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COMPREHENSIVE ANALYSIS OF INTERNATIONAL BEST PRACTICES FOR MITIGATING VEHICLE-RELATED MORTALITY OF THE NORTHERN WHITE-BREASTED HEDGEHOG (ERINACEUS ROUMANICUS)

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The aim of the study is to explore possible approaches for addressing ecological challenges in urban areas and the risks associated with linear infrastructures, focusing on the northern white-breasted hedgehog as a specific case. The research seeks to examine the relationship between habitat requirements and potential threats, particularly in Hungary. The primary concern arises from the increasing danger posed to the population of northern white-breasted hedgehogs, a protected species in Hungary, due to the expanding impact of linear road structures. This has led to higher mortality rates among these animals caused by habitat fragmentation and isolation effects. An analysis of a growing city was carried out using QGis mapping techniques to identify potential hedgehog habitats and assess how road systems may be threatening them. A comprehensive survey collected data on sightings of hedgehogs, types of habitats, garden characteristics (where applicable), human activity patterns throughout each day, and frequency of transportation usage. Our findings suggest that effective urban planning and raising community awareness are crucial in mitigating risks faced by hedgehogs. Implementing measures such as creating wildlife corridors or introducing traffic calming strategies can significantly lower mortality rates among hedgehogs while aiding conservation efforts for this vulnerable species.

1. Introduction

The northern white-breasted hedgehog *(Erinaceus roumanicus* Barrett-Hamilton, 1900) is one of the most easily recognisable members of the domestic mammal fauna. Systematically, it belongs to the order *Erinaceomorpha* and the family *Erinaceidae,* of which it is the only native representative (Fadeeva et al., 2024) in Hungary. The northern white-breasted hedgehog is classified as a synanthropic species because it occurs in higher densities in man-made environments (Rodewald and Shustack, 2008) than in the wild (Chace and Walsh, 2006), mainly due to the fact that it has a higher food availability and lower predator abundance than in the wild (Hubert et al., 2011). Hedgehogs living in artificial, human-inhabited environments tend to become active after midnight in search of food and are mostly found in larger numbers in green areas, parks, gardens and roadsides (Müller, 2018). Factors such as access to food sources or favourable microclimatic conditions play a key role in the survival of hedgehogs, with individual animal food or food or rubbish placed on the ground being an additional source of diet (Hubert et al., 2011). Apart from the fact that these habitats are excellent for hedgehogs, the roads and fences separating the habitats pose a significant challenge for the population (Wilson and Wembridge, 2018). Although some research suggests that hedgehogs are up to 35 % less likely to be found near roads, there are countless cases of roadkill on roads across Europe (Huijser, 1998). Transportation infrastructure can have a negative impact on ecosystems as it poses a threat to the survival of vulnerable populations and disrupts ecosystem dynamics through wildlife collisions with vehicles (Backs et al., 2017). The modification of transportation infrastructure, along with the growth and alteration of road systems, can influence the extent and nature of interactions between wildlife and roads. Therefore, ongoing observation and evaluation of distinct processes and trends are essential for developing sustainable transport solutions and preserving wildlife (Rendall et al., 2021). Since the inception of modern automobile and vehicle usage, a range of cautionary symbols have been established within international legal agreements to enhance road safety and effectiveness (Tryjanowski et al., 2021). Dynamic barriers and retention nets are designed to enhance road safety and safeguard wildlife, especially in areas with elevated risk levels (Yavartanoo et al., 2023). The spatial and temporal analysis will enable the development of more focused road safety measures by identifying these high-risk areas (Steiner et al., 2014). Recognising the seasonal patterns of animal accidents may lead to reinforcing existing measures, using temporary warning signs, and implementing short-term road closures in specific areas (Grilo et al., 2020). The reduction of animal deaths from vehicle collisions with wildlife can be achieved through active or passive measures. Currently, a common approach involves blocking linear infrastructure elements to restrict wildlife access to vehicles (Pagany, 2020). The overall finding suggests that drivers can prevent collisions with wildlife by detecting animals in advance, using warning signs or animal detection systems (Huijser et al., 2006). The visibility of vehicles is an important factor for humans, but its role as a deterrent for animals is sometimes minimal (Ulrich et al., 2014). In an urban setting, the increasing use of e-mobility vehicles could have a negative impact on urban ecology. A proposal has been made to incorporate an automated vehicle intervention system, especially for autonomous vehicles, in addition to warning drivers (Viani et al., 2016). Wild animals can become accustomed to warning signals when they are not consistently followed by positive or negative reinforcement (Gilsdorf et al., 2002). Choosing the right technology for the northern white-breasted hedgehog is challenging, especially given its size.

As the world is urbanising at an ever-faster pace, cities are not only serving as places to meet people's needs but also as important habitats for the creatures around us. Recently, the loss and fragmentation of natural habitats have forced wildlife species to settle in urban areas (Smith et al., 2014). For this reason, finding the optimal way for people and wildlife to live together in harmony will be of paramount importance in the future (Magle et al., 2019), not only for the functioning of ecosystems (Cohn, 2005) but also for human mental health. The population's positive or negative attitudes and decisions have a wide range of social, psychological, and ecological consequences (Bramley et al., 2009; Cook et al., 2012).

People generally have positive attitudes towards hedgehogs. According to the survey of Kontsiotis et al. (2023) most participant expressed a willingness to financially support hedgehog conservation. In Hungary, the creation of "hedgehog-friendly gardens" is a widely applied program. This is an exceptionally important initiative, as hedgehogs are increasingly found in and around urban areas (Parrott et al., 2014; Pettett et al., 2017; van de Poel et al., 2015), and gardens associated with properties are considered favourable habitats (Dowding et al., 2010; Pettett et al., 2017). Cities, as heterogeneous ecosystems, possess complex ecological characteristics and processes (Band et al., 2005). Human activities directly and indirectly influence the ecological features of urban areas and habitats by altering both ecosystem components and abiotic and biotic infrastructure elements (Cook et al., 2012).

Although the northern, white-breasted hedgehog is widespread in Hungary and frequently reported as a roadkill (Borza et al., 2021), there are few published studies on its population size and distribution. This species is not part of the regular mammal monitoring within the Hungarian Biodiversity Monitoring System (Csorba and Pecsenye, 1997) but it is included in a popular citizen science data collection program in Hungary (vadonleso.hu). More than 1700 hedgehog observations have been contributed by civilians through this website.

The main goal of this study is to examine how the ecological requirements of the northern white-breasted hedgehog are fulfilled in typical urban and suburban areas, as well as to devise a method for evaluating the impact of roads. Győr, chosen as an example due to its high level of urbanization, was used for this investigation. A map of the city and its surrounding suburban areas was created using QGIS (2023) to identify potential habitat locations and road systems that separate them. Additionally, a questionnaire survey was conducted to assess the frequency with which citizens observe hedgehogs and explore links between observation frequency and housing area type movement habits (modes and timings).

2. Materials and methods

Our research focuses on a regional scale. Therefore, an example city, Győr, was chosen to demonstrate our methods. Győr is a developing industrial city situated in the northwestern part of the Transdanubian Region in the most densely populated county of Hungary. In our study, the geographic information system QGIS 3.36.3 was utilised to create map assessments and display areas where roads threaten the habitats of the northern white-breasted hedgehog. Version 3.36.3 of QGIS offers various beneficial features that have allowed us to efficiently process and analyse data with accuracy. Our work was initiated by using a map from the CORINE Land Cover database (EEA, 2020), which was then integrated with specific map data from the Geofabric database. All types of land cover suitable for hedgehogs were chosen, and roads intersecting those habitats were identified.

Our questionnaire survey included 31 different factors such as demographics, transportation methods, times of activity, housing details (such as type, yard size, fencing types and pets), and observations of hedgehogs and other migrating mammals. The timing of the questionnaire launch was adjusted to align with the annual activity patterns of the target species (in May 2024). A total of 138 respondents completed the questionnaires online while maintaining anonymity (78 were from Győr's agglomerate). The responses underwent statistical analysis using both the complete data set and a filtered dataset specific to our geographical region of interest. Contingency tables were gathered to test all relevant factors using chi-square tests and Fisher's exact test, while Spearman rank tests were used for ordinal parameter pairs in order to identify correlations among these parameters.

3. Results

3.1. Potential risk areas for linear road infrastructure of Győr

The ultimate map (Figure 1) assesses the risks associated with the local transportation infrastructure and its intersection with green spaces in the city of Győr. It takes into account primary, secondary, and tertiary roads, as well as intersections between these roads and green areas to identify potential hazard zones. Based on this foundation, various potentially hazardous areas that may be impacted by hedgehogs could be recognised.

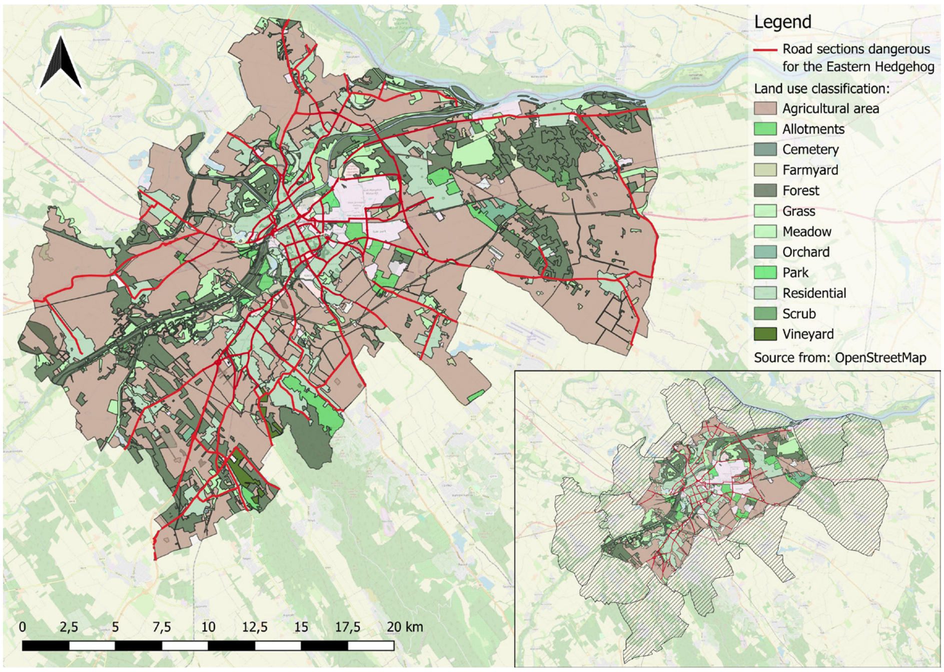

Figure 1: Hedgehog habitat map of Győr and its agglomerate with emphasis on roads that may pose the greatest risk to these habitats

3.2. Observation Questionnaire

The overwhelming majority of respondents (98.6 %) reported that they had seen a hedgehog in the wild on multiple occasions. Additional free notes definitely reflect a positive attitude toward the species.

Responses to the matrix question "How often do you drive a car/travel as a passenger in a car /use public transport /ride a bike or scooter/ walk more than 500 m?" on a six-point scale from never to daily were combined with "Have you ever seen a hedgehog alive along a road/ carcass on the road?" on a 5-point scale from never to more than 4 times questions. For all pairs of parameters, contingency tables and Spearman rank test was performed. Calculated p-values are shown in Table 1. The results suggest no significant correlation among most parameters. Particularly, biking more often shows the least connection to observing more hedgehogs, either alive or dead. However, we observed a significant correlation between the frequency of walking and spotting live hedgehogs along roads. A near 0.05 p-value between the regularity of using public transport and observing live hedgehogs on the road can be explained by the significant correlation between the usage of public transport and walking.

Table 1: The p-values of Spearman rank test about correlations among travelling behaviour and observations of hedgehogs along roads

	Driver	Passenger	Public transport	Biking	Walking
Alive on road	0.4240	0.1011	0.0547	0.8974	0.0409
Carcass on road	0.1437	0.5233	0.7543	0.9278	0.6277

Answers to the matrix question "How frequently do you spend time outdoors at specific times of the day?" were collected using a five-point scale ranging from rarely to daily for 8 time intervals and compared to the matrix question "How often have you seen hedgehogs [location]?". The p-values obtained from Spearman rank tests are presented in Table 2. The strongest association between outdoor presence and responses was observed during late night hours, while extremely high p-values in periods 8-12 and 15-17 indicate a lack of correlations.

Table 2: The p-values of the Spearman rank test about correlations among periods of daily activity outside and observations of hedgehogs in different places

Locations \ time (h)	4-6	6-8	8-12	12-15	15-17	17-20	20-22	22-4
Alive on road	0.0082	0.5624	0.7059	0.0805	0.7579	0.5490	0.0019	0.0004
Carcass on road	0.5569	0.1677	0.5404	0.0054	0.6760	0.5490	0.2299	0.8577
In own yard	0.6948	0.0993	0.2532	0.6353	0.4122	0.5635	0.2321	0.7768
In others' yard	0.1705	0.5483	0.7899	0.4113	0.8958	0.5628	0.5814	0.0703
In green area in town	0.1294	0.2873	0.6999	0.0434	0.6299	0.2086	0.0370	0.0014
In green area outskirts	0.1455	0.0579	0.6238	0.1926	0.3612	0.9050	0.5438	0.0068

In case of "What the size of the green area (grass, bushes) inside your yard?" contra "How often have you seen hedgehogs [in your own yard]?" the Spearman rank test revealed no significant correlation ($p=0.1244$), despite some association observable in the graphical representation (Figure 2A). When the number of categories for yard size was reduced to "under and over 301 m²" a significant but moderate positive association was found using Kendall's tau test ($p=0.03$, $\tau=0.2259$).

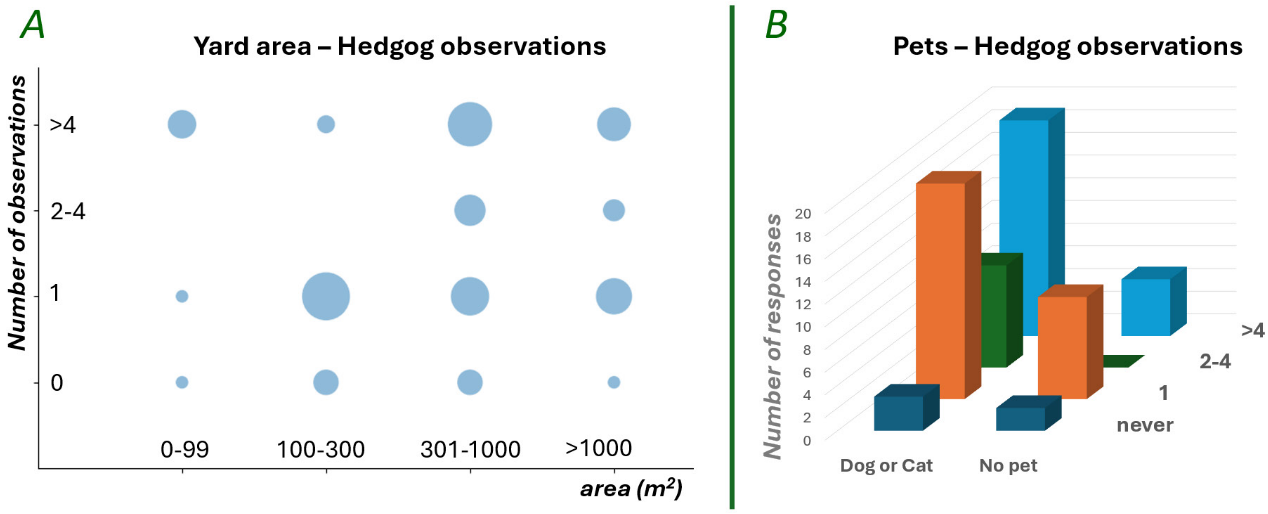

Figure 2: A) Correlation between the green area in the enclosed yard and the number of hedgehog observations. Bubble sizes represent the number of respondents with a specific combination of answers (filtered to Győr agglomerate and having a fenced garden). B) Relationship between having a pet in one's own yard and the number of hedgehog observations

Based on responses to "What kind of pets do you keep in your yard?" and "How often have you seen hedgehogs [in your own yard]?", there was no significant correlation found for having a cat (p=0.312) or a dog (p=0.255). Since a considerable number of respondents have both cats and dogs, a chi-square test was also calculated for the combined categories of "having a cat or dog" versus "no cat or dog" (p=0.198) (Figure 2B).

As there were no respondents who have never seen a hedgehog or any other mammal larger than a hedgehog and have only fence types that are impermeable to hedgehogs, it can be inferred that the fences in the region are generally permeable to hedgehogs.

4. Conclusions

Our questionnaire results are in accordance with the former data, which shows that the northern white-breasted hedgehog is widely common. Generally, there are significant connections among observational parameters (seeing hedgehogs as carcasses on the roads/ alive on roads/in their own yards/ in others' yards/ in open green areas within the settlement / outside the settlement). This suggests that some people may be more observant or that seeing hedgehogs multiple times can make it difficult to remember where they were seen. Hedgehogs are more often observed in larger yards. However, a further increase in yard size over 300 m^2 has no additional positive effect. In accordance with hedgehogs' activity patterns, human outdoor activity in the late night and early morning is significantly correlated with hedgehog observations. Keeping cats and dogs has no significant effect on hedgehog occurrence. The permeability of common fence structures allows hedgehogs to use yards as a continuous habitat, with roads being the only considerable barriers. Consequently, mapping habitable areas and their conflict with busy roads is a reliable tool for integrating urban ecological planning at the settlement and regional levels. The positive attitude of humans toward hedgehogs could be leveraged to enhance public involvement in citizen science data collection and roadkill prevention programs.

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