental; temperature varies between -43°C and 38°C and the annual precipitation is 165 mm (Tseren-Ochir et al., 2018; Wallis de Vries et al., 1996). The national park contains relatively diverse wildlife (Nyamsuren et al., 2016), and is also home to approximately nomadic herders, with a total of 120,000 livestock grazing around the park (National Statistics Office of Mongolia, 2022).

2.2.2. Survey data collection

2.2.2.1. Interview-based survey

We conducted an interview-based survey in the summer of 2023 by visiting households in Hustai National Park. We interviewed the head of the household and often began with informal conversations about herding, Pallas's cats, and other wildlife. Participants were informed of their anonymity and that they could decline to answer questions or end the interview at any time. Interview took about 15–20 minutes to complete.

2.2.2.2. Design of interview

The survey consisted of eleven questions encompassing four main sections: respondents' attributes, species identification using photographs of small felids, threats, and species presence and absence. If a respondent misidentified the species, the interview was not proceeded further, and the data from that interview were excluded from the analysis. This is a standard method in interview-based surveys to ensure reliable species information (Chimed et al., 2021; Garcia-Alaniz et al., 2010).

2.2.2.3. Questionnaire-based survey

The survey was conducted online via Google Forms from February to April 2022 and was sent to game management units (GMUs). We used the Universal Transverse Mercator (UTM) coordinate system to assess species occurrence, with 10x10 km grid cells. All Hungarian GMUs have an individual code connected to respondents (Csányi et al., 2010), allowing us to geographically localize data using UTM cells.

2.2.2.4. Design of questionnaire

The survey included an introduction page and three pages of questions in Hungarian, covering the GMU code, threats, and wildcat occurrences. The questionnaire consisted of close-ended questions with single- and multiple-choice answer options.

2.2.3. Camera-trapping data collection

We installed 11 camera traps in Central Mongolia, covering approximately 80 km^2 between 30 June 2022 and 23 May 2024. Motion sensitive cameras were installed mostly in pairs at 5 locations. The purpose of this survey was to detect Pallas' cats while moving, approaching notable rock features or patrolling along marking sites (Li et al., 2013) in order to study their temporal activity. Three consecutive pictures were captured when animals triggered the cameras.

2.3. Data analysis

2.3.1. Field based research

2.3.1.1. Distribution of Pallas's cat: Interview – based survey.

We gathered presence (1) and absence (0) of Pallas's cats during the interviews. We selected environmental variables including land cover and topographic to test the occurrence of Pallas's cats in the national park. The land cover data from 2020 was obtained using the publicly available dataset of Wang et al. (2022). Terrain ruggedness index and elevation was calculated from the 90 m resolution Digital Elevation Model (Robinson et al., 2014) using QGIS v. 3.32.3 (QGIS "Geographic Information System" 2022). We evaluated the occurrence of Pallas's cats in function of these covariates with mixed effects logistic regression in R software v. 4.1.2. (R Core Team 2021) using the *glmmTMB* package (Brooks et al., 2017).

Before model fitting, variables were tested for collinearity and meadow steppe and elevation were excluded from analysis. This non-collinearity was verified by calculating the variance inflation factor (VIF) of each model using the *performance* package (Lüdecke et al., 2021) to sort out variables with critical multicollinearity. Model visualizations were created with the *sjPlot* (Lüdecke et al., 2024) and *ggplot2* (Wickham, 2016) packages.

2.3.1.2. Distribution of wildcat: Questionnaire - based survey.

We created detection histories for each grid cell and each sampling period by creating a dichotomous variable on wildcat occurrence. Seven different land cover types were selected to evaluate which habitat types influenced wildcat occurrence, using CORINE Land Cover database (*CORINE Land Cover*, 2006, 2012, 2018). The percent cover of land cover classes was calculated relative to the total area of each relevant UTM cell and used as an explanatory variable in the statistical analysis.

Wildcat occurrence was analyzed using binomial logistic regression in R (*R Core Team*, 2021). The best model structure was chosen using likelihood ratio tests to select which variable was a significant predictor of wildcat occurrence. The coefficients of the fitted logistic regression model were expressed in their exponentiated form resulting in the more comprehensible odds ratio (OR). This metric ranges from 0 to infinity, where OR=1 functions as a threshold to divide negative and positive associations. If $0<OR<1$ the preferred event of interest (i.e. wildcat is present) is less likely to occur; if $1 < OR$ the preferred event is more likely to occur. Values farther from 1 in a given direction represent a stronger association (Agresti, 2019). In addition, we directly compared the area of the land cover classes between UTM cells with and without wildcat occurrence by performing Welch's two-sample t-tests. The figures were created using the ggplot2 (Wickham, 2016) and ggpubr (Kassambara, 2020) packages, while the diversity indices were calculated using the vegan package (Oksanen et al. 2020) in R. We created maps to visualize the presence and absence of wildcats in the three time periods using QGIS v. 3.32.3.

2.3.1.3. Activity pattern of Pallas's cat: Camera-trapping.

We counted the number of images of Pallas's cat and other wildlife captured by the camera traps. Each photograph of trapped animals was identified by species and recorded with time and date. Camera trap data were analyzed by grouping detections if Pallas's cat occurred within ten and thirty minutes in one capture, which is a widely used method in camera trapping (Li et al., 2010).

We normalized the data in order to fairly compare the results collected from different camera traps. We averaged the number of captures within the adjacent two hours as the number of captures for each species to build the daily activity curves followed by Li et al. (2013). The daily and annual activity index were calculated with the following formula:

$$\text{Activity index of time point: } A = \frac{\text{(captures at this time point)}}{\text{(captures in the whole time frame)}}$$

3. RESULTS

3.1. Literature survey: Threat assessments and rankings globally

3.1.1. Threat assessments

According to the IUCN Threats Classification System, the group invasive and other problematic species represents the most significant threats to both species, including hybridization with domestic cat, disease, and predation by herding dogs. This was followed by biological resource use, the second most frequent threat category (see Table 1 for details). Secondary poisoning was a significant threat for Pallas's cats while roadkill was notable for wildcats (10%). Other threat categories were less prominent for both cats (Figure 1).

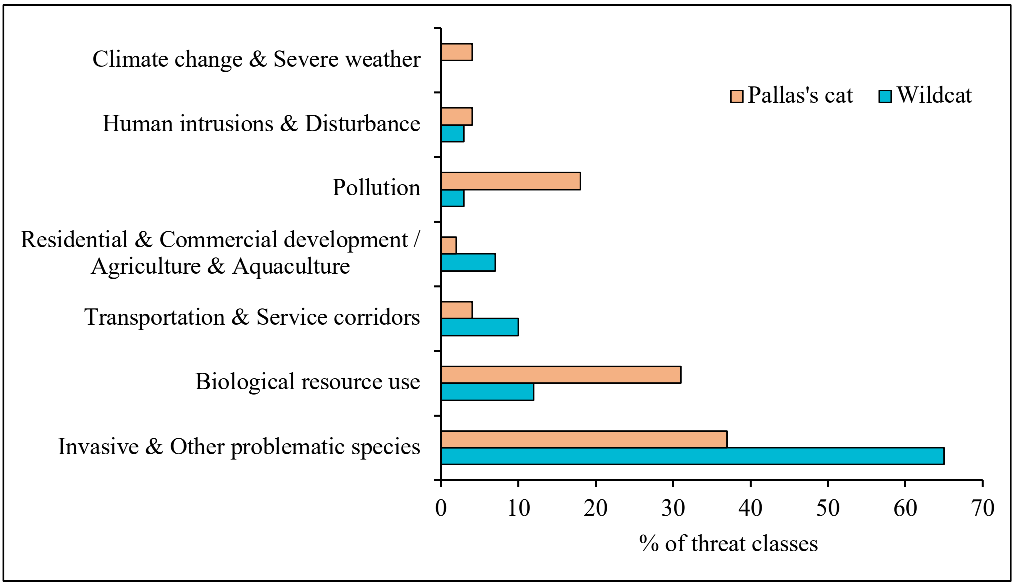

Figure 1: Classified threats to both cats, based literature search (n = 88 sources for wildcats, n = 23 sources for Pallas's cats) using the IUCN Threats Classification System.

3.1.2. Threat rankings

Pallas's cat: Overall, seven threat categories were recorded, with invasive and other problematic species and biological resource use ranked as serious threats to Pallas's cats (Table 2). Specifically, the first threat category encompassed the most frequently documented threat, predation by herding dogs (27%) as direct threat to the species. The latter category included overgrazing by livestock (15%) and illegal hunting and trade (10%), both considered potential threats. Moreover, secondary poisoning was evaluated as a medium potential threat to Pallas's cats. The other threats shown in Table 2 were classified as 'minor' threats and have been rarely addressed in the existing literature.

Table 2: Threat rankings for Pallas's cats and wildcats are categorized as Serious (Red), Medium (Orange), and Minor (Yellow).

Threats	Pallas's cat	Wildcat
Invasive & Other problematic species	Serious	Serious
Biological resource use	Serious	Medium
Transportation & Service corridors	Minor	Minor
Residential & Commercial	Minor	Minor
Pollution	Medium	Minor
Human intrusions & Disturbance	Minor	Minor
Climate change & Severe weather	Minor	

Wildcat: Six threat categories were identified for wildcats and ranked according to their severity (Table 2). Of these, only one category, invasive and other problematic species, was ranked as a serious direct threat, with hybridization (41%) and disease (23%) emerging as the primary concerns. In addition, biological resource use category ranked as a medium-level threat, including more than eight threat types (see Table 1 for more details). Although, considered relatively minor, the remaining categories still posed notable threats such as road kills to the wildcat population in Europe (Table 2).

3.2. Field-based research

3.2.1. Respondent demographics

Pallas's cat: We carried out 107 interviews in Hustai National Park. Table 3 presents a breakdown of all respondent attributes.

Table 3: Participant demographics (n = 107)

Category	Sub-category	Frequency	Percentage (%)
Occupation	Herder	91	85%
	Ranger	13	12%
	Other	3	3%
Gender	Male	86	80%
	Female	21	20%
Time spent	1-5 years	3	3%
	6-10 years	7	7%
	11-15 years	8	7%
	16-20 years	10	9%
	more than 20	79	74%
Age	18-25	4	4%
	26-35	14	13%
	36-45	34	32%
	46-55	32	30%
	56-65	23	21%

3.2.2. Species awareness

3.2.2.1. Respondents' ability to identify the study species: Both cats

79% (85) of all respondents identified correctly the Pallas's cat in the given photographs while 21% (22) were unable to recognize the species. On the contrary, 95% of all respondents were able to identify the wildcat correctly while a mere 5% (10) of surveys were discarded due to contradictory answers, leaving 196 surveys available for the final analysis. No additional impact variables for the species identification were gathered.

3.2.2.2. Influential factors in ability to identify the Pallas's cat

Respondents who encountered Pallas's cat previously and male participants were more likely to identify the species correctly. There was no significant impact of either age, occupation, or years lived in the area (Table 4).

Table 4: Analysis of influential factors on ability to identify Pallas's cats

Variable	χ^2 test (DF)	p
Gender	χ^2 (2) =8.9	0.01
Age	χ^2 (8) =4.2	0.84
Occupation	χ^2 (4) =8.7	0.06
Time spent	χ^2 (8) =6.2	0.62
Previous sighting	χ^2 (2) =41	< 0.001

3.2.3. Perceived threats locally: Both cats

Pallas's cat: 65% (59) of all participants from the Pallas's cat sample reported that there were no threats to the species in the HNP and the remaining believed there were one or more threats (35%). Among the respondents who indicated threats to Pallas's cat, the most serious one was lack of prey (11%) and lack of habitat (10%). Other threats were less frequently reported by respondents.

Wildcat: 99% of all respondents (n = 196) from the wildcat sample believed there were one or more threats to the species and only 1% believed there was none. Respondents identified hybridization with feral cats (32%) as the top threat to wildcats, followed by habitat loss (31%). Other moderate threats included disease (12%) and roadkill (6%), respectively. The least serious threats reported in the survey were lack of prey, poisoning (both 4%), and hunting (2%).

3.2.4. Distribution of small felids

3.2.4.1. Pallas's cat distribution and influencing factors

A total of 107 respondents participated, of which 85 were deemed able to reliably identify Pallas's cats. The herders that were deemed to identify the Pallas's cat reliably reported 56 observations of Pallas's cats in the year of 2023. For the final analysis, we used 85 (79%) of these interviews, excluding 22 (21%) respondents who were unable to correctly recognize Pallas's cats.

Adding grid cell as a random effect significantly increased model performance based on the likelihood ratio test ($\chi^2 = 4.9$, $p = 0.027$). The percentage cover of steppe ($\chi^2 = 6.4$, $p = 0.011$) and terrain ruggedness index ($\chi^2 = 3.4$, $p = 0.054$) remained the only variables that provided significant explanatory power to the model explaining the variation in occurrence of Pallas's cats as fixed effects (Table 5).

Table 5: Effects of different landscape types on Pallas's cat occurrence, analyzed by a mixed-effects logistic regression using grid cell identity as a random (intercept) factor. Variables were scaled for the model and expressed as standardized estimates. Significant effects are highlighted in bold.

		95% Confidence Interval			
	Standardized estimates	lower	upper	z value	**p**
Steppe	0.45	0.09	0.81	2.51	**0.013**
Terrain Ruggedness Index	0.26	-0.01	0.53	1.82	0.064
Water	0.2	-0.08	0.48	1.42	0.157
Forest	0.38	-0.21	0.97	1.27	0.202
Sand	0.16	-0.13	0.45	1.11	0.271
Barren land	-0.14	-0.4	0.13	-1.03	0.304
Cropland	0.09	-0.14	0.34	0.81	0.419
Built area	-0.06	-0.26	0.13	-0.63	0.529
Desert steppe	0.04	-0.2	0.28	0.33	0.738
Variance of random effects (Cell grid): 1.008					

The low variance inflation factor did not indicate any problems of multi-collinearities (VIF: 1.57, confidence interval: 1.37 - 1.77). Steppe cover significantly and positively associated with Pallas's cat occurrence (Table 5), i.e. higher percentage cover resulted in a significantly higher probability of occurrences with one or more individuals of the species (Figure 2).

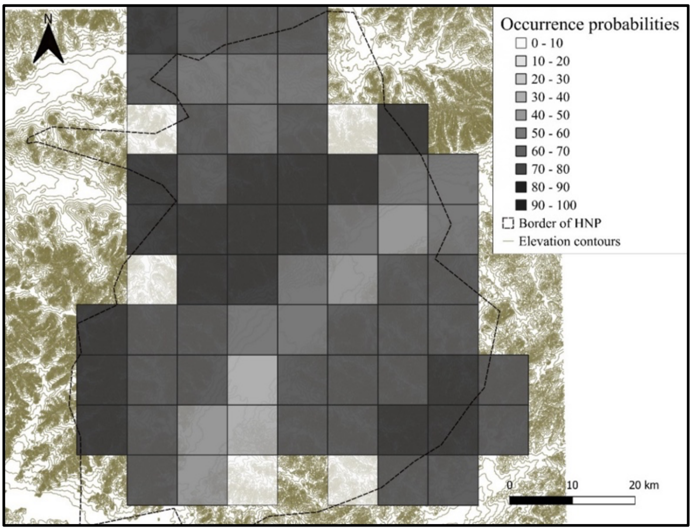

Figure 2: Occurrence probabilities of Pallas's cat in Hustai National Park estimated from the mixed logistic regression model.

The predicted error tends to be decreasing at higher steppe cover values (Figure 3a). Terrain ruggedness index, while near significance, may also play an important positive role in the species' occurrence (Figure 3b). The 95% confidence interval indicates that its importance can be highly variable depending on the terrain relief and land cover type. Terrain ruggedness index average values were 22.95 ± 9.4 SD with presence and 19.06 ± 10.8 SD with absence.

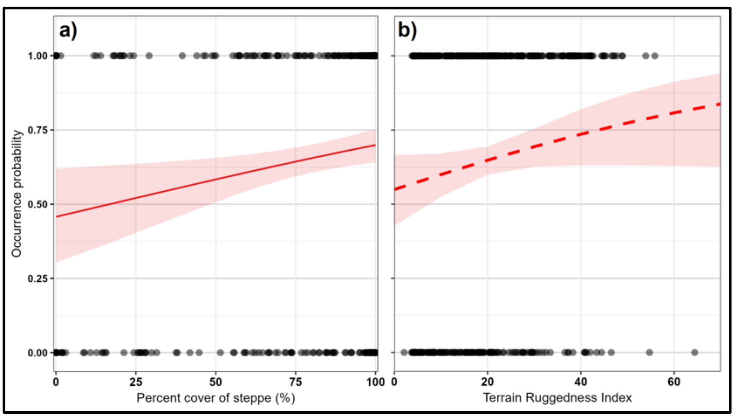

Figure 3: Effects of steppe cover and terrain ruggedness index on Pallas's cat occurrence in Hustai National Park. The effect of (a) the percent cover of steppe was statistically significant, whereas the effect of (b) the terrain ruggedness index was only a tendency (p = 0.064; details in Table 5). Regression lines including their 95% confidence band are based on the model estimates provided in Table 5.

3.2.4.2. Wildcat distribution and associated land cover factors

Game management units in Hungary reported wildcats' presence and absence, in 2004, 2014, and 2022. Given that only 200 respondents completed the questionnaire in 2022, we included only those who reported from the same units in all three years. Although the number of respondents decreased over time, this sample loss was spatially balanced. Therefore, the number of covering UTM cells of interest remained stable during the study (Table 6).

Table 6: The total number of respondents and the related UTM cells per survey year with the relative proportion of reported wildcat occurrence.

Year	**2004**		**2014**		**2022**	
Respondents	n	presence %	n	presence %	N	presence %
	551	52	354	51	200	86
UTM cells	182	67	201	66	201	85

The increase of wildcat detections was also reflected in the UTM grid scale. The majority the studied cells had at least one GMU connected to it that reported wildcat detection in each survey year (Table 6). The covered area of detections slightly increased from 1207 thousand ha to 1304 thousand ha between 2004 and 2014 and reached 1688 thousand hectares in 2022. Overall, about half of the studied UTM cells (51.1%) could be coded as “occupied” by wildcats based on data from 200 respondents across all three survey years within the corresponding GMUs (Figure 4) indicating a stable presence.

Wildcat appeared as present starting from 2014 in 9.9% of the cells and were only detected first time in 2022 in 12.5% of the UTM cells.

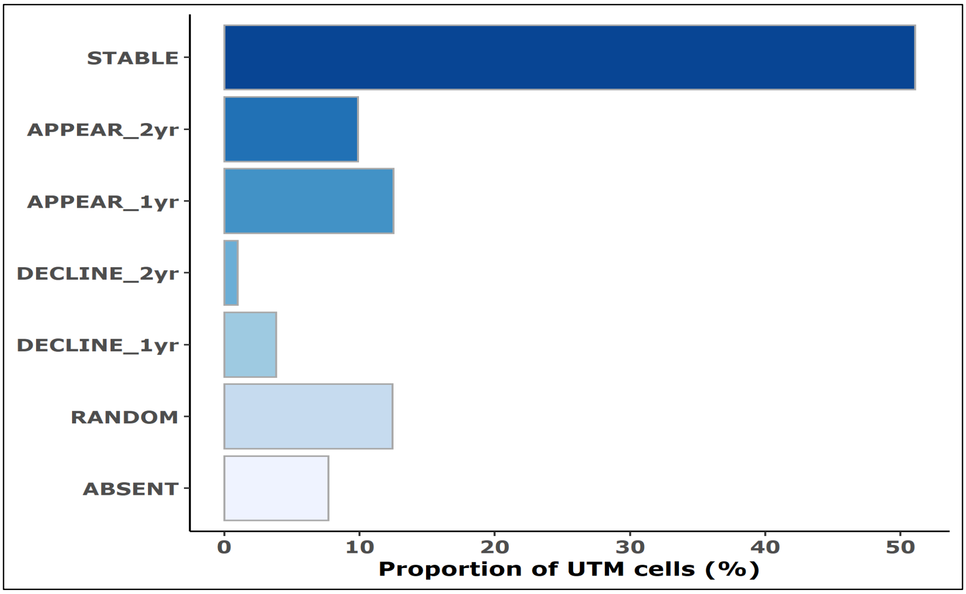

Figure 4: Trends of wildcat occurrence during the survey's time frame based on the relative proportion of the studied UTM cells. **STABLE** = wildcats were reported present in each survey year, **APPEAR_2yr** = wildcats were reported present in the last two survey years, **APPEAR_1yr** = wildcats were reported present in the last survey year only, **DECLINE_2yr** = wildcats were reported present in the first two survey years only, **DECLINE_1yr** = wildcats were reported present in the first year of the survey only; **RANDOM** = wildcats temporarily disappeared or reappeared in 2014, **ABSENT** = wildcat was reported absent in each survey year.

The number of regions in which wildcats disappeared was slightly lower: after nearly two decades, wildcats were reported absent in 2022 in 1% of the grid cells, while 3.8% of the cells had wildcat detections only from 2004. There were many GMUs and thereby UTM cells (12.4%) in which the wildcat detections were quite sporadic: wildcats were detected in 2014 in contrast with their absence in the previous and subsequent survey years or reappeared after a temporary absence in 2014. Consecutive absence was reported in 7.7% of the UTM cells (Figure 5).

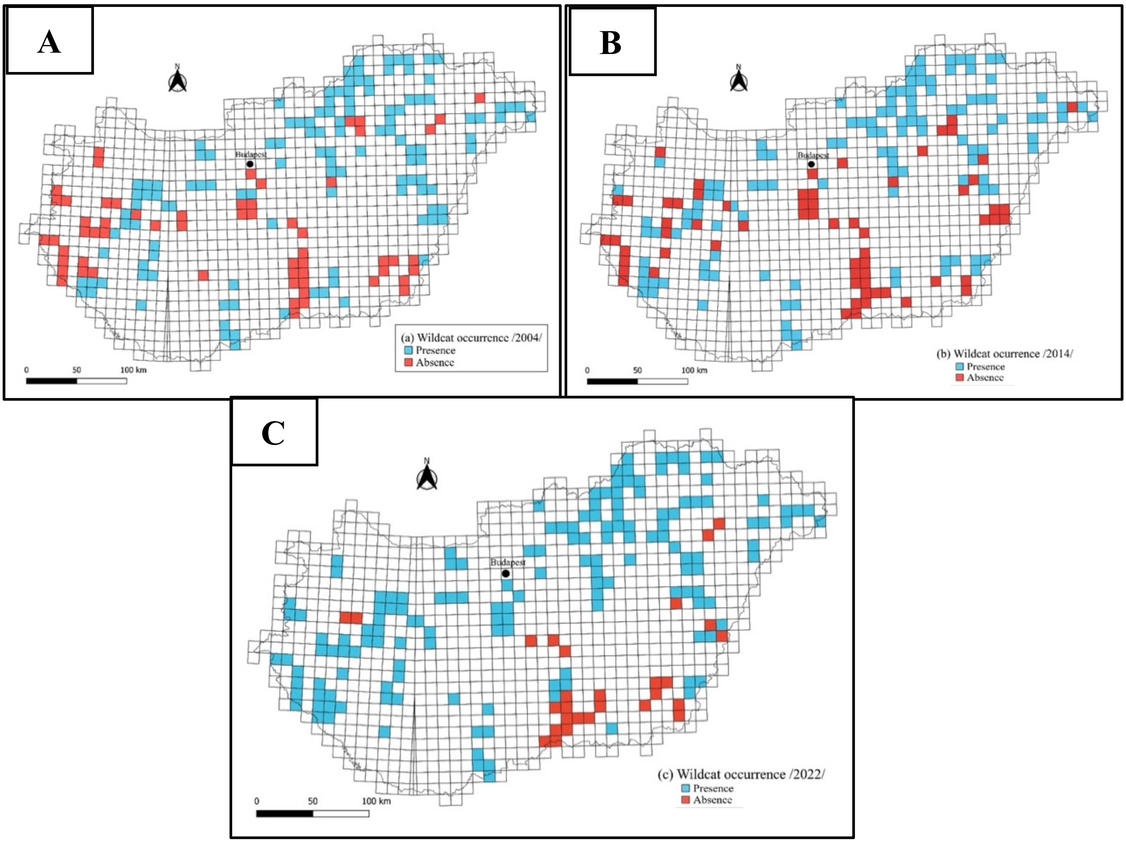

Figure 5: Reported occurrence for wildcats in Hungary between 2004 and 2022 (**A - C**)

The average area of broadleaved forest was also high (1.942 ± 1.845 ha) but less dominant in the UTM cells (19 ± 19%). The survey years and the percent cover of the land cover types constituted the final set of explanatory variables. The logistic regression model found a significantly increasing trend on the larger time frame between 2004 and 2022 in wildcat detections (Table 7). Among land cover types, the broad-leaved forest cover was positively associated with wildcat occurrence, but the estimated odds remained low nevertheless, staying near to the threshold of 1 (OR=1.06, 95 confidence interval: 1.03-1.08). On the contrary, mixed forest cover (woodlands where the standing volume of coniferous and broad-leaved tree species was nearly equal) turned out to be negatively associated with wildcat presence, but also with a weak OR (Table 7).

Table 7: Temporal changes in the reported wildcat presence and effects of land cover types on wildcat occurrence estimated using binomial logistic regression. Year 2004 was used as reference category for the variable Year. The coefficients and their corresponding confidence intervals are expressed in odds ratios, the exponentiated form of the default 'log of the odds output of the model.

		95% Confidence Interval			
	Estimate	**Lower**	**Upper**	**Z value**	**p**
Intercept	1.50	0.44	5.12	0.65	0.519
Year					
2014	0.92	0.57	1.47	-0.35	0.724
2022	3.47 ***	1.99	6.03	4.4	< 0.001
Relative proportion of land cover types					
Road, rail and associated land	0.60	0.29	1.25	- 1.36	0.172
Non-irrigated arable land	0.99	0.98	1.01	- 0.78	0.433
Pastures	1.02	0.98	1.07	1.05	0.295
Broad-leaved forest	1.06 ***	1.03	1.08	4.77	< 0.001
Coniferous forest	0.92	0.80	1.06	-1.13	0.260
Mixed forest	0.87 *	0.78	0.97	-2.43	0.015
Water bodies	1.00	0.94	1.06	0.00	0.999

*** $p < 0.001$ * $p < 0.05$

3.2.6. Camera trap captures

In 317 trap days from July 1, 2022, through May 13, 2023, we obtained 1141 captures of carnivores including Pallas's cats (567 captures), grey wolves (262 captures), red foxes (259 captures), beech martens (43 captures), Eurasian polecats (10 captures). Our targeted species was the most frequently photographed carnivore followed by grey wolves and red foxes. Furthermore, 145 images of herbivores were captured with wapiti (130 captures) and Argali (15 captures). A rodent species recorded was the Siberian marmot (200 captures) (Table 8).

Table 8: Number of captures of each species captured by camera trapping

Group	English name	Latin name	IUCN	Red List	Capture
Large carnivores	Grey wolf	*Canis lupus*	LC	NT	262
Small carnivores	Red fox	*Vulpes vulpes*	LC	NT	259
	Pallas's cat	*Otocolobus manul*	LC	NT	567
	Beech marten	*Martes foina*	LC	DC	43
	Steppe polecat	*Mustela eversmanni*	LC	LC	10
Herbivores	Wapiti or Elk	*Cervus canadensis*	LC	CR	130
	Argali	*Ovis ammon*	NT	EN	15
	Livestock				13214
Rodents	Siberian marmot	*Marmota sibirica*	LC	EN	200

[1]IUCN endangered species category (Red List): LC: least concern, NT: near threatened
[2] Category of Mongolian Red List of Mammals: NT: near threatened, DC: data deficient, CR: critically endangered, EN: endangered

3.2.6.1 Temporal activity patterns of Pallas's cats

A total of four camera traps captured images of the target species during the study period: Cam1 (n = 93), Cam2 (n = 2), Cam3 (n = 68), and Cam5 (n = 404 captures). Cam5, in particular, recorded a high number of Pallas's cat images, as well as the highest capture rate (27 captures per 100 days over an active period of 240 effective study days). Cam1 also showed notable records, with 18 captures per 100 days over an active period of 71 days. While Cam2 and Cam3, worked for just one day with few captures due to battery failures. No images were recorded by the other cameras.

Daily activity pattern: Among the large and small carnivores, Pallas's cats were active both day and night, showing a slight crepuscular trend, similar to the daily activity patterns of red foxes. Pallas's cats' highest activity peaks were being recorded at 20:00 and minimum activity being recorded during midday (Figure 6).

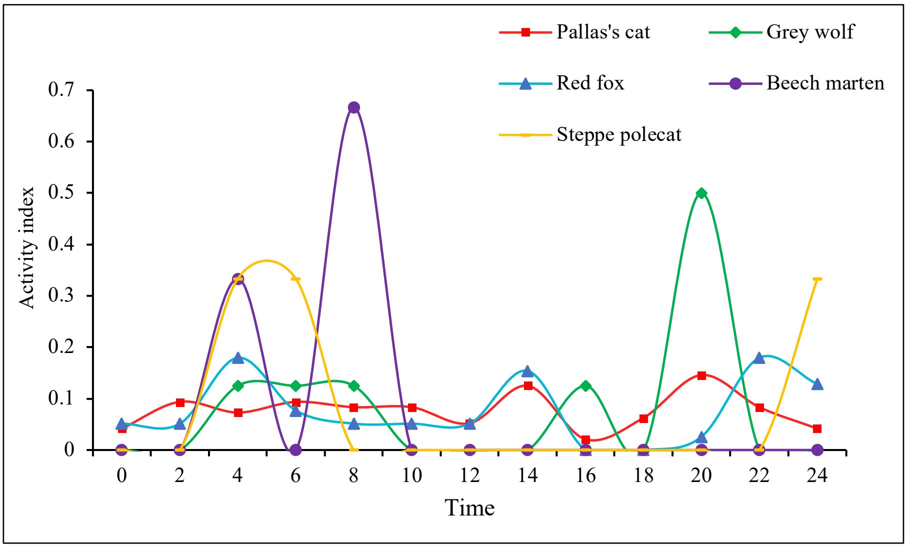

Figure 6: Daily activity patterns of Pallas's cat (n=567), grey wolf (n=262), red fox (n=259), beech marten (n=43), and steppe polecat (n=10).

Annual activity patterns: As for the annual activity patterns, Pallas's cats visited all four sites throughout the year, except in September and October, with their activity peaking in January. Similarly, red foxes were present during the same months and showed a peak in summer. In contrast, grey wolves occurred in winter, but they were mainly active between June and August. (Figure 7).

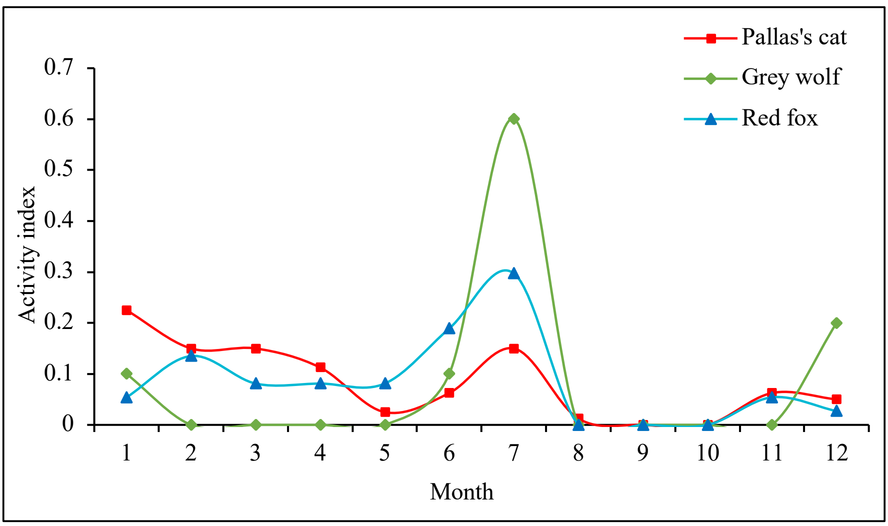

Figure 7: Annual activity patterns of Pallas's cat (n=567), grey wolf (n=262), and red fox (n=259).

4. DISCUSSION

4.1. Literature survey: Threats and conservation behavior of small felids

4.1.1. Threats to Pallas's cat

Based on a literature survey, the categories invasive and other problematic species, and biological resource use were identified as the most critical threats to Pallas's cats in Asia. In other words, non-native animals have harmful effects, and the small felid faces danger from both deliberate and unintentional hunting (*IUCN, Threats Classification Scheme*).

The primary driver of the 'invasive and other problematic species' threat, ranked as serious for Pallas's cats, was predation by herding dogs. Herding dogs and overgrazing by livestock are among the most serious threats to Pallas's cats and are consistent with anthropogenic threats related to land use, driven by the dramatic expansion of animal husbandry throughout the species' range (Barashkova et al., 2017; Damdinsuren et al., 2008; Ross, et al., 2020). Increasing livestock numbers in Mongolia result in an increasing number of herding dogs, which is one of the most important causes of human-related mortality in Pallas's cats (Barashkova et al., 2017; Barashkova & Smelansky, 2011; Ross, 2009; Ross et al., 2012). Dog-caused mortality of the species has also been reported in other parts of its range such as Russia (Barashkova & Smelansky, 2011) and Iran (Farhadinia et al., 2016).

Another threat category, 'biological resource use,' which includes overgrazing by livestock, illegal hunting, and illegal trade, was also identified as a significant threat in this classification.

Habitat loss, primarily due to the expansion of livestock numbers, infrastructure development, mining activities, and the conversion of steppe grasslands into arable farmland, constitutes a major threat to Pallas's cats (Ross et al., 2019b). The species' populations are increasingly fragmenting, and isolated subpopulations are likely to disappear without our knowledge as a consequence of habitat loss and degradation (Ross et al., 2020). Increasing numbers of livestock can lead to habitat loss and degradation for Pallas's cats (Ross et al., 2020). Their habitat is largely used for domestic livestock grazing across much of the species' distribution range, including Mongolia, China, Iran, and India, where studies have widely reported habitat degradation caused by grazing (Dhendup et al., 2019; Pal et al., 2019). Traditional pastoralism is widespread, notably in Mongolia, where livestock numbers have increased dramatically over the past two decades, reaching 57.6 million free-ranging domestic animals (including goats, sheep, cattle, horses, and camels) as of 2024 (*National Statistics Office of Mongolia*, 2022). Herders in Mongolia move between camp sites less frequently today compared to 30 years ago, and their lifestyle is becoming more sedentary. This has likely led to increased grazing pressure around herder camps and watering holes, which, in turn has affected grassland quality (Pringle & Landsberg, 2004). Additionally, Pallas's cats shows behavioral shifts, becoming more nocturnal to avoid livestock (Greco et al., 2022). The presence of livestock can negatively impact Pallas's cats by reducing the availability of main prey, such as rodents, due to pasture exploitation (Ross et al., 2012).

Hunting and illegal hunting is another potentially important threat to Pallas's cat although hunting is prohibited in all range countries except Mongolia (Ross et al., 2020). Yet, the current study has reported illegal hunting of Pallas's cats as medium-level threat, whereas Murdoch et al. (2006) confirmed illegal hunting occurred locally, with herders using their skin, fat, and body parts for medical purposes (Murdoch et al., 2006; Ross et al., 2020). Pallas's cats have been overhunted due to its skin trade around the 1950s in Mongolia and Russia (Clark et al., 2006; Wingard & Zahler, 2006), but since 1980 the international trade in its pelts has ceased (Ross et al., 2020). However, illegal trade still occurs from the species' range countries (Kretser et al., 2012).

Small mammal poisoning campaigns have led to prey loss for Pallas's cats in Central Asian strongholds (Ross et al., 2020), and this secondary poisoning is another concern for the species. Small rodents, for example, Brandt's vole (*Lasiopodomys brandti*) and pikas, have been targets of extensive poisoning campaigns across Mongolia to reduce their populations (Zahler et al., 2004). Unfortunately, the aerial application of bromadiolone has had serious negative impacts not only on the targeted species but also on non-targeted wildlife, including predators, raptors, livestock, and even human health (Winters et al., 2010). Besides, poisoning of small mammals occurs on a local scale in China, Russia, and Kazakhstan. As a result, pika populations have sharply declined, particularly in China, where the poisoning program is ongoing. However, it is likely that instances of small mammal poisoning have decreased over recent decades (Lai & Smith, 2003; Palden et al., 2016; Ross et al., 2019), but no information is available on the current prevalence in Mongolia. The broad literature survey on Pallas's cat in Asia reveals a critical gap in regional research, highlighting that the species remains severely understudied, especially concerning threat patterns and the underlying causes.

4.1.2. Threats to wildcat

The most significant threat to the species is hybridization with feral and domestic cats, which leads to a severe loss of genetic integrity (Daniels et al., 2001; Tiesmeyer et al.. 2020). According to the literature survey, hybridization poses the greatest threat to wildcats across Europe, indicating that this phenomenon is a global concern for this small felid. The domestic cat does not derive from the European wildcat; however, hybridization between the two species has been observed in various part of its range, notably in Scotland and Hungary, where high levels of admixture were found (Pierpaoli et al., 2003). While relatively low levels of introgressive hybridization have been observed in Central and Southeastern Europe (Tiesmeyer et al., 2020), these variations in admixture levels among regions can be attributed to factors such as population history, differences in ecological barriers, and environmental conditions (Mattuci et al., 2016, Pierpaoli et al., 2003; Gil-Sanchez, 2015). Archaeozoological data suggest that domestic cats first appeared in Central Europe during the Roman period and became more widespread in medieval times, serving both as a valuable tool for controlling vermin and pests and as a traded commodity for their pelts (Ewing, 1981; Faure & and Kitchener, 2009). The Roman Empire played a key role in the expansion of the domestic cat throughout Europe, the Mediterranean region, and North Africa, following its domestication journey that began approximately 9,000 years ago in the Near East. Nieto-Blázquez et al. (2022) suggested that the interbreeding between wildcats and domestic cats occurred around the time the domestic cat was introduced during the Roman period.

The rate of hybridization in wildcats may be increasing due to decreasing wildcat population density, the widespread presence of domestic cats, and habitat loss and fragmentation (Kilshaw, 2011; Nussberger et al., 2018).

The wildcat is considered a habitat generalist and appears to use a wide range of habitats (Klar et al., 2008), making it less susceptible to habitat loss. However, given the species' extremely restricted range and alarmingly low number of remaining genetically pure individuals, habitat loss is likely to rapidly separate its populations (Kilshaw, 2011). Additionally, behavioral differences in habitat use between wildcats and hybrids play a significant role in the hybridization process, potentially increasing opportunities for feline virus transmission (Macdonald, 2016). Disease, another primary human-caused threat to wildcats, is likely exacerbated by domestic cats, which raise the risk of transmission (Gerngross et al., 2022). It was also one of the most frequently recorded serious threats to the wildcat in Europe in the current results. Studies have revealed that wildcats, particularly in Western European countries such as Germany, Scotland, and the Iberian Peninsula, are affected by lungworms, nematodes, feline leukemia virus, and other endoparasites. Disease outbreaks frequently occur near human settlements due to the large populations of feral and domestic cats. However, in some countries like Turkey, a certain percentage of domestic cats are systematically eradicated (Gerngross et al., 2022). Nonetheless, behavioral insights can be applied to support wildcat conservation efforts. For example, Miyazaki et al. (2017) used urinary extract from domestic cats as a lure to manipulate the behavior of both wild and free-roaming cats, which could be helpful for conservation and effective behavior-based management of small endangered felids.

Among the human-related threats to wildcats, road and railway kills were the major causes of mortality (Bastianelli et al., 2021; Gerngross et al., 2022), a finding that was also confirmed in our results. Piechocki (1990) reported that most wildcat deaths in Central Europe due to road kills occurred during the mating season. Around 130 wildcats were released into the wild for reintroduction in Central Europe but 18 of them were killed by cars, mostly in Germany (Nowell & Jackson, 1996; Stahl & Artois, 1994). It is possible that mainly young wildcats were involved in the reintroduction, which may have made them more susceptible to road killings than resident individuals. However, road kills are influenced by various factors, including species population density, road density, and habitat types in the area (Barrientos & Bolonio, 2009; Grilo et al., 2009).

Decline in prey availability was considered a medium-level potential threat in these results, and wildcats are facultative specialists that consume a variety of prey depending on availability (Malo et al. 2004). In Hungary, the primary components of wildcat diet are small mammals such as common vole and field mouse with occasional prey including birds, lagomorphs, and grass-like plants (Biró et al., 2005). They have higher feeding flexibility and are considered selective predators in the given habitat, making them potentially more adaptable to changes in prey availability (Jose María, 1999; Ruta, 2018).

Hunting and poisoning were considered less significant among the human-caused threats to wildcats. Historically, the species was regarded as vermin and hunted across Eurasia to protect livestock, while its pelage was a valuable resource for the fur market (Council of Europe, 1993; Stahl & Artois, 1994). This direct persecution was the primary cause of the species' extinction in countries like Austria, but there is no longer any interest in its fur trade today (Gerngross et al., 2022).

Although primary and secondary poisoning were reported less frequently in this study, rodenticide use is still present (Guitart et al., 2009) and has increased on farms in Great Britain (Garthwaite & Thomas, 2003).

4.2. Field-based research: Distribution of small felids

4.2.1. Distribution of Pallas’s cat

Central Mongolia is thought to be a stronghold for Pallas's cats, based on the availability of suitable habitat and its historical fur trade (Wingard and Zahler 2006; Ross et al., 2019a); however, only a few studies have been performed and research in the region remains limited (Murdoch et al., 2006; Ross et al., 2010, 2012).

Our results showed that the distribution of the Pallas’s cat within the national park was significantly and positively correlated with steppe habitats in this montane steppe region, which is consistent with the species' typical habitat, comprising montane grasslands and steppe (Ross et al., 2019a). Additionally, the Pallas's cat has also been documented in dry steppe areas (Bangjie, 1984) and Dhendup et al. (2019) suggested that the species could be widespread across a range of diverse steppe habitats. Our study also showed that the distribution of Pallas’s cats was associated as a trend with terrain ruggedness. Earlier studies indicated that Pallas’s cats appear to prefer steep and rugged areas with high coverage of rocky terrain and ravines (Greenspan and

Giordano 2021; Ross et al., 2020). Furthermore, Chimed et al. (2021) revealed that the distribution of the Pallas's cat was positively correlated with terrain ruggedness and Greco et al. (2022) also found that Pallas's cats are associated with steeper slopes and natural vegetation. Studies on the Pallas's cat in Iran have shown that they prefer lower altitudes and a diversity of topography (Lorestani et al., 2022).

Hustai National Park is one of the most well-protected areas in Mongolia and serves as a key site for biodiversity, particularly abundant in prey for Pallas's cats (Batsaikhan et al., 2016; Tseren-Ochir et al., 2018). Although an earlier study on Pallas's cats in the national park found a limited effect of prey availability on home range size (Ross et al., 2012), the species' distribution in our study area may be influenced by prey availability, which is an important factor determining its distribution (Greenspan and Giordano, 2021).

Our data is consistent with the preliminary understanding of the distribution of Pallas's cats in HNP. However, we acknowledge that combining interview-based surveys with other research and monitoring techniques could be more effective.

4.2.2. Distribution of wildcat

Our study suggests that the distribution area of wildcats in Hungary has increased over the past two decades. Wildcats are typically considered a forest species (Nowell & Jackson, 1996). Our results showed that the occurrence of wildcats in Hungary was most strongly associated with broad-leaved forest cover, with these forests significantly increasing the likelihood of wildcat detection. This result is supported by previous studies, such as Mattucci et al. (2013) who found that the distribution of the wildcat is closely linked to broad-leaved forests. On the other hand, the wildcat is considered a habitat generalist (Silva et al., 2013), using various types of habitats. Studies, particularly in western Europe (e.g., Germany and Scotland), have shown that their presence is linked to coniferous forests, grasslands, and scrubland, while being limited by forests, forest ecotones, and meadows (Corbett, 1979; Daniels et al., 1998; Klar et al., 2008). In contrast, in Mediterranean countries, scrub areas are considered key habitats for their distribution (Lozano et al., 2003). Nevertheless, we found that broad-leaved forests are the most important habitat for wildcats, positively impacting their distribution at a broad scale. This finding is supported by an earlier small-scale study conducted in Hungary (Biró et al., 2004).

Wildcats avoid pasture areas because grassland-covered areas are often connected to agricultural lands, where farmers are present, and these areas are less suitable for their prey due to intensive grazing (Daniels et al., 2001). However, agricultural landscapes with diverse structures can be suitable habitats for wildcats, even supporting their successful reproduction (Jerosch et al., 2018). In contrast, wildcats use open pastures and cattle pastures for hunting, as these areas support higher prey density, such as that of the montane water vole (Lozano et al. 2006; Rodríguez et al., 2020). But we found no significant association between pasture areas and wildcat occurrence in Hungary.

Wildcats avoid residential areas, including roads, rail networks, and adjacent land, which may contribute to its absence (Klar et al., 2008). Likewise, Silva et al. (2013) found no evidence to suggest that urban areas and roads have a significant impact on wildcat presence. They even avoided human settlements, as shown by radiotelemetry data in Hungary (Biró et al., 2004).

4.2.3. Activity pattern of Pallas's cat

During the survey period, we detected Pallas's cats both during the day and at night, with activity peaking around dusk. The species was consistently active at night, but we observed a slight increase in crepuscular hours. Earlier studies revealed that the activity of Pallas's cat was mainly crepuscular, especially throughout summer (Anile et al., 2021; Ross, 2009), which is concordant with our results, though the highest activity was observed in January. The activity peak in January may be due to their mating season.

Besides that, Anile et al. (2021) also found that Pallas's cats showed diurnal activity between September and November, as captured by camera traps in Mongolia. Unfortunately, there was no detection of Pallas's cats in our survey during autumn because some cameras were lost, and others failed due to dead batteries. Likewise, daytime activity of Pallas's cats recorded in western Mongolia (Greco et al., 2022), is consistent with our findings; in our study, Pallas's cats were active during the day but showed reduced activity around midday. Anile et al. (2021) and Ross et al. (2012) corroborated that Pallas's cats face the dilemma of avoiding predators while also increasing the likelihood of a successful daytime hunt.

5. CONCLUSIONS AND RECOMMENDATIONS

Based on the findings of our literature survey, we identified key geographical and threat-related patterns for both the wildcat and Pallas's cat across continents. Scientific articles on threats to Pallas's cats are limited, using the wildcat as an example**,** highlighting the need to bridge these knowledge gaps. Our findings emphasize the distinct conservation challenges faced by each species and how anthropogenic threats influence small felid survival. In order to minimize negative impacts, monitoring and controlling feral and free-ranging domestic cat populations, implementing Trap-Neuter-Return (TNR) programs, promoting indoor cat keeping, and raising public awareness about the risks of allowing pet cats to roam freely are essential. Additionally, herders should use trained livestock guardian dogs which are less aggressive towards wildlife, while promoting controlled grazing practices that balance both conservation and pastoral needs such as changing camps seasonally and reviving nomadic traditions to prevent the unprecedented loss of the world's most majestic predators, both big and small.

Over the last two decades, the distribution of wildcats in Hungary appears to have expanded and show a significant association with broad-leaved forest habitats. The country provides important habitat for the species, in particular close to nature old-growth broad-leaved forests rather than plantation forests. Further research is needed to fully understand its habitat use and distribution on a broader scale. Conservation efforts should prioritize habitat management, including the protection and maintenance of core areas with stable populations, to safeguard the wildcat and its critical habitats in Hungary.

The distribution of Pallas's cat in Hustai National Park was higher in areas with a greater proportion of steppe habitat, underscoring the importance of this habitat as a key area for the species in Central Mongolia. Its presence also tended to increase in more rugged habitats of the study area. As the first preliminary estimate of the species' distribution in the park, more research is using direct methods is required to better understand these processes. Despite any shortcomings, we hope our findings will serve as a foundation for future conservation efforts targeting this elusive cat.

The Pallas's cat was active both day and night, with peak activity occurring around dusk (e.g., 20:00) and the highest annual activity recorded in winter, notably in January. Winter, particularly January, may be the best time for camera-trapping surveys to investigate its temporal activity patterns, as Pallas's cats tend to show peak activity during this season.

6. NEW SCIENTIFIC RESULTS

- Based on the literature review, hybridization with domestic cats emerged as the most significant direct threat to wildcats across Europe, whereas predation by herding dogs posed a serious threat to Pallas's cats within their range countries. Additionally, overgrazing by livestock is recognized as another major potential threat to Pallas's cats in Asia.
- Hybridization with domestic cat was reported as a major local concern for wildcats, while lack of prey emerged as the most frequently reported threat to Pallas's cats. Drawing on community knowledge, habitat loss was also emphasized as a shared challenge for both species in Hungary and Mongolia.
- Wildcat detections differed significantly between 2004 and 2022, with a clear increasing trend observed over the broader time frame. In Hungary, wildcat presence was strongly associated with broad-leaved forests among various land cover types, underscoring the importance of these habitats as key areas for the species within the country.
- This study provided the first assessment of Pallas's cats in Hustai National Park, Central Mongolia, revealing a significant correlation between their presence and steppe habitat. A higher percentage of steppe cover was associated with a significantly greater probability of species occurrence. Besides that, the species' distribution showed a positive trend with terrain ruggedness in the national park.
- The annual activity pattern of the Pallas's cat was most prominent in winter and summer, with peak activity recorded in January. The species' daily activity increased at dusk (around 20:00–21:00), consistent with its crepuscular behavior.

7. LIST OF PUBLICATIONS

- Publication (Journal Article: Q1 – IF = 1.9) – Peer reviewed

Otgontamir, C., Fehér, Á., Heltai, M., Lkhagvasuren. D., Batzaya, Ts., Biró, Z. (2025). A preliminary approximation to determine the distribution of Pallas's cats in Hustai National Park, Mongolia. *Mammalian Biology*. 10.1007/s42991-025-00496-w

- Publication (Journal Article: Q1 – IF = 2.7) – Peer reviewed

Otgontamir, C., Fehér, Á., Schally, G., Heltai, M., Szabó, L., Lehoczki, R., Lkhagvasuren, D., & Biró, Z. (2024). Assessing changes in the distribution patterns of the European wildcat in Hungary. *Animals*, *14*(5). 10.3390/ani14050785

- Publication (Journal Article: Q3 – IF = 1.1) – Peer reviewed

Otgontamir, C., Lkhagvasuren, D., Alexander, J. S., Barclay, D., Bayasgalan, N., Lkhagvajav, P., Nygren, E., Robinson, S. L., & Samelius, G. (2023). Delivery of educational material increased awareness of the elusive Pallas's cat in Southern Mongolia. *Applied Environmental Education & Communication*, *22*(1), 1–12. 10.1080/1533015X.2023.2169785

- Publication (Journal Article: Q1 – IF = 1.9) – Peer reviewed

Otgontamir, C., Alexander, J. S., Samelius, G., Lkhagvajav, P., Davaa, L., Bayasgalan, N., & Sharma, K. (2021). Examining the past and current distribution of Pallas's cat in Southern Mongolia. *Mammalian Biology*, *101*(6), 811–816. 10.1007/s42991-021-00132-3

- Oral presentation

Otgontamir, C., Zsolt, B., (2023). The Grand Master of Stealth in Endangerment III - The Situation of the Wildcat (*Felis silvestris*) in the Pilis-Buda Mountains, Hungary. 8th December 2023.

- Conference Abstract (published online)

Otgontamir, C., Zsolt, B. (2024). Crossing the border of a small felid conservation: A case study to investigate the threats to the European wildcat in Hungary and Pallas's cat in Mongolia, *The 3rd International Electronic Conference on Diversity session Biodiversity Conservation*. 11th November 2024.

- Poster (Conference Abstract)

Otgontamir, C., Zsolt, B., Lkhagvasuren, D., Alexander, J. S., Sharma, K., Samelius, G., Lkhagvajav, P., Bayasgalan, N. (2022). Examining the past and current distribution of Pallas's cat in Southern and Central Mongolia, *29th Poster Day.* Bratislava, Slovakia. 9th November 2022.

- Poster (Conference Abstract)

Otgontamir, C., Lkhagvasuren, D., Purevjav, L., Barclay, D. (2017). Understanding and developing community awareness of Pallas's cat in Mongolia, *Biodiversity Research of Mongolia*, Mongolia. 2017.

Other publications

- Conference Article

Otgontamir. C, Zsolt. B, Lkhagvasuren. D, Justine. S.A, Koustubh. S, Gustaf. S, Purevjav. Lk, Narangarav. B. (2022). Examining the past and current distribution of Pallas's cat in Southern and Central Mongolia. In: Vitková, J., Botyanszká, L. (eds.). Interdisciplinary Approach in Current Hydrological Research. IH SAS, E-Book, Bratislava, p. 242. ISBN: 978 80-89139-53-8.