Ornis Hungarica 2023. 31(1): 88–110.
DOI: 10.2478/orhu-2023-0006

Relationship between landscape structure and the diet of Common Barn-owl *(Tyto alba)* at different distances from the Drava River ecological corridor

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Received: May 02, 2023 – Revised: May 16, 2023 – Accepted May 17, 2023

Horváth, Gy. F., Mánfai, K. & Horváth, A. 2023. Relationship between landscape structure and the diet of Common Barn-owl *(Tyto alba)* at different distances from the Drava River ecological corridor. – Ornis Hungarica 2023(1): 88–110. DOI: 10.2478/orhu-2023-0006

Abstract This study investigated the relationship between landscape structure at different distances from the Drava River in South Hungary and the food composition of the Common Barn-owl. Pellets were collected from 15 villages between 2006 and 2008. Based on the CORINE land cover elements, five land use types were determined, and five landscape metrics were calculated to compare land use and landscape structure in the three distance zones. There were significant differences in the Shannon and Simpson diversity of small mammal assemblages between the three areas. A positive relationship was detected between the distance categories and the abundance distribution of the Striped Field Mouse and Field Vole. The relative abundance of the Striped Field Mouse in the diet of Common Barn-owl was influenced by the increase in the mean perimeter/area ratio and the mean of the contiguity index. The value of the trophic level index was negatively influenced by the decrease in crop patches and the increase in pasture and grassland areas, which land use types facilitate the distribution of insectivores. Our results suggest that landscape characteristics influence prey occurrence in hunting areas and the frequency-dependent availability of small mammal prey, which determines the resource utilization of Common Barn-owl.

Keywords: diet composition*, Tyto alba,* pellet analysis, CORINE land cover, landscape structure

Összefoglalás Jelen tanulmányban a Dráva folyótól különböző távolságokban jellemző tájszerkezet és a gyöngybagoly táplálék-összetétele közötti összefüggést vizsgáltuk köpetelemzés alapján. A felhasznált mintákat 15 faluból gyűjtöttük 2006 és 2008 között. Az elemzéshez a CORINE felszínborítás alapján 5 tájhasználati típust határoztunk meg, illetve 5 tájindexet számítottunk. Mind a Shannon, mind a Simpson diverzitási mutató szignifikánsan különbözött a három távolság összehasonlításában. Pozitív összefüggést mutattunk ki a három távolságkategória és a pirók erdeiegér, valamint a csalitjáró pocok abundanciája között. Emellett a pirók erdeiegér gyakoriságát a kerület/terület arány és a szomszédsági index értékének növekedése is befolyásolta. A trofikus index (TLI) értékére negatív hatással volt az agrárterületek arányának emelkedése, és pozitívan befolyásolta a legelők és gyepek mennyiségének növekedése, amely utóbbi területhasználati módok elősegítik a rovarevők elterjedését. Eredményeink arra utalnak, hogy a táj jellemzői befolyásolják a zsákmány előfordulását és gyakoriságtól függő elérhetőségét a baglyok vadászterületén, ami meghatározza a gyöngybaglyok forráshasznosítását.

Kulcsszavak: táplálék-összetétel*, Tyto alba,* bagolyköpet elemzés, CORINE felszínborítás, tájszerkezet

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Introduction

Human-induced land use and intensive agricultural practice with the extensive use of fertilizers and pesticides have a significant impact on biodiversity (Sala *et al.* 2000, Stoate *et al.* 2001, 2009, Zebisch *et al.* 2004, Geiger *et al.* 2010). The rich diversity of agricultural landscapes greatly depends on the types of land use, sizes and shapes of fields, as well as the abundance and pattern of semi-natural elements of the landscape (Billeter *et al.* 2008). However, the change in agricultural practices and intensification led to the reduction of heterogeneity and quality of landscape composition and structure as available habitat for wildlife, especially for the environmentally sensitive Common Barn-owl *(Tyto alba)* (Colvin 1985, Gorman & Reynolds 1993, Burel *et al.* 2004, Martin *et al.* 2010, Hindmarch *et al.* 2012). This opportunistic owl species occurs in most of these human-modified and disturbed open landscapes (grasslands, farmlands, agriculture fields, fallow, crop margins and hedgerows, woodland edges, river banks) (Andries *et al.* 1994, Salvati *et al.* 2002, Meek *et al.* 2003, Martínez & Zuberogoitia 2004, Frey *et al.* 2011), and as a top predator, it has an important role in the trophic cascades of agricultural ecosystems, especially in rodent control (Meyrom *et al.* 2009, Paz *et al.* 2013). Diet analysis of Common Barn-owl is widely used all over the world because it is a cosmopolitan nocturnal raptor, which prefers mainly small mammals (Jaksić *et al.* 1982, Mikkola 1983, Taylor 2004). This method, as an indirect approach, has been extensively used to investigate the distribution and evaluate the population and community response of small mammals at various temporal and spatial scales in a given region (e.g. Meek *et al.* 2012, Torre *et al.* 2015a), or along geographical and vegetative gradients (e.g. Leveau *et al.* 2006, Trejo & Lambertucci 2007, Torre *et al.* 2015b), as well as, along rural-urban gradients (Teta *et al.* 2012, Hindmarch & Elliott 2015, Iannella *et al.* 2016). In addition, numerous studies used diet analysis of Common Barn-owl as a suitable tool to investigate the composition of small mammal assemblages and species or guild frequency depending on the change in agricultural activity (Love *et al.* 2000, Bose & Guidali 2001, Millán de La Peña *et al.* 2003, Askew *et al.* 2007, Charter *et al.* 2009, Lyman 2012). Based on landscape analysis, the results of several studies suggested that the diet of Common Barn-owl, particularly small mammal composition and diversity, was affected by agricultural activity (Millán de La Peña *et al.* 2003, Askew *et al.* 2007, Marti 2010), landscape heterogeneity (Torre *et al.* 2015a) as well as land use and landscape composition (Burel *et al.* 2004, Milchev 2015, Veselovský *et al.* 2017, Horváth *et al.* 2018, Horváth *et al.* 2022).

The Common Barn-owl is a widely distributed owl species in Hungary, particularly along the lowland farmland areas. Analyses of the food habits of Common Barn-owl, focusing on the composition of small mammals, were intensive in the last three decades in the southern part of Transdanubia, which included the region of Drava River (Horváth 1998, 2000, Purger 1998). Although most of these studies were baseline surveys and did not investigate the dependence of food composition on the type of land use, the difference in small mammal communities was investigated by pellet analysis in a previous study that compared the three Drava River sections using landscape features (Horváth *et al.* 2005).

The aims of the present study are: 1) to compare the food habits of Common Barn-owl, especially the small mammal assemblages at the three different distances from the Drava

River ecological corridor, 2) to compare the estimates of species richness and diversity of small mammal prey assemblages along this environment gradient, and 3) to analyse the effects of landscape structure on the distribution of relative frequencies of different small mammal taxa.

Material and Methods

Study area

The study was conducted in the south-eastern part of the Transdanubian region in South Hungary, where sampling sites were situated in Baranya county (4429.6 km²) (32° 30′ N, 35° 30′ E) in two mesoregions (Drava Floodplain, Mecsek and Tolna-Baranya hill country) at three different distances (see below) from the Drava River ecological corridor. The climate of these regions is determined by a Mediterranean effect, with a high number of sunny hours, relatively low temperature fluctuations, and mild winters. The area of the Drava Floodplain includes the flood-basin of the Drava River; altitude varies between 89 and 212 metres, its area is 1,300 km^2. The Drava River represents the southern border of both the mesoregion and the country. The climate of this mesoregion is moderately warm and humid. The annual amount of precipitation increases from east to west: 630–680 mm in the east, while more than 720 mm in the west. The Mecsek and Tolna-Baranya hill country is situated in the north of the previous mesoregion and its area is 4,400 km^2, where the yearly mean precipitation is 680–720 mm.

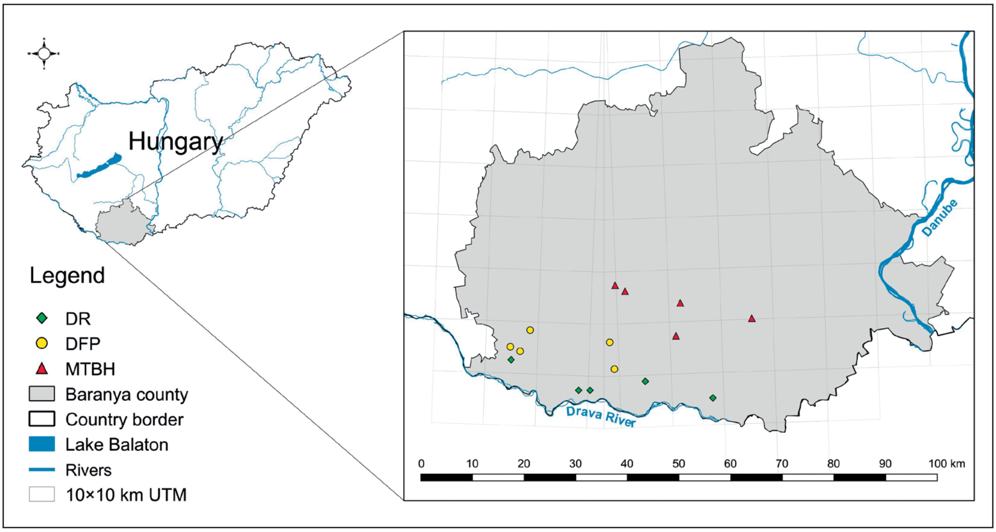

Figure 1. Study area in the South Transdanubia region, Hungary, showing the location of sampled nesting sites (settlements) in the distance categories to the north of the Drava River (DR: Drava River, DFP: Drava Floodplain, MTBH: Mecsek and Tolna-Baranya hill country)

1. ábra A mintavételi terület Dél-Dunántúlon, Magyarországon, feltüntetve a vizsgált költőpárok fészkelőhelyeit a Drávától északra fekvő különböző távolságkategóriákban (DR: Dráva, DFP: Drávamenti-síkság, MTBH: Mecsek és Tolna-Baranyai dombvidék)

Pellets and prey remains were collected from 15 villages (nest boxes were placed in 11 villages, while 'natural' environment of church towers were sampled in 4 villages) at the end of the Common Barn-owl breeding season between 2006 and 2008. Settlements belonged in three distance categories to the north of Drava River: near Drava River (DR: 3.56 ± 1.24 km SE, n = 5), in Drava Floodplain (DFP: 9.17 ± 2.6 km SE, n = 5) and further north in Mecsek and Tolna-Baranya hill country (MTBH: 20.04 km, ± 4.25 km SE, n = 5) *(Figure 1)*. The distance between the three sampling zones differed significantly (one-way ANOVA: $F_{2, 12} = 39.92$, $P < 0.001$; Tukey's HSD test – DR vs DFP: $P = 0.028$, DR vs MTBH: $P < 0.001$, DFP vs MTBH: $P < 0.001$). A total of 121 samples and 2,552 pellets (DR: 105.4 ± 29.11 SE; DFP: 261.2 ± 88.17 SE; MTBH: 143.8 ± 66.74 SE) were analysed from the 15 localities.

Sample collection methodology

Pellets were processed by the dry technique that is, the individual pellets were broken down by hand (Schmidt 1967) and prey items were identified to the lowest taxonomical level. Small mammals and bats were identified based on skeletal parameters (features of skull, mandible and teeth), following published literature (Schmidt 1967, März 1972, Yalden 1977, Niethammer & Krapp 1978, 1982, 1990, Yalden & Morris 1990). Three different *Apodemus* species, the Wood Mouse *(Apodemus sylvaticus)*, the Yellow-necked Wood Mouse *(A. flavicollis)* and the Pygmy Field Mouse *(A. uralensis)* were categorised commonly as Wood Mice (*Apodemus* spp.). In cases when the Striped Field Mouse *(A. agrarius)* could not be separated from the *Sylvaemus* group (*Apodemus* spp.), the individuals were treated as 'unidentified *Apodemus*'. The sibling species of the *Mus* genus were determined by works of Macholán (1996) and Kryštufek and Macholán (1998). In addition, birds were identified by their skulls, bills, feet, pelvises and feathers (Kessler 2015), and frogs (Anura) by their skulls and bones of postcranial skeleton (Schaefer 1932). If major skeletal elements were missing, prey items were identified to genus (small mammals, birds), to order (frogs) and to class (birds) level.

The number of preys was estimated as the minimum number of individuals (MNI), which were determined according to the same anatomical parts of bones for small mammals (Klein & Cruz-Uribe 1984, Torre *et al.* 2015a, Tulis *et al.* 2015) and skulls, mandibles and long bones for birds, as well as skulls, remnants of ilium or frontoparietal bones for frogs. Furthermore, the percent frequency of occurrence (MNI%) was calculated from the total number of prey found in all the pellets at the three different distance zones. The ratio of insectivores to rodents as an environmental (Paspali *et al.* 2013) or trophic level index (TLI) (Prete *et al.* 2012) and the ratio of Microtinae/Murinae (MMR) were also calculated. The first index is a suitable indicator of possible biotope alteration (Mazzotti & Caramori 1998, Paspali *et al.* 2013), while the MMR is a suitable environmental index for the indication of the agronomic value (Prete *et al.* 2012) of intensively cultivated landscapes.

Determining land use and landscape structure

Landscape features were assessed using photointerpretation of aerial photographs based on the CORINE land cover project (Bossard *et al.* 2000, European Environmental Agency

2007). We used a 1 km radius around each nest sites because this results in an area that approximates the home range (3 km^2) of a Common Barn-owl (Shawyer & Shawyer 1995, Taylor 2004, Bond *et al.* 2005, Hindmarch *et al.* 2012, Horváth *et al*. 2018, 2022). GIS analysis was performed in ArcGIS 10.1 (Environmental Systems Research Institute 2012). Based on CORINE land cover elements of the 15 nest sites, five selected land use types were determined to compare land use in the three landscape zones north of Drava River. The land use classification system included: the percentage of forest (all forest habitats), grassland (including meadows, dry and semi-dry grasslands), cropland (including all agricultural crops and arable fields), pasture, wetland (including river banks, streams, artificial lakes, fishponds, marshes) and urban (all built-up surfaces) areas.

To evaluate the landscape structure of sampling sites, FRAGSTATS version 4.2 was used for spatial statistical analysis (McGarigal *et al.* 2012). This analysis was used only at the landscape level and five landscape indices were calculated: area weighted mean shape index (ha) (SHAPE_MN, mean patch shape complexity weighted by patch area), largest patch index (%) (LPI, percentage of total landscape area comprised by the largest patch), perimeter-area ratio (PARA_MN, mean of perimeter-area ratio, which describes the compactness of patches), mean fractal dimension (FRAC_MN) and the mean of the contiguity index (CONTIG_MN; these indices defined the patch shape complexity and patch boundaries connectedness, respectively), patch richness (PR, which measures the number of patch types present), Shannon diversity of landscape (SHDI, which measures the equitability of the number of patch types and the proportional distribution of area among patch types) (McGarigal 2015).

Statistical analysis

All proportion data of prey abundance were arcsin-square root transformed prior to analyses and tested for normal distribution (Shapiro-Wilk test) and for homogeneity of variance (Levene test). According to the results of these tests, normal distribution was found in case of major small mammal taxa (shrews, rodents, mice), the values of TLI and the Common Vole *(Microtus arvalis)*, the main prey of the Common Barn-owl and a major pest rodent species in Central Europe (Jacob *et al.* 2014, Pavluvčík *et al.* 2015), therefore, one-way analysis of variance (ANOVA) with Tukey's HSD multiple comparison was performed to test eventual significant differences among the landscape units (nest sites) classified into the three distance categories north from Drava River. In case of the total abundance of small mammals, mice, birds and frogs, the assumptions of one-way ANOVA were not met after transformation. Therefore, nonparametric Kruskal-Wallis median test with Dunn's procedure for post hoc comparisons was used. The distribution of different land use categories was analysed similarly by one-way ANOVA comparison of the three different landscape zones.

To evaluate the species richness and diversity of small mammal assemblages among the samples located at three different distances, we estimated Hill numbers (q = 0, species richness; q = 1, Shannon diversity (H); q = 2, Simpson diversity (1-D)), which are ecologically relevant metrics for describing and comparing diversity (Jost 2006, Chao *et al.* 2014). This method is based on seamless rarefaction and extrapolation (R/E) sampling curves of the α diversity metrics (Chao *et al.* 2014, Hsieh *et al.* 2016). In each case, 100 replicate bootstrap runs were used to estimate the 95% confidence interval. Based on publication of Colwell and Elsensohn (2014), the rarefaction curves were extrapolated by doubling the number of individuals.

Variables of land use categories and landscape metrics were summarised by means of Principal Component analysis (PCA) on the correlation matrix. This method allows for independent components of maximum explanatory capacity to be obtained, avoiding the problems of collinearity. To meet the assumptions of homogeneity, arcsin-square root transformed values of land-use relative frequency and log-transformed values of landscape metrics were used in PCA analyses.

Stepwise linear regression was implemented to identify and quantify the relationships between the abundance of different small mammal taxa and the landscape structure. For this analysis, an automated stepwise model selection procedure with the "stepAIC" function was used, with forward selection to obtain the best model using the Akaike Information Criterion (AIC) (Venables & Ripley 2002). We separated two model groups based on the use of the land use categories or the landscape metrics. In case of both model groups, the initial (global) linear models included the arcsin-square root transformed abundance of small mammal species and genera as dependent variables, the distance from the Drava River as a categorical variable, and the first two PCA scores of the landscape variables (land use categories or landscape indices) as continuous variables and all combinations of these variables as interaction effects. We used the R^2 measure to assess the error since the R^2 statistic is commonly interpreted to be the proportion of variance explained by the regression. The best candidate model was selected based on the AIC value and the highest significant (F-statistic) coefficient of determination (R^2). The one-way and Kruskal-Wallis ANOVA, PCA and stepwise linear regression analyses were performed in the statistical program R v3.4.0 (R Development Core Team 2019). Rarefaction curves were drawn using the 'iNEXT' package (Hsieh *et al.* 2016) for R. The statistical tests were considered significant at the level $P \leq 0.05$ as standard in all analyses (Sokal & Rohlf 1995).

Results

Based on all samples, 9,720 prey items were identified from the pellets examined during the three years *(Table 1)*. The diet of the Common Barn-owl was mostly based on small mammal prey (99.33% of all the prey consumed), which was similar in all three sampling distance zones north of Drava River (DR: 98.72%, DFP: 99.52%, MTBH: 99.41%; Kruskal-Wallis test: H(2, 15) = 1.620, P = 0.445). Among other prey, the percent frequency of occurrence of birds (H(2, 15) = 1.340, P = 0.512) and frogs (H(2, 15) = 6.898, P = 0.032) were not significantly different between the three landscape categories, although consumption of frogs was higher near Drava River. Rodents rather than insectivores dominated in the diet of Common Barn-owls. Rodents were highly frequent in the food composition (79.76% of all the preys consumed) and their relative proportion showed an increasing trend from

Table 1. Diet composition of the Common Barn-owl in the three distance categories to the north of Drava River (MNI: minimum number of individuals, MNI%: percentage frequency of occurrence)

1. táblázat A gyöngybagoly táplálék-összetétele a Drávától mért három különböző távolságkategóriában (MNI: minimum ismert egyedszám, MNI%: az előfordulási frekvencia százalékos értéke)

Prey taxon	**Drava River (DR)**		**Drava Floodplain (DFP)**		**Mecsek and Tolna-Baranya hill country (MTBH)**	
	MNI	**MNI%**	**MNI**	**MNI%**	**MNI**	**MNI%**
Mammals						
Sorex araneus	150	7.67	284	5.63	51	1.88
Sorex minutus	51	2.61	74	1.47	15	0.55
Neomys anomalus	45	2.30	34	0.67	31	1.14
Neomys fodiens	8	0.41	24	0.48	5	0.18
Neomys sp.	4	0.20	23	0.46	3	0.11
Crocidura leucodon	96	4.91	143	2.83	81	2.98
Crocidura suaveolens	171	8.74	494	9.79	115	4.23
Myodes glareolus	17	0.87	43	0.85	8	0.29
Microtus agrestis	14	0.72	146	2.89	19	0.70
Microtus arvalis	754	38.55	2076	41.13	1358	50.00
Microtus subterraneus	9	0.46	14	0.28	11	0.41
Arvicola amphibius	26	1.33	77	1.53	6	0.22
Rattus norvegicus	16	0.82	16	0.32	14	0.52
Rattus rattus	0	0.00	2	0.04	0	0.00
Rattus sp.	0	0.00	2	0.04	1	0.04
Apodemus agrarius	199	10.17	347	6.87	161	5.93
Apodemus spp.	184	9.41	578	11.45	441	16.24
Unidentified *Apodemus*	49	2.51	208	4.12	159	5.85
Micromys minutus	44	2.25	95	1.88	24	0.88
Mus spicilegus	40	2.04	106	2.10	71	2.61
Mus musculus	17	0.87	46	0.91	26	0.96
Mus sp.	30	1.53	156	3.09	85	3.13
Muscardinus avellanarius	7	0.36	36	0.71	14	0.52
Glis glis	0	0.00	0	0.00	1	0.04
Eptesicus serotinus	0	0.00	1	0.02	0	0.00
Totals	1931	98.72	5025	99.54	2700	99.41
Birds						
Passer domesticus	5	0.26	5	0.10	4	0.15
Passer montanus	6	0.31	1	0.02	3	0.11
Passer sp.	5	0.26	2	0.04	1	0.04
Hirundo sp.	0	0.00	0	0.00	1	0.04

Prey taxon	**Drava River (DR)**		**Drava Floodplain (DFP)**		**Mecsek and Tolna-Baranya hill country (MTBH)**	
	MNI	**MNI%**	**MNI**	**MNI%**	**MNI**	**MNI%**
Erithacus rubecula	0	0.00	1	0.02	0	0.00
Unidentified Aves	1	0.05	13	0.26	6	0.22
Totals	17	0.87	22	0.44	15	0.55
Frogs						
Pelobates fuscus	6	0.31	1	0.02	1	0.04
Unidentified Anura	2	0.10	0	0.00	0	0.00
Totals	8	0.41	1	0.02	1	0.04
Total MNI	1956		5048		2716	

Drava River to Mecsek and Tolna-Baranya hill country (DR: 71.88%, DFP: 78.21%, MTBH: 88.33%). The transformed percentage by number of rodents differed significantly between landscape zones (one-way ANOVA: $F_{2,12} = 4.892$, $P = 0.028$) and the percent values were significantly higher in the Mecsek and Tolna-Baranya hill country than in the area near the Drava River (post hoc Tukey's HSD test: $P = 0.033$). The percentage of shrews (Soricidae) (all samples: 19.57%) changed conversely along the investigated landscapes (DR: 26.84%, DFP: 21.32%, MTBH: 11.08%) and transformed data differed significantly in comparison of various distances ($F_{2,12} = 4.892$, $P = 0.028$). The abundance of shrews was significantly higher in the ecological corridor near the Drava River than the area of Mecsek and Tolna-Baranya hill country (Tukey's HSD test: $P = 0.033$). According to these results, the ratio of insectivores to rodents was significantly different between the studied areas ($F_{2,12} = 3.887$, $P = 0.049$). The environmental index (TLI) oscillated in a larger range of values in the area near the Drava River (DR: min = 0.11, max = 0.57) than in the other two distance zones (DFP: min = 0.11, max = 0.38; MTBH: min = 0.07, max = 0.17) and showed a decreasing trend depending on the measured distance from the river. Within the group of rodents, mice (Murinae) (DR: 29.60%, DFP: 30.82%, MTBH: 36.16%) and *Microtus*

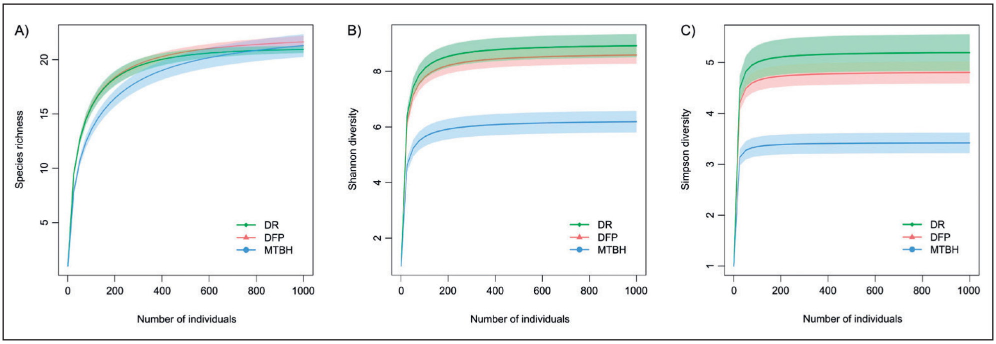

Figure 2. Rarefaction curves illustrating the species richness (A), Shannon diversity (B) and Simpson diversity (C) of the small mammal assemblages of the three different distance categories

2. ábra A három különböző távolságkategóriába tartozó kisemlős együttesek fajgazdagságát (A), Shannon diverzitást (B) és Simpson diverzitást (C) szemléltető ritkasági görbék *arvalis* (DR: 39.05%, DFP: 41.32%, MTBH: 50.30%) occurred in a higher proportion in the diet composition of Common Barn-owls, but these values did not differ between landscape zones (mice: Kruskal-Wallis test: H(2, 15) = 1.040, P = 0.595; *M. arvalis*: one-way ANOVA: $F_{2,12} = 3.042$, P = 0.085).

Rarefaction analysis demonstrated that the species richness did not differ significantly between the three different distances because the 95% confidence bands of the rarefaction curves overlapped *(Figure 2)*. In the case of Shannon (H) and Simpson (1-D) diversity, due to non-overlapping 95% confidence intervals, these alpha diversity metrics were significantly lower in Mecsek and Tolna-Baranya hill country than the other two landscape distance zones *(Figure 2)*. The rarefaction curves' confidence band of the Drava River and the Drava Floodplain overlap, so the diversity of the small mammal communities of these two areas did not differ significantly *(Figure 2)*.

The first two axes of the PCA performed on land use variables accounted for 70.87% of the common variance (PC1: eigenvalue = 2.823, PC2: eigenvalue = 1.429) *(Table 2)*. The first component (47.10% of the variance) was related positively to the area of forest, grass and pasture while negatively to the area of croplands. The second component (23.80%) was negatively correlated with the forest, wetland and urban patches *(Table 2)*. In case of the PCA performed on landscape indices, the first two axes accounted for 78.70% of the common variance (PC1: eigenvalue = 3.503, PC2: eigenvalue = 2.004). The first component (50.05% of the variance) was negatively associated with the index of CONTIG_MN and Shannon diversity of landscape (SHDI), while positively correlated with PARA_MN *(Table 2)*. The second component (28.63%) was positively related to the indices SHAPE_MN and FRAC_MN and to patch richness (PR) *(Table 2)*.

Considering the relationship between land use categories and small mammal species' abundance, significant final models were detected in the cases of two species; these models included only the distance from Drava River (DR) as a categorical predictor *(Table 3)*. Based on the results of the analysis, a positive association was detected between the distance categories and the abundance distribution of the Striped Field Mouse; the area near the

Table 2. Results of the Principal Component Analyses carried out to synthesis the variation in land use and landscape metrics (bold indicates the absolute values > 0.4)

2. táblázat A vizsgált változók főkomponens értékei a tájhasználat és a tájindexek vonatkozásában (a 0,4 abszolút értéknél nagyobb értékek félkövéren szerepelnek a táblázatban)

	Land use			**Landscape metrics**	
Variable	**PC 1**	**PC 2**	**Variable**	**PC 1**	**PC 2**
Forest	**0.469**	-0.280	LPI	0.380	-0.147
Grass	**0.457**	0.165	SHAPE_MN	0.253	**0.574**
Crop	-0.499	0.403	FRAC_MN	0.313	**0.547**
Pasture	**0.514**	0.132	PARA_MN	**0.484**	-0.094
Wetland	-0.220	**-0.585**	CONTIG_MN	**-0.468**	-0.030
Urban	-0.099	**-0.610**	PR	-0.243	**0.535**
			SHDI	-0.426	0.232

Table 3. Final models of linear regression analysis at species level (significant models are in bold)
3. táblázat A lineáris regresszió végső modelljei a fajok szintjén (a szignifikáns modellek félkövéren szerepelnek a táblázatban)

Small mammal species / Final model	**Model parameters**			
	AIC	**R²**	**F**	**P**
Land use				
M. arvalis ~ Distance	-71.87	0.34	3.04	0.085
***A. agrarius* ~ Distance**	-89.11	0.48	5.63	0.019
Apodemus spp. ~ PC1×Distance + Distance×PC2	-72.06	0.69	1.66	0.276
S. araneus ~ PC1×Distance + PC2×Distance	-71.38	0.71	1.83	0.240
C. suaveolens ~ PC1×Distance + PC2×Distance	-71.55	0.67	1.50	0.320
C. leucodon ~ PC2	-79.93	0.21	3.38	0.089
***M. agrestis* ~ Distance**	-87.20	0.48	5.46	0.021
Landscape metrics				
M. arvalis ~ Distance	-71.87	0.34	3.04	0.085
***A. agrarius* ~ PC1 + Distance + PC2 + PC1×Distance**	-93.22	0.77	4.46	0.028
Apodemus spp. ~ PC2	-72.18	0.22	3.58	0.081
***S. araneus* ~ PC1 + Distance + PC2**	-73.69	0.57	3.48	0.050
***C. suaveolens* ~ Distance + PC2**	-75.57	0.50	3.71	0.046
C. leucodon ~ PC1×Distance + PC2×Distance	-77.91	0.64	1.35	0.544
M. agrestis ~ PC1×Distance + PC2×Distance	-84.93	0.73	1.99	0.209

Drava River (DR) positively influenced the species' abundance in owl pellets compared to the Drava Floodplain (DFP) (β = -0.065 ± 0.029, t = 2.207, P = 0.048) *(Figure 3A)*. Based on the determination coefficient, the same final model of the Field Vole *(Microtus agrestis)* demonstrated a significant impact of the distance categories on the abundance *(Table 3)*. The standardised regression coefficient demonstrated that area near the Drava River (DR) (β = -0.090 ± 0.031, t = 2.859, P = 0.014) and the Mecsek and Tolna-Baranya

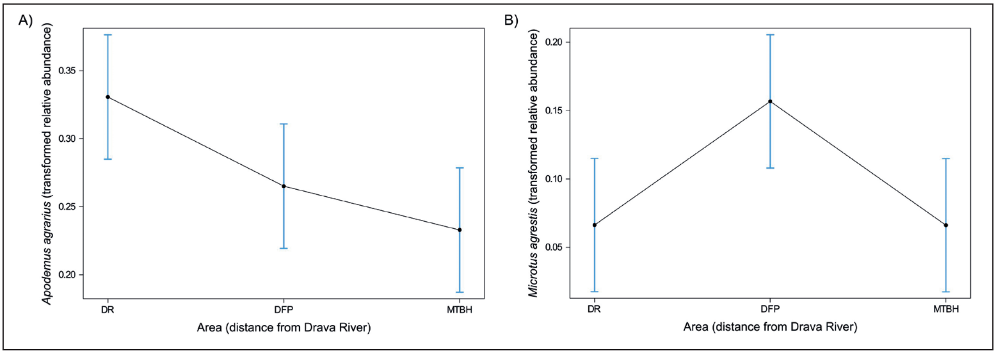

Figure 3. Impact of distance categories on the Striped Field Mouse's *(A. agrarius)* (A) and on the Field Vole's *(M. agrestis)* (B) abundance distribution
3. ábra A távolságkategóriák hatása a pirók erdeiegér *(A. agrarius)* (A) és a csalitjáró pocok *(M. agrestis)* (B) tömegességi eloszlására

hill country (MTBH) (β = -0.091 ± 0.032, t = 2.863, P = 0.014) negatively influenced the abundance of the Field Vole in the Common Barn-owls' food composition compared to the Drava Floodplain (DFP) *(Figure 3B)*.

Regarding the relationship between landscape metrics and small mammals' abundance at the species level, the best candidate model was significant for three species *(Table 3)*. The significant final model of the Striped Field Mouse included the main impact of distance categories and the first two PC scores of landscape metrics as well as the cumulative effect of PC1 score and distance categories (PC1×Distance) *(Table 3)*. Distance dependence as the main effect in this model also showed a similar result as in the land use evaluation, the variation in the Striped Field Mouse' abundance was negatively determined by the distance of the Mecsek and Tolna-Baranya hill country (MTBH) (β = -0.102 ± 0.043, t = 2.384, P = 0.044). As regards the interaction effect, the estimated regression coefficient demonstrated a significant positive relationship between PC1 scores and the quantity of the Striped Field Mouse in case of the Mecsek and Tolna-Baranya hill country (MTBH) (β = 0.145 ± 0.065, t = 2.367, P = 0.049) in contrast to the other two distance categories. Based on the correlation of the PC1 scores and the value of the landscape metrics *(Figure 4A)*, the results suggested that the proportion of the Striped Field Mouse in the diet of the Common

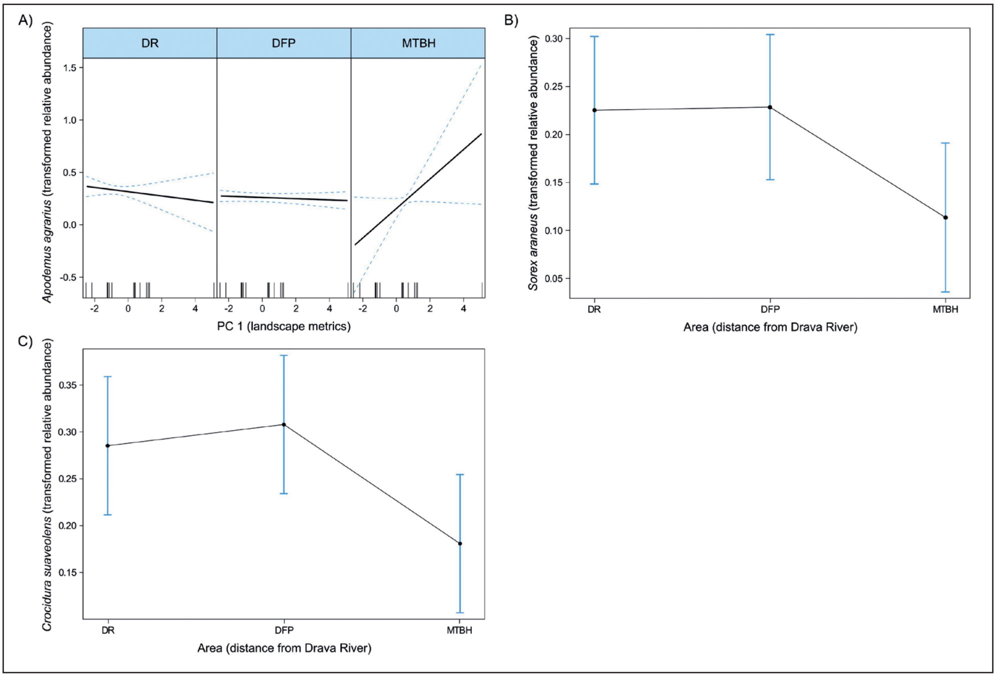

Figure 4. Interaction effect plot based on the relationship between the Striped Field Mouse's *(A. agrarius)* abundance and PC1 scores of landscape metrics (A) and the impact of distance categories on the Common Shrew's *(S. araneus)* (B) and on the Lesser White-toothed Shrew's *(C. suaveolens)* (C) abundance distribution

4. ábra A pirók erdeiegér *(A. agrarius)* és a PC1 főkomponens értékek közötti összefüggés interakciós ábrája (A), valamint a távolságkategóriák hatása az erdei cickány *(S. araneus)* (B) és a keleti cickány *(C. suaveolens)* (C) abundanciájára

Barn-owls was influenced by the increase in the mean of perimeter/area ratio and the mean of the contiguity index (CONTIG_MN), which determined the patch shape complexity. In addition, the final models were significant for two of the three studied shrew species. In case of the Common Shrew *(Sorex araneus)*, the best candidate model included distance categories, and PC1 and PC2 scores of the landscape metrics as main effects *(Table 3)*. According to the estimated standardised coefficient, the abundance distribution of this species was negatively influenced by the Mecsek and Tolna-Baranya hill country (MTBH) (β = -0.115 ± 0.049, t = 2.343, P = 0.041) *(Figure 4B)*. This distance-dependent effect can be interpreted in relation to the area of the Drava Floodplain. The stepwise regression analysis supported similar results also in case of Lesser White-toothed Shrew *(Crocidura suaveolens)*. The significant final model included distance categories as nominal and PC2 scores of landscape metrics as continuous predictors *(Table 3)*, of which the distance effect from the Drava River was significant in the model. Based on the significant estimated parameter, the abundance variation of this shrew species was negatively influenced by the area of the Mecsek and Tolna-Baranya hill country (MTBH) compared to the Drava Floodplain (DFP) (β = -0.112 ± 0.046, t = 2.398, P = 0.035) *(Figure 4C)*.

Considering the results of the forward selection regression method at the genus and derived index (TLI, MMR) level, in the case of the relationship between land use and response variables, two significant final models were detected by the analysis. The best model of the *Crocidura* genus included only the PC1 scores of the land use variables. Despite the fact that this final model explained a smaller proportion of the total variance, based on the significance of the R^2 value, we interpreted the results of this model *(Table 4)*. The estimated regression coefficient showed the significant relationship between PC1 scores of land use and quantity distribution of this shrew group (β = 0.049 ± 0.035, t = 2.240, P = 0.043). Based on the correlation between PC scores and land use categories,

Table 4. Final models of linear regression analysis at genus level (significant models are in bold)
4. táblázat A lineáris regresszió végső modelljei a genusok szintjén (a szignifikáns modellek félkövéren szerepelnek a táblázatban)

Small mammal genus / Final model	Model parameters			
	AIC	R^2	F	P
Land use				
Sorex ~ PC1× Distance + PC2×Distance	-65.13	0.67	1.52	0.315
***Crocidura* ~ PC1**	**-68.48**	**0.34**	**4.38**	**0.048**
Apodemus ~ PC1×Distance + PC2×Distance	-78.78	0.74	2.18	0.179
MMR ~ PC1×Distance + PC2×Distance	-14.10	0.43	0.58	0.769
TLI ~ PC1×Distance + PC2×Distance	**-66.34**	**0.82**	**4.91**	**0.036**
Landscape metrics				
***Sorex* ~ Distance + PC2**	**-69.14**	**0.51**	**3.76**	**0.044**
***Crocidura* ~ Distance + PC2**	**-69.52**	**0.45**	**3.64**	**0.048**
Apodemus ~ PC1 + Distance + PC1×Distance	-72.42	0.42	1.28	0.351
TLI ~ Distance	**-60.21**	**0.39**	**3.89**	**0.050**

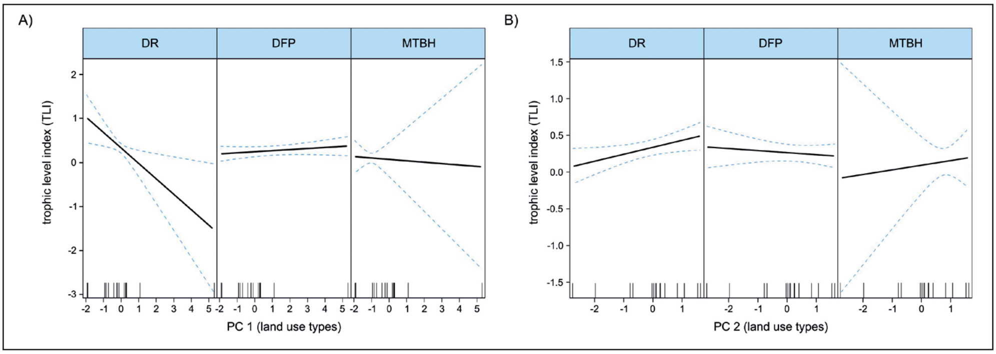

Figure 5. Interaction effect plot based on the relationship between the values of trophic level index (TLI) and PC1 scores (A) as well as TLI and PC2 scores of land use variables (B) compared between different distances from the Drava River

5. ábra A trofikus index (TLI) és a PC1 főkomponens értékek (A), valamint a trofikus index és a PC2 főkomponens értékek közötti összefüggés interakciós ábrái, összehasonlítva a Drávától mért különböző távolságkategóriákat

this result supported that the hunting success of these drought tolerant shrew species was influenced by the increasing proportion of grasslands and pastures, and the decrease in crop area proportion in the local landscapes. As regards of the derived indices, the final model of TLI included two cumulative effects of PC scores and distance categories (PC1×Distance, PC2×Distance). This best candidate model was significant, because the interaction of predictor variables explained more than 80% of the total variance *(Table 4)*. The estimated regression coefficient of the interaction effect showed a significant negative relationship between PC1 scores and the value of TLI in case of the area near the Drava River (DR) (β = -0.365 ± 0.114, t = 3.219, P = 0.018) *(Figure 5A)*, and a positive relationship between PC2 scores and the value of TLI in case of the area near the Drava River (DR) in contrast to the other two distance categories (β = 0.125 ± 0.051, t = 2.469, P = 0.049) *(Figure 5B)*. The PC1 scores of land use were positively correlated with the forest, pasture, and grassland proportions, and negatively associated with the

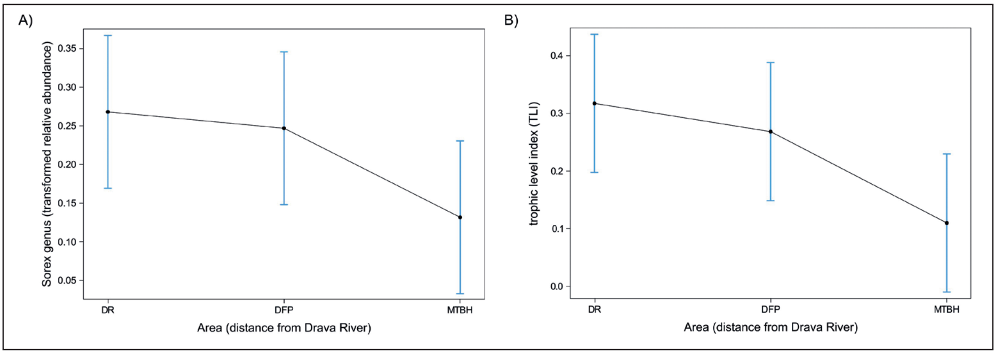

Figure 6. Impact of distance categories on the *Sorex* genus' abundance distribution (A) and on the distribution of the values of trophic level index (TLI) (B)

6. ábra A távolságkategóriák hatása a *Sorex* genus abundancia eloszlására (A) és a trofikus index (TLI) értékeinek eloszlására (B) proportion of croplands. According to this, the value of TLI was negatively influenced by the decrease in crop patches and the increase in pasture and grassland area, which land use types facilitate the distribution of insectivores. In case of the other interaction, PC2 scores of land use were positively associated with the proportion of cropland areas and negatively correlated with the relative frequency of wetland and urban patches in the local landscapes. Therefore, the significant regression in the case of the second interaction shows that the variation of TLI values were positively influenced by the increase in cropland areas and negatively associated with the decreasing proportion of wetland and built-up surface areas, all of which determines the availability of rodent and shrew prey.

Considering the effect of landscape metrics at genus and derived index level, the significant final model was selected by the forward stepwise regression method in case of three response variables. In the case of the *Sorex* genus, the best candidate model included distance categories and PC2 scores of landscape metrics as main effects, explaining 51% of the total variance. Based on the distance from the Drava River, the estimated regression parameter showed that the abundance distribution of this shrew group was negatively influenced by the Mecsek and Tolna-Baranya hill country (MTBH) compared to the Drava Floodplain ($\beta = -0.142 \pm 0.057$, $t = 2.457$, $P = 0.032$) *(Figure 6A)*. Similarly, a significantly negative relationship was detected between the PC2 scores of landscape metrics and the abundance of *Sorex* genus by the regression analysis ($\beta = -0.037 \pm 0.017$, $t = 2.124$, $P = 0.057$). The significant final model of the *Crocidura* genus included the PC2 scores and the distance categories similarly as in the previous prey group *(Table 4)*. In this case, the regression method did not confirm the distance dependence, while based on the estimated regression coefficient, a significant positive relationship was detected between PC2 scores and the relative frequency of the *Crocidura* genus ($\beta = 0.052 \pm 0.019$, $t = 2.314$, $P = 0.041$). In addition, in the case of the TLI values, the multiple regression method confirmed the significant distance effect from the Drava River. The Mecsek and Tolna-Baranya hill country (MTBH) negatively influenced the TLI values compared to the Drava Floodplain (DFP) ($\beta = -0.159 \pm 0.078$, $t = 2.354$, $P = 0.049$) *(Figure 6B)*.

Discussion

In this paper, we studied the food composition of Common Barn-owls at different distances from the Drava River. The diet of this nocturnal raptor varies in different landscape types and land use (Trejo & Lambertucci 2007, Charter *et al.* 2009, Hindmarch & Elliot 2015, Milchev 2015, Horváth *et al*. 2018), however, the small mammals are the main prey group for Common Barn-owl (Marti 1988, Durant *et al.* 2013, Romano *et al.* 2020). In our study, we also found that small mammals were a significant part of the owls' food composition at all three distances (>98%). Among the small mammals, rodents were dominant in the diet, and the abundance of this prey group was significantly higher in Mecsek and Tolna-Baranya hill country than near the Drava River, because the open landscapes such as agrarian areas are advantageous for habitat generalist prey species like the Common Vole or *Mus* species (Millán de la Peña *et al.* 2003, Baláž *et al.* 2013, Milchev 2015, Veselovský *et al.*

2017). On the contrary, the quantity of shrews in the food composition was significantly higher along the Drava River. This area is heterogeneous and rich in semi-natural habitats and wetlands, and a greater diversity of the landscape is beneficial to the occurrence of rare species such as shrews (Milchev 2015, Veselovský *et al.* 2017, Horváth *et al.* 2018, 2022). Based on the above and as already described in several studies, habitat quality and landscape structure are important factors in determining the food composition of the Common Barn-owl because these features influence the availability of the prey (Milchev 2015, Szép *et al.* 2017).

Common Barn-owls occasionally consume non-mammalian prey like birds and frogs, but these species are insignificant in the owls' diet (Milchev 2015, Roulin 2015, Szép *et al.* 2017, Moysi *et al.* 2018). Higher bird consumption can be observed in heterogeneous landscapes with larger and more diverse vegetation cover than in uniform arable lands (Møller 1984, Hanowski *et al.* 1997, Moreira *et al.* 2005, Charter *et al.* 2009). Nevertheless, we could not detect a significant difference in the proportion of birds in the food composition at the three different distances, despite these areas being different in landscape characteristics. Common Barn-owl hunt a higher proportion of anurans at riverbanks (Rocha *et al.* 2011) and during periods when the availability of rodents decreases, because owls respond to lower numbers of rodents by changing their diet and can consume more anurans (Hodara & Poggio 2016), as we have shown in the areas near the Drava River.

According to our results, Shannon (H) and Simpson (1-D) diversity are significantly higher near the Drava River and in the Drava Floodplain than in the Mecsek and Tolna-Baranya hill country, characterised by the highest level of agricultural cultivation. This is coherent with several studies, in which it has been described that heterogeneous environmental conditions and semi-natural patches provide more habitats and resources, and as a result, species richness and diversity increase (Tews *et al.* 2004, Billeter *et al.* 2008), while the increase in agricultural cultivation causes the loss of biodiversity (Benton *et al.* 2003, Millán de la Peña *et al.* 2003, Gentili *et al.* 2014).

Based on the result of ANOVA and multiple regression, the distance from the Drava River proved to be an important predictor variable in the quantity distribution of Striped Field Mouse. This species is well adapted to a variety of habitats (Kozakiewicz *et al.* 1999, Łopucki *et al.* 2013, Gentili *et al.* 2014,), though, as previously described, it is more common in natural, semi-natural, and heterogeneous areas than in homogeneous, simplified landscapes (Fischer & Schröder 2014, Gentili *et al.* 2014). Our result is consistent with these studies, because the abundance of Striped Field Mouse was the highest near the Drava River, where there are more natural, semi-natural and heterogeneous habitats than further north from the river. This is also supported by the analysis at landscape metrics level in the case of the Mecsek and Tolna-Baranya hill country, as we have shown that the abundance of this species declines with the decrease of patch diversity in this area.

Based on the result of multiple linear regression, the three distance categories were also a determining factor of the abundance of the Field Vole, because it was detected in the highest proportion in the floodplain and the other two distance categories significantly negatively affected the distribution of the abundance of the Field Vole. It is a general belief that this *Microtus* species lives in open areas like meadows, grasslands, clear cuts, dunes and moorlands (Alibhai & Gipps 1991, Borowski 2003, Horváth 2007, Kryštufek *et al.* 2008, Szép *et al.* 2017), but it also occurs in hedgerows, woodlands and forests (Hansson 1977, Kowalski & Ruprecht 1981, Alibhai & Gipps 1991, Kryštufek *et al.* 2008). Agricultural landscapes, field margins, unlike cropped areas, can be important habitats for field voles (Tattersall *et al.* 2002, Broughton *et al.* 2014) because they provide them with sufficient resources (Yletyinen & Norrdahl 2008) and connect patches that may be suitable habitats for this species (Renwick & Lambin 2011). This is also supported by our results, because in the Drava Floodplain, where the species is most frequent, there are many natural, semi-natural open areas and also agricultural areas, thus, the variety of landscape types provides a suitable habitat for the species.

In case of *Crocidura* genus, the results of multiple linear regression at land use and landscape metrics level are consistent with each other. The amount of forests, grass and pastures in the owl hunting area had a positive, while the proportion of cropped areas a negative effect on the abundance of white-toothed shrews. The latter is related to the result that the Mecsek and Tolna-Baranya hill country dominated by agricultural areas also negatively affect the frequency of the Lesser White-toothed Shrew. Several studies have revealed that *Crocidura* species prefer open, dry grassy areas (Bosé & Guidali 2001, Bego *et al.* 2008, Fischer *et al.* 2011, Paspali *et al.* 2013, Szép *et al.* 2019), but are less frequently associated with forest edges and forests as described in Moravia (Suchomel & Heroldová 2004, Suchomel & Purchart 2011), Slovakia (Lešo *et al.* 2008) and also Romania (Barti 2011). Based on the results of the land use level analysis, cultivated areas have a negative effect on the abundance of the *Crocidura* genus, which contradicts some studies in which the possible positive effect of agricultural areas on the abundance of this species has been highlighted (Bosé & Guidali 2001, Heroldová *et al.* 2007, Veselovský *et al.* 2017). The structure of the landscape is also a determining factor in the occurrence of a species, we found a positive relationship between the mean patch shape complexity, mean fractal dimension, patch richness and the frequency of *Crocidura* shrews, which means that heterogeneous habitats are more favorable for these species. Szép *et al.* (2017) showed the opposite, as during their work in the south-western part of Hungary, they found that the abundance of the Lesser White-toothed Shrew was higher in homogenous landscapes.

The Common Shrew and the Pygmy Shrew *(Sorex minutus)* can be found in most habitat types (Tattersall *et al.* 2002, Heroldová *et al.* 2007, Wang & Grimm 2007, Mortelliti & Boitani 2009, Hutterer & Kryštufek 2016, Hutterer *et al.* 2016), based on which we would expect that land use and landscape composition will not have an important effect. Although ANOVA did not show a significant difference in comparing the three distance categories, the Mecsek and Tolna-Baranya hill country had a negative effect on the abundance of both the Common Shrew and the *Sorex* genus, based on the result of multiple regression analysis. This can be explained by the fact that human-made landscape modification (Love *et al.* 2000, Balestrieri *et al.* 2019) and intensive agricultural farming (Suchomel & Heroldová 2004, Heroldová *et al.* 2007) caused the decline of these species. In the case of landscape metrics, the opposite effect was shown for *Crocidura* species. Based on multiple regression analysis, there is a negative relationship between the SHAPE_MEAN, FRAC and PR landscape metrics and the abundance of *Sorex* species, so as the landscape complexity increases, the occurrence of these species decreases. This is consistent with the finding of Fisher *et al.* (2011). They have shown that the Common Shrew disappear in complex landscapes.

The trophic level index expresses the importance of shrews, and the abundance of these species is influenced by the quality of their habitat and the landscape structure (Paspali *et al.* 2013, Szép *et al.* 2017, Veselovský *et al.* 2017). This finding is also supported by our results, according to which the value of the index significantly differed in the comparison of the three distance categories characterised by different landscape patterns. Based on our multiple regression analysis at the land use level, the Mecsek and Tolna-Baranya hill country dominated by agrarian lands had a negative impact on the value of TLI. The intensification of agriculture (e.g. mechanical agriculture, use of chemical products) caused the landscape to become simpler and more homogeneous and the habitat quality to decline (Contoli 1980, Battersby 2005, Michel *et al.* 2006, Balestrieri *et al.* 2019, Battisti *et al.* 2019), which led to a decrease in the number of shrews and an increase in the number of rodents linked to agriculture. In case of the Drava River, there is a positive relationship between most of the landscape metrics describing the complexity and diversity of the landscape and the TLI. Therefore, the regression analysis reaffirmed that the landscape structure also plays a key role in the composition of small mammal communities and thus, in the relative proportion of insectivores and rodents in the diet of barn-owls.

The results suggest that on a landscape scale, the composition and structure of the landscape influences prey occurrence in owl hunting areas and the frequency-dependent availability of each prey species and categories, which determines the food niche pattern of owls in space and time. In order to reveal further details of the landscape dependence of the Common Barn-owl feeding pattern, additional studies are needed on several spatial scales, based on higher sampling effort.

Acknowledgement

The Common Barn-owls' pellet analysis was carried out with the support of Duna-Dráva National Park Directorate and the Hungarian Biodiversity Monitoring System. Thanks to László Bank, secretary of the Baranya County Group of BirdLife Hungary for providing the pellet samples. We thank the volunteers and university students for their dedicated work in helping us disassemble and process the owl pellets. Finally, we would like to thank the two reviewers for many helpful comments.

References

Alibhai, S. K. & Gipps, J. H. W. 1991. Field Vole *Microtus agrestis*. – In: Corbet, G. B. & Harris, S. (eds.) The Handbook of British Mammals. – Blackwell Scientific Publications, London, pp. 203–208.

Andries, A. M., Gulinck, H. & Herremans, M. 1994. Spatial modelling of the Barn Owl *Tyto alba* habitat using landscape characteristics derived from SPOT data. – Ecography 17: 278–287. DOI: 10.1111/j.1600-0587.1994.tb00104.x

Askew, N. P., Searle, J. B. & Moore, N. P. 2007. Agri-environment schemes and foraging of Barn Owls *Tyto alba*. – Agriculture, Ecosystems & Environment 118(1): 109–114. DOI: 10.1016/j.agee.2006.05.003

Baláž, I., Ambros, M., Tulis, F., Veselovský, T., Klimant, P. & Augustiničová, G. 2013. Hlodavce a hmyzožravce Slovenska [Rodents and insectivores of Slovakia]. – FPV UKF, Nitra, edícia Prírodovedec č. 547 [FNS KFU, edition Prírodovedec č. 547] Nitra

Balestrieri, A., Gazzola, A., Formenton, G. & Canova, L. 2019. Long-term impact of agricultural practices on the diversity of small mammal communities: a case study based on owl pellets. – Environmental Monitoring and Assessment 191(12): 1–14. DOI: 10.1007/s10661-019-7910-5

Barti, L. 2011. Unusual occurrence of the Bicoloured White-toothed Shrew (*Crocidura leucodon*, Soricomorpha: Soricidae) in a mature beech forest in the Ciomad-Puturosu Mountains (Eastern Carpathians, Central Romania). – Acta Siculica 2011: 119–124.

Battersby, J. 2005. UK Mammals: Species Status and Population Trends. First Report by the Tracking Mammals Partnership. – JNCC/Tracking Mammals Partnership

Battisti, C., Dodaro, G., Di Bagno, E. & Amori, G. 2019. Small mammal assemblages in land-reclaimed areas: do historical soil use changes and recent anthropisation affect their dominance structure? – Ethology, Ecology & Evolution 32(3): 282–288. DOI: 10.1080/03949370.2019.1693433

Bego, F., Kryštufek, B., Paspali, G. & Rogozi, E. 2008. Small terrestrial mammals of Albania: annotated list and distribution. – Hystrix 19(2): 83–101.

Benton, T. G., Vickery, J. A. & Wilson, J. D. 2003. Farmland biodiversity: is habitat heterogeneity the key? – Trends in ecology and evolution 18(4): 182–188. DOI: 10.1016/S0169-5347(03)00011-9

Billeter, R., Liira, J., Bailey, D., Bugter, R. & Arens, P. 2008. Indicators for biodiversity in agricultural landscapes: a pan-European study. – Journal of Applied Ecology 45(1): 141–150. DOI: 10.1111/j.1365-2664.2007.01393.x

Bond, G., Burnside, N. G., Metcalfe, D. J., Scott, D. M. & Blamire, J. 2005. The effects of land-use and landscape structure on Barn Owl *(Tyto alba)* breeding success in southern England, UK. – Landscape Ecology 20(5): 555–566. DOI: 10.1007/s10980-004-5037-7

Borowski, Z. 2003. Habitat selection and home range size of Field Voles *Microtus agrestis* in Słowiński National Park, Poland. – Acta Theriologica 48(3): 325–333. DOI: 10.1007/BF03194172

Bosé, M. & Guidali, F. 2001. Seasonal and geographic differences in the diet of the Barn Owl in an agro-ecosystem in northern Italy. – Journal of Raptor Research 35(3): 240–246.

Bossard, M., Feranec, J. & Otahel, J. 2000. CORINE land cover technical guide – Addendum 2000. Technical Report No 40, European Environmental Agency

Broughton, R. K., Shore, R. F., Heard, M. S., Amy, S. R. & Meek, W. R. 2014. Agri-environment scheme enhances small mammal diversity and abundance at the farm-scale. – Agriculture, Ecosystem & Environment 192: 122–129. DOI: 10.1016/j.agee.2014.04.009

Burel, F., Butet, A., Delettre, Y. R. & Millán de la Peña, N. 2004. Differential response of selected taxa to landscape context and agricultural intensification. – Landscape and Urban Planning 67(1): 195–204. DOI: 10.1016/S0169-2046(03)00039-2

Charter, M., Izhaki, I., Meyrom, K., Motro, Y. & Leshem, Y. 2009. Diets of Barn Owls differ in the same agricultural region. – The Wilson Journal of Ornithology 121(2): 378–383. DOI: 10.1676/08-083.1

Chao, A., Gotelli, N. J., Hsieh, T. C., Sander, E. L., Ma, K. H., Colwell, R. K. & Ellison, A. M. 2014. Rarefaction and extrapolation with Hill numbers: a framework for sampling and estimation in species diversity studies. – Ecological Monographs 84(1): 45–67. DOI: 10.1890/13-0133.1

Colvin, B. A. 1985. Common Barn-owl population decline in Ohio and the relationship to agricultural trends. – Journal of Field Ornithology 56(3): 224–235.

Colwell, R. K. & Elsensohn, J. E. 2014. EstimateS turns 20: statistical estimation of species richness and shared species from samples, with non-parametric extrapolation. – Ecography 37(6): 609–613. DOI: 10.1111/ecog.00814

Contoli, L. 1980. Borre di Strigiformi e ricerca teriologica in Italia [Owl pellet analysis and theriological research in Italy]. – Natura e montagna 3: 73–94. (in Italian)

Durant, J. M., Hjermann, D. Ø. & Handrich, Y. 2013. Diel feeding strategy during breeding in male Barn Owls *(Tyto alba)*. – Journal of Ornithology 154(3): 863–869. DOI: 10.1007/s10336-013-0956-1

Environmental Systems Research Institute (ESRI) 2012. ArcGIS Desktop Software, Release 10.1. – Redlands

European Environmental Agency 2007. Land-use scenarios for Europe: qualitative and quantitative analysis on a European scale. – EEA Technical report No 9/2007, European Environmental Agency

Fischer, C. & Schröder, B. 2014. Predicting spatial and temporal habitat use of rodents in a highly intensive agricultural area. – Agriculture, Ecosystem & Environment 189: 145–153. DOI: 10.1016/j.agee.2014.03.039

Fischer, C., Thies, C. & Tscharntke, T. 2011. Small mammals in agricultural landscapes: opposing responses to farming practices and landscape complexity. – Biological Conservation 144(3): 1130–1136. DOI: 10.1016/j.biocon.2010.12.032

Frey, C., Sonnay, C., Dreiss, A. & Roulin, A. 2011. Habitat, breeding performance, diet and individual age in Swiss Barn Owls *(Tyto alba)*. – Journal of Ornithology 152(2): 279–290. DOI: 10.1007/s10336-010-0579-8

Geiger, F., Bengtsson, J., Berendse, F., Weisser, W. W. & Emmerson, M. 2010. Persistent negative effects of pesticides on biodiversity and biological control potential on European farmland. – Basic and Applied Ecology 11(2): 97–105. DOI: 10.1016/j.baae.2009.12.001

Gentili, S., Sigura, M. & Bonesi, L. 2014. Decreased small mammals species diversity and increased population abundance along a gradient of agricultural intensification. – Hystrix 25(1): 39–44.

Gorman, M. L. & Reynolds, P. 1993. The impact of land-use change on voles and raptors. – Mammal Review 23: 121–126. DOI: 10.1111/j.1365-2907.1993.tb00423.x

Hanowski, J. M., Niemi, G. J. & Christian, D. C. 1997. Influence of within-plantation heterogeneity and surrounding landscape composition on avian communities in hybrid poplar plantations. – Conservation Biology 11: 936–944. DOI: 10.1046/j.1523-1739.1997.96173.x

Hansson, L. 1977. Spatial dynamics of Field Voles *Microtus agrestis* in heterogeneous landscapes. – Oikos 29: 539–544. DOI: 10.2307/3543592

Heroldová, M., Bryja, J., Zejda, J. & Tkadlec, E. 2007. Structure and diversity of small mammal communities in agriculture landscape. – Agriculture, Ecosystem & Environment 120(2–4): 206–210. DOI: 10.1016/j.agee.2006.09.007

Hindmarch, S. & Elliott, J. E. 2015. A specialist in the city: the diet of Barn Owls along a rural to urban gradient. – Urban Ecosystem 18(2): 477–488. DOI: 10.1007/s11252-014-0411-y

Hindmarch, S., Krebs, E. A., Elliott, J. E. & Green, D. J. 2012. Do landscape features predict the presence of Brn Owls in a changing agricultural landscape? – Landscape and Urban Planning 107(3): 255–262. DOI: 10.1016/j.landurbplan.2012.06.010

Hodara, K. & Poggio, S. L. 2016. Frogs taste nice when there are few mice: do dietary shifts in Barn Owls result from rapid farming intensification? – Agriculture, Ecosystems & Environment 230: 42–46. DOI: 10.1016/j.agee.2016.05.027

Horváth, G. F. 2000. Comparative analysis of the small mammal fauna of the river Drava plain region. I. Species richness, diversity and biomass based on the analysis of Barn Owl *Tyto alba* (Scop., 1769) pellets. – Tiscia 32: 47–53.

Horváth, G. F. 2007. Csalitjáró pocok *Microtus agrestis* [Field vole *Microtus agrestis*]. – In: Bihari, Z., Csorba, G. & Heltai, M. (eds.) Magyarország emlőseinek atlasza [Atlas of the Hungarian Mammals]. – Kossuth Kiadó, Budapest, pp. 160–161. (in Hungarian)

Horváth, G. F. 1998. Kisemlős (Mammalia) faunisztikai vizsgálatok a gyöngybagoly *(Tyto alba)* köpetanalízise alapján a Dráva mentén (1995–1997) [The investigation of the small mammal fauna of the River Dráva plain region, based on the analysis of Brn Oowl *(Tyto alba)* pellets between 1995–1997.]. – Dunántúli Dolgozatok Természettudományi Sorozat 9: 475–488. (in Hungarian with English Summary)

Horváth, A., Morvai, A. & Horváth, G. F. 2018. Food-niche pattern of the Barn Owl *(Tyto alba)* in intensively cultivated agricultural landscape. – Ornis Hungarica 26(1): 27–40. DOI: 10.1515/orhu-2018-0002

Horváth, A., Morvai, A. & Horváth, G. F. 2022. Difference in small mammal assemblages in the diet of the Common Barn-owl *Tyto alba* between two landscapes. – Acta Zoologica Academiae Scientiarum Hungaricae 68(2): 189–216. DOI: 10.17109/AZH.68.2.189.2022

Horváth, G. F., Molnár, D., Németh, T. & Csete, S. 2005. Landscape ecological analysis of Barn Owl pellet data from the Drava lowlands, Hungary. – Natura Somogyiensis 7: 179–189. DOI: 10.24394/NatSom.2005.7.179

Hsieh, T. C., Ma, K. H. & Chao, A. 2016. iNEXT: an R package for rarefaction and extrapolation of species diversity (Hill numbers). – Methods in Ecology and Evolution 7(12): 1451–1456. DOI: 10.1111/2041-210X.12613

Hutterer, R. & Kryštufek, B. 2016. *Sorex araneus*, The IUCN Red List of Threatened Species. – https://www.iucnredlist.org/species/29661/115170489.

Hutterer, R., Kryštufek, B., Fernandes, M. & Meinig, H. 2016. *Sorex minutus*, The IUCN Red List of Threatened Species. – https://www.iucnredlist.org/species/29667/115171222.

Iannella, M., Liberatore, L. & Biondi, M. 2016. The effects of a sudden urbanization on micromammal communities: a case study of post-earthquake L'Aquila (Abruzzi Region, Italy). – Italian Journal of Zoology 83(2): 255–262. DOI: 10.1080/11250003.2016.1149235

Jacob, J., Manson, P., Barfknecht, R. & Fredricks, T. 2014. Common Vole *(Microtus arvalis)* ecology and management: implications for risk assessment of plant protection products. – Pest Management Science 70(6): 869–878. DOI: 10.1002/ps.3695

Jaksić, F. M., Seib, R. L. & Herrera, C. M. 1982. Predation by the Barn Owl *(Tyto alba)* in Mediterranean habitats of Chile, Spain and California: A comparative approach. – The American Midland Naturalist 107(1): 151–162. DOI: 10.2307/2425196

Jost, L. 2006. Entropy and diversity. – Oikos 113(2): 363–375. DOI: 10.1111/j.2006.0030-1299.14714.x

Kessler, J. E. 2015. Osteological guide of songbirds from Central Europe. – Ornis Hungarica 23(2): 62–155. DOI: 10.1515/orhu-2015-0016

Klein, R. G. & Cruz-Uribe, K. 1984. The analysis of animal bones from archeological sites. – University of Chicago, Chicago

Kowalski, K. & Ruprecht, A. L. 1981. The Field Vole *(Microtus agrestis)*. – In: Pucek, Z. (ed.) Keys to vertebrates of Poland, Mammals. – Polish Scientific Publishers, Warsaw, pp. 189–190.

Kozakiewicz, M., Gortat, T., Kozakiewicz, A. & Barkowska, M. 1999. Effects of habitat fragmentation on four rodent species in a Polish farm landscape. – Landscape Ecology 14(4): 391–400. DOI: 10.1023/A:1008070610187

Kryštufek, B. & Macholán, M. 1998. Morphological differentiation in *Mus spicilegus* and the taxonomic status of mound-building mice from the Adriatic coast of Yugoslavia. – Journal of Zoology 245(2): 185–196. DOI: 10.1111/j.1469-7998.1998.tb00086.x

Kryštufek, B., Voharalík, V., Zima, J. & Zagorodnyuk, I. 2008. *Microtus agrestis*, The IUCN Red List of Threatened Species. – https://www.iucnredlist.org/species/13426/115112050.

Lešo, P., Le, O. & Kropil, R. 2008. Unusual occurrence of the Bicoloured White-toothed Shrew *(Crocidura leucodon)* in a fir-beech forest in central Slovakia (Soricomorpha: Soricidae). – Lynx 39(1): 191–194.

Leveau, L. M., Teta, P., Bogdaschewsky, R. & Pardiñas, U. F. J. 2006. Feeding habits of the Barn Owl *(Tyto alba)* along a longitudinal-latitudinal gradient in central Argentina. – Ornitologia Neotropical 17(3): 353–362.

Łopucki, R., Mróz, I., Berliński, Ł. & Burzych, M. 2013. Effects of urbanization on small-mammal communities and the population structure of synurbic species: an example of a medium-sized city. – Canadian Journal of Zoology 91(8): 554–561. DOI: 10.1139/cjz-2012-0168

Love, R. A., Webon, C., Glue, D. E., Harris, S. & Harris, S. 2000. Changes in the food of British Barn Owls *(Tyto alba)* between 1974 and 1997. – Mammal Review 30(2): 107–129. DOI: 10.1046/j.1365-2907.2000.00060.x

Lyman, R. L. 2012. Rodent-prey content in long-term samples of Barn Oowl *(Tyto alba)* pellets from the northwestern United States reflects local agricultural change. – The American Midland Naturalist 167(1): 150–163. DOI: 10.1674/0003-0031-167.1.150

Macholán, M. 1996. Multivariate morphometric analysis of European species of the genus *Mus* (Mammalia, Muridae). – Zeitschrift fur Saugetierkunde 61: 304–319.

Marti, C. D. 1988. A long-term study of food-niche dynamics in the Common Barn-owl: comparisons within and between populations. – Canadian Journal of Zoology 66(8): 1803–1812. DOI: 10.1139/z88-261

Marti, C. D. 2010. Dietary trends of Barn Owls in an agricultural ecosystem in northern Utah. – The Wilson Journal of Ornithology 122: 60–67. DOI: 10.1676/09-025.1

Martin, J. M., Branch, L. C., Raid, R. N. & Beyeler, S. C. 2010. Temporal instability of agricultural habitat reduces reproductive success of Barn Owls *(Tyto alba)*. – The Auk 127(4): 909–916. DOI: 10.1525/auk.2010.09211

Martínez, J. A. & Zuberogoitia, I. 2004. Habitat preferences and causes of population decline for Barn Owls *Tyto alba*: a multi-scale approach. – Ardeola 51(2): 303–317.

März, R. 1972. Gewöll- und Rupfungskunde [The science of pellets and pluck]. – Akademie Verlag, Berlin (in German)

Mazzotti, S. & Caramori, G. 1998. Analysis of small mammal communities in south-eastern Po Valley. – Gortania Atti Museo Friulano Storia Naturale 20: 253–262.

McGarigal, K. 2015. Fragstats help version 4.2. – http://www.umass.edu/landeco/research/fragstats/documents/fragstats.help.4.2.pdf.

McGarigal, K., Cushman, S. A. & Ene, E. 2012. FRAGSTATS v4: Spatial pattern analysis program for categorical and continuous maps. – http://www.umass.edu/landeco/research/fragstats/fragstats.html.

Meek, W. R., Burman, P. J., Nowakowski, M., Sparks, T. H. & Burman, N. J. 2003. Barn Owl release in lowland southern England – a twenty-one year study. – Biological Conservation 109(2): 271–282. DOI: 10.1016/S0006-3207(02)00155-6

Meek, W. R., Burman, P. J., Sparks, T. H., Nowakowski, M. & Burman, N. J. 2012. The use of Barn owl *Tyto alba* pellets to assess population change in small mammals. – Bird Study 59(2): 166–174. DOI: 10.1080/00063657.2012.656076

Meyrom, K., Motro, Y., Leshem, Y., Aviel, S., Izhaki, I., Argyle, F. & Charter, M. 2009. Nest-box use by the Barn Owl *Tyto alba* in a biological pest control program in the Beit She'an valley, Israel. – Ardea 97(4): 463–467. DOI: 10.5253/078.097.0410

Michel, N., Burel, F. & Butet, A. 2006. How does landscape use influence small mammal diversity, abundance and biomass in hedgerow networks of farming landscapes? – Acta Oecologica 30(1): 11–20. DOI: 10.1016/j.actao.2005.12.006

Mikkola, H. 1983. Owls of Europe. – T. & AD. Poyser, Carton

Milchev, B. 2015. Diet of Barn Owl *Tyto alba* in Central South Bulgaria as influenced by landscape structure. – Turkish Journal of Zoology 39(5): 933–940. DOI: 10.3906/zoo-1409-24

Millán de la Peña, N., Butet, A., Delettre, Y., Paillat, G., Morant, P., Le Du, L. & Burel, F. 2003. Response of the small mammal community to changes in western French agricultural landscapes. – Landscape Ecology 18(3): 265–278. DOI: 10.1023/A:1024452930326

Møller, A. P. 1984. Community structure of birds in agricultural areas in summer and winter in Denmark. – Ecography 7: 413–418. DOI: 10.1111/j.1600-0587.1984.tb01142.x

Moreira, F., Beja, P., Morgado, R., Reino, L., Gordinho, L., Delgado, A. & Borralho, R. 2005. Effects of field management and landscape context on grassland wintering birds in southern Portugal. – Agriculture, Ecosystems & Environment 109: 59–74. DOI: 10.1016/j.agee.2005.02.011

Mortelliti, A. & Boitani, L. 2009. Distribution and coexistence of shrews in patchy landscapes: a field test of multiple hypotheses. – Acta Oecologica 35(6): 797–804. DOI: 10.1016/j.actao.2009.07.006

Moysi, M., Christou, M., Goutner, V., Kassinis, N. & Iezekiel, S. 2018. Spatial and temporal patterns in the diet of Barn Owl *(Tyto alba)* in Cyprus. – Journal of Biological Research-Thessaloniki 25(1): 1–8. DOI: 10.1186/s40709-018-0080-8

Niethammer, J. & Krapp, F. 1978. Handbuch der säugetiere Europas. – Teil 1, Nagetiere 1 [Handbook of the Mammals of Europe. – Part 1, Rodents 1]. – Akademische Verlagsgesellschaft, Wiesbaden (in German)

Niethammer, J. & Krapp, F. 1982. Handbuch der Säugetiere Europas – Teil 2, Nagetiere 2 [Handbook of Mammals of Europe – Part 2, Rodents 2]. – Akademische Verlagsgesellschaft, Wiesbaden (in German)

Niethammer, J. & Krapp, F. 1990. Handbuch der Säugetiere Europas – Teil 3, Insektenfresser, Herrentiere [Handbook of Mammals of Europe – Part 3, Insectivores, Primates]. – Akademische Verlagsgesellschaft, Wiesbaden (in German)

Paspali, G., Oruci, S., Koni, M., Wilson, I., Kryštufek, B. & Bego, F. 2013. Seasonal variation of small mammals in the diet of the Barn Owl *(Tyto alba)* in the Drinos River valley, southern Albania. – Turkish Journal of Zoology 37(1): 97–105. DOI: 10.3906/zoo-1203-25

Pavluvčík, P., Poprach, K., Machar, I., Losík, J., Gouveia, A. & Tkadlec, E. 2015. Barn Owl productivity response to variability of vole populations. – PloS One 10(12): e0145851. DOI: 10.1371/journal.pone.0145851

Paz, A., Jareño, D., Arroyo, L., Viñuela, J., Arroyo, B., Mougeot, F., Luque-Larena, J. J. & Fargallo, J. A. 2013. Avian predators as a biological control system of Common Vole *(Microtus arvalis)* populations in north-western Spain: experimental setup and preliminary results. – Pest Management Science 69(3): 444–450. DOI: 10.1002/ps.3289

Prete, S., Battisti, C., Marini, F. & Ciucci, P. 2012. Applying abundance/biomass comparisons on a small mammal assemblage from Barn Owl *(Tyto alba)* pellets (Mount Soratte, central Italy): a cautionary note. – Rendiconti Lincei 23(4): 349–354. DOI: 10.1007/s12210-012-0183-3

Purger, J. J. 1998. A Dráva mente Somogy megyei szakaszának kisemlős (Mammalia) faunája, gyöngybagoly, *Tyto alba* (Scopoli, 1769) köpetek vizsgálata alapján [Small mammal fauna of the region of Dráva river in country Somogy (Hungary), obtained by Bam Owl, *Tyto alba* (Scopoli, 1769) pellet analysis]. – Dunántúli Dolgozatok Természettudományi Sorozat 9: 489–500. (in Hungarian with English Summary)

R Development Core Team 2019. R: A Language and Environment for Statistical Computing. – https://www.r-project.org/.

Renwick, A. R. & Lambin, X. 2011. Abundance thresholds and the underlying ecological processes: Field Voles *Microtus agrestis* in a fragmented landscape. – Agriculture, Ecosystems & Environment 144(1): 364–369. DOI: 10.1016/j.agee.2011.10.006

Rocha, R. G., Ferreira, E., Leite, Y. L., Fonseca, C. & Costa, L. 2011. Small mammals in the diet of Barn Owls, *Tyto alba* (Aves: Strigiformes) along the mid-Araguaia River in central Brazil. – Zoologia (Curitiba) 28(6): 709–716. DOI: 10.1590/S1984-46702011000600003

Romano, A., Séchaud, R. & Roulin, A. 2020. Global biogeographical patterns in the diet of a cosmopolitan avian predator. – Journal of Biogeography 47(7): 1467–1481. DOI: 10.1111/jbi.13829

Roulin, A. 2015. Spatial variation in the decline of European birds as shown by the Barn Owl *Tyto alba* diet. – Bird Study 62(2): 271–275. DOI: 10.1080/00063657.2015.1012043

Sala, O. E., Chapin, F. S., Armesto, J. J., Berlow, E., Bloomfield, J., Dirzo, R., Huber-Sanwald, E., Huenneke, L. F., Jackson, R. B., Kinzig, A., Leemans, R., Lodge, D. M., Mooney, A. H., Oesterheld, M., Poff, N. L., Sykes, M. T., Walker, B. H., Walker, M. & Wall, D. H. 2000. Global biodiversity scenarios for the year 2100. – Science 287(5459): 1770–1774. DOI: 10.1126/science.287.5459.1770

Salvati, L., Ranazzi, L. & Manganaro, A. 2002. Habitat preferences, breeding success and diet of Barn Owls in Rome: urban versus rural territories. – Journal of Raptor Research 36: 224–228.

Schaefer, H. 1932. Die Artbestimmung der deutschen Anuren nach dem Skelet [Identification of the German anurans based on the skeleton]. – Zeitschrift für Anatomie und Entwicklungsgeschichte 97(6): 767–779. DOI: 10.1007/BF02121644 (in German)

Schmidt, E. 1967. Bagolyköpet vizsgálatok [Owl pellet analyses]. – Madártani Intézet, Budapest (in Hungarian)

Shawyer, C. R. & Shawyer, V. M. 1995. An investigation of the Barn Owl population within the Arun and Western Rother catchments. – Hawk and Owl Trust, London

Sokal, R. R. & Rohlf, F. J. 1995. Biomety: the Principles and Practice of Statistics in Biological Research. – New York, W. H. Freeman

Stoate, C., Báldi, A., Beja, P., Boatman, N. D. & Herzon, I. 2009. Ecological impacts of early 21st century agricultural change in Europe – a review. – Journal of Environmental Management 91(1): 22–46. DOI: 10.1016/j.jenvman.2009.07.005

Stoate, C., Boatman, N. D., Borralho, R. J., Carvalho, C. R., De Snoo, G. R. & Eden, P. 2001. Ecological impacts of arable intensification in Europe. – Journal of Environmental Management 63(4): 337–365. DOI: 10.1006/jema.2001.0473

Suchomel, J. & Heroldová, M. 2004. Small terrestrial mammals in two types of forest complexes in intensively managed landscape of South Moravia (The Czech Republic). – Ekologia (Bratislava) 23(4): 377–384.

Suchomel, J. & Purchart, L. 2011. Occurrence of *Crocidura leucodon* in plantings of forest trees in southern Moravia, Czech Republic (Soricomorpha: Soricidae). – Lynx 42: 271–274.

Szép, D., Klein, Á. & Purger, J. J. 2017. The prey composition of the Barn Owl with respect to landscape structure of its hunting area (Zala County, Hungary). – Ornis Hungarica 25(2): 51–64. DOI: 10.1515/orhu-2017-0015

Szép, D., Klein, Á. & Purger, J. J. 2019. Investigating the relationship between the prey composition of Barn Owls and the habitat structure of their hunting range in the Marcal Basin (Hungary), based on pellet analysis. – Ornis Hungarica 27(1): 32–43. DOI: 10.2478/orhu-2019-0002

Tattersall, F. H., Macdonald, D. W., Hart, B. J., Johnson, P., Manley, W. & Feber, R. 2002. Is habitat linearity important for small mammal communities on farmland? – Journal of Applied Ecology 39(4): 643–652. DOI: 10.1046/j.1365-2664.2002.00741.x

Taylor, I. 2004. Barn Owls: Predation-prey relationships and conservation. – Cambridge University Press, Cambridge

Teta, P., Hercolini, C. & Cueto, G. 2012. Variation in the diet of western Barn Owls *(Tyto alba)* along an urban-rural gradient. – The Wilson Journal of Ornithology 124: 589–596. 10.1676/11-173.1

Tews, J., Brose, U., Grimm, V., Tielbörger, K., Wichmann, M. C., Schwager, M. & Jeltsch F. 2004. Animal species diversity driven by habitat heterogeneity/diversity: the importance of keystone structures. – Journal of Biogeography 31(1): 79–92. DOI: 10.1046/j.0305-0270.2003.00994.x

Torre, I., Gracia-Quintas, L., Arrizabalaga, A., Baucells, J. & Díaz, M. 2015a Are recent changes in the terrestrial small mammal communities related to land use change? A test using pellet analyses. – Ecological Research 30(5): 813–819. DOI: 10.1007/s11284-015-1279-x

Torre, I., Fernández, L. & Arrizabalaga, A. 2015b Using Barn Owl *Tyto alba* pellet analyses to monitor the distribution patterns of the Yellow-necked Mouse (*Apodemus flavicollis* Melchior 1834) in a transitional Mediterranean mountain. – Mammal Study 40(3): 133–142. DOI: 10.3106/041.040.0302

Trejo, A. & Lambertucci, S. 2007. Feeding habits of Barn Owls along a vegetative gradient in northern Patagonia. – Journal of Raptor Research 41: 277–287. DOI: 10.3356/0892-1016(2007)41[277:FHOBOA]2.0.CO;2

Tulis, F., Baláž, M., Obuch, J. & Šotnár, K. 2015. Responses of the Long-eared Owl *Asio otus* diet and the numbers of wintering individuals to changing abundance of the Common Vole *Microtus arvalis*. – Biologia 70(5): 667–673. DOI: 10.1515/biolog-2015-0074

Venables, W. N. & Ripley, B. D. 2002. Modern Applied Statistics with S. – New York, Springer Publishing

Veselovský, T., Bacsa, K. & Tulis, F. 2017. Barn Owl *(Tyto alba)* diet composition on intensively used agricultural land in the Danube Lowland. – Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis 65(1): 225–233. DOI: 10.11118/actaun201765010225

Wang, M. & Grimm, V. 2007. Home range dynamics and population regulation: an individual-based model of the Common Shrew *Sorex araneus*. – Ecological Modelling 205(3–4): 397–409. DOI: 10.1016/j.ecolmodel.2007.03.003

Yalden, D. W. 1977. Identification of Remains in Owl Pellets. – Mammal Society, London

Yalden, D. W. & Morris, P. A. 1990. The Analysis of Owl Pellets. – Mammal Society, London

Yletyinen, S. & Norrdahl, K. 2008. Habitat use of Field Voles *(Microtus agrestis)* in wide and narrow buffer zones. – Agriculture, Ecosystems & Environment 123(1–3): 194–200. DOI: 10.1016/j.agee.2007.06.002

Zebisch, M., Wechsung, F. & Kenneweg, H. 2004. Landscape response functions for biodiversity – assessing the impact of land-use changes at the county level. – Landscape and Urban Planning 67(1–4): 157–172. DOI: 10.1016/S0169-2046(03)00036-7