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Weak influence of natural vegetation in urban green spaces compared to agricultural ecosystems on House Martin populations: Insights from nationwide citizen science data in the Czech Republic

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ABSTRACT

The House Martin (*Delichon urbicum*) is a common farmland bird species in the European landscape, yet its population numbers are currently in decline. However, it is not yet sufficiently explained why this long-term decline occurs. To fill this gap in our knowledge, we investigated how land cover composition affects the abundance of House Martins on the landscape scale by using nationwide citizen science data. Utilizing a generalised linear mixed-effect model (GLMM), we evaluated 12,094 records from the Czech Republic spanning 2009–2017. Our analysis underscores the significance of land cover type in shaping House Martin abundance. More specifically, our results indicate that within agricultural land covers "naturally managed arable lands" exhibited significant positive effect, while forests, orchards, and vineyards were deemed less favourable for House Martin populations. Within urban land covers, we found a clear distinction in the impact on House Martin populations, with a positive effect observed in urban infrastructure, development areas, and post-industrial sites (i.e., UrbanAreas), while an indifferent impact was noted within urban green spaces and landscaped areas (i.e., GreenUrban). Notably, our findings suggest that the simple spatial, age, and species structure typical of forests in Europe, and similarly, the uniform structure of parks and gardens, may be responsible for the decline in the abundance of the House Martin. We advocate for the preservation or enhancement of urban greenery, expansion of natural vegetation in rural areas and adoption of ecological management practices in orchards and vineyards to mitigate further declines in House Martin populations.

1. Introduction

Much research shows that the abundance and biomass of common bird species (i.e., passerines: swallows, finches, sparrows, chaffinches, fieldfares or Great Tits) have declined in Europe (Gross, 2015; Inger et al., 2015; Schrauth and Wink, 2018; Burns et al., 2021). Therefore, it is important to understand the decline of common species, not only the rare or endangered ones. Another reason may be their high abundance, which makes them to be important species in influencing levels of ecosystem functions and delivering ecosystem services (Gaston, 2011). Possible factors responsible for the declines in bird species are food availability (Hildén, 1965; Fretwell and Lucas, 1969; Schrauth and Wink, 2018), climatic conditions (Dolenec and Dolenec, 2011; McClure et al., 2012; Forrest, 2016), nest parasitism and parasites (Bouldin, 1968; Piersma, 2013; Tomás et al., 2017; Bulgarella et al., 2019), natural predators (Collias and Collias, 1984; Loss et al., 2013) and land use changes (Kettel et al., 2021). In Europe, a significant reduction in the population of many species, including the most common ones, is primarily attributed to intensified agriculture and the abandonment of extensive landscape management (Guilherme and Miguel Pereira, 2013; Reif and Hanzelka, 2016; Boynton et al., 2020; Burns et al., 2021), for example, shrub-rich grassland species (e.g., *Lanius collurio*), forest birds (e.g., *Streptopelia turtur*), farmland birds (e.g., *Perdix perdix*) (Zámečník, 2013) and wetland birds (e.g., *Crex crex*) (Cherkaoui and Hanane, 2011; Pykal et al., 2021). However, the decrease in the abundance of aerial-feeding insectivorous birds (e.g., House Martin *Delichon urbicum*) remains inadequately explained (Kettel et al., 2021; Møller et al., 2021). The following possible explanations for the decline of insectivorous birds are most often mentioned in scientific papers: a) the global decrease of insect populations; b) land use changes; c) landscape homogenisation; d) climate change; e) pollution; and f) farmland intensification (Sánchez-Bayo and Wyckhuys, 2019; Kettel et al., 2021; Møller

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et al., 2021; Wagner et al., 2021; Šálek and Mayer, 2022). According to Šťastný et al. (2021), House Martin is also threatened by the illegal destruction of nests during the reconstruction or maintenance of the buildings.

The House Martin (*Delichon urbicum* Linnaeus, 1758) is a long-distance migratory species (Cepák, 2013). The natural habitat of this species includes rock walls and overhangs, but in recent times, it is very rare for these bird colonies to nest in their original habitat (Lovette and Fitzpatrick, 2016). The House Martin is now considered a synanthropic species. It occurs in open countryside, ranging from the lowlands to the mountains (Šťastný and Hudec, 2011). They build nests on the outside of buildings, window ledges, arcades, bridges, etc. Nesting usually occurs in colonies, with individual nests connected to each other. Such colonies can be comprised of several hundred nests. The House Martin is still a relatively abundant bird species in the Czech Republic. The estimated population of breeding pairs in the Czech Republic was 0.6–1.2 million pairs from 1985 to 1989, and this remained stable until 2001–2003. A slight increase in the population to 0.6–1.3 million pairs, occurred between 2014 and 2017 (Šťastný et al., 2021), and the population index slightly increased from 1982 to 2020 (CSO, 2020). Since the beginning of the 21st century, the House Martin has been classified as a near-threatened species on the Red List of the Czech Republic (Šťastný et al., 2021). In the Pan-European common bird monitoring scheme, the House Martin is now a species with significant decline, but not significantly more than 5% per year (Brlík et al., 2021). The European population of House Martin is estimated to range between 22.4 million and 47.2 million mature individuals, while the global population is estimated to range between 10.5 million and 500 million mature individuals. According to the IUCN (2016), the population trend for House Martin is decreasing.

The agricultural landscape and urban areas are important factors that influence the nesting preferences of House Martins (Šťastný et al., 2021). The agricultural landscape surrounding the nesting sites of House Martins in urban areas could provide prey availability. Changes in agriculture, such as intensification and the replacement of mixed and livestock farming with arable land, negatively affect and pose a threat to hirundine species through the loss of insect population (Kettel et al., 2021). Due to the high availability of prey, the agricultural landscape, which includes farms with livestock, is considered better for hirundine species than a landscape with arable land only (Grüebler et al., 2010; Kettel et al., 2021). Šálek and Mayer (2022) also found that farmstead modernization adversely affects farmland birds.

In terms of urban areas, urbanisation modifies the structure and quality of House Martin habitats (Šálek and Mayer, 2022). Specific characterisation of urbanised areas contributes to the survival of synanthropic species (Cody, 1985). Factors important to synanthropic species include: human and pet density, chemical pollution, artificial light in cities, noise or predators. All these urban stressors probably generate selection pressures on birds (Isaksson, 2018). The composition of House Martin and other synanthropic species in urban areas is highly driven by the distribution and structure of urban greenery (parks, trees, green roofs, roadside vegetation, etc.) (Claro et al., 2020). Increases in the presence and size of green areas in cities have positive effects on urban biodiversity (Leveau et al., 2019).

In the present paper, we used land cover data representing landscape structure on a large-scale and unique nationwide citizen science dataset covering the occurrence of House Martin within the entire territory of the Czech Republic. We assumed that these changes in land cover can be reflected in changes in the bird population on large spatial scales. This is supported by publications that have determined that land cover is an important landscape parameter influencing bird diversity (Reif and Hanzelka, 2016; Šálek et al., 2021).

More specifically, we focused on landscape characteristics (Kopij, 2000; Dolenec and Dolenec, 2011; Pedersen and Krøgli, 2017; Mikusiński et al., 2018) that may affect the habitat and nesting preferences of House Martins, such as the percentage of coverage of different land cover types. By evaluating the House Martins data from the public ornithological database, we tried to estimate which landscape factors have the most impact on the species. Our hypothesis is that the main driver of bird population size will be the presence of a moderately heterogeneous urban-agricultural landscape with good access to sources of food for foraging and nesting places. The objectives of the work are to determine, at the landscape level: a) which types of land cover affect abundance of the House Martin; b) comparing the effect size of the different land cover types; and c) create a model to predict their potential distribution based on the most important factors.

2. Material and methods

2.1. Study area

The studied area encompasses the entire territory of the Czech Republic. The Czech Republic is landlocked country located in the middle of Europe. The area is total of 78,887 km^2 and approximately human population of 10,000,000. The climate in Czech Republic is continental, with some parts experiencing an oceanic influence. The land cover of the Czech Republic mostly consists of lowlands surrounded by lowhills. The forested area in Czech Republic represents 36.8% and cultivated areas consists of 40.8%. The main lowlands follow the Elbe river in the Czechia region and the Morava river in the Moravian region (Hauner et al., 2024). Appendix Fig. S1 shows typical examples of land cover photographed in the cultural landscape of the Czech Republic.

2.2. Ornithological data

The primary data on the abundance of House Martins in the Czech Republic is sourced from the public ornithological database (CSO, 2009–2017), operated by the Czech Society for Ornithology (CSO). This data is freely available for non-commercial or study purposes in CSV (Comma-separated values) format. The public, which participates in the collection of data to the database, consists of amateur ornithologists and experts. The data set contains information on the presence of individual bird species detected at a certain place at a certain time. It also contains additional information about the species, such as the age of the species, the number of individuals, and coordinate information. We processed 12,094 records of House Martin species present in the Czech Republic, covering the entire area of the country homogeneously (Appendix Fig. S2), due to its high abundance and relatively straightforward identification. The database we used operates with semi-structured data, which was sorted before actual use. Incomplete records were removed, meaning only complete records with geographic coordinates and accurately identified bird species were retained. Records with uncertain species identification were also excluded. The dataset used for analysis spans the time interval from 2009 to 2017.

2.3. Environmental data

For information about environmental data, we used a ground-based analytical data set from the Czech Statistical Office (CZSO). The dataset contains information on the human population and land use in and around the city, within which we used information on the number of human inhabitants. The number of human inhabitants represents the population in cities (CZSO, 2009–2017). The CZSO dataset that was used shares the same time interval as the CSO data to ensure maximal evaluation accuracy.

For the estimate of urban areas (%), cultivated vegetation (cultural vegetation) (%) (Tuanmu and Jetz, 2014) habitat homogeneity and heterogeneity (Tuanmu and Jetz, 2015), we used data from EarthEnv. The data set contains rasters in grid cells at 1 km resolution. Homogeneity is estimated by the similarity of the enhanced vegetation index (EVI) between adjacent pixels, and heterogeneity is estimated by the diversity of EVI (i.e., Simpson index of diversity). Data on the normalized difference vegetation index (NDVI) come from NASA's observations of Earth and represent the measurement of vegetation by the difference of the red and near-infrared light spectrums. The raster data set has a grid cell resolution of 11 km (NASA Earth Observations, 2009–2017). The elevation information came from ArcČR 500 version 3.3. The database includes information about the landscape and topography of the Czech Republic. Information on altitude is measured in meters above sea level (m.a.s.l.) (Arcdata Praha, 2016). Soil data came from the International Soil Reference and Information Centre (ISRIC) World Soil Database, which contains publicly available datasets. We used two variables that represent soil texture and soil clay content (%) at a depth of 0 cm (Hengl et al., 2017). Both are in raster format with 0.25 km resolution, and the data time interval is 1950–2015.

Land cover data collected from the databases include pastures and cropland, with raster grid cells in 10 km resolution. The global data set represents the proportion of land area used as pasture land and crop land in the year 2000. The data came from satellite Moderate Resolution Imaging Spectroradiometer (MODIS) and Satellite Pour l'Observation de la Terre (SPOT), (Ramankutty et al., 2008). The next dataset used is Corine land cover, which is part of the Copernicus database. The Copernicus program is the European Union's Earth observation programme, which makes it possible to monitor our planet and its environment. This provides information services based on satellite and in situ data from Earth observation. The raster data include land cover areas in 100-m resolution from the year 2012 (European Environment Agency, 2019). The representation of the individual Corine land cover classes was considerably unbalanced, so we merged similar classes to create new ones (Appendix Table S1). All used datasets are shown in Appendix Table S2.

2.4. Data processing

The information obtained was processed into one CSV data file. Initially, CSO and CZSO data were paired using the unique nomenclature of municipalities codes (CISOB). Every city in the Czech Republic has this unique code, which helped pair data correctly. Subsequently, data from raster dataset sources were connected with GPS coordinates in the geographical information system ArcMap by using a spatial analysis function by extracting raster values to points. The extracted data was added to the attribute table according to the desired point coordinates (Esri, 2019). A map depicting predicted abundance values of House Martins in the Czech Republic from 2009 to 2017 (see Appendix Fig. S2) was generated in ArcGis Pro using the natural breaks (Jenks) method (Esri, 2021). A situational map for the years 2009–2017 also offers a visual representation of the study sites where House Martins were monitored (Appendix Fig. S2).

2.5. Statistical methods used

We chose a generalised linear mixed-effect model (GLMM) with a poisson error distribution and log link function to test the relationship between House Martin abundance and environmental factors. We constructed the mixed-effect model by using the "glmer" function of the lme4 package in R software (Bates et al., 2015). Explanatory variables were standardised to zero mean and unit variance before data were analysed. We used poisson error distribution because the average value of the maximum and minimum abundance estimates rounded up reported in CSO database was used as the dependent variable. The collected data had a clustered structure due to repeated data collection in time (i.e., sampling year) and space (i.e., individual districts). Therefore, we used a two crossed random intercept effect for the district (NUTS 3) and year of observation in the model.

The most reasonable combination of explanatory variables that explains the highest variability in the bird abundance was estimated with a stepwise procedure for the GLMM model using the dredge function (Bartoń, 2022). This function returns a list of models with every possible combination of predictor variables and selects the best model by comparing the Akaike information criterion for a small sample size (AICc). To incorporate estimates from multiple candidate models that have similar support (ΔAICc $\leq$2) in the data, we have summarized the information using the model averaging procedure by applying AICc weights (Appendix Table S3). Parameter estimation was performed based on the 'full average' method (i.e., averages were obtained from the regression coefficients of all the models considered). The results of the stepwise selection were then used for the prediction of the House Martin distribution in the landscape. To avoid a possible confounding effect coming from spatial autocorrelation of the environmental conditions and different sampling effort resulting from differently populated districts, district ID was used as a variable with random effect and human population size was used as a covariate (Fig. 1). To ensure the reliability of our final model, we also addressed the issue of multicollinearity, which can influence the averaging of regression coefficients (Cade, 2015). We assessed multicollinearity by calculating the variance inflation factor (VIF) for each explanatory variable using the "vif" function (Fox and Weisberg, 2019). For the visualization of the predicted values of the final GLMM model, we applied the two-dimensional kernel density estimation method. With the "kde2d.weighted" function which is part of the "ggtern" R package, we estimated densities on a regular grid and based on this we make a contour plot (Hamilton and Ferry, 2018). The analysis was conducted using the R statistical program (R Core Team, 2022).

3. Results

3.1. The distribution on a landscape scale

To illustrate the suitable land cover types at the landscape level, we created a map depicting the potential distribution of House Martin abundance. This prediction was derived from a Generalised Linear Mixed Model (GLMM) utilizing the most relevant combination of explanatory variables (Fig. 2). We visualized this prediction using ArcGIS and further details can be found in Appendix Fig. S2. Both maps illustrate a similar potential distribution of species abundance. The maps (Fig. 2; Appendix Fig. S2) indicate that hotspots of predicted House Martin abundance are primarily concentrated around the largest cities and the main agricultural areas in Bohemia, including the cities of Prague and Pilsen, as well as the Polabí lowland. In Moravia, these areas include the cities of Brno, the Haná agricultural region with its centre in Olomouc, and another hotspot of abundance in southeastern Moravia, where important wetlands and aquatic ecosystems are situated. The map visualization also clearly indicates that House Martin avoid mountainous areas and regions with dense forest cover.

3.2. Anthropogenic habitats

The urban landscape (i.e., urban infrastructure, development areas and post-industrial sites) (a detailed list of land covers can be found in (Appendix Table S4) was identified as one of the factors that had a significant positive effect on House Martin abundance (Fig. 3; Appendix Table S4, Fig. S2). On the other hand, the factors that represent urban greenery (i.e., parks, gardens, cemeteries and greenery within city squares or city blocks) did not significantly affect the abundance of House Martin. Additionally, its confidence intervals show a positive and also a negative effect on House Martin population size (Fig. 3). Our results suggest that not all types of urban habitat are appropriate for House Martin occurrences, especially considering the negative effect linked with polluted and intensively used areas (e.g., mining areas). This relationship is also shown in Fig. 3 where a large range of confident interval shows a negative, but also positive effect of mining areas on House Martin.

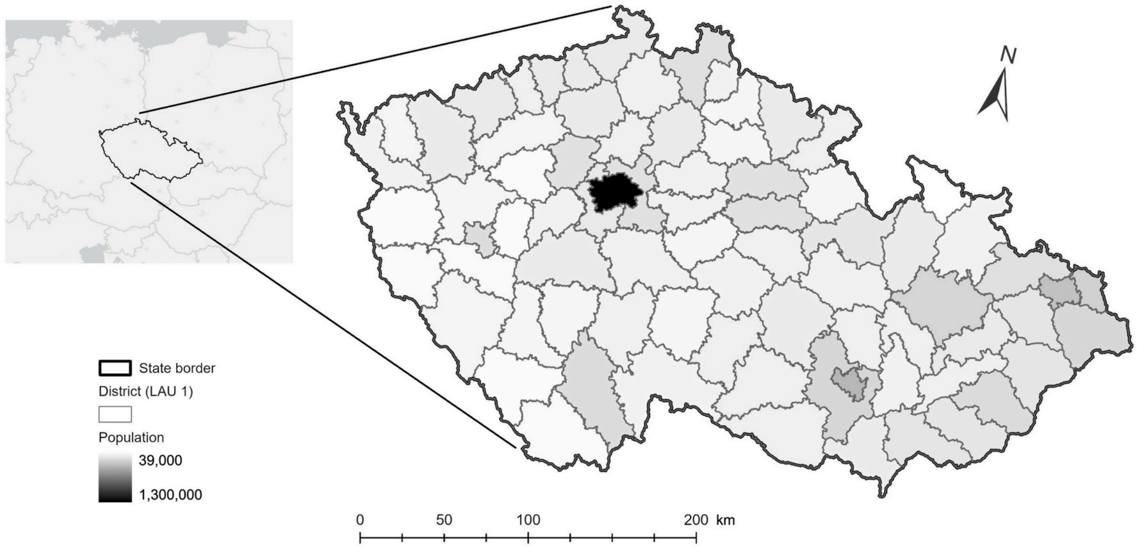

Fig. 1. Map showing Central Europe and the Czech Republic with marked districts (LAU 1). The background data for the map comes from the ArcČR 500 database, version 3.3 (Arcdata Praha, 2016). The map was created using ArcGis software (Esri, 2021).

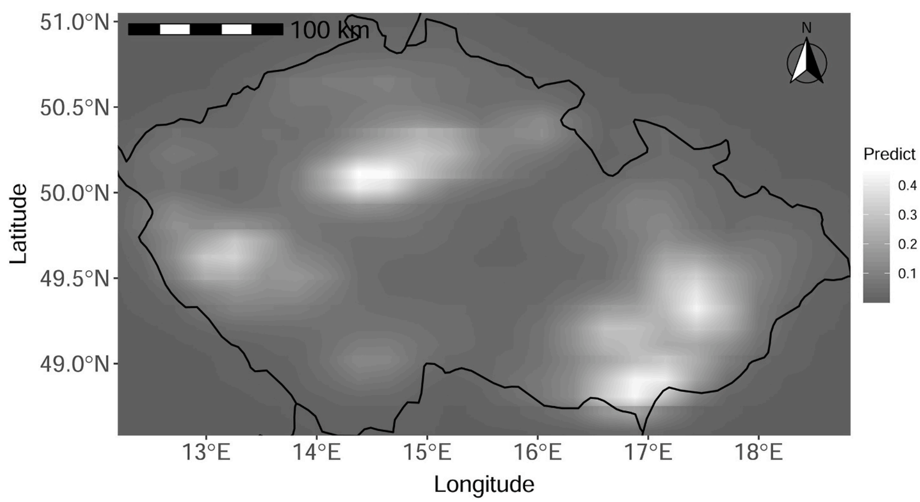

Fig. 2. Visualization of the model averaging results for the final generalised linear mixed effect-model. The combination of used explanatory variables was based on the result of step-wise selection (see Appendix Table S4). We used the two-dimensional kernel density estimation technique to estimate the regions of highest probability density distribution for the Czech Republic. The predicted values are marked in a grey scale, the lighter the shade, the greater the abundance of House Martin in the given area.

3.3. Agricultural systems

Based on our results, we revealed that agricultural areas had an inconsistent effect on the population size of House Martins (Fig. 3). The positive effect of agricultural landscapes was observed primarily in areas with a significant proportion of natural vegetation or a mosaic pattern of small, cultivated land parcels (i.e., Corine land cover classes: complex cultivation pattern and land principally occupied by agriculture, with significant areas of natural vegetation). In contrast, orchards and vineyards had a notably negative impact on House Martin abundance (Fig. 3). These environments typically exhibit a homogeneous spatial and species structure and are commonly managed intensively with pesticides. Another significant negative effect on House Martin abundance was attributed to dense forest, as indicated by mixed forest and NDVI factor (Fig. 3; Appendix Fig. S2, Table S4).

3.4. Water habitats

The presence of water was another crucial landscape category that significantly influenced House Martin abundances (Fig. 3). Specifically, we revealed that the most positive effect on the presence of House Martins was caused by waterbodies. The other type of aquatic habitat was marshes, but this type of environment did not significantly influence House Martin (Fig. 3). The wide range of confidence intervals shows that a negative effect will also be present among these types of habitats.

4. Discussion

In our study, we evaluated the various types and characteristics of land cover that influence the abundance of House Martin using citizen science data. In the case of "citizen science data", one of the main issues is uneven sampling, which can lead to bias in the resulting model. This can generate spatial imbalance due to the preference of birdwatchers to visit areas with rarer bird species, which can skew the distribution of

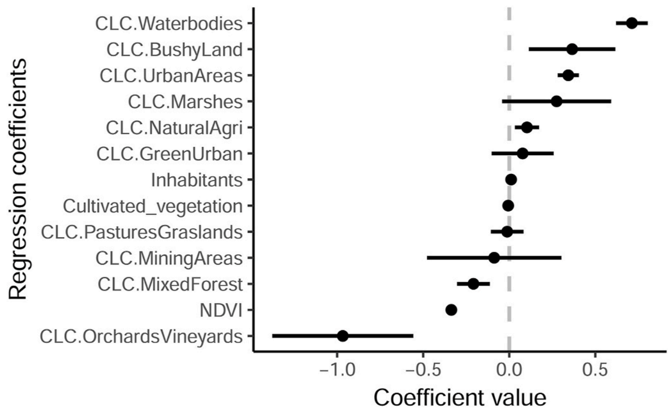

Fig. 3. Coefficient plots from the generalised linear mixed-effect model (GLMM) with random structure defined as a two crossed random intercept effect for the district and year of observation. Explanatory variables were standardised to zero mean and unit variance. The GLMM model predicts which land cover type or landscape characteristic positively or negatively correlates with House Martin abundance. Coefficients were predicted based on model averaging procedures that have similar support in the data (with a delta AIC ≤2). Combination of environmental variables was selected based on stepwise selection from the GLMM regression according to the small-sample corrected Akaike Information Criterion (AICc). Dots represent the coefficients from the regression analysis (i.e., GLMM) and lines represent 95% confidence intervals. The CLC means that data come from Corine land cover database. The abbreviation of NDVI represents normalized difference vegetation index.

observed birds (Johnston et al., 2020). In the case of our data, the survey effort was not notably skewed depending on the population size of the studied area (Appendix Table S5). Furthermore, in areas with the highest survey effort, the model did not predict the largest population size of the House Martin (Appendix Table S5). Another issue may arise from variations in the knowledge of the observers, which can also introduce inaccuracies into the datasets. One way to reduce the impact of uneven sampling effort and varying levels of experience on modeling the distribution of species abundance is to include covariates in the regression model that account for these confounding characteristics, such as: population size of the area, bird body size, or the name of the individual who conducted the sampling (Callaghan et al., 2021; Hertzog et al., 2021; Shen et al., 2023).

Our models predict that House Martin is more likely to be found in large numbers in built-up and populated villages and towns situated in a thoroughly agricultural landscape. This statement is supported by similar results of the prediction map of the probability of occurrences of House Martins (Šťastný et al., 2021). It is well known that urbanised areas provide suitable places for the nesting of mainly synanthropic species in agricultural landscapes (Ptaszyk, 2001; Šťastný et al., 2021). Surprisingly, the population of House Martins has recently slightly decreased with the increasing trend of urbanisation (James Reynolds et al., 2019; Brlík et al., 2021). The expansion of urban areas, known as urban sprawl, is creating new challenges for bird survival. Birds that use urban areas, synanthropic or otherwise, have to deal with new challenges such as an increasingly fragmented space surrounded by new things, such as new buildings or roads. These factors exacerbate problems in urbanised areas such as pollution, noise, food availability, and predatory pressures (Isaksson, 2018; Žibret et al., 2018). We must consider the urban landscape as a complex environment composed of different types of habitat and a specific mosaic that will uniquely support the population of House Martins.

We found that mining areas exhibited broad spectrum of effects on the population size of House Martins. The wide range of confidence intervals for the effect size of mining areas suggests that these types of anthropogenic environments involve many types of mining areas with a wide range of impacts on the population size of House Martins. Cramp and Gooders (1967) observed that improved pollution conditions caused recolonization of birds in previously contaminated plots. On the other hand, many studies have pointed out that declining bird populations are linked to pollution (Richard et al., 2021). The studies directly state that polychlorinated biphenyls, metals, or organophosphates could have lethal or sub-lethal effects on the Hirundinidae bird family. The impact of these substances can occur directly from the contaminated area or indirect through prey insects (Imlay and Leonard, 2019). A study carried out in Czechoslovakia in the 1980s (Newman et al., 1985) states that House Martin tend to avoid polluted environments, which aligns with our findings regarding the ambiguous impact of mining areas.

Surprisingly, the factor of urban greenery appears to have an inconsistent (i.e., positive and also negative) effect on House Martin population. We found that the effect size of urban landscape (i.e., urban infrastructure, development areas and post-industrial sites) had a significantly higher positive impact on the House Martin population size compared to urban greenery. Our study results are consistent with those of Silva et al. (2015) which found that the municipal green areas were more homogeneous than non-municipal green areas, leading to a negative effect on bird density. However, other studies show the positive impact of urban greenery in large cities (>100,000 inhabitants) on species occurrence (Ptaszyk, 2001; Alberti, 2005; Pellissier et al., 2012; Izakovičová et al., 2017). We attribute the discrepancy to local specificities at the study sites and the small scale of the surveys conducted. Urban greenery, like the presence of vegetation in cities, could provide a healthy environment (Braubach et al., 2017; Diener and Mudu, 2021) and habitats for aerial invertebrates (Jones and Leather, 2012) that provide a supply of food for House Martins (Turner, 1982; Bryant, 2008). According to the previous findings we can say that the advancing urbanisation and reduction of the proportion of greenery in cities will therefore lead to a negative effect on House Martins in the future (Schlesinger et al., 2008; Isaksson, 2018; Kettel et al., 2021). Our results complement these findings by highlighting the importance of the structure and features of urban green spaces, as well as the management of abandoned areas linked to industrial activities, for House Martin populations in urban environments.

Forested areas were one of the factors that negatively affected the population size of House Martins. This result is in agreement with other studies mentioning forested areas as unsuitable habitat as well (Viktora, 2020; Šťastný et al., 2021; Dvořáková et al., 2023). The same negative effect of the forested landscape on foraging success was observed for species guild of aerial insectivores (e.g., *Hirundo rustica*, *Tachycineta bicolor*, *Progne subis*, *Riparia riparia*) (Dreelin et al., 2018; Garrett et al., 2022a, 2022b). This group of species specialize on the aerial plankton that creates ephemeral clumps in the air column (Dreelin et al., 2018). The dominant foraging activity is concentrated in these places, especially within a few meters of the ground (Elkins, 2010). During the nesting season, they also consume a diet consisting mainly of insects with aquatic larval stages (e.g., Ephemeroptera and Diptera: Nematocera) in landscapes composed mainly of crop fields and pastures (Bellavance et al., 2018). In addition to the insufficient density of food, forested areas could give better opportunities to predators that hunt House Martins, as vegetation could obstruct the martins' field of view (Beauchamp, 2015). Birds may simply avoid forested areas due to the increased risk of predation. On the contrary, Mikusiński et al. (2018) mention that the forest canopy could be a suitable place for the foraging activities of House Martins.

The presence of orchards and vineyards in the agricultural landscape mosaic has negatively influenced the abundance of House Martin. This may be an unexpected result, because vineyards and orchards often serve as a refuge for many species of insects (Sisterson et al., 2020). On the other hand, it is still monoculture with a homogeneous spatial structure, where large amounts of pesticides are often applied (Bruggisser et al., 2010; Linhart et al., 2019; Kettel et al., 2021). The negative impact of these landscape types is explained by their lower habitat heterogeneity, resulting in a lower number of potential breeding sites and refuges for animal species (Assandri et al., 2017; Paiola et al., 2020). This result does not mean that all vineyards and orchards, especially those that apply ecological management, negatively affect the House Martin abundances.

Based on our results, we can say that agricultural land was one of the preferred types of habitat. Specifically, they preferred agricultural land with a high proportion of natural and bushy vegetation. This habitat type represents the mosaic pattern of small cultivated land parcels, forests, shrubs, and wetlands. This finding is consistent with the study of Fahrig et al. (2015), where the mean crop field size had a negative effect on biodiversity in crop fields and recommendations were made to reduce field sizes. This means that the biodiversity in crop fields depended on the presence of semi-natural boundary habitats of crop fields to increase fine-grained landscape mosaic heterogeneity more than large natural patches such as forests or pastures. Agriculture land (Šťastný et al., 2021) with elements of natural vegetation were also important landscape components, most likely due to food availability in the form of flying insects (Kopij, 2000; Robinson et al., 2001; Atkinson et al., 2005; Jasso, 2017). It has been found that insects are an important factor for House Martins when choosing nesting areas, as important insect taxa are mentioned: Hymenoptera, Diptera, and Hemiptera (Turner and Rose, 1989; Boukhemza-Zemmouri et al., 2013). These insect taxa have been found to be declining species, so in the future this could have a negative impact on House Martin occurrences (Sánchez-Bayo and Wyckhuys, 2019).

Additionally, we found that House Martin tend to prefer areas with aquatic ecosystems such as waterbodies and also marshes. Unlike water bodies, the influence of wetlands on their abundance has had both positive and negative impacts. This can be explained by the fact that while wetlands provide sufficient food, House Martins may not find suitable nesting sites in the vicinity of wetlands. Aerial insectivorous birds often depend in various forms on water and wetland habitats (Uesugi and Murakami, 2007). Šťastný et al. (2021) and Kettel et al. (2021) stated that the presence of freshwater areas in a landscape increases the nest success of House Martins. Wetland habitats could provide building materials in the form of mud, which House Martins collect to build nests (Murgui, 2002; Tsikalas and Butler, 2015). Wetland habitats around urban nesting sites could also provide good feeding sites in the form of flying invertebrates (Kettel et al., 2021). The relationship between insectivorous birds and insects in wetland ecosystems can be influenced by vegetation structure, water quality, and pollution (Alberts et al., 2013; Sullivan et al., 2021). Additionally, urban-induced alterations in streams and rivers can also influence bird occurrences. Urban et al. (2006) revealed that human interventions in aquatic habitats have resulted in a reduction in the species richness of aquatic invertebrates. Especially the abundance and richness of emergent aquatic insect is negatively correlated with human activities within watersheds (e.g., urbanisation and intensive agriculture) (Sullivan et al., 2021). Invertebrate communities in human-altered watersheds are shifted toward populations dominated by non-emergent taxa or by smaller species (e.g., Nematocera) (Stenroth et al., 2015). This community change imposes significant negative impacts on aerial insectivorous birds (Manning and Sullivan, 2021). It was also found that riparian swallows breeding in urban habitats were more dependent on emergent insects than rural swallows (Alberts et al., 2013).

5. Conclusion

We revealed that House Martin prefers urbanised ecosystems and agricultural land with a high proportion of natural vegetation. Other habitats whose positive influence we have confirmed include aquatic ecosystems, such as waterbodies and marshes. Furthermore, we can say that among anthropogenic areas, we found significant differences between strict urban or mining areas and urban greenery habitats. We also found that the negative impact of mining areas on the House Martin abundance varies greatly. This represents the possibility that House Martins do not completely avoid these types of habitat but instead choose between them based on their management.

Our findings revealed a stronger correlation between the population of House Martins and urban infrastructure, development areas, or post-industrial sites than with urban greenery. This suggests that the current structure of urban greenery areas, including spatial and species composition, may limit the occurrence of House Martins in urban environments.

To conclude, the gradual decline of this common species may be attributed not only to the global trend in declining insect biomass (Shortall et al., 2009; Hallmann et al., 2017) but also to the deterioration in the quality of urban greenery and the increased rate of urbanisation in towns (e.g., alterations in streams and rivers), as well as the intensification of agriculture, which leads to the decline of natural vegetation and wetlands.

Based on our results, we believe that conserving the House Martin population will require a primary focus on managing close-to-nature areas within human settlements and agricultural landscapes. Urban greenery must be supplemented with sources of food and nest-building materials, which means primarily removing human encroachment from water bodies (e.g., removal of stream channel fortifications). In agricultural landscapes, the percentage of natural vegetation and wetlands will need to be increased. For the conservation of this species in cities, and for much of urban biodiversity in general, it will be essential not to neglect the impact of post-industrial habitats. The form of their reclamation will be crucial, providing nesting sites for House Martins and similar species, as well as sources of food and nest-building material.

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Ethics statement

Ethics approval was not required for this study. We did not manipulate with living individuals. Data was obtained from the public database.

CRediT authorship contribution statement

Denisa Dvořáková: Writing – review & editing, Writing – original draft, Methodology, Data curation, Conceptualization. **Jan Šipoš:** Writing – review & editing, Methodology, Data curation, Conceptualization. **Josef Suchomel:** Writing – review & editing, Methodology, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.

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