Coláiste na Tríonóide, Baile Átha Cliath
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Habitat Use and Mortality Causes of Western European Hedgehogs *(Erinaceus europaeus)* in Urban Areas: A Combined Analysis of Field Surveys and Citizen Science Data for Conservation Recommendations.

A dissertation submitted to fulfil the degree of
Master of Science in Biodiversity and Conservation

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Word count: 10,421
Date: 25. August 2025

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Abstract

The overall aim of this research project was to investigate habitat use and mortality causes of the Western European hedgehog *(Erinaceus europaeus)* in an urban setting in Hesse, Germany to derive targeted conservation action and tackle the decline in hedgehog populations in the face of an increased threat level assigned to the Western European hedgehog in the IUCN red list, the placement of the species on the early warning list in Hesse and a lack of studies on habitat use in hedgehogs from Germany. A combined approach modeling systematic field survey data in Bad Homburg and opportunistic citizen science records from the wider area was chosen to investigate habitat preferences of hedgehog while accounting for spatial bias in citizen science data. Main findings were that hedgehogs use urban over rural areas and that they tend to avoid areas with higher tree densities except if they are associated with higher temperatures, possibly in proximity to human settlements. This flexibility in habitat use was also observed on the urban habitat scale, where hedgehogs were found to avoid areas close to water or those characterized by high imperviousness densities. However, there was an increase of the use of those habitats, if they were associated with high levels of shrubby vegetation – an important landscape element for hedgehog with regard to shelter and foraging. The finding also indicates that there is no suitable substitute for shrubby vegetation, unlike natural water resources which seem to be relevant for hedgehog on the landscape scale, with an increasing independence from water in the urban context, possibly due to substitution. With regard to mortality, roadkill was found to be the main cause of mortality in Hesse based on citizen science. Temporal peaks in roadkill were in May and June, possibly due to an increased activity of males during the breeding season. Mortality hotspots were concentrated in the Rhine-Main metropolitan region, where multiple logistic regression revealed an increased roadkill probability at high traffic roads and road segments surrounded by residential and recreational areas. Conservation implications therefore include: an increase in planting endemic hedges especially in rather unsuitable habitats, and temporal speed limits at streets surrounded by leisure or residential areas as well as crossing structures at high traffic roads. Those conservation actions make sense to be implemented across Hesse to tackle the decline in hedgehogs through enhancing habitat attractiveness, while reducing vehicle associated mortalities.

Acknowledgements

I would like to thank my supervisor Dr. Thomas Connor for his guidance, specifically on any statistical issues and super quick replies which made me feel well supported. Additionally, I would like to thank Irene Glatzle, who took the role as my Co-supervisor, and Dr. Andreas Opitz from HLNUG for providing me with the data of the Hessian hedgehog reporting platform and their support along the way. I also want to thank Dr. Nicholas Payne for lending me his thermal imaging camera, Norbert Lehrer for allowing me enter the “Schlosspark” in Bad Homburg at night, Margot Winkler as well as the BUND Bad Homburg for their idea to check out the hedgehog hotels, Heike Dehmer as a representative of the “Mariannengarten”, Ranger Boris Heinrich and Dr. Markus Dietz for answering my questions, Dr. Sebastian Scholz for his proof-reading skills, and Dominik Scholz for his support during field work and for always listening to my troubles. Lastly, this work is dedicated to Nadine Metzger.

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List of abbrevations

AIC	Akaike information criterion
AUC	Receiver operating curve
DEM	Digital elevation model
DLM	Digital landscape model
GLM	Generalized linear model
HLNUG	Hessian Agency for Nature Conservation, Environment and Geology
NDVI	Normalized difference vegetation index
VIF	Variance inflation factor

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1 Introduction

1.1 Background

1.1.1 Hedgehog Biology

Western European hedgehog (*Erinaceus europaeus*) – hereafter referred to as hedgehog – occur throughout central and Western Europe (Berger et al. 2023). A hedgehog is a small mammal that weighs up to 1700 grams, has a length of up to 30 centimetres, and can reach seven years of age (Berger et al. 2023). Morphological characteristics include black and white spines which cover their back and top of the head, while their face and belly are covered with brownish-grey hair (Berger et al. 2023). Hedgehogs use their spines as a way of defence and curl up into a ball when they face danger (Berger et al. 2023). They belong to the family Erinaceidae where they are most closely related to gymnures (Myres et al. 2025). Hedgehogs are insectivorous and help to control insect populations as such (Gazzard et al. 2025). Moreover, they are nocturnal, live mostly solitary, and behave secretively.

The Western European hedgehog is a species that undergoes hibernation. Their activity period starts from mid-March to mid-April and ends around mid-October to mid-November, with the breeding season commencing right after hibernation and lasting until August (Berger et al. 2023). However, activity patterns of hedgehogs are still not fully understood (Parrott et al. 2014). What is known, is that the activity increases with temperature as well as around midnight (Dowding et al. 2010). In Norway, hedgehogs were found to leave their nest around 11 pm (Korslund et al. 2023), while hedgehogs held in captivity showed activity peaks between 6 and 10 pm, 12 and 2.30 am, and 4 and 5.30 am during summer (Herter 1934). They have also been known to forage around sunset during energetically demanding periods such as directly after hibernation or for females, during their lactation period.

1.1.2 Habitat Use of Hedgehogs

Western European hedgehogs are considered an urban adapter species (Dietz et al. 2023) with their preferred habitats being parks and lawns (Young et al. 2006) as well as residential gardens (Gazzard et al. 2022) and less occurrence in forest habitats or pasture fields (Hubert et al. 2011). Nesting sites, e.g. under hedgerows, and material, e.g. leaves, are considered to be important habitat factors for hedgehogs with regard to hibernation, breeding, and sleeping during the day (Berger et al. 2023, Korslund et al. 2023). In the urban landscape, they tend to avoid areas associated with water or high impervious surface cover (Turner et al. 2021). Home range sizes of hedgehogs vary with season, age, sex and habitat, and range from 5.5 to 100 hectares with smaller home ranges in urban than rural areas. These differences are also true for the distances that hedgehogs cover each night, which are estimated to amount up to an average of 2.5 kilometres (Berger et al. 2023) with smaller distances in urban than rural environments. However, males can move up to 5 kilometres during mating season (Igelzentrum Zürich 2019).

There remains uncertainty as to why hedgehogs prefer urban over rural areas. A suggested higher availability of food resources including pet food could not fully explain the higher density of hedgehogs in urban areas of France (Hubert et al. 2011). The same is true for a lower occurrence of natural predators, such as the Eurasian eagle owl (*Bubo bubo*) and Eurasian badger (*Meles meles*). While a study from the Netherlands on the effect of badgers on hedgehog presence found a significant negative relationship (Poel et al. 2015), a study from France on influential factors of higher hedgehog densities in urban areas could not find any evidence for the effect of badger presence (Hubert et al. 2011). One environmental condition that is different in rural and urban environments is temperature (Pickett et al. 2001), which is mentioned as a possible explanation for hedgehog abundance that needs further investigation (Berger et al. 2023, Hubert et al. 2011). Turner et al. (2021) highlight that the factors influencing hedgehog distribution within urban areas are another aspect that is less understood.

1.1.3 Hedgehog Mortality and Conservation Status

Hedgehog populations are in decline with the relative effects of natural (predation, parasites/ illness, age) and human-induced causes (road traffic, robotic lawn mowers, decline in insects and habitat loss due to intensive farming) of this decline still remaining unclear (Berger et al. 2023). A study on two hedgehog populations in Eastern Hesse found that most hedgehogs don’t even make it through their first reproductive cycle and die at the age of eight to seventeen months (Heddergott and Müller 2008).

However, road traffic is considered to be a main issue (Gazzard et al. 2025, Moore et al. 2020) with estimations that roadkill alone could reduce the total hedgehog population of the Netherlands by 9–26 % (Huijser 2000). A study from Ireland found seasonal variation in hedgehog roadkill with peaks in male deaths occurring in May and June (breeding season) and female deaths in July and August (lactation period) (Haigh et al. 2014). Moreover, Haigh et al. (2014) observed clusters of roadkill at certain locations, suggesting the use of specific crossing points.

Road mortality is discussed as an indicator of population trends in mammals. Baker et al. (2004) support this idea, while Moore et al. (2020) emphasize the importance of considering additional factors – such as total population size, reproduction, and migration – for road mortality to serve as a reliable indicator. The reduction in hedgehog roadkill is well documented all over Europe (Gazzard et al. 2025). Studies carried out in Hesse and Bavaria, federal states of Germany, showed a more significant reduction in and close to residential areas, where the number of roadkill is generally higher due to hedgehog's preference of urban over rural environments (Müller 2018, Reichholf 2015). The decline of hedgehogs in the urban landscape is further supported by a study from Switzerland, which highlights that this is a reason for concern as urban areas had been considered a refuge habitat for hedgehogs (Taucher et al. 2020).

The decline in hedgehog populations has been reflected by the reassessment of the Western European hedgehog in the IUCN red list of threatened species in 2023. It is now categorized as "near threatened" (Gazzard and Rasmussen 2024) which implicates a higher risk of local extinctions (Berger et al. 2023). The reassessment has been noted in Hesse, where the Western European hedgehog has been put on the early warning list of the red list of mammals in 2023 (Dietz et al. 2023). However, it is missing in the red list of mammals for the whole of Germany, which was last updated in 2020. There, the Western European hedgehog is still categorized as "not threatened" with the addition that "risk factor(s) is/are present and effective" (Meinig et al. 2020).

Gazzard et al. (2025) highlight that the assessment of the conservation status of hedgehogs remains a challenge because the species is understudied and lacks systematic monitoring. This perception is supported by Taucher et al. (2020) who emphasise that citizen science can be a useful tool to further investigate causes of declining hedgehog numbers in urban environments as well as Moore et al. (2020) who call for research on how hedgehogs use roads to develop effective conservation measurements. For Germany, Dietz et al. (2023) underline the need for additional data to better assess the distribution, threats, and population trends of hedgehogs. Such information is crucial for developing effective conservation strategies and a targeted protection program for the species. In Great Britain, urban hedgehog populations were found to be stabilizing after periods of decline and IUCN listing hedgehogs as "vulnerable to extinction" in Great Britain (Wembridge et al. 2022). A "National Hedgehog Monitoring Programme" with camera traps and surveys was established involving citizens as volunteers for species identification on camera trap pictures (People's Trust for Endangered Species 2025) to further keep an eye on trends in urban and rural populations, which are still in decline (Wembridge et al. 2022). Additionally, a "National Hedgehog Conservation Strategy" was established mentioning the "decrease in availability of natural food and habitat" and "increase in vehicle collisions" as top priorities to be addressed (IUCN and CPSG 2024).

1.2 Objectives and Research Questions

This research project was prompted by the red list classification of the Western European hedgehog in Hesse and the finding that hedgehog populations are declining not only in rural but also in urban areas (Taucher et al. 2020). In the light of growing concerns about local extinctions in Germany (Berger et al. 2023), and given the lack of studies on habitat use, as well as limited systematic monitoring and conservation efforts for hedgehogs (Gazzard et al. 2025), this project aims to investigate habitat use and mortality factors of hedgehogs in the urban landscape of Hesse, with a special emphasis on landscape variables. This is mostly because ecological variables, e.g. predator and prey abundance, did not seem to be sufficient to fully explain habitat use in hedgehogs.

To address this, a methodological combination was employed: field survey records were complemented with citizen science reports in Bad Homburg to assess hedgehog habitat use at different scales within a medium-sized city in the Rhine-Main metropolitan region. Moreover, citizen science data was used to identify spatial and temporal patterns of hedgehog roadkill in Hesse with a closer analysis of hedgehog road mortality in the Rhine-Main metropolitan region. The overall goal of these investigations was to inform and design targeted conservation actions that can assist to slow down the decline of this species. Accordingly, the key research questions were:

1. What environmental variables drive hedgehog habitat use in Bad Homburg?
2. Which landscape (urban or rural) and land use types are used most frequently by hedgehogs in Bad Homburg?
3. What environmental characteristics are associated with urban hedgehog sightings, and what do they suggest about habitat preferences within urban landscapes?
4. Which are the most frequently reported causes and contexts of hedgehog mortality in citizen science records in Hesse?
5. Are there spatial or temporal patterns in reported hedgehog deaths that indicate high-risk areas or periods per cause in Hesse?
6. Can different land use or road types be linked to an increased risk of hedgehog roadkill?
7. Which conservation actions can be derived from the observed mortality and habitat use patterns?

With regards to habitat use, it was hypothesized that hedgehogs are observed more frequently in the urban than in the rural landscape of Bad Homburg. It was further assumed that the likelihood of hedgehog sightings increases at lesser distances from water, higher temperatures, lower tree densities and lower elevation levels. Scaling down on habitat use in the urban landscape, it was expected that hedgehog sightings are more likely to occur in areas whose type of land use is leisure or residential, at higher distances from main traffic roads, in areas with higher levels of shrubby vegetation cover, and at lower imperviousness densities. In contrast to the total landscape, it was further assumed that the likelihood of a hedgehog sighting increases with increasing distance from water in the urban landscape because of a higher availability of artificial water resources for drinking. A special emphasis was put on the investigation of the role of temperature on hedgehog presence in the overall landscape, and on the influence of shrubby vegetation cover in the urban landscape.

Following the thought that hedgehogs use urban areas more frequently than rural areas, it was hypothesized that hedgehog mortality is most frequently caused by anthropogenic dangers with roadkill being a main issue. It was further assumed that mortality rates are higher during the mating season as males travel long distances during this time and that high traffic roads increase the risk of roadkill significantly.

2 Materials and Methods

2.1 Field Survey

2.1.1 Study Area

Bad Homburg is the district town of the Hochtaunuskreis and includes the main city and five districts: Kirdorf, Gonzenheim, Dornholzhausen, Ober-Eschbach, and Ober-Erlenbach (Magistrat der Stadt Bad Homburg v. d. Höhe 2022). Located 13 km in northwest of Frankfurt am Main (Landesgeschichtliches Informationssystem Hessen 2022), it is considered to be a medium-sized city (Hessen Agentur 2024) in the Rhine-Main metropolitan region.

Bad Homburg has a total area of 51.15 km² (Landesgeschichtliches Informationssystem Hessen 2022) and had 56,000 residents by the end of 2023, with a population density of 1,095 inhabitants per km² (Hessen Agentur 2024). The city features varied topography with elevation levels between 125 metres in the East and 686 metres in the West (Konopatzki 2024) and an average elevation of around 194 metres above sea level (Landesgeschichtliches Informationssystem Hessen 2022). Land use consists of 27 % agricultural and 41 % forest area (Hessen Agentur 2024). As a spa town the settlement areas of Bad Homburg contain lots of parks and green spaces – habitats that hedgehogs favour (Young et al. 2006). Besides the varied landscape, which might provide usable inference for other areas in Hesse, the installment of seven artificial nesting sites for hedgehogs in the city's biggest park ("Kurpark") makes Bad Homburg interesting for sampling. This is the case as conservation interventions with regard to hedgehog are still rare (Gazzard et al. 2025), and the present measure may alter patterns of habitat use by enhancing the suitability and attractiveness of specific habitat types.

Figure 1: Photo of a hedgehog hotel in the "Kurpark" of Bad Homburg. Source: Author's own image.

2.1.2 Survey Design

For the field survey, 50 transect starting points were randomly placed in Bad Homburg using the random points tool in ArcGIS Pro with a chosen distance of 1000 metres to generate approximately one point per square kilometre. This was done to avoid bias and ensure representability across the wider area. For accessibility reasons, the points had to be manually moved to the closest path or road with the Digital Landscape Model (DLM) of Hesse as a reference (Hessisches Landesamt für Bodenmanagement und Geoinformation 2025b). Another manual adjustment had to be done because 68 % of the total area of Bad Homburg are dominated by rural areas like forest and agriculture, which is why the random points tool placed more points there. However, a partial distribution of transects was desired to ensure representability with regard to the question, if habitat use varies between urban and rural areas. To address this, some starting points were moved from rural to urban areas to achieve 25 transects in urban and 25 transects in rural environments.

Locations were then loaded into the app "Gaia GPS" on the investigator's smartphone, which was used in the field to record location information of the 50 transect lines to be walked. While the directions in which the transect lines were walked were predetermined by paths and streets, the chosen length was 500 metres each. This distance was found to be reasonable to detect some hedgehogs, while avoiding any double counting due to their walking distances per night (Hubert et al. 2011). "Gaia GPS" was also applied to record location information on detected hedgehogs as well as temperature and precipitation during each walk. The app sources this information from the National Oceanic and Atmospheric Administration Weather Prediction Center for each transect location (Outside Interactive Inc. and Trailbehind Inc. 2025). This was found to be more precise than usual weather apps, which only showed one temperature for Bad Homburg as a whole. Positional accuracy for field GPS points in Bad Homburg is estimated at ± 5 to 20 metres, depending on local conditions.

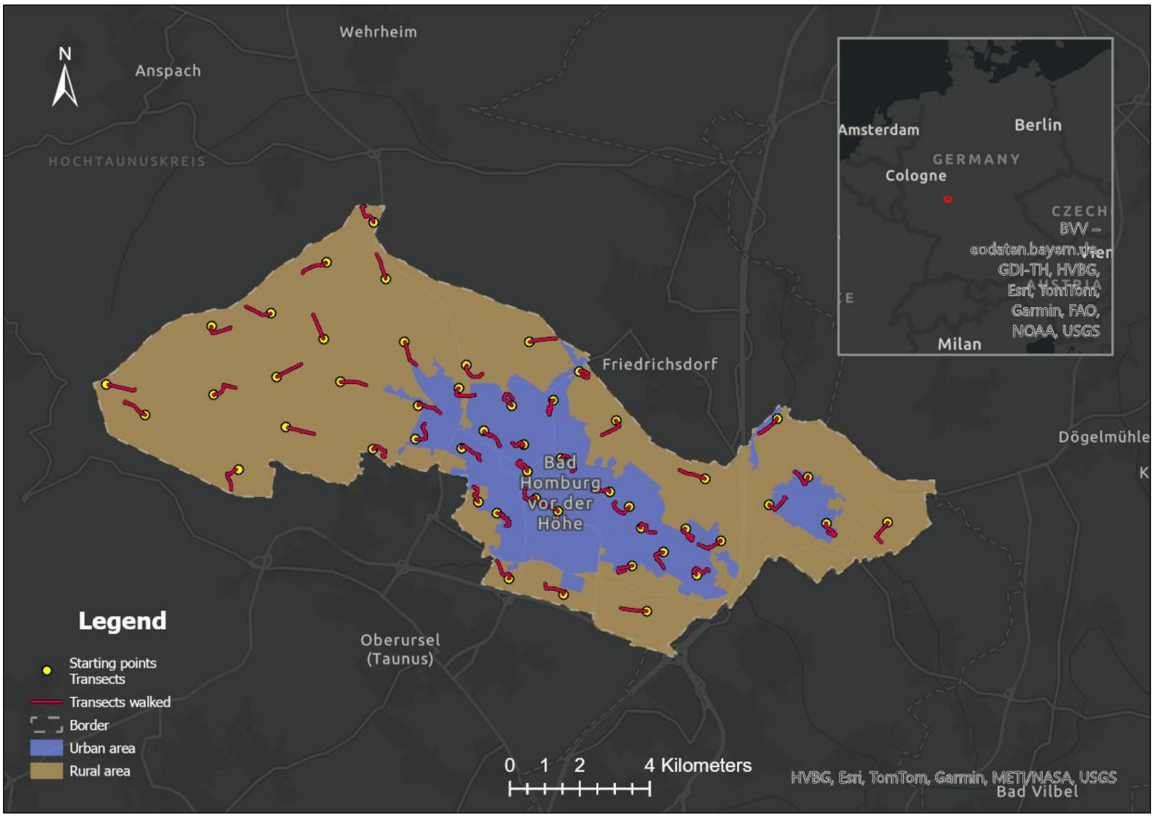

Figure 2: Map of Bad Homburg showing the relative proportions of urban and rural landscape as well as the spatial distribution of the 50 transect lines and their starting points. The inset map illustrates Bad Homburg's spatial location in Germany. Source: Author's own illustration.

Transect lines were walked at nighttime using a thermal imaging camera (FLIR E6 with a 240 × 180 thermal resolution), which was found to be sufficient for data collection given an average body temperature of 35 °C in hedgehogs (Fowler and Racey 1990, Herter 1934) and cooler night temperatures in May in the Frankfurt area (Wetter2.com 2025). There are other ways of sampling hedgehogs, for example via footprint tunnels to estimate relative population size, camera traps or the use of a torch (Berger et al. 2023). However, thermal imaging cameras like the FLIR E60 have proven to be effective for hedgehog sampling in the past as they are able to detect hedgehogs at greater distances than it would be possible with a torch (Bowen et al. 2019) and enable the investigator to ensure the collection of data from different individuals, which can be problematic with camera traps or footprint tunnels.

During the walks, the temperature range of the camera was manually set to approximately 10 °C minimum and 15 to 18 °C maximum temperature depending on the surrounding temperature with “above alarm” being the chosen colour range. Alarm temperature has been varied between 15 and 18 °C, again according to night temperature. These settings were chosen to ensure a sufficient contrast given the higher body temperature of the hedgehog.

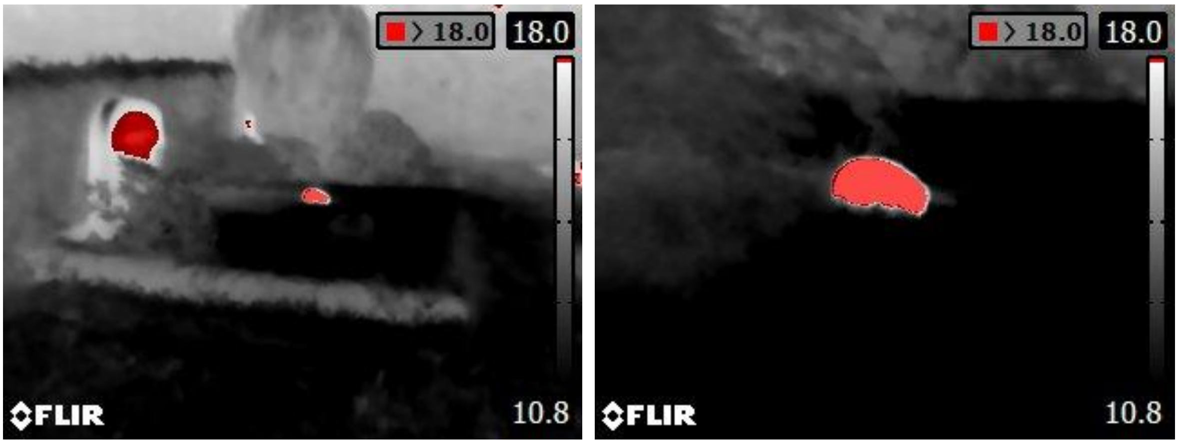

Figure 3: Photos of a detected hedgehog on a cemetery to illustrate the settings of the FLIR E6. Source: Author’s own image.

A stop every 10 metres allowed to scan the surroundings carefully for hedgehogs with the FLIR E6. If a hedgehog was detected and the walking noise of the investigator was not sufficient to stop it from moving, an additional hand torch was shone onto the individual to make it freeze as suggested in the literature (Bowen et al. 2019).

Approximately three transect lines were walked each night from Sunday to Thursday for 17 days starting from the 12th of May 2025. As the sun set between 9 and 9.30 pm in Bad Homburg between the middle to the end of May (Time and Date AS 2025), the night walks started around 10 pm, where hedgehogs were already out foraging. Another advantage that comes with the season is their enhanced activity due to the mating season.

Lastly, collected information was summed up in an excel spreadsheet with columns for transect number, survey date, temperature, precipitation, coded information if hedgehogs were detected (1 = hedgehog sighting, 0 = no hedgehog sighting), the amount of hedgehogs detected, and a column for comments. Hedgehogs were not picked up to ensure a minimum invasive survey method and reduce any disturbance.

The study design reflects the original intention of this project to estimate hedgehog population density within Bad Homburg using distance sampling. While the study design itself proved to be sufficient for this cause, the limited time frame prevented to get the necessary sample size of at least 50 individuals. The revised focus on habitat use and causes of mortality in hedgehog allowed to make full use of the collected data while developing conservation implications critical for hedgehogs to thrive again.

2.2 Citizen Science Data

The Hessian Agency for Nature Conservation, Environment and Geology (HLNUG) initiated a reporting platform for hedgehog sightings, either dead or alive, in April 2024 to better address the problem of data deficiency on hedgehog numbers and population trends in Hesse (Glatzle n.d.). Every citizen is eligible to report hedgehog observations in Hesse, which makes it opportunistic data. Although the collected reports are visualised on a publicly accessible map (Terra GmbH 2025), the underlying dataset is not publicly available and was provided by HLNUG specifically for this research project. The provided data set contained reports from May 2024 to April 2025 and occasionally reports dating back to the year 2023. Observations were categorized into alive, dead (roadkill), and dead (other causes). The data set also held information on the location a hedgehog was seen (accurate to approximately 100 metres), the amount of individuals observed and a column for comments.

2.3 Spatial Data

Landscape and land use types were defined based on the DLM Hesse (Hessisches Landesamt für Bodenmanagement und Geoinformation 2025b). While the landscape was divided into “rural” and “urban” corresponding to areas defined as continuously built-up areas in the DLM (Arbeitsgemeinschaft der Vermessungsverwaltungen der

Länder der Bundesrepublik Deutschland 2022), land use types included forest, agriculture, residential, industrial, mixed use, municipal (hospitals and schools) and leisure (sports- and playgrounds, parks, cemeteries). Information on the microhabitat a hedgehog was found in was recorded in the field for the survey data and, if filled, extracted from the comments column for the citizen science data. This categorisation system was chosen because there is no universal scheme to classify habitats in an urban setting, which is mostly due to the fact that urban habitats are highly diverse and changing fast (Elmqvist et al. 2008). It is therefore difficult to distinguish where one habitat category ends and another begins (Fodor and Hâruţa 2015).

Other spatial information used included raster layers on tree density (resolution 20 metres), imperviousness density (resolution 10 metres), and shrubby vegetation cover (resolution 5 metres), which were obtained from Copernicus (European Environment Agency 2018, 2020, 2023). NDVI was calculated with the tool "NDVI colorized" provided by ArcGIS based on Band 4 and 8a extracted from a Sentinel 2 Level 2a with a 20 metre resolution (European Space Agency 2025). Distance to water and distance to main road were calculated with locations of main roads based on the DLM250 (Bundesamt für Kartographie und Geodäsie 2023a) and the location of waterbodies in the DLM Hesse (Hessisches Landesamt für Bodenmanagement und Geoinformation 2025b) in combination with a digital elevation model (DEM) for Bad Homburg with a 1 metre resolution (Hessisches Landesamt für Bodenmanagement und Geoinformation 2025a). The latter was also used to calculate mean elevation levels. Road types were classified based on the DLM Hesse. Other layers used were spatial information on borders of Germany (Bundesamt für Kartographie und Geodäsie 2023b), metropolitan regions (Esri Deutschland 2021) and counties (Bundesamt für Kartographie und Geodäsie 2024).

2.4 Alternative Data Sources

Alternative data sources like hedgehog intakes in wildlife rescues were explored as they might have conservation related impacts (Gazzard et al. 2025). However, this data source was rejected again due to data fragmentation and the lack of a central rescue facility in Bad Homburg. This decision also avoids the risk of duplicated sightings from both citizen scientists and rescue intakes. The same is true for another nationwide citizen science project with regard to hedgehog sightings (Berger and

Knoblauch 2024) or the hedgehog database available from the Global Biodiversity Information Facility (GBIF Secretariat 2023).

2.5 Data Analysis

2.5.1 Habitat Use and Preference

2.5.1.1 Landscape Scale

To investigate habitat use in hedgehogs and relevant environmental predictors in an urban region on a macro scale, the field survey data was assessed using ArcGIS Pro (version 3.2.497) and R (version 4.5.0). While ArcGIS was applied to divide every 500 m transect line into five separate sub transect lines equal in length to create a bigger sample size (250), R was used to fit a GLM with interaction using a binomial error distribution and logit link function. Chosen environmental predictors with relevance on the landscape scale were: mean distance to water as water shapes landscapes and hedgehogs generally depend on water like most mammals, mean elevation because it is an important topographic variable due to its linkage with climatic conditions which shape landscapes and ecosystems, and because hedgehogs are typically found in low lying regions with maximum elevation levels of 400 to 600 metres (Gazzard et al. 2023), temperature as this might be a decisive factor for hedgehogs with regard to habitat use (Berger et al. 2023, Hubert et al. 2011), precipitation as a second climatic variable, landscape type (urban or rural) to test for a preference of urban areas, and tree density (European Environment Agency 2018) to assess if hedgehogs utilize more open or forested areas with regard to the total landscape. Moreover, some interaction terms were included to investigate the effects of temperature more closely. In particular, the interaction between temperature and the landscape category "urban" was included to assess whether temperature helps explain why hedgehogs prefer urban habitats as suggested by the literature (Berger et al. 2023, Hubert et al. 2011).

Additional interactions were incorporated to examine the influence of temperature on general habitat use when combined with other factors: with mean tree density, as hedgehogs tend to avoid heavily forested areas, and with distance to water, as hedgehogs may select habitats near water on warmer days as those are typically cooler. Precipitation was removed from the GLM as it was constant (0 mm) throughout the survey period, which made it uninformative. Remaining predictors were checked for multicollinearity based on VIF, applying a threshold of VIF > 5. ArcGIS was applied to calculate mean distance to water and mean elevation per transect. Tools used were: “Split Line into equal parts”, “Generate Points along Lines” with a distance of 20 metres, “Distance Accumulation”, “Extract Multi Points to Values” and “Summary Statistics”.

Despite the violated assumption of the binomial error distribution (dispersion parameter > 2), the distribution was used to allow a stepwise selection of predictor variables based on AIC. The best fitting model was recalculated with a quasi-binomial error distribution and logit link function. Model fit was further evaluated by examining whether the residual deviance decreased relative to the null deviance, and by calculating Tjur’s r^2. With regard to binary response variables, Tjur’s r^2 is defined as the difference of the mean predicted probability of both variables (Wollschläger 2012). Values approaching 1 indicate a better fit and greater explained variation in the response variable. Moreover, AUC was calculated to assess the model’s discriminatory power. Values exceeding 0.7 were interpreted as satisfactory as they translate to a good discriminatory power in 70 percent of cases. However, as AUC was calculated based on the same data on which the model was trained, it might only serve as an indication as an overestimation of the predictive accuracy is likely.

For further exploration of habitat use of hedgehogs in the total landscape, survey detections (n = 16) were combined with reports of alive hedgehogs from citizen scientists (n = 29) in Bad Homburg. The latter were cleaned to avoid doublets and records submitted prior to April 2024 to ensure temporal consistency and data reliability. A map with proportional symbols for the amount of reported hedgehog in an area colorised according to data source and landscape type, and a bar chart to illustrate the amount of observed hedgehogs per land use type were produced using ArcGIS and R.

2.5.1.2 Urban Habitat Scale

As more hedgehogs were observed in the urban landscape by the investigator (n = 12, after exclusion of one observation in a new development areas that is not yet included in the 2018 spatial data on imperviousness density) as well as citizen scientists (n = 28), the decision was made to combine the reports (n = 40) to follow the aim of a more detailed assessment of hedgehog habitat use and preferences within the urban landscape of Bad Homburg. This area was defined based on the “continuously built-up area” specified in the DLM Hesse. To receive a binary response variable, 500 pseudo absences were created within the predefined area using the “random points” tool provided by ArcGIS.

A GLM with quasi-binomial error distribution and logit link function with was fitted to assess potential relationships between hedgehog sightings with environmental predictors. Chosen predictors on the urban scale differed from those that were selected for the total landscape due to the expectancy that they exert their effects primarily in urban settings, where habitat structure, human activity, and resource distribution differ markedly. Selected predictors were: imperviousness density as a proxy for habitat fragmentation within cities, which hedgehog can tolerate at intermediate (Berger et al. 2020) but not high levels (Turner et al. 2021), distance to water as hedgehogs seem to prefer habitats at greater distances from water in the urban landscape (Turner et al. 2021), distance to closest main road because they act as main barriers within the urban landscape (Rondinini and Doncaster 2002), land use type because of the high variety of land use types within urban landscapes, and because hedgehogs are thought to occur more frequently in residential and leisure areas and associated habitats like gardens or parks (Turner et al. 2021, Young et al. 2006), shrubby vegetation cover as an important natural habitat feature for shelter (Berger et al. 2023) as well as foraging, and NDVI as an indicator for green spaces, which again are important for foraging.

However, NDVI had to be rejected later due to high levels of multicollinearity and correlation with imperviousness density. Percentages of shrubby vegetation cover and imperviousness density were calculated in ArcGIS for 150 and 250 metre buffer zones to allow the investigation of fine-scale habitat preferences while paying off for spatial inaccuracies in citizen science data. Results indicated that it made sense to use the smaller buffer for shrubby vegetation cover as it has a more direct effect on hedgehog presence while the effect of imperviousness density acts indirectly.

To allow a closer investigation of the positive effects of shrubby vegetation cover and the expected change of the effect of the predictor “distance to water” compared to the total landscape scale, two interaction terms were included in the model: the interaction between distance to water and shrubby vegetation cover, and a three-way interaction between distance to water, shrubby vegetation cover, and imperviousness density. Both were included because the negative effects of high imperviousness density and proximity to water were expected to be partially mitigated by the positive influence of higher levels of shrubby vegetation cover, thus proving the relevance of this habitat feature with regard to hedgehog conservation.

To adjust the model fit in R a stepwise selection of predictors based on AIC was performed despite violated assumption of the binomial error distribution (dispersion parameter > 2). The final GLM was then recalculated using a quasi-binomial error distribution and logit link function. To evaluate the model fit, AUC and Tjur's r^2 were calculated. The robustness of the GLM was tested against four more data sets containing the same presence but different pseudo absence data ($n = 500$) which again was created using the "random points" tool in ArcGIS.

Significant predictors and interactions were visualised using prediction grids, which involve creating a raster of combinations of the significant predictors while holding non-significant variables constant (e.g., at their mean). The only exception from this rule was temperature in the plot "Effect of Tree Density on Hedgehog Sighting Probability" (Figure 4) where temperature was fixed at 12 degrees to allow the visualization of the negative effect of higher tree densities on hedgehog presence. This was not possible with mean temperature, because of its relatively high value and a positive interaction with tree density. While one predictor was set as the continuous explanatory variable, others were divided into meaningful categories (e.g. 10th, 50th, and 90th percentiles to represent low, medium, and high levels of the variable) to display the interaction effects. Grids were then passed through the final fitted models to obtain predicted response values and create meaningful plots.

2.5.2 Hedgehog Mortality

2.5.2.1 Causes, Spatial and Temporal Patterns in Hesse

Hedgehog's preference for urban habitats implicates a higher exposure to human-made dangers as well. To investigate mortality causes in hedgehogs, a subset of the citizen science data set was created containing only dead (roadkill) and dead (other causes) reports in Hesse. The data was cleaned as many reports were categorized as dead (other causes) despite mentioning “roadkill” as a reason of mortality in the comments section. The comments column was also used to extract details on mortality causes for the remaining dead (other causes) reports. Furthermore, records submitted prior to April 2024, and at approximately the same location with the same reporting date were excluded from the analysis. Reports in spatial proximity, where the difference in reporting dates was < 1 day were kept to ensure the capture of possible hedgehog crossing points (Haigh et al. 2014) by the data.

The data was descriptively explored using bar charts. R was used to visualise the amount of mortalities per cause. Causes were roadkill and reports of hedgehogs dead (other causes), which were manually subdivided into drowned, mowing, starvation, injury, disease, predation, cannibalism, and missing information based on the comments section to allow potential conclusions for conservation. Another bar chart was used visualise reported deaths per month to assess temporal patterns. Additionally, a Kernel density analysis (cell size of 1 km²) was applied to investigate spatial patterns in roadkill and dead (other causes). Two heat maps were created to visualise hotspots per cause.

2.5.2.2 Roadkill Assessment Rhine-Main Metropolitan Region

Based on the Kernel density, investigations on habitat use in Bad Homburg and the overall aim to assess habitat use and mortality causes especially with regard to urban areas, it was decided to restrict the area of Hesse to the Rhine-Main metropolitan region for the roadkill analysis. 1,000 pseudo absence points of roadkill were generated using ArcGIS. Vertices were added to the road network within the Rhine-Main metropolitan region every 100 metres using “Densify”. Next, “Points at Vertices” was applied and a random value assigned to each point. After sorting these values in ascending order, the first 1,000 points were selected to serve as a representative sample of potential non-mortality locations.

R was applied to fit a GLM to the dead (roadkill) presence and absence data to assess potential relationships between hedgehog roadkill and covariates describing urbanization. Chosen predictor variables were: type of road, and dominant type of land use, which was calculated based on the total area per land use type within a 250 metre buffer. Tools used were “Intersect” and “Summary Statistics”. Road types were reclassified based on expected traffic volume and allowed speed limits with regard to wildlife permeability: highways and major federal roads were reclassified as high traffic roads, whereas regional and district roads became medium traffic roads, and local or non-public roads low traffic roads. Predictors were checked for multicollinearity according to VIF. Then, a logistic regression using a binomial error distribution and logit link function with and without interaction between all covariates was performed on the data. It was examined, whether the assumptions of the model (dispersion parameter close to 1) were met, which was then followed by a stepwise selection of predictors based on AIC.

For model validation, Tjur’s r^2 was calculated, and four more data sets were generated with the same mortality presences but different pseudo absence data (n = 1,000). Significant relationships were plotted. R packages used in both parts of the analysis were: tidyverse, ggpubr, viridis, broom, car, pROC, and performance analytics.

3 Results

3.1 Habitat Use and Preference

3.1.1 Landscape Scale

During the field survey 16 hedgehogs were detected on 12 of the 250 sub transect lines sampled across Bad Homburg. The best fitting model was a GLM with quasi binomial distribution as the dispersion parameter was > 2, logit link function and selected 2-way-interaction terms. The model output showed that mean tree density had a significant negative effect on the probability of hedgehog sightings. Additionally, a significant positive interaction between mean tree density and temperature was identified, suggesting that the negative effect of dense forest cover is attenuated at higher temperatures. Temperature itself showed a marginal significance ($p = 0.0566$).

term	estimate	std.error	statistic	p.value	Significant
(Intercept)	19.254748242	11.873393658	1.621672	0.10618113	
mean_tree_dens_percent	−0.173661083	0.083423370	−2.081684	0.03842700	**
mean_elevation_m	−0.003801691	0.003230741	−1.176724	0.24046650	
temperature_degrees_celsius	−1.568542935	0.818812846	−1.915631	0.05659550	
mean_dist_water_m	−0.021018743	0.018394424	−1.142669	0.25430984	
landscape_caturban	−11.954575574	9.154529071	−1.305865	0.19284370	
mean_tree_dens_percent:temperature_degrees_celsius	0.012860362	0.005812385	2.212579	0.02786466	**
temperature_degrees_celsius:mean_dist_water_m	0.001376311	0.001213359	1.134298	0.25779657	
temperature_degrees_celsius:landscape_caturban	0.918079646	0.629393119	1.458674	0.14595678	

Table 1: Summary of regression coefficients from modeling habitat use of hedgehog on the land-scape scale with mean tree density, mean elevation, mean temperature, mean distance to water, landscape category (urban or rural), and relevant interaction terms as chosen predic-tors. Source: Author's own calculations.

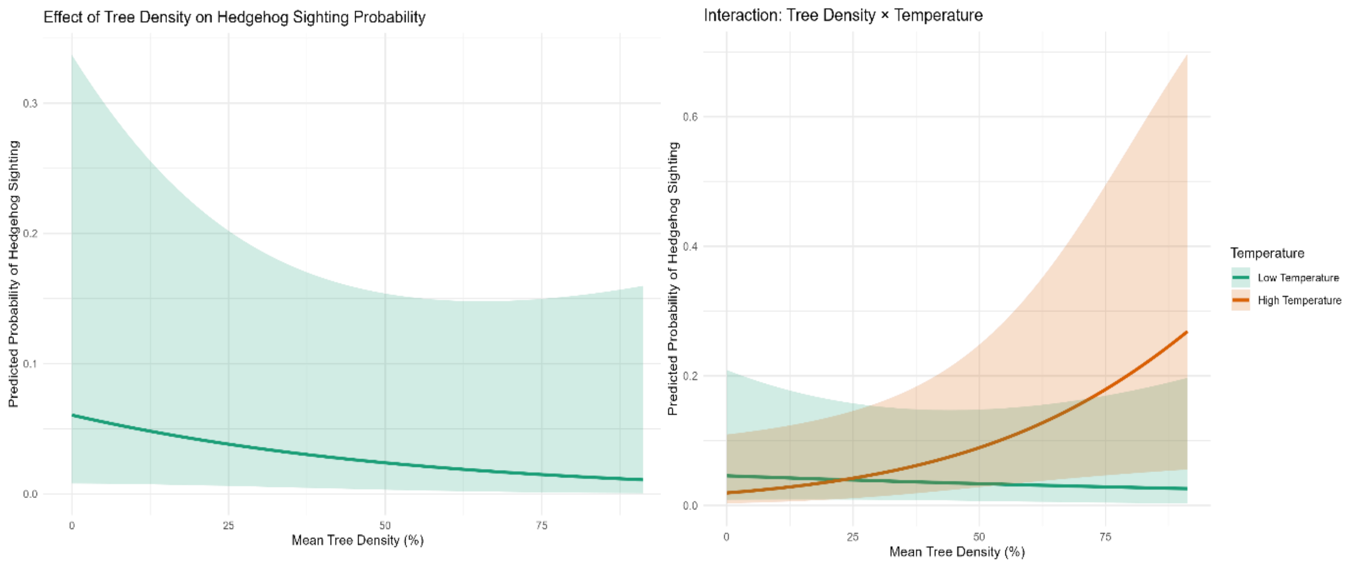

Figure 4: Plots of significant predictors at the landscape scale, illustrating the significantly negative effect of mean tree density on hedgehog sighting probability (left), and its significant interaction with temperature, where the effect reverses and becomes positive at higher temper-atures (right). Source: Author's own illustrations.

The model achieved an AUC of 0.80, indicating good discriminatory ability between sightings and absences. This value is substantially higher than the commonly used threshold of 0.70, providing a buffer to account for potential overestimation. Despite a moderate Tjur's r^2 of 0.10, the model shows a useful predictive power on the occur-rence of a hedgehog sighting as the zero deviance was 96.29 on 249 degrees of freedom and could be reduced to 80.54 on 241 degrees of freedom by the predictors chosen.

For further investigation of habitat use, and to increase the sample size, citizen science reports of alive hedgehog sightings in Bad Homburg were combined with field survey detections and assessed descriptively. In the field survey, three hedgehogs were recorded in the rural landscape and 13 in the urban landscape of Bad Homburg. In comparison, citizen scientists reported 29 hedgehog sightings in the same area, all but one in urban environments.

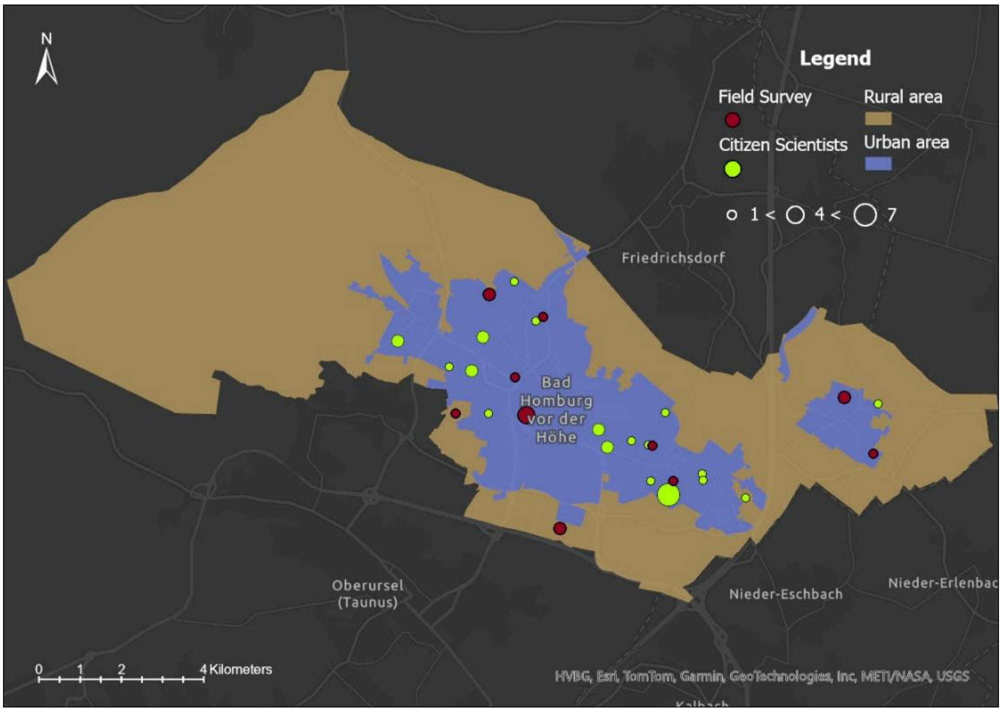

Figure 5: Map to illustrate counted hedgehogs per landscape type and data source in Bad Homburg. Source: Author's own illustration.

Figures 5 to 7 and tables 2 and 3 are partially based on data from the Hessian Agency for Nature Conservation, Environment and Geology (HLNUG).

The land use types hedgehogs were found in showed a trend towards leisure areas in the field survey and residential areas in citizen science reports. 17 of the 29 hedgehogs reported by citizen scientists were found in private gardens. For the field survey, seven detections were on – or in direct proximity to – playgrounds, five in parks and four on cemeteries. Twelve of the 16 detections were on lawns, while four were associated with hedgerows as a habitat type. No hedgehogs were detected or reported in forests, industrial areas or the big parks: "Kurpark" and "Jubiläumspark".

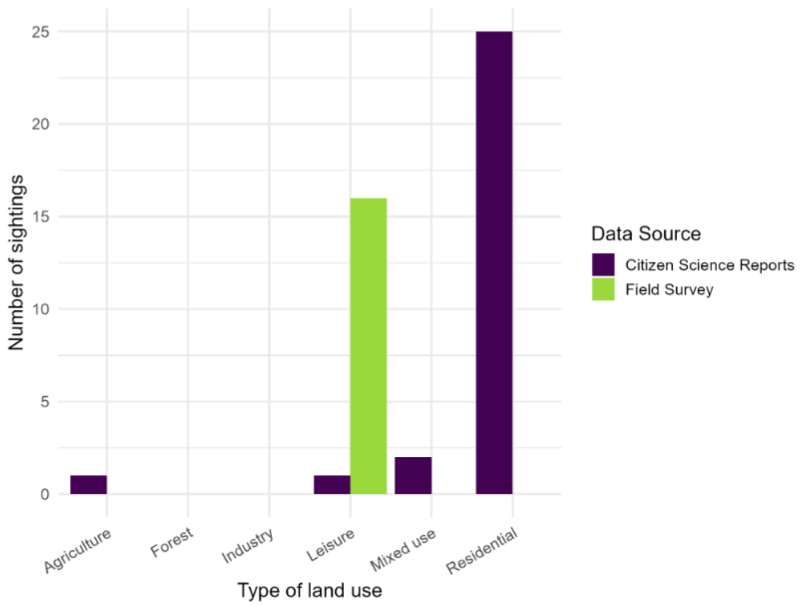

Figure 6: Bar chart to display hedgehog sightings per data source by types of land use. Source: Author's own illustration.

3.1.2 Urban Habitat Use

The GLM on habitat use in the urban landscape, fitted with a quasi-binomial error distribution and logit link function, revealed two statistically significant interaction terms affecting the predicted probability of a hedgehog sighting: the first between distance to water and shrubby vegetation cover within a 150 m radius, and the second between distance to water, imperviousness density within a 250 m radius, and shrubby vegetation cover. The negative coefficient of the two-way interaction term suggests that a higher proportion of shrubby vegetation increases the likelihood of hedgehog sightings even in proximity to water. This indicates an interdependency of both factors, which is further supported by the positive the three-way interaction term where higher levels of shrubby vegetation appear to mitigate the negative effects of higher imperviousness densities even in proximity to water.

term	estimate	std.error	statistic	p.value	Significant
(Intercept)	−1.978204e+01	1.219701e+03	−1.621876e-02	0.987065986	
distance_water_m	1.347161e-03	2.171149e-03	6.204828e-01	0.535207164	
distance_main_road_m	−3.514998e-04	9.760490e-04	−3.601252e-01	0.718897235	
imperviousness_density_percent_250m_radius	−1.412026e-02	1.824688e-02	−7.738455e-01	0.439367845	
land_useleisure	1.849071e+01	1.219701e+03	1.516004e-02	0.987910218	
land_usemixed use	1.608470e+01	1.219701e+03	1.318741e-02	0.989483243	
land_usemunicipal	1.672782e-01	1.840362e+03	9.089415e-05	0.999927511	
land_useresidential	1.705715e+01	1.219701e+03	1.398470e-02	0.988847463	
prop_shrubby_veg_percent_150m_radius	1.110775e-02	2.349926e-02	4.726853e-01	0.636632697	
distance_water_m:prop_shrubby_veg_percent_150m_radius	−4.278641e-04	1.495059e-04	−2.861854e+00	0.004378482	**
distance_water_m:imperviousness_density_percent_250m_radius:prop_shrubby_veg_percent_150m_radius	1.423554e-05	4.231314e-06	3.364330e+00	0.000822941	**

Table 2: Summary of regression coefficients from modeling habitat use of hedgehog in the urban landscape with mean distance to water, mean distance to main road, mean imperviousness density within a 250 metre radius, types of land use, proportion of shrubby vegetation cover within a 150 metre radius, and relevant interaction terms as chosen predictors. Source: Author's own calculations.

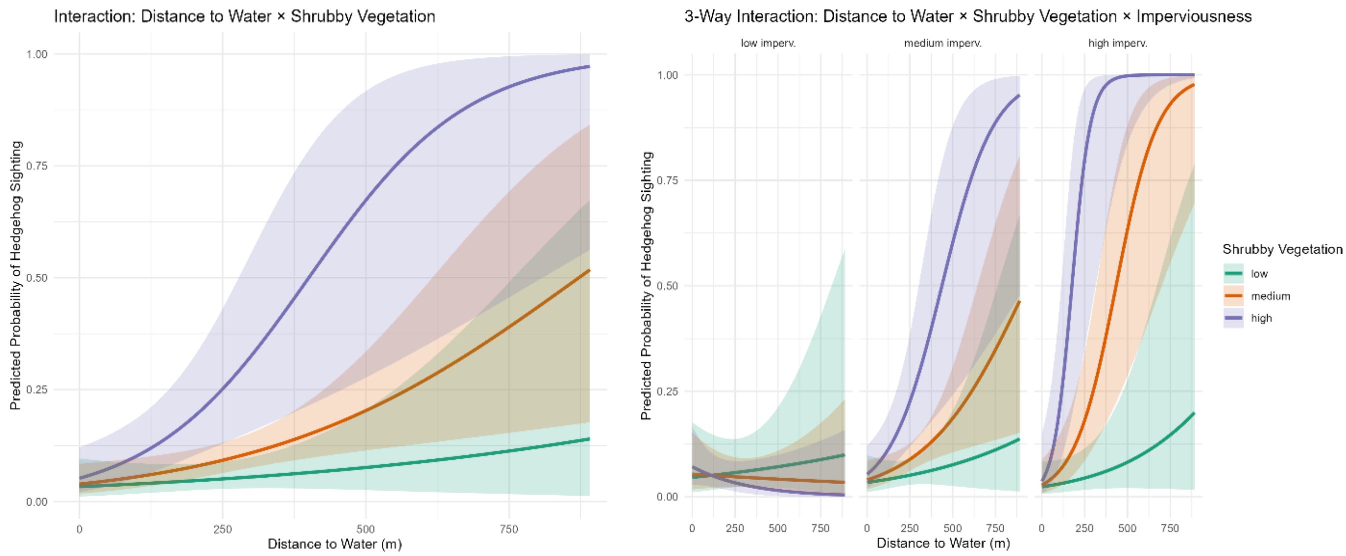

Figure 7: Plots of predictor interactions with a significant effect on hedgehog sighting probability in the urban landscape, illustrating the significantly negative effect of the interaction between mean distance to water and shrubby vegetation cover on hedgehog sighting probability (left), and the significantly positive effect of the three-way-interaction between mean distance to water, shrubby vegetation cover, and mean imperviousness density (right). Source: Author's own illustrations.

The GLM showed an improved explanatory power on the occurrence of a hedgehog sighting compared to simpler models without interaction, with an AUC of 0.78 and a Tjur's r^2 of 0.08, indicating a good classification performance and moderate model fit. Compared to the null model, the full model shows a good predictive power, reducing the deviance from 285.18 to 239.77. Tests against four more data sets containing different pseudo absence data supported the significance of the two interaction terms with the two-way interaction showing a robust negative association and the three-way interaction a stable positive effect on the probability of hedgehog sightings.

term	mean_coef	sd_coef
(Intercept)	-1.946475e+01	1.116775e+00
distance_main_road_m	-4.458072e-04	6.926815e-04
distance_water_m	2.216746e-05	1.697656e-03
distance_water_m:imperviousness_density_percent_250m_radius:prop_shrubby_veg_percent_150m_radius	1.881683e-05	4.032585e-06
distance_water_m:prop_shrubby_veg_percent_150m_radius	-5.120756e-04	5.840034e-05
imperviousness_density_percent_250m_radius	-1.631319e-02	1.334351e-02
land_useleisure	1.876318e+01	6.222203e-01
land_usemixed use	1.607890e+01	3.169555e-01
land_usemunicipal	-6.832065e-02	5.744922e-01
land_usemunicipal	1.672782e-01	NA
land_useresidential	1.698879e+01	4.552296e-01
prop_shrubby_veg_percent_150m_radius	-7.125298e-04	1.897828e-02

Table 3: Mean coefficients and standard deviations of GLM on habitat use in the urban landscape across five data sets containing different pseudo absences. Source: Author's own calculations.

3.2 Hedgehog Mortality

3.2.1 Causes, Spatial and Temporal Patterns in Hesse

173 reports of hedgehog mortalities were identified in the citizen science data set. With 115 reports of roadkill, roadkill was the cause of mortality that was reported most frequently in Hesse. For the dead (other causes) reports, only a few reports featured detailed information on the actual causes in the comments column. While three juvenile hedgehogs were reported to have been killed by a male hedgehog, two hedgehogs were reported as drowned (both in a pond, once despite an exit aid), two more were reported as dead after a mowing event, and two showed signs of disease. One hedgehog each was reported as starved, killed by the Eurasian eagle owl, and injured. 50 hedgehogs were reported as dead (other causes) with no additional information, labelled as “missing information” in the bar chart.

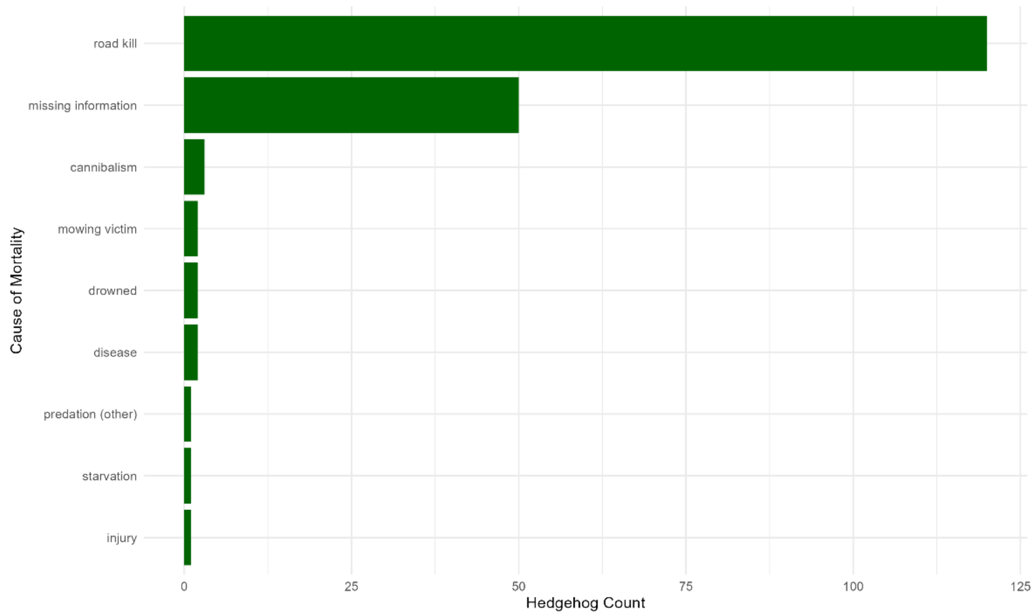

Figure 8: Bar chart of counted hedgehogs per cause of mortality. Source: Author's own illustration.

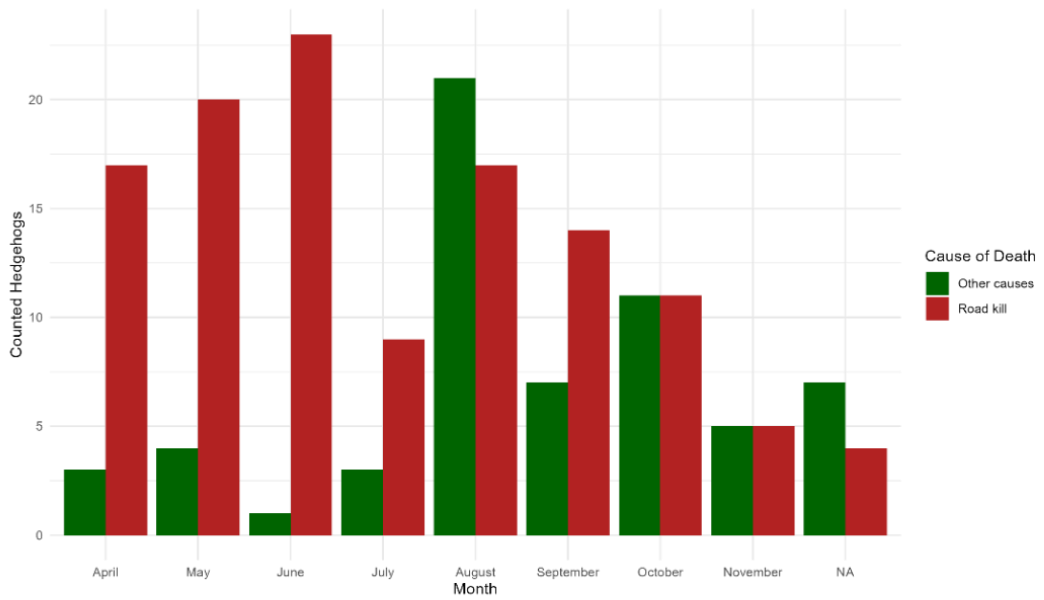

Figure 9: Bar chart of counted hedgehogs per cause of death and month. Source: Author's own illustration.

Figures 8 to 11 and tables 4 and 5 are based on data from the Hessian Agency for Nature Conservation, Environment and Geology (HLNUG).

The number of reported hedgehogs per mortality cause varied temporally with most reported road mortalities from April to June and in August, peaking in June. Dead (other causes) reports were most prevalent from August to September with a peak in

August. Due to hibernation, reports started in April and ended in November 2024. Undated reports were displayed as “NA”.

In addition to temporal trends, there were spatial trends identified in hedgehog mortalities per cause based on a Kernel Density analysis. The analysis indicated mortality hotspots in the rural district Gießen and the cities Frankfurt am Main, Offenbach am Main including rural district Offenbach for roadkill, and rural districts Gießen, Offenbach as well as the city of Darmstadt for hedgehogs reported as dead (other causes).

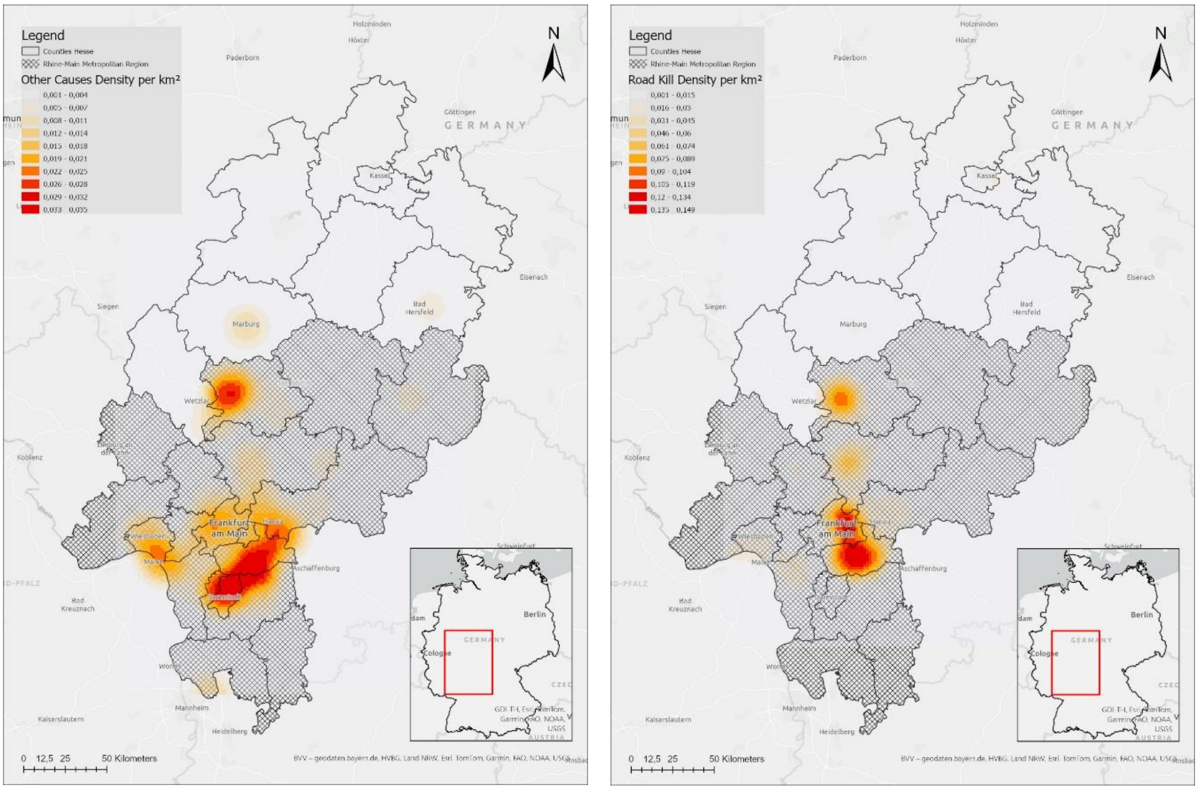

Figure 10: Heat maps of hedgehog deaths (left: dead other causes, right: dead roadkill) in Hesse based on a Kernel density analysis. Source: Author’s own illustrations.

3.2.1 Roadkill Assessment Rhine-Main Metropolitan Region

Because roadkill appeared to be the main cause of mortality for hedgehogs in Hesse and seemed to occur most frequently in the Rhine-Main metropolitan region (114 road victims with 39 being killed on high, 33 on medium and 42 on low traffic roads), the potential relationship of roadkill with factors of urbanization were assessed for the area. A GLM with binomial error distribution, logit link function, without interaction and two predictors (road and land use type) was chosen as the best fitting model

(AIC: 656.61). The final model revealed four significant predictors: low and medium traffic roads as well as land use type “leisure” and land use type “residential”. Because “high traffic road” was used as a reference category in the model, the negative effect of low and medium traffic roads indicates a significantly lower probability of hedgehog roadkill on those road types compared to high traffic roads, which in turn indicates a higher probability of hedgehog roadkill on high traffic roads. The positive effects of leisure and residential area, indicate a significantly higher probability of hedgehog roadkill at road segments that are mainly surrounded by those land use types. Both contexts are illustrated in Figure 11.

term	estimate	std.error	statistic	p.value	Significant
(Intercept)	−0.6040352	0.2413380	−2.502859	1.231944e−02	**
Road_typelow traffic road	−2.7768683	0.3174568	−8.747232	2.186490e−18	**
Road_typemedium traffic road	−1.5297090	0.2884365	−5.303451	1.136335e−07	**
Dom_land_use_type_250mforest	−0.5784210	0.4086463	−1.415456	1.569347e−01	
Dom_land_use_type_250mindustry	−0.3491290	0.5355306	−0.651931	5.144457e−01	
Dom_land_use_type_250mleisure	1.4955271	0.6077406	2.460798	1.386282e−02	**
Dom_land_use_type_250mmixed use	−0.8511529	0.7520520	−1.131774	2.577294e−01	
Dom_land_use_type_250mresidential	0.8916690	0.2793507	3.191935	1.413234e−03	**

Table 4: Summary of regression coefficients from modeling hedgehog roadkill probability within the Rhine-Main metropolitan region with type of road (high, medium or low traffic road), and dominating type of land use within a 250 metre radius as chosen predictors. Source: Author’s own calculations.

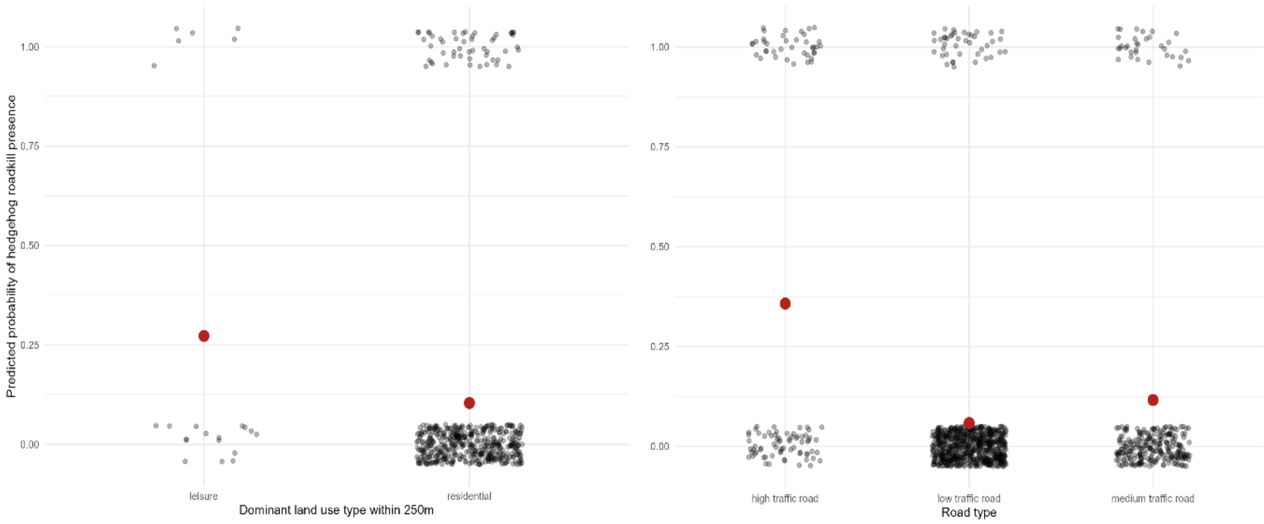

Figure 11: Scatter plots of predictors with a significant effect on the predicted probability of hedgehog roadkill in the Rhine-Main metropolitan region. Left: Predicted probability of roadkill increases at street segments predominantly surrounded by leisure or residential areas. Right: Roadkill probability increases across all road types, with high traffic roads posing the greatest risk. Source: Author’s own illustrations.

The final model explained approximately 11 % of the variance in hedgehog roadkill (Tjur's $r^2 = 0.1123$). Although this is a moderate effect size, the model shows a useful predictive power regarding the occurrence of hedgehog roadkill as the null deviance was 735.64 on 1113 degrees of freedom and could be reduced to 640.61 on 1106 degrees of freedom by the two predictors.

To verify the robustness of the model, the data set was tested against four more data sets containing different random pseudo absences. Land use type "residential" showed a strong significance in all data sets, while "leisure" was significant in four of five. Positive mean coefficients and a low mean standard deviation for "residential" and relatively low mean standard deviation for "leisure" support the robustness of the two predictors. For the road types, "low traffic roads" and "medium traffic roads" showed a strong significance in all data sets, with consistently negative mean coefficients and low mean standard deviations, supporting the robustness of those two predictors as well.

term	mean_coef	sd_coef
(Intercept)	−0.6233605	0.2015456
Dom_land_use_type_250mforest	−0.6721440	0.1222247
Dom_land_use_type_250mindustry	−0.2121972	0.1844634
Dom_land_use_type_250mleisure	1.4740425	0.2673609
Dom_land_use_type_250mmixed use	−0.9159107	0.2556099
Dom_land_use_type_250mresidential	0.8104198	0.1380572
Road_typelow traffic road	−2.7147351	0.2865093
Road_typemedium traffic road	−1.4082297	0.2080603

Table 5: Mean coefficients and standard deviations of GLM on hedgehog roadkill probability in the Rhine-Main metropolitan region across five data sets containing different pseudo absences. Source: Author's own calculations.

Furthermore, there was a consistently negative relationship between the predicted occurrence of a hedgehog roadkill and land use type forest – a predictor that showed a marginal significance in three of the five models. This would indicate a lesser occurrence of hedgehog roadkill at street segments directly surrounded by forest. However, this has to be interpreted cautiously.

4 Discussion

4.1 Interpretation of Results

For the total area of Bad Homburg, the model showed a significantly negative relationship between hedgehog sighting probability and mean tree cover density based on field survey data. Thus, higher hedgehog occurrences are predicted in areas with lower tree densities. This seems to make sense with regard to the general perception that hedgehogs prefer open areas like lawns (Young et al. 2006) over forest habitats (Hubert et al. 2011) where tree cover density is typically higher. However, the model showed that higher temperatures can mitigate this correlation to some degree, predicting an increased probability of hedgehog occurrence at higher temperatures in areas with higher tree densities – probably because hedgehog use them as a thermal refugia during periods of higher temperatures. Even, if this finding has to be treated with caution due to a relatively low number of hedgehog detections, it aligns with the assumption that temperature could be a decisive factor in hedgehog habitat use (Berger et al. 2023, Hubert et al. 2011). In combination with the thought that temperature is different in the urban and rural landscape (Pickett et al. 2001) and the non-significance of both landscape categories in the model, this could indicate an occasional use of areas with higher tree densities in or close to urban areas. A finding, that would match hedgehog's preference for edge habitats (Berger et al. 2023) but could also be season specific as some hedgehogs were observed to be mating in areas with higher tree densities during the field survey. All in all, temperature is an aspect worth considering in future research as in the face of climate change and declining hedgehog populations, it is of increasing importance to better understand the overall effect of temperature on hedgehog occurrence.

On the landscape scale of Bad Homburg, hedgehogs were observed more frequently in the urban than in rural areas in the field survey as well as in reports of alive hedgehogs by citizen scientists. This finding aligns hedgehogs' classification as an urban adapted species (Dietz et al. 2023) and highlights the species' preference for urban areas. Moreover, hedgehogs were mostly present in areas whose land use types were classified as leisure for the field survey, and residential for the citizen science data. This is almost certainly a consequence of access restrictions on private land to the investigator. Most of the hedgehogs observed by citizen scientists were found in private gardens, while most hedgehogs in the field were recorded close to playgrounds, cemeteries and in a park, called “Schlosspark”. The latter is an interesting circumstance with regard to the large size and availability of parks in Bad Homburg and the perception of Young et al. (2006) that hedgehogs favor park habitats. However, parks were found to only have a limited influence on hedgehog occurrence before, e.g. in a study by Turner et al. (2021), where stronger management associated with mostly short grass was mentioned as one possible explanation. For Bad Homburg, this might not be the case as most parks were still not mowed in May where field work was performed. With regard to the “Schlosspark”, a decisive factor for hedgehog might have been that the area is not publicly accessible during the night with an exception for this study. Cemeteries and playgrounds were also found to be less frequented by humans during the night than bigger parks, e.g. the “Kurpark”. This matches the perception of Dowding et al. (2010) that hedgehogs try to avoid human presence even in urban environments to reduce risk factors such as encountering a pet dog. However, other factors associated with less human frequency such as lower levels of artificial light and noise – which hedgehogs seem to prefer (Berger et al. 2020) – might also be worth considering in future studies to fully understand habitat use in hedgehogs, specifically in urban contexts.

Zooming in further, the effect of water changed from a negative effect in the total landscape of Bad Homburg, which indicates an enhanced hedgehog sighting probability close to water, to a positive association within the urban context, indicating an enhanced hedgehog sighting probability at greater distance from water. While this might indicate lesser dependency of hedgehog on streams and rivers for drinking in urban contexts through an increased use of artificial water resources like ponds, the GLM revealed that higher levels of shrubby vegetation cover were able to significantly increase the probability of a hedgehog sighting even in proximity to water. This phenomenon was also observed for higher imperviousness densities, whose actually negative effect on hedgehog presence was mitigated through higher levels of shrubby vegetation cover even in close proximity to water. This suggests a flexibility of hedgehogs to use habitats they would usually avoid, if they are associated with higher densities of shrubby vegetation cover. The finding highlights the importance of hedgerows as a place of refuge, nesting site (Berger et al. 2023, Korslund et al. 2023) and potential food source, while it refines the finding of Turner et al. (2021) that hedgehogs rather avoid being close to water in urban areas. The finding further aligns with observations from the field, where hedgehogs were most frequently found on playgrounds, cemeteries, and the “Schlosspark”, which were characterized by the availability of hedgerows, and for the first two also some “wild” corners, while the “Schlosspark” might offer good foraging grounds due to a high number of fruit trees which are attractive for arthropods.

With regard to mortalities, the most frequently reported cause in Hesse was roadkill based on citizen science records. Though spatial distortions are likely in citizen science data, this finding matches the perception that roadkill is a main issue (Gazzard et al. 2025, Moore et al. 2020). Spatially, roadkill hotspots were found to be in the rural district Gießen and the core of the Rhine-Main metropolitan region: Frankfurt am Main, and Offenbach am Main including Offenbach rural district. Bad Homburg had no reported road mortalities but is located in the middle of the two mortality hotspots close to the rural district Main-Kinzig-Kreis – where intermediate levels of roadkill were interpolated by the Kernel density analysis. Road mortalities peaked in June with the second highest number of reports in May. This does reflect the increased activity in males during mating season (Igelzentrum Zürich 2019) and is largely supported by literature, even if Haigh et al. (2014) as well as Reichholf (2015) find their peaks to be in July, where the dispersal phase of juvenile hedgehogs starts (Berger et al. 2023). For the Hessian data, August is the month where reports on hedgehog deaths related to causes other than road mortality peak, with the second highest level in October and interpolated mortality hotspots in rural districts Gießen, Offenbach, and the cities Darmstadt and Wiesbaden. While the month of August could still feature the increased movement of females during the lactation period as well as the dispersal phase of young associated with higher levels of natural selection, the October peak could reflect an extensive foraging behaviour in hedgehog to prepare for hibernation accompanied by a proportional increase in threats. However, this cannot be proved due to lacking information in the comments column for most of the dead (other causes) reports and the fact that some reports could still relate to roadkill as the cleaning process of the data highlighted (see 2.5.2).

What is certain, however, is the positive relationship that was found between the roadkill data in the Rhine-Main metropolitan region and street segments that were largely surrounded by leisure as well as residential areas, which contrasts the finding that these land use types were not significantly linked to hedgehog occurrence. While this highlights the need to account for spatial bias accessible and populated areas in opportunistic citizen science data, the finding corresponds the systematic field survey where hedgehogs were observed most frequently within recreational areas. Despite spatial biases being possible both findings find support within the literature where Haigh et al. (2014) reports residential to be the land use type every fifth hedgehog roadkill in Ireland was associated with. The findings also correspond with Wright et al. (2020) who found an increased probability of hedgehog roadkill in urban landscapes, where leisure and residential areas usually belong to. Conclusively, the road type analysis showed that the probability of a hedgehog roadkill is the highest at roads characterised by high, and followed by roads with medium traffic. This makes sense as these road types tend to be less permeable for wildlife in general due to higher speed limits, an increased traffic volume and often more than two lanes. The finding is further supported by a study on hedgehog roadkill from Wright et al. (2020) who found a higher probability of hedgehog roadkill on major roads and Neumann et al. (2012) who found an association between increasing wildlife collisions and roads with high speed limits.

4.2 Conservation Implications

Conservation implications that can be derived from these findings feed into different categories, with the first being the availability of food and shelter in and close to urban areas. Shrubby vegetation cover has proven to be a landscape feature that enhances otherwise unsuitable habitat conditions so that hedgehog presence significantly increases, as bushy vegetation provides suitable grounds for nesting, resting and foraging. Local governments should consider this important habitat feature for the benefit of hedgehogs and many more species. This is not only important in general, but also plays a significant role during the approval process of development areas, as Berger et al. (2023) highlight the growing problem of a lack of shrubby vegetation in newly developed areas, which often feature only trees and green spaces. With regard to the fact that food resources are a limiting factor for hedgehogs in rural as well as urban environments (Berger et al. 2023, Hubert et al. 2011), it is furthermore important to address the general decline in insect numbers. Incorporating more endemic and flowering plants into planting schemes can be one way to do so (Berger et al. 2023). Another measure to attract more arthropods is lower-intensity park management, including prolonged periods without mowing and a reduced removal of dead wood. Untidy or "wild" corners – as they are often found on cemeteries and occasionally on playgrounds – are also attractive to arthropods as well as hedgehogs. In the case of Bad Homburg, it would be advisable to monitor whether hedgehogs actually use the artificial nesting sites known as "hedgehog hotels" that were installed in the "Kurpark" and "Jubiläumspark", since no hedgehogs were detected near these installations or along the transects walked within either park during this study.

Secondly, the removal of barriers to movement has the potential to enhance habitat quality while helping to reduce hedgehog roadkill. An important factor is the kind of bordering element that is used to surround plots of land in the urban landscape. It was observed in the field that cemeteries were generally bordered by walls, while playgrounds tended to be enclosed by twin wire mesh fences or, alternatively, by hedges. These fences mostly reached to the ground with gaps being too narrow for hedgehogs to pass through. While this might not actually hinder hedgehog movement, it might be a problem with regard to roadkill as options for dispersal after a hedgehog crossed the street are limited. This might increase the actual time that hedgehogs spend along the street, looking for ways to pass (Moore et al. 2020). The consideration of fences with an enhanced permeability – typically characterised by gaps of at least 10x10 centimetres (Igelzentrum Zürich 2013) – is therefore an important conservation tool. Even better is the total removal of a fence, if thick and tall hedgerows seem sufficient as a bordering element, e.g. for recreational areas. Another option for fences already installed is cutting a hole of at least the mentioned size in them as promoted by the campaign "Hedgehog Highways" (PTES and BHPS n.d.), which has its origin in Great Britain but was picked up by "Deutsche Wildtier Stiftung" – a German non-governmental organization on wildlife conservation (Hinrichs 2024).

With regard to road mortality, reduction speed limits have been previously found to be of little use because hedgehog's defence mechanism is curling up into a ball instead of running away (Müller 2018). However, speed reduction – be it through speed limits or speed bumps – can be helpful to enhance a driver's brake readiness to avoid a collision with a curled up hedgehog (Berger et al. 2023, Moore et al. 2020). Following the findings of this study, the instalment of those tools does make sense on road segments surrounded by residential or leisure areas even on low traffic roads where mortality risk was found to be lower. This is supported by Moore et al. (2020) who propose the improvement of certain crossing locations for hedgehogs as they are known to act in a way of active risk reduction with a preference to cross roads associated with less traffic (Dowding et al. 2010). The actual design of a speed limit should include a reduction to at least 30 km/h and can be temporally limited as hedgehogs are only active at night. Thus, a speed limit from 10 pm to 6 am seems sufficient. This kind of speed limit comes with the advantage that drivers in Germany are well used to it as it is frequently found in residential areas with the goal to reduce noise at night. It would be an interesting study to assess the side effects on wildlife collisions at streets where these speed limits were put up recently, especially if their primary goal was noise reduction. Regarding medium and high traffic roads, which pose the highest mortality risk to hedgehogs according to the findings of this project, a combined approach of exclusionary fencing and road tunnels or green bridges to reduce roadkill but avoid population isolation has proved to be effective for hedgehogs as well as other wildlife (Berger et al. 2020a, Moore et al. 2020).

Lastly, the hedgehog is a species that enjoys a good public reputation (Gazzard et al. 2025) which can be useful in order to create conservation impact through, e.g. conservation actions on the individual level, and the promotion of hedgehog reporting platforms with regard to scientific research. Conservation actions on the individual level and their promotion could include but are not limited to: back-building of fences for enhanced wildlife permeability and/ or artificial lights on houses that shine throughout the night for enhanced habitat attractiveness and less distraction of nocturnal species in combination with a monetary incentive or for an example the distribution of 100 free motion detectors with limited sensibility, planting of endemic bushes for hedges and wild flowers (Berger et al. 2023) with the first being prescribed in planting schemes and the second being promoted though free seeds that can be collected at the reception of government buildings, encouragement to provide a source of water and leave “wild” corners (Wembridge et al. 2022) with dead leaf material (Berger et al. 2023) in private gardens for hedgehogs and other wildlife through public campaigns or information events, and lastly, promotion of cutting holes into fences (Wembridge et al. 2022) by doing so on fences at playgrounds or other public places and signing the new holes with some explanatory words to educate people, just like the example of “Hedgehog Highways” illustrates (PTES and BHPS n.d.).

4.3 Limitations

A limitation of this research project is the relatively low detection rate of hedgehogs during the field survey, given the limited time frame and difficult conditions encountered in the field due to tall and dense grass in most parks and green spaces in the urban landscape of Bad Homburg during May. Citizen science reports were used to balance this problem as citizen science has proven to provide valuable data in studying birds (Horns et al. 2018), plants, and insects like butterflies (Dennis et al. 2017). Citizen science has also been used in several studies on habitat suitability (Turner et al. 2021), population trends (Hof and Bright 2016) and roadkill (Moore et al. 2020) in hedgehogs. However, the reports may have introduced observation bias as they were collected opportunistically instead of following a predefined protocol to ensure a standardized methodology as proposed by the literature (Dennis et al. 2017). This makes spatial sampling bias towards accessible, well-lit and populated areas in mammal data likely (Calcutt et al. 2018). For the field survey data, there might be investigator bias with regard to sampling effort in areas where hedgehog presence has been argued to be unlikely according to literature, e.g. agricultural and forest areas. Both biases together might explain why hedgehogs were observed most frequently in residential and leisure areas, whereas both types of land use showed no significant effect with regard to the predicted probability of hedgehog occurrence in the GLM on habitat use on the urban landscape scale. Another limitation refers to the methodology of this study, as only presence data was used within the GLMs on hedgehog roadkill probability, and habitat use in the urban landscape. The generated pseudo absences could have introduced false absences. However, randomly created absences are mentioned to be an effective way in mitigating this problem, especially when using regression techniques (Barbet-Massin et al. 2012). Other limitations refer to inconsistent definitions of urban habitats due to their high diversity (Elmqvist et al. 2008) and interconnectivity (Fodor and Hâruţa 2015).

5 Conclusion and Outlook

5.1 Key Findings

The overall aim of this project to investigate habitat use and mortality causes of hedgehog in an urban setting in Germany to derive conservation implications was achieved. The positive and negative effects on hedgehog occurrence presented in the hypotheses were generally supported and further refined through significant interactions. Supported hypotheses on the landscape scale were that hedgehogs were observed more frequently in the urban than in the rural landscape of Bad Homburg with peaks in residential and recreational areas, and that the likelihood of hedgehog sightings decreases with higher tree densities, indicating an avoidance of densely forested areas. The assumption that higher temperatures would also be a significant predictor was refined by the finding that higher temperatures only gained significance in an interaction with tree density, indicating hedgehog's flexibility in using densely forested areas when they are associated with higher temperatures – possibly near typically warmer human settlements. Elevation level and distance from water both showed negative but non-significant effects on hedgehog sighting probability, supporting the hypothesis that hedgehogs prefer low-lying habitats in proximity to water in the overall landscape.

As expected, the effect of water changed in the urban landscape, predicting more hedgehog sightings with increasing distance from water. While this indicates the use of artificial water resources for drinking, the avoidance of water bodies could be related to human-altered river courses and steep banks, which make it difficult for hedgehogs to climb out, and therefore pose a higher risk for drowning than, e.g. drinking from pot saucer. While distance to water was not a significant predictor on its own, it gained significance in interactions with shrubby vegetation cover, and shrubby vegetation cover and imperviousness density combined. Shrubby vegetation cover and imperviousness density were also non-significant on their own but showed the expected positive and negative effects on hedgehog presence. Conclusively, hedgehog showed some flexibility in habitat use even at places they usually tend to avoid like those associated with water or high imperviousness densities, if they show high levels of shrubby vegetation cover. This further supports their flexibility in habitat use on the one hand but indicates that their substitution ability, e.g. with regard to natural water resources, is limited when it comes to natural places of shelter like bushes. Lastly, they also tend to avoid being close to main traffic roads as the positive but non-significant effect of the predictor “distance from main traffic road” suggests. This reflects their behaviour of active risk reduction and aligns with the expected findings that roadkill is a main issue with regard to hedgehog mortality in Hesse. It also mirrors the pattern of higher roadkill likelihood observed on medium- and especially high traffic roads, as well as on street segments primarily surrounded by residential and recreational areas.

5.2 Outlook for Future Research and Applications

The findings of this research project will help conservation managers not only to set priorities but also provide a first guideline on which conservation actions make sense to be implemented across Hesse. A deeper understanding of local habitat use and mortality causes may encourage policymakers to integrate hedgehog conservation into legislation and to allocate subsidies that incentivize landowners to participate actively in conservation efforts.

However, keeping in mind that 81 % out of all mammals categorized as data deficient either with regard to population trends or threat level on the IUCN red list are nocturnal (Bennie et al. 2014), what is needed in the future to conserve hedgehogs and other nocturnal mammals is more interest by politicians, conservationists, donors and researchers (Kimmig et al. 2025) – in a similar vein to what happened with marine ecology, which was also a long neglected field of research. Citizen science can be a useful tool in future studies (Kimmig at al. 2025) even in the face of its limitations. Moreover, sniffer dogs trained on hedgehogs can enhance the success of systematic field surveys carried out with a thermal imaging camera over large areas (Bearman-Brown et al. 2020).

Building on these needs, recent research has also produced promising and creative approaches to hedgehog conservation. For instance, the development of hedgehog dummies aims to reduce mortality caused by robotic lawn mowers (Rasmussen et al. 2023), while studies on the species’ sense of hearing explore whether audio warning signals – such as sound-based repellents for vehicles – could help lower roadkill rates

(Gazzard et al. 2025). Such innovative strategies, alongside broader political engagement, targeted funding, and advanced field survey methods will ultimately determine whether hedgehogs will thrive again, or get caught in the extinction vortex.

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Appendices

Object ID	Transect name	Hedgehog sighted (0 = no, 1 = yes)	Detec-tion number	Mean elevation (m)	Mean distance to water (m)	Mean tree density (%)	Temperature (°C)	Precipi-tation (mm)	Land-scape category
1	Transect 1.1	0		194.215802	365.3677612	30.8	15	0	rural
2	Transect 1.2	0		193.2074005	141.0601089	0	15	0	rural
3	Transect 1.3	0		196.5420013	241.7755798	0	15	0	rural
4	Transect 1.4	0		195.3171967	303.6337402	0	15	0	rural
5	Transect 1.5	0		190.178598	49.82360554	12.8	15	0	rural
6	Transect 10.1	0		285.9745972	566.1870483	83.2	17	0	rural
7	Transect 10.2	0		307.4129944	908.6514526	83.2	17	0	rural
8	Transect 10.3	0		301.5100037	827.4397095	87.2	17	0	rural
9	Transect 10.4	0		296.1328003	730.0770264	85.2	17	0	rural
10	Transect 10.5	0		291.2716003	640.2047729	84	17	0	rural
11	Transect 11.1	0		399.9939941	707.3466309	87	13	0	rural
12	Transect 11.2	0		393.1347961	1044.629077	84.4	13	0	rural
13	Transect 11.3	0		396.1876038	972.8987793	88.4	13	0	rural
14	Transect 11.4	0		398.5572021	900.4039429	88.6	13	0	rural

Object ID	Transect name	Hedgehog sighted (0 = no, 1 = yes)	Detec-tion number	Mean elevation (m)	Mean distance to water (m)	Mean tree density (%)	Temperature (°C)	Precipi-tation (mm)	Land-scape category
15	Transect 11.5	0		399.1403992	805.7947632	89	13	0	rural
16	Transect 12.1	0		191.0282516	237.1083183	0	12	0	urban
17	Transect 12.2	0		189.9134979	137.6288395	0	12	0	urban
18	Transect 12.3	0		189.9967499	196.1624374	0	12	0	urban
19	Transect 12.4	0		191.9414978	260.8896408	0	12	0	urban
20	Transect 12.5	0		191.2107506	270.8085175	0	12	0	urban
21	Transect 13.1	0		212.722998	191.4456329	50.2	14	0	rural
22	Transect 13.2	0		212.7196014	177.1308289	89.8	14	0	rural
23	Transect 13.3	0		209.272403	134.3356522	89	14	0	rural
24	Transect 13.4	0		203.7712006	86.24536285	83.6	14	0	rural
25	Transect 13.5	0		206.1152039	115.5251968	84.8	14	0	rural
26	Transect 14.1	0		418.3075989	722.0372803	86.2	11	0	rural
27	Transect 14.2	0		401.4202026	560.1412231	83.2	11	0	rural
28	Transect 14.3	0		408.8044006	625.3488892	85	11	0	rural
29	Transect 14.4	0		413.2317993	675.0002075	86	11	0	rural
30	Transect 14.5	0		391.4895935	489.0790344	81	11	0	rural

Object ID	Transect name	Hedgehog sighted (0 = no, 1 = yes)	Detec-tion number	Mean elevation (m)	Mean distance to water (m)	Mean tree density (%)	Temperature (°C)	Precipi-tation (mm)	Land-scape category
31	Transect 15.1	0		135.9967987	2.695051789	0	14	0	rural
32	Transect 15.2	0		132.9903992	91.25891876	0	14	0	rural
33	Transect 15.3	0		133.1511993	15.06989298	12.8	14	0	rural
34	Transect 15.4	0		134.0521973	5.303147793	0	14	0	rural
35	Transect 15.5	0		134.7808014	3.076003599	0	14	0	rural
36	Transect 16.1	0		162.9450012	430.2942017	10.8	16	0	urban
37	Transect 16.2	0		164.3368011	546.9762695	38	16	0	urban
38	Transect 16.3	0		165.051001	583.7267822	0	16	0	urban
39	Transect 16.4	0		164.8674011	513.96297	25	16	0	urban
40	Transect 16.5	0		164.1115997	474.3180664	36.8	16	0	urban
41	Transect 17.1	0		155.6976674	20.83870268	12	16	0	urban
42	Transect 17.2	0		152.7536647	33.34094715	13	16	0	urban
43	Transect 17.3	0		153.2678324	21.91174126	0	16	0	urban
44	Transect 17.4	0		153.6851679	14.6182518	0	16	0	urban
45	Transect 17.5	0		154.5985006	14.50784429	12.5	16	0	urban
46	Transect 18.1	0		224.1203979	199.1926971	0	16	0	urban

Object ID	Transect name	Hedgehog sighted (0 = no, 1 = yes)	Detec-tion number	Mean elevation (m)	Mean distance to water (m)	Mean tree density (%)	Temperature (°C)	Precipi-tation (mm)	Land-scape category
47	Transect 18.2	0		217.7771973	317.0417236	30.4	16	0	urban
48	Transect 18.3	0		221.1863983	289.9682678	13.8	16	0	urban
49	Transect 18.4	0		222.7187988	280.5040588	0	16	0	urban
50	Transect 18.5	0		224.7620026	274.7360046	13.4	16	0	urban
51	Transect 19.1	0		193.4164001	97.46212769	60.2	10	0	urban
52	Transect 19.2	0		194.7284027	96.34969482	43.2	10	0	urban
53	Transect 19.3	0		190.1526001	8.904647827	78.6	10	0	urban
54	Transect 19.4	0		191.8320038	9.632822704	56.6	10	0	urban
55	Transect 19.5	1	7,8	194.3426025	43.58695602	0	10	0	urban
56	Transect 2.1	0		415.2188049	463.3004395	86.2	12	0	rural
57	Transect 2.2	0		401.2366028	731.0745972	82.8	12	0	rural
58	Transect 2.3	0		404.7203979	676.5822266	73.8	12	0	rural
59	Transect 2.4	0		411.7424011	573.2530151	82.2	12	0	rural
60	Transect 2.5	0		413.0834045	532.4341797	79.2	12	0	rural
61	Transect 20.1	0		206.1362	397.294342	79.6	15	0	urban
62	Transect 20.2	0		202.2783997	404.8136047	43.4	15	0	urban

Object ID	Transect name	Hedgehog sighted (0 = no, 1 = yes)	Detec-tion number	Mean elevation (m)	Mean distance to water (m)	Mean tree density (%)	Temperature (°C)	Precipi-tation (mm)	Land-scape category
63	Transect 20.3	0		201.6924011	462.3950317	71.4	15	0	urban
64	Transect 20.4	0		200.6164032	413.0474487	43.4	15	0	urban
65	Transect 20.5	0		204.1810028	375.7682129	77.6	15	0	urban
66	Transect 21.1	0		197.4514008	5.953586543	70.4	16	0	urban
67	Transect 21.2	0		194.0596008	11.77521009	74.6	16	0	urban
68	Transect 21.3	0		195.3287994	19.17686539	79.4	16	0	urban
69	Transect 21.4	0		196.410199	10.667661	77.4	16	0	urban
70	Transect 21.5	0		192.3998016	33.37690458	46.4	16	0	urban
71	Transect 22.1	0		229.7612	230.1843994	87	14	0	rural
72	Transect 22.2	0		216.338797	32.00817709	0	14	0	rural
73	Transect 22.3	0		218.5480011	43.76377258	0	14	0	rural
74	Transect 22.4	0		219.7628021	34.32303715	26.4	14	0	rural
75	Transect 22.5	0		224.8642029	131.5680145	43.2	14	0	rural
76	Transect 23.1	0		379.6598022	49.9968895	86.4	12	0	rural
77	Transect 23.2	0		342.7391968	27.14831581	85.8	12	0	rural
78	Transect 23.3	0		352.276001	27.98294716	86.8	12	0	rural

Object ID	Transect name	Hedgehog sighted (0 = no, 1 = yes)	Detection number	Mean elevation (m)	Mean distance to water (m)	Mean tree density (%)	Temperature (°C)	Precipitation (mm)	Landscape category
79	Transect 23.4	0		360.8563965	24.63118286	86.8	12	0	rural
80	Transect 23.5	0		370.6365967	42.43577881	86.8	12	0	rural
81	Transect 24.1	1	15,16	174.6436005	332.6917725	42	15	0	rural
82	Transect 24.2	0		182.1867981	688.4456177	0	15	0	rural
83	Transect 24.3	0		180.534201	606.7242676	0	15	0	rural
84	Transect 24.4	0		179.107605	508.65401	0	15	0	rural
85	Transect 24.5	0		176.8990021	404.7927673	0	15	0	rural
86	Transect 25.1	0		653.5368042	687.7758911	88.8	14	0	rural
87	Transect 25.2	0		628.431604	460.6356506	85.2	14	0	rural
88	Transect 25.3	0		631.1160034	490.1233826	88.2	14	0	rural
89	Transect 25.4	0		637.264209	544.6927368	90.2	14	0	rural
90	Transect 25.5	0		644.7603882	610.3512573	89	14	0	rural
91	Transect 26.1	0		148.4304016	251.099585	27.6	16	0	urban
92	Transect 26.2	0		138.6779999	15.89603558	31	16	0	urban
93	Transect 26.3	0		138.9976013	15.70139446	65.6	16	0	urban
94	Transect 26.4	0		140.1921997	70.6958168	16.2	16	0	urban

Object ID	Transect name	Hedgehog sighted (0 = no, 1 = yes)	Detec-tion number	Mean elevation (m)	Mean distance to water (m)	Mean tree density (%)	Temperature (°C)	Precipi-tation (mm)	Land-scape category
95	Transect 26.5	0		144.9986023	167.3933655	27.2	16	0	urban
96	Transect 27.1	0		251.8026031	169.1568024	47.8	18	0	rural
97	Transect 27.2	0		244.6402008	364.9077698	84.8	18	0	rural
98	Transect 27.3	0		245.7174011	325.4122742	85.4	18	0	rural
99	Transect 27.4	0		247.6282013	245.3817505	65.2	18	0	rural
100	Transect 27.5	0		249.1252014	162.1941071	70	18	0	rural
101	Transect 28.1	0		167.7634033	18.99107032	45.8	15	0	urban
102	Transect 28.2	0		174.2469971	115.0392761	14.8	15	0	urban
103	Transect 28.3	0		172.4389984	130.3788834	11.4	15	0	urban
104	Transect 28.4	0		170.4117981	105.2891464	22.4	15	0	urban
105	Transect 28.5	0		169.0255981	43.33397827	64.2	15	0	urban
106	Transect 29.1	0		397.0682068	951.3904785	85.6	13	0	rural
107	Transect 29.2	0		430.3926025	791.1633545	87.4	13	0	rural
108	Transect 29.3	0		409.7619995	878.2732666	85.2	13	0	rural
109	Transect 29.4	0		472.9778076	641.2751099	79.2	13	0	rural
110	Transect 29.5	0		453.7949951	712.8415527	84.6	13	0	rural

Object ID	Transect name	Hedgehog sighted (0 = no, 1 = yes)	Detection number	Mean elevation (m)	Mean distance to water (m)	Mean tree density (%)	Temperature (°C)	Precipitation (mm)	Landscape category
111	Transect 3.1	0		222.8866028	92.58974609	46.6	16	0	urban
112	Transect 3.2	0		219.9099945	65.56227722	0	16	0	urban
113	Transect 3.3	0		213.514801	10.20292492	36.4	16	0	urban
114	Transect 3.4	0		216.4355988	12.99266768	44.2	16	0	urban
115	Transect 3.5	0		217.6280029	32.63006916	28	16	0	urban
116	Transect 30.1	0		138.8468018	189.0229767	0	16	0	urban
117	Transect 30.2	0		141.1115967	246.4224792	0	16	0	urban
118	Transect 30.3	0		141.4363983	239.7560822	0	16	0	urban
119	Transect 30.4	0		139.8076019	197.1362274	0	16	0	urban
120	Transect 30.5	1	3	139.0890015	185.1517792	26.4	16	0	urban
121	Transect 31.1	0		319.6641968	38.57012329	84	17	0	rural
122	Transect 31.2	0		313.2324036	33.19068041	84	17	0	rural
123	Transect 31.3	0		313.1661987	39.93184013	80.8	17	0	rural
124	Transect 31.4	0		298.6614014	120.4220779	87.2	17	0	rural
125	Transect 31.5	0		307.1669983	89.07501068	83.4	17	0	rural
126	Transect 32.1	0		169.8326019	18.55254421	80.8	10	0	urban

Object ID	Transect name	Hedgehog sighted (0 = no, 1 = yes)	Detec-tion number	Mean elevation (m)	Mean distance to water (m)	Mean tree density (%)	Temperature (°C)	Precipi-tation (mm)	Land-scape category
127	Transect 32.2	0		167.529599	13.88639088	87	10	0	urban
128	Transect 32.3	0		169.0583984	12.47761402	76.8	10	0	urban
129	Transect 32.4	0		165.935199	21.02747612	46.4	10	0	urban
130	Transect 32.5	0		166.745401	8.538520575	85.2	10	0	urban
131	Transect 33.1	0		479.6079956	282.9305054	87.6	12	0	rural
132	Transect 33.2	0		504.0416077	112.8655289	81	12	0	rural
133	Transect 33.3	0		497.8159973	88.83420105	82.6	12	0	rural
134	Transect 33.4	0		491.7135986	141.5577133	84.8	12	0	rural
135	Transect 33.5	0		485.6970032	213.5967041	85.8	12	0	rural
136	Transect 34.1	0		261.5096008	183.7983185	43.8	15	0	rural
137	Transect 34.2	0		242.1735992	119.3542465	0	15	0	rural
138	Transect 34.3	0		247.2608002	163.3544281	58.2	15	0	rural
139	Transect 34.4	0		250.4594025	147.2349457	78.4	15	0	rural
140	Transect 34.5	0		255.4232056	140.3718964	59.2	15	0	rural
141	Transect 35.1	0		555.8290039	155.7040985	90.8	14	0	rural
142	Transect 35.2	0		587.9876099	276.1240143	88.4	14	0	rural

Object ID	Transect name	Hedgehog sighted (0 = no, 1 = yes)	Detec-tion number	Mean elevation (m)	Mean distance to water (m)	Mean tree density (%)	Temperature (°C)	Precipi-tation (mm)	Land-scape category
143	Transect 35.3	0		579.9150024	213.0467987	91	14	0	rural
144	Transect 35.4	0		572.1110107	160.0861084	91.2	14	0	rural
145	Transect 35.5	0		563.9884033	119.447168	90.6	14	0	rural
146	Transect 36.1	0		190.185202	545.7257813	0	13	0	urban
147	Transect 36.2	0		185.7820007	357.8598511	0	13	0	urban
148	Transect 36.3	0		186.2391968	428.9895325	11.8	13	0	urban
149	Transect 36.4	0		187.5118011	474.0926025	24.8	13	0	urban
150	Transect 36.5	0		189.0259979	494.8856934	11	13	0	urban
151	Transect 37.1	0		143.6848053	73.0435051	11.8	18	0	urban
152	Transect 37.2	0		138.4676025	8.175604916	71.4	18	0	urban
153	Transect 37.3	0		141.0100006	64.48939819	28.4	18	0	urban
154	Transect 37.4	0		141.8949982	43.0617424	25.8	18	0	urban
155	Transect 37.5	0		139.3972046	23.58898773	53.6	18	0	urban
156	Transect 38.1	0		418.4860535	226.2189972	47.4	16		urban
157	Transect 38.2	0		206.5330414	220.5155975	0	16		urban
158	Transect 38.3	0		445.5932678	223.4414001	34.2	16		urban

Object ID	Transect name	Hedgehog sighted (0 = no, 1 = yes)	Detection number	Mean elevation (m)	Mean distance to water (m)	Mean tree density (%)	Temperature (°C)	Precipitation (mm)	Landscape category
159	Transect 38.4	0		286.2287018	221.2268036	13	16		urban
160	Transect 38.5	0		377.3358704	221.875	26	16	0	urban
161	Transect 39.1	0		766.5750366	200.7365967	83.4	16	0	rural
162	Transect 39.2	0		1001.234973	216.4835999	84.4	16	0	rural
163	Transect 39.3	0		977.4405273	212.4839996	82.4	16	0	rural
164	Transect 39.4	0		911.4985352	207.7332001	82.4	16	0	rural
165	Transect 39.5	0		843.6892334	203.6562012	82.2	16	0	rural
166	Transect 4.1	0		336.143457	164.9417999	28.2	16	0	urban
167	Transect 4.2	0		393.4293823	168.9970001	19.6	16	0	urban
168	Transect 4.3	0		338.9612	167.3225983	0	16	0	urban
169	Transect 4.4	1	2	276.3705475	164.5026001	29	16	0	urban
170	Transect 4.5	1	1	252.3342285	161.6996002	47.4	16	0	urban
171	Transect 40.1	0		47.52222557	153.1825989	40.6	16	0	urban
172	Transect 40.2	1	5	23.92624779	151.2217987	29.8	16	0	urban
173	Transect 40.3	0		107.1402939	153.3442017	0	16	0	urban
174	Transect 40.4	0		110.9242813	153.1614014	12.6	16	0	urban

Object ID	Transect name	Hedgehog sighted (0 = no, 1 = yes)	Detection number	Mean elevation (m)	Mean distance to water (m)	Mean tree density (%)	Temperature (°C)	Precipitation (mm)	Landscape category
175	Transect 40.5	0		70.98682327	152.4242035	14.4	16	0	urban
176	Transect 41.1	0		16.116292	180.5609985	0	12	0	urban
177	Transect 41.2	0		63.68953018	182.9654022	0	12	0	urban
178	Transect 41.3	0		50.12164993	184.3694	26.4	12	0	urban
179	Transect 41.4	0		7.298836291	183.6016022	40.6	12	0	urban
180	Transect 41.5	1	6	10.54433174	181.9370026	25.4	12	0	urban
181	Transect 42.1	0		275.3392883	146.1338043	11	16	0	urban
182	Transect 42.2	0		47.18227463	143.0302002	37.4	16	0	urban
183	Transect 42.3	0		125.7368011	144.2745972	0	16	0	urban
184	Transect 42.4	0		221.2372986	145.240799	0	16	0	urban
185	Transect 42.5	0		301.7724976	145.5451996	37.2	16	0	urban
186	Transect 43.1	0		424.3251221	144.7054016	32.6	15	0	urban
187	Transect 43.2	0		199.4934326	139.4490021	28.2	15	0	urban
188	Transect 43.3	0		285.0012207	141.9071991	24.8	15	0	urban
189	Transect 43.4	0		384.3188904	143.7623993	0	15	0	urban
190	Transect 43.5	0		332.0704895	142.9776031	0	15	0	urban

Object ID	Transect name	Hedgehog sighted (0 = no, 1 = yes)	Detec-tion number	Mean elevation (m)	Mean distance to water (m)	Mean tree density (%)	Temperature (°C)	Precipi-tation (mm)	Land-scape category
191	Transect 44.1	0		101.4675049	413.1549988	86.4	17	0	rural
192	Transect 44.2	0		111.3669922	432.2772034	77.4	17	0	rural
193	Transect 44.3	0		197.7181702	433.127002	80.8	17	0	rural
194	Transect 44.4	0		228.4782227	434.1544006	79.2	17	0	rural
195	Transect 44.5	0		167.5424927	427.1743958	77.6	17	0	rural
196	Transect 45.1	0		1082.214185	163.5947998	0	18	0	rural
197	Transect 45.2	0		925.6433594	161.3929993	0	18	0	rural
198	Transect 45.3	0		1013.046802	162.3665985	0	18	0	rural
199	Transect 45.4	0		775.6913452	159.2891998	0	18	0	rural
200	Transect 45.5	0		845.9867432	160.3502014	0	18	0	rural
201	Transect 46.1	0		411.2876709	576.7699951	87	12	0	rural
202	Transect 46.2	0		597.8605957	548.3578003	90	12	0	rural
203	Transect 46.3	0		520.8187622	552.8584106	89.4	12	0	rural
204	Transect 46.4	0		442.3616333	560.3145996	89	12	0	rural
205	Transect 46.5	0		373.9604187	559.844397	89.4	12	0	rural
206	Transect 47.1	0		22.70421863	156.0935974	56	10	0	urban

Object ID	Transect name	Hedgehog sighted (0 = no, 1 = yes)	Detec-tion number	Mean elevation (m)	Mean distance to water (m)	Mean tree density (%)	Temperature (°C)	Precipi-tation (mm)	Land-scape category
207	Transect 47.2	0		20.0555768	154.260199	85.6	10	0	urban
208	Transect 47.3	0		34.93575096	153.3873993	80.6	10	0	urban
209	Transect 47.4	0		22.94063835	152.6003998	78.2	10	0	urban
210	Transect 47.5	0		16.57229834	154.334201	72	10	0	urban
211	Transect 48.1	0		2.0328439	149.5867981	0	19	0	rural
212	Transect 48.2	0		3.250596809	154.6476013	0	19	0	rural
213	Transect 48.3	0		0.894060183	153.1541992	0	19	0	rural
214	Transect 48.4	0		1.23883009	151.8235992	0	19	0	rural
215	Transect 48.5	0		1.217663717	150.4401978	0	19	0	rural
216	Transect 49.1	0		63.53738098	182.6917999	0	16	0	urban
217	Transect 49.2	0		19.50337677	181.1410034	39.8	16	0	urban
218	Transect 49.3	1	9	10.73064938	180.8328003	76	16	0	urban
219	Transect 49.4	0		9.273558331	180.4369995	71	16	0	urban
220	Transect 49.5	0		26.78564148	181.060199	25.6	16	0	urban
221	Transect 5.1	1	4	215.4275238	151.7660004	55.4	16	0	urban
222	Transect 5.2	0		468.2255859	159.3115997	25.2	16	0	urban

Object ID	Transect name	Hedgehog sighted (0 = no, 1 = yes)	Detec-tion number	Mean elevation (m)	Mean distance to water (m)	Mean tree density (%)	Temperature (°C)	Precipi-tation (mm)	Land-scape category
223	Transect 5.3	0		371.3344727	158.1502014	0	16	0	urban
224	Transect 5.4	0		302.9138733	156.8568024	72.8	16	0	urban
225	Transect 5.5	0		241.1134857	154.3067993	71.2	16	0	urban
226	Transect 50.1	0		150.1096252	156.5800018	82.6	10	0	urban
227	Transect 50.2	0		20.00740223	159.9186005	59.8	10	0	urban
228	Transect 50.3	0		42.86413879	159.2793976	31.4	10	0	urban
229	Transect 50.4	0		29.03701448	158.1354004	84.8	10	0	urban
230	Transect 50.5	0		112.1639725	157.4269989	64.6	10	0	urban
231	Transect 6.1	0		511.646698	207.5766022	78	14	0	rural
232	Transect 6.2	1	10	535.5119263	205.620401	83.2	14	0	rural
233	Transect 6.3	0		676.0190918	202.1403992	0	14	0	rural
234	Transect 6.4	0		654.4769287	201.9206024	78.8	14	0	rural
235	Transect 6.5	0		577.5015015	202.9368011	79.4	14	0	rural
236	Transect 7.1	0		26.75271034	215.5195984	44.8	15	0	rural
237	Transect 7.2	0		40.92934036	206.5166016	0	15	0	rural
238	Transect 7.3	0		8.614481449	204.9679993	77	15	0	rural

Object ID	Transect name	Hedgehog sighted (0 = no, 1 = yes)	Detec-tion number	Mean elevation (m)	Mean distance to water (m)	Mean tree density (%)	Temperature (°C)	Precipi-tation (mm)	Land-scape category
239	Transect 7.4	0		10.81264181	206.9919983	76.8	15	0	rural
240	Transect 7.5	0		9.774598885	210.2822052	75.2	15	0	rural
241	Transect 8.1	1	11,12	106.8793808	176.8252014	67.4	14	0	urban
242	Transect 8.2	0		24.94588089	179.3593994	71.8	14	0	urban
243	Transect 8.3	0		16.01389747	176.3656006	76.4	14	0	urban
244	Transect 8.4	0		25.58175035	175.7084015	78	14	0	urban
245	Transect 8.5	1	13,14	17.29759144	178.4940002	80.8	14	0	urban
246	Transect 9.1	0		1073.648926	581.5897522	82.25	12	0	rural
247	Transect 9.2	0		1115.161987	588.7314911	90.25	12	0	rural
248	Transect 9.3	0		1133.300323	585.8432617	90.75	12	0	rural
249	Transect 9.4	0		1156.103821	583.1334839	87	12	0	rural
250	Transect 9.5	0		1152.72525	581.9222565	81.25	12	0	rural

Table 6: Summary of raw data collected during the field survey in Bad Homburg, containing information on transect name, the sighting of a hedgehog, mean elevation level in metres, mean distance to water in metres, mean tree density in percent, temperature in degrees Celsius, precipitation during the survey in millimetres, and landscape category ("urban" or "rural"). Source: Author's own data.

Figure 12: Photo of a hedgehog in the "Schlosspark" of Bad Homburg during field work. Source: Author’s own image.