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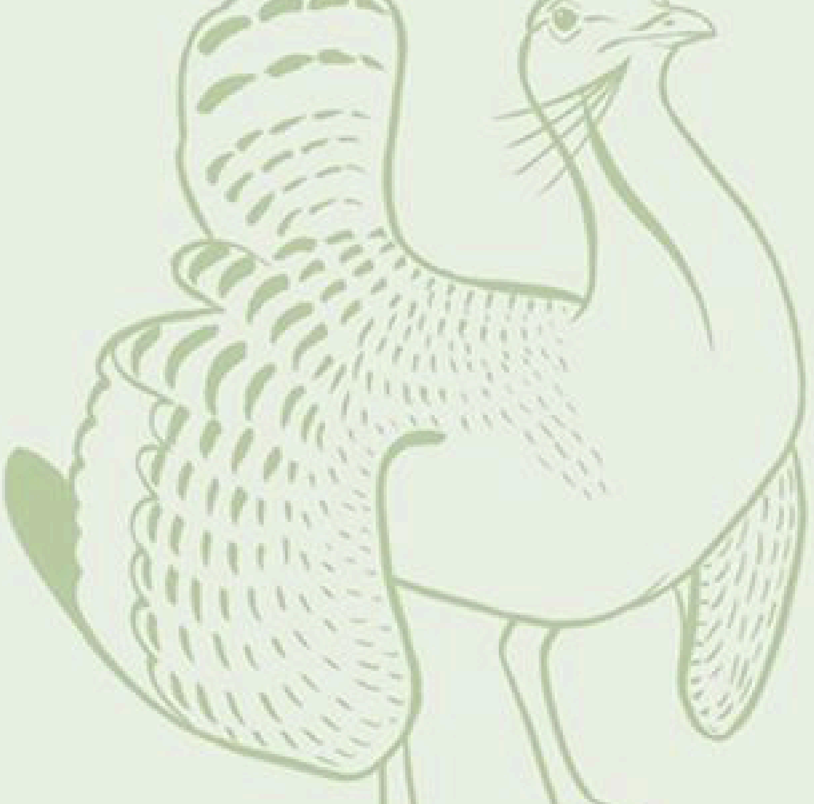

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Raptors and linear infrastructure in Chhattisgarh, India: species composition and conservation concern

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Abstract We investigated the species diversity of diurnal raptors along the selected linear infrastructure projects in northern Chhattisgarh, India, between December 2020 and September 2022. The study identified a total of 14 raptor species, consisting of 11 species in Accipitridae, two in Falconidae, and one in Pandionidae families. Two species were under threatened category of the IUCN red list, the Vulnerable Indian Spotted Eagle *(Clanga hastata)* and the Near Threatened Pallid Harrier *(Circus macrourus)*. Linear infrastructure development, such as roads, railways, pipelines, canals, and power lines, is expanding rapidly, causing the degradation and fragmentation of habitats, and leading to the loss of biodiversity. Unfortunately, the impacts of linear infrastructure on bird populations in India have not been adequately studied, resulting in limited understanding and few measures to mitigate these impacts. This study specifically focuses on the status of raptors along selected linear infrastructure intrusions and provides baseline information that can help in understanding their conservation needs. The findings of this study underline the necessity of implementing appropriate measures to mitigate the negative effects of linear infrastructure development in India.

Keywords: raptors, linear infrastructure, Chhattisgarh, Accipitridae, Falconidae, Pandionidae

Összefoglalás 2020 decembere és 2022 szeptembere között vizsgáltuk a nappali ragadozómadarak fajdiverzitását kiválasztott vonalas infrastruktúra projektek mentén Chhattisgarh északi részén Indiában. A kutatás során összesen 14 ragadozómadár-fajt azonosítottunk, amelyek közül 11 az Accipitridae, kettő a Falconidae és egy a Pandionidae családba tartozott. A feljegyzett 14 faj közül két faj szerepelt az IUCN vörös listájának veszélyeztetett kategóriájában: a sebezhető indiai békászó sas *(Clanga hastata)* és a mérsékelten veszélyeztetett fakó rétihéja *(Circus macrourus)*. A vonalas infrastruktúra-fejlesztés, mint az utak, vasutak, csővezetékek, csatornák és elektromos vezetékek, gyors ütemben épülnek, amelyek az élőhelyek degradációját és feldarabolódását okozzák, és a biológiai sokféleség csökkenéséhez vezetnek. Sajnos a vonalas infrastruktúra indiai madárpopulációkra gyakorolt hatásait eddig nem vizsgálták megfelelően, így az információk hiányában limitált a hatások enyhítésére tehető beavatkozások lehetősége is. Ez a kutatás a vonalas infrastruktúra-beruházások mentén élő ragadozómadarak helyzetére összpontosít, és olyan alap információkkal szolgál, amelyek segíthetnek kialakítani a szükséges védelmi intézkedéseket. A tanulmány megállapításai kiemelik a megfelelő intézkedések végrehajtásának szükségességét az indiai vonalas infrastruktúra-fejlesztés negatív hatásainak mérséklése érdekében.

Kulcsszavak: ragadozómadár, vonalas infrastruktúra, Chhattisgarh, Accipitridae, Falconidae, Pandionidae

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Introduction

The decline in biodiversity is occurring at an unprecedented rate, globally, primarily caused by human activities that have affected approximately 50–70% of the Earth's land surface. Consequently, ecosystem functioning has been altered, significantly changing global biodiversity patterns. Several factors drive this loss of biodiversity, including land use and land cover modifications, pollution, climate change, and infrastructure development (Sala *et al.* 2000, Mace & Baillie 2007, Butchart *et al*. 2010, Ceballos *et al*. 2015, McCallum 2015).

The significant expansion of linear infrastructure (LI) always had a negative role resulting in the massive degradation and decline of natural habitats and an irrevocable scar on the Earth's surface (Ramachandran *et al*. 2018, Nayak *et al*. 2020). Linear infrastructure, which includes roads, railways, pipelines, canals, power lines, etc., is essential for human progress and covers a significant part of the Earth's surface (Dulac 2013, Meijer *et al*. 2018). They are critical for contributing to the economic growth of any country by facilitating the transportation of people, energy, fuel, and goods from one place to another (WII 2016). The effect of linear infrastructure developments on wildlife is significant and includes not only direct harm caused by collisions or electrocution but also the deterioration and fragmentation of habitats resulting in barriers that hinder connectivity between habitat patches and populations. The fragmentation of large, continuous habitats into smaller, isolated patches may eventually result in the loss of viable populations and genetic diversity in the long term (Fahrig 2003, Loss *et al*. 2014, Santos *et al*. 2016).

Linear infrastructures are expanding globally and can pose a severe threat to wildlife, including avifauna (van der Ree *et al*. 2015, Demeter *et al.* 2018). Birds that are flying in flocks, immature individuals lacking experience, and species with larger biometrics, such as weight and wing load (e.g. raptors, cranes, and bustards), which are associated with faster flight but lower manoeuvrability, are at a higher risk of colliding with lines (Bevanger 1998, Drewitt & Langston 2008, Wiącek *et al*. 2020). Due to the larger body size and preference for elevated perches, raptors are more susceptible to colliding with the lines and this source of non-natural mortality is contributing to declines in raptor populations (Slater *et al*. 2020, Dwyer *et al*. 2023). Among other linear infrastructure intrusions; power lines are one of the primary causes of avian mortality and it is estimated to cause the deaths of over 60 million birds annually in the United States and Canada (Loss *et al*. 2014). Most of the research on avian electrocution is concentrated in North America and Europe, as evidenced by the references cited in recent reviews by Bernardino *et al.* 2018 and Slater *et al*. 2020.

There is an increasing amount of research on avian electrocution coming out of Asia, as evidenced by recent studies such as Harness *et al.* 2013, Dixon *et al.* 2020, Kolnegari *et al.* 2020, Guil and Pérez-García 2022. These studies are helping to broaden our understanding of avian electrocution patterns and impacts in different geographic regions. India is recognized as one of the 17 mega-diverse countries globally, known for its high number of endemism (Mittermeier *et al.* 2011). In recent years, India's economy has witnessed rapid growth, and as a result, Indian infrastructure networks, such as roads, railways, and power lines, have been extensively expanded and modernized. India has the world's second-largest road system, covering 5.2 million km, and the third largest railway network, spanning over

64,000 route km. Furthermore, India ranks fifth globally in terms of its installed power generation capacity, which is 271 GW (WII 2016). Among that, Chhattisgarh is a state in India that is undergoing significant development in its power sector, to provide reliable and affordable electricity to all citizens.

Additionally, the railway network in the state is being rapidly expanded to enhance connectivity and facilitate economic growth. However, the expansion of linear infrastructure, including power lines and railway networks, can have a detrimental impact on avifauna. Despite the rapid progress in developing these infrastructure projects, there has been a lack of attention given to researching and understanding the impacts of these projects on bird populations in India. This lack of attention has resulted in a limited understanding of the impacts, and consequently, very few measures are in place to mitigate these impacts. Avifauna is an essential part of India's biodiversity, and the country is home to many endemic bird species. The degradation and loss of habitat due to linear infrastructure projects can lead to a significant decline in bird populations and a loss of biodiversity. Furthermore, birds that collide with power lines and other linear infrastructure can suffer fatal injuries, leading to a decline in their populations. Therefore, it is crucial to conduct thorough research on the impact of linear infrastructure projects on avifauna in India to develop effective management strategies that can mitigate the negative effects of these projects.

Without appropriate measures in place, the development of linear infrastructure in Chhattisgarh and other parts of India could lead to irreversible damage to bird populations and their habitats. The current research concentrates on the status of the raptor population along selected linear infrastructure intrusions located in the northern region of Chhattisgarh. The study aims to generate crucial baseline information regarding the raptor population in the area, which can help in understanding their conservation needs and devising effective conservation measures.

Methods

Study area

Chhattisgarh state covers an area of 135,191 km^2, which is 4.1% of the total area of the country. The forest area of the state is approximately 59,772 km^2, accounting for 44.21% of the state's total area. Chhattisgarh is located in the East Deccan physiographic zone, and its southern part is part of the Deccan Plateau. The Deccan physiographic zone is divided into three agro-climatic zones: the Chhattisgarh Plains, the Northern Hills of Chhattisgarh, and the Bastar Plateau. Chhattisgarh experiences very warm weather, with an average daily high temperature of 33 °C. The climate is hot and humid throughout the year, with an annual average temperature of 33 °C, as it is located near the Tropic of Cancer and receives rainfall from the monsoon season.

The current study area for raptor surveys was initiated by September 2020 and continued till September 2022 covering five linear infrastructures projects: the Ranchi – Dharamjaigarh Transmission Line (RDTL), Korba – Jabalpur Transmission Line (KJTL), Champa – Kurukshetra Transmission Line (CKTL), East Rail Line (ERL) and East-West Rail Line (EWRL). Surveys were carried out along the five Linear Infrastructure corridors in respective districts i.e., Korba, Bilaspur, Janjgeer-Champa, Raigarh and Jashpur in the state of Chhattisgarh *(Figure 1, Table 1)*.

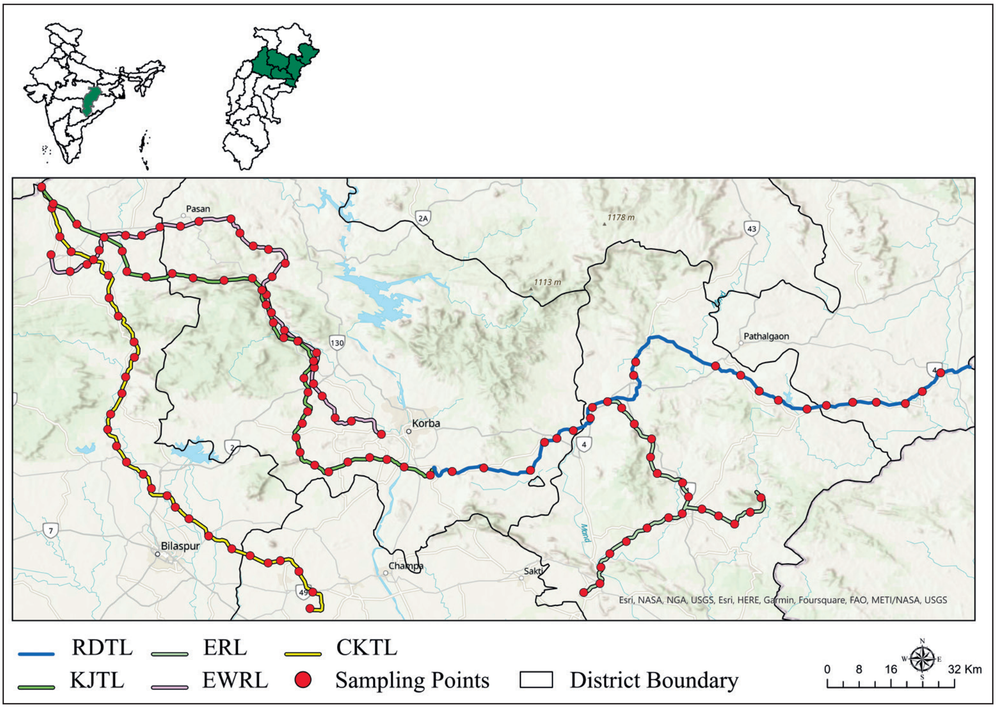

Figure 1. Study area in Chhattisgarh state, India (see *Table 1* and text for abbreviations)
1. ábra Kutatási terület Chhattisgarh államban, Indiában (rövidítéseket ld. az 1. táblázatban és a szövegben)

Table 1. Details of the Linear Infrastructures surveyed
1. táblázat A felmért vonalas infrastruktúra létesítmények adatai

Linear infrastructures studied	Abbreviation	Districts	Length (km)	Operational Status
Korba – Jabalpur Transmission Line (765 kV)	KJTL	Korba Bilaspur	153.28	Operational
Champa – Kurukshetra Transmission Line (800 kV)	CKTL	Bilaspur Janjgeer-Champa	154.77	Operational
Ranchi – Dharamjaigrah Transmission Line (765 kV)	RDTL	Korba, Raigarh& Jashpur	168.27	Operational
East Rail Line	ERL	Raigarh	100.55	Operational
East-west Rail Line	EWRL	Korba Bilaspur	134.66	Under Construction

Survey design and data collection

A systematic survey was carried out to determine the composition and abundance of raptors in the vicinity of selected linear infrastructure project sites from December 2020 to September 2022. Raptors were sampled at intervals of four kilometres along the selected linear infrastructures to obtain the necessary data (Kajzer-Bonk *et al.* 2019). The sampling points were located adjacent to the lines with maximum visibility to detect the soaring raptors. The sampling locations were defined as the area within a 500-meter radius of the observer (Planillo *et al.* 2015). The raptor survey was conducted by the observer in a 360-degree circle around a fixed point for 15 minutes, identifying birds through direct sightings and calls. The surveys were carried out between 11:00 and 15:00.

A special search was made to identify the raptor nests on the pylons along the lines. Fieldwork was carried out on days without wind or rain to prevent weather-related biases in sampling (Bibby *et al.* 2000). The "Avian Sensitivity Tool for Energy Planning" (AVISTEP) was employed to determine areas in the study region that are sensitive to bird species with the existing transmission line infrastructure (BirdLife International 2022). AVISTEP was also utilized to map out the study area, providing valuable insight into its level of sensitivity. All the maps were made with the help of ArcGIS. Pearson's correlation coefficient between the predicted sensitivity score (by AVISTEP) and the recorded raptor abundance was computed using IBM SPSS Statistics V23.0.

The raptors were scrutinized through Nikon Monarch (10×42) binoculars, while Nikon COOLPIX P900 was used to capture photographs that facilitated the identification of the challenging species. Additionally, standard field guides were consulted to aid in the identification of the raptors (Grimmett *et al.* 2011) and the nomenclature of birds was followed by Praveen and Jayapal 2023.

Result and Discussion

We recorded a total of 14 diurnal raptor species, consisting of nine residents, four winter migrants, and one partial migrant. Two of these species were under threatened category of the IUCN red list, the Vulnerable Indian Spotted Eagle *(Clanga hastata)* and the Near Threatened Pallid Harrier *(Circus macrourus)*. The most recorded species was the Black Kite *Milvus migrans* (81 individuals), followed by the Shikra *Accipiter badius* (22), Oriental Honey Buzzard *Pernis ptilorhynchus* (9), Black-winged Kite *Elanus caeruleus* (8), and Eurasian Sparrowhawk *Accipiter nisus* (5). The Accipitridae family had the highest number of individuals observed (134), followed by Falconidae (4) and Pandionidae (1). The overall species diversity of the five Linear infrastructures we studied was measured at 1.51 (Shannon's H index).

Among the lines *(Figure 2)* surveyed, the Champa – Kurukshetra transmission line had the highest number of individuals recorded (36 individuals of 6 species). The Korba – Jabalpur transmission line had the second-highest number of individuals recorded (33 individuals of 9 species), followed by the East-west rail (28 individuals of 5 species), the East Rail

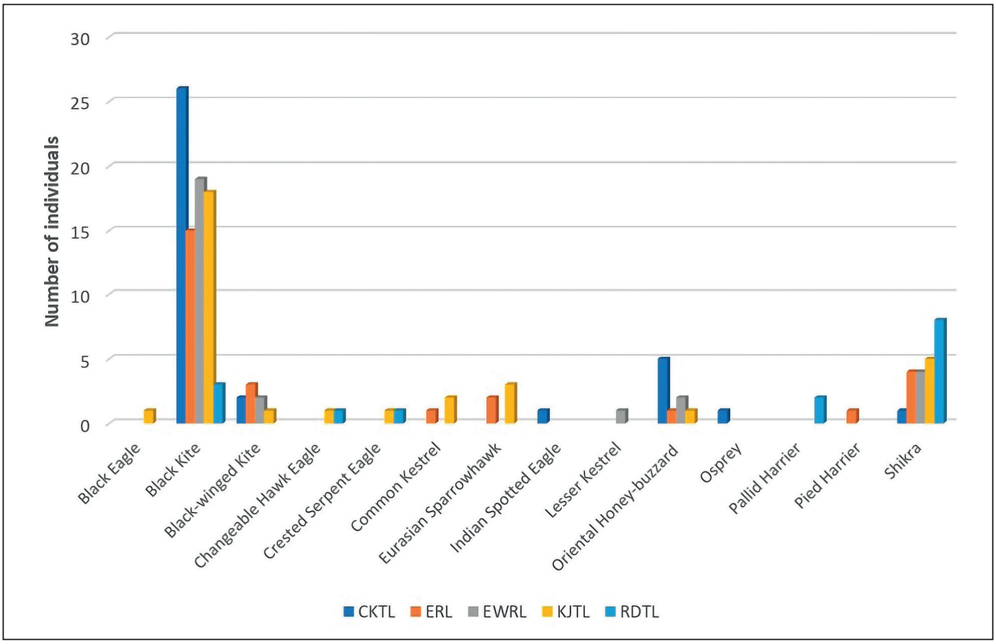

Figure 2. The abundance of raptor species along the five linear infrastructures surveyed. Black Eagle (BLEA), Black Kite (BLK), Black-winged Kite (BWKI), Changeable Hawk Eagle (CHEA), Crested Serpent Eagle (CSEA), Common Kestrel (COKE), Eurasian Sparrowhawk (EUSP), Indian Spotted Eagle (ISEA), Lesser Kestrel (LEKE), Oriental Honey-buzzard (OHBU), Osprey (OSPR), Pallid Harrier (PAHA), Pied Harrier (PIHA), Shikra (SHIK)

2. ábra A ragadozómadár fajok egyedsűrűsége az 5 vonalas infrastruktúra létesítménye mentén. Maláj sas (BLEA), barna kánya (BLK), feketeszárnyú kuhi (BWKI), főkötős vitézsas (CHEA), bóbitás kígyászsas (CSEA), vörös vércse (COKE), karvaly (EUSP), indiai békászósas (ISEA), fehérkarmú vércse (LEKE), bóbitás darázsölyv (OHBU), halászsas (OSPR), fakó rétihéja (PAHA), tarka rétihéja (PIHA), sikra (SHIK)

Corridor (27 individuals of 7 species), and the Ranchi – Dharamjaigarh transmission line (15 individuals of 5 species).

The Korba-Jabalpur transmission line has the highest raptor diversity, with Shannon's H value of 1.53, followed by the East Rail Corridor (H = 1.41), Ranchi-Dharamjaigarh transmission line (H = 1.29), East-west rail (H = 1.04), and Champa-Kurukshetra transmission line (H = 0.97).

The results of this study are significant because they highlight raptor status along the lines and also the importance of considering the possible impact of linear infrastructure on raptor populations. The presence of good diversity along with the threatened species emphasizes the need for effective planning and management of linear infrastructures to minimize its impact on bird communities. The variation in raptor diversity across the different linear infrastructures emphasizes the need for site-specific management strategies and future studies must be carried out by emphasising bird mortality along the lines.

Furthermore, certain species are attracted to infrastructure. For instance, power line poles are often utilized by raptors as perches for hunting and roosting, and also serve as support structures for nesting sites of multiple species (Benítez-López *et al.* 2010, Mainwaring 2015). The group of birds most frequently subjected to electrocution are raptors, and such non-natural deaths are playing a major role in the reduction of Asian raptor populations. The significant decline of Steppe Eagle *(Aquila nipalensis)* populations in the Caspian steppes of Kazakhstan and southern Russia, from 20,000 pairs to 1,100 pairs is attributed to electrocution by transmission lines (Karyakin 2013, Dwyer *et al.* 2022). The attraction of raptors to power line poles may lead to non-natural deaths, leading to their population decline (Walters *et al.* 2014).

During the present study period, we documented seven active nests of Black Kites on the pylons located adjacent to the cross arms of the Champa-Kurukshetra Transmission line. Various species of birds were found to be utilizing the powerline poles for activities such as roosting, hunting, and feeding as well. This creates both challenges and opportunities. However, it is important to note that the birds' utilization of powerline poles also increases the risk of electrocution by contacting the lines (Lehman *et al*. 2007, Kemper *et al.* 2013). The interactions between these birds and power line structures can also lead to economic costs such as power outages (Jenkins *et al.* 2013). Information on the effect of power lines on nesting birds and their breeding performance is often overlooked. Breeding on power poles also makes birds more vulnerable to heavy rains, intense solar radiation, and strong winds, which may have adverse effects on the hatching success and survival of nestlings compared to breeding on trees (Gilmer & Wiehe 1977, Janiszewski *et al.* 2015).

During our rapid surveys along the LI routes, we did not find any instance of bird mortality related to lines. However, with the exponential growth of linear infrastructure, the likelihood of such collisions occurring is high. Birdlife International has developed a tool called „The Avian Sensitivity Tool for Energy Planning" (AVISTEP) that identifies bird-sensitive areas in relation to transmission line networks *(Figure 3)*. Essentially, the tool helps to identify locations where bird species are likely to be impacted by the transmission lines, allowing policymakers and researchers to better understand the potential ecological impacts of the infrastructure on the local avian population. The AVISTEP has identified sensitive areas for birds throughout India, based on a sensitivity index that considers the presence of sensitive bird species, habitats, and overlaps with protected areas and Important Bird and Biodiversity Areas. According to AVISTEP, most of the areas in Chhattisgarh fall under moderate to very high sensitivity for bird collisions. We analysed five LI corridors with AVISTEP's bird-sensitive areas and found that the Champa-Kurukshetra Transmission Line (TL) and Korba – Jabalpur TL routes are most likely to have high chances of bird collisions, followed by the Ranchi – Dharamjaigarh TL route.

The Champa – Kurukshetra transmission line spans various areas with distinct sensitivities. It covers 26 km of very highly sensitive areas, where bird abundance was recorded as 2. Additionally, the line passes through 11 km of highly sensitive area. Moreover, the transmission line crosses 115 km of moderately sensitive areas with a recorded bird abundance of 36. In a 2 km stretch of low sensitive area, no birds were recorded. The Korba – Jabalpur TL traverses a route that encompasses 34 km of very highly sensitive areas, where the bird abundance is recorded as 5, and an additional 100 km of moderately sensitive areas, where the bird abundance is observed to be 28. No birds were recorded from the 19 km low sensitive area. The Ranchi-Dharamjaigarh TL passes through 153 km of moderately sensitive areas and 15 km of low sensitive areas whereas the moderately sensitive area was recorded bird abundance as 15 and no birds were recorded from the low sensitive areas. Out of the total East rail length, 93 km traverses moderately sensitive areas, and the bird abundance in this region is recorded at 27. Conversely, the remaining 7 km of the rail line passes through low sensitive areas, where no bird presence has been recorded. The East-West rail area spans a total of 134 km, of which 67 km passes through highly sensitive areas with a recorded bird abundance of 15. Additionally, 56 km of the rail line traverses moderately sensitive areas, where the bird abundance is recorded as 13. Lastly, an 11 km segment of the line passes through low sensitive areas, with no bird sightings recorded.

The Pearson's correlation coefficient between sensitivity score and abundance is -0.08, which indicates a weak negative correlation between sensitivity score and abundance. The two-tailed significance value associated with the correlation coefficient is 0.518 (p>0.05), indicating that the correlation between sensitivity score and abundance is not statistically significant at the 0.05 level. Altogether the routes of linear infrastructures and the abundance of raptors along these sensitive areas especially in moderate, high and very high regions predict the higher vulnerability or chance of bird mortality related to linear infrastructures.

Our field data on the raptor abundance, combined with AVISTEP, highlights the conservation concern of linear infrastructure routes of Chhattisgarh from the avian conservation point of

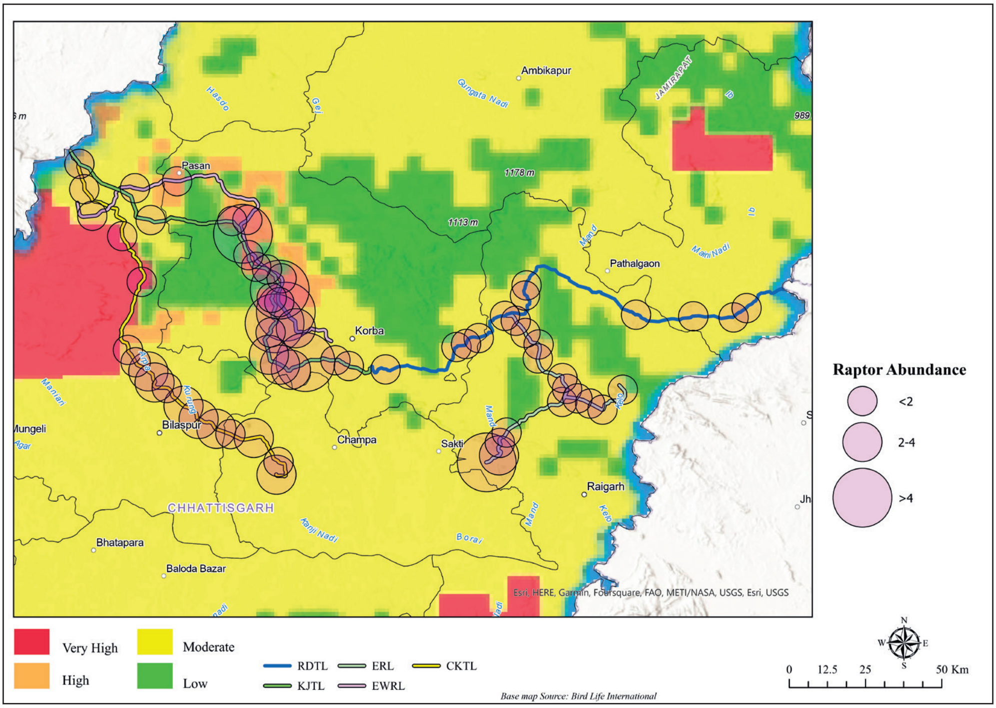

Figure 3. Bird sensitive area map according to AVISTEP tool (©AviStep – BirdLife International 2022) and the abundance of raptors recorded at sampling locations along the five linear infrastructures surveyed

3. ábra A területek érzékenységének térképe az AVISTEP (©AviStep – BirdLife International 2022) eredményei alapján, feltüntetve a ragadozómadarak egyesűrűségét az egyes vizsgálati pontokon view. The AVISTEP model proves to be a valuable and versatile asset, encompassing a wide array of species and habitats. Nevertheless, its strength lies in generating predictions rather than fine-tuned projections for individual taxa. In instances where precise insights are required for a particular taxon, it becomes imperative to complement the model's output with targeted field surveys. This synergy between the model's overarching trends and on-ground observations can yield a more comprehensive and accurate understanding of the ecological dynamics. Nevertheless, it serves as a valuable baseline dataset that can be strategically leveraged for the meticulous formulation of developmental projects within the specific region. The visual aid *(Figure 3)* holds the potential to play a pivotal role in steering and ranking forthcoming research endeavours, especially in scenarios demanding a judicious allocation of resources and a focused approach to conservation initiatives.

Conservation implication

Linear infrastructure, such as roads, power lines, and railways, can pose risks to raptors and their habitats. These birds of prey, including kites, eagles, hawks, and owls, are particularly susceptible to the disturbances caused by linear infrastructure, which can impact their survival, reproductive success, movement patterns, and habitats. Effective planning and management of linear infrastructure are crucial in minimizing its impact on raptor populations. Best management practices, such as reducing light pollution and managing vegetation growth near infrastructure, can help reduce the risks of collisions and electrocutions, while innovative technology like bird diverters and underground power lines can also help to minimize the impact of linear infrastructure on raptors. Monitoring and research are essential to assess the impact of linear infrastructure on raptor populations and to frame management strategies. Remote sensing technologies, such as satellite tracking and drones, can provide valuable insights into raptor movements and behaviour, identifying key habitat areas that need protection. Modelling tools can also predict the potential impact of linear infrastructure on raptor populations and help in management decisions. Effective conservation of raptors in the context of linear infrastructure requires collaborative efforts among stakeholders from the transportation, energy, and wildlife management sectors. This proactive and comprehensive approach considers the needs of both raptors and human communities to ensure that linear infrastructure is planned, designed, and managed with minimal impact on raptor populations. By adopting such an approach, we can protect these magnificent birds of prey and enable them to thrive in their natural habitats.

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Appendix 1. A checklist of raptors recorded along the five Linear Infrastructures
1. melléklet Az öt lineáris infrastruktúra mentén rögzített ragadozómadarak fajlistája

Sl. No.	English Name	Scientific Name	Order	Family	IUCN Status	WPA Schedule	Resident/ Migrant
1	Black Eagle	*Ictinaetus malaiensis*	Accipitriformes	Accipitridae	LC	Schedule-I	R
2	Black Kite	*Milvus migrans*	Accipitriformes	Accipitridae	LC	Schedule-II	R
3	Black-winged Kite	*Elanus caeruleus*	Accipitriformes	Accipitridae	LC	Schedule-II	R
4	Changeable Hawk Eagle	*Nisaetus cirrhatus*	Accipitriformes	Accipitridae	LC	Schedule-I	R
5	Common Kestrel	*Falco tinnunculus*	Falconiformes	Falconidae	LC	Schedule-II	R
6	Crested Serpent Eagle	*Spilornis cheela*	Accipitriformes	Accipitridae	LC	Schedule-I	R
7	Eurasian Sparrowhawk	*Accipiter nisus*	Accipitriformes	Accipitridae	LC	Schedule-I	WM
8	Indian Spotted Eagle	*Clanga hastata*	Accipitriformes	Accipitridae	VU	Schedule-I	R
9	Lesser Kestrel	*Falco naumanni*	Falconiformes	Falconidae	LC	Schedule-II	PM
10	Oriental Honey Buzzard	*Pernis ptilorhynchus*	Accipitriformes	Accipitridae	LC	Schedule-II	R
11	Osprey	*Pandion haliaetus*	Accipitriformes	Pandionidae	LC	Schedule-I	WM
12	Pallid Harrier	*Circus macrourus*	Accipitriformes	Accipitridae	NT	Schedule-I	WM
13	Pied Harrier	*Circus melanoleucos*	Accipitriformes	Accipitridae	LC	Schedule-I	WM
14	Shikra	*Accipiter badius*	Accipitriformes	Accipitridae	LC	Schedule-I	R

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Comparison of avian diversity between managed and unmanaged wetlands in Patna, Bihar, India

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Abstract We compared the bird diversity of a managed (Rajdhani Jalashay) and an unmanaged wetland (Mustafapur) in Patna, Bihar, India. We recorded bird species by using point counts and fixed-route monitoring. At Rajdhani Jalashay, a total of 73 species were recorded, of which 15 species were winter visitors. Two species were in the Near-threatened category: Ferruginous Duck *(Aythya nyroca)* and Alexandrine Parakeet *(Psittacula eupatria)*, while the others were of least concern. At Mustafapur wetland, 67 species were recorded with 11 species as winter visitors. Simpson's species diversity index was 0.78 at Rajdhani Jalashay, and 0.81 at Mustafapur wetland. The number of species of waders was 17 at Mustafapur wetland and 11 at Rajdhani Jalashay. The total number of Lesser Whistling-duck *(Dendrocygna javanica)*, a resident bird was almost double (526) at Mustafapur wetland than that at Rajdhani Jalashay (234). The nitrate level was twice higher and the phosphate level was four times higher at Mustafapur wetland than those at Rajdhani Jalashay. The difference in species number and composition between the two wetlands may be attributed to the eutrophication resulting from high nitrate and phosphate levels at Mustafapur wetland. Unfortunately, the Mustafapur wetland is under threat due to human influences. The protection and sustainable management of natural wetlands is required for saving the biodiversity of the area.

Keywords: wetland management, conservation, avian diversity, eutrophication

Összefoglalás Jelen tanulmányban a madárvilág sokféleségét hasonlítottuk össze a kezelt (Rajdhani Jalashay) és a nem kezelt vizes élőhelyek (Mustafapur) között, az indiai Patnában (Bihar). A madárfajokat pontszámlálással és rögzített útvonalon történő megfigyeléssel jegyeztük fel. A Rajdhani Jalashayban összesen 73 fajt figyeltünk meg, amelyek közül 15 faj téli vendég volt. A cigányréce *(Aythya nyroca)* és a Nagy Sándor-papagáj *(Psittacula eupatria)* a mérsékelten fenyegetett természetvédelmi kategóriába tartozott. A Mustafapur vizes élőhelyen 67 fajt jegyeztünk fel, amelyek közül 11 faj téli vendég volt. A Simpson-féle faji diverzitási index a Rajdhani Jalashayban 0,78, míg a Mustafapur vizes élőhelyen 0,81 volt. A Mustafapur vizes élőhelyen 17, míg a Rajdhani Jalashayban 11 partimadár faj volt jelen. A bengáli fütyülőlúd *(Dendrocygna javanica)* össz-egyedszáma a Mustafapur vizes élőhelyen majdnem kétszerese (526) volt a Rajdhani Jalashay 234 egyedéhez viszonyítva. A Mustafapur vizes élőhelyen a nitrát szintje kétszer, a foszfát szintje pedig négyszer magasabbnak bizonyult a Rajdhani Jalashayhoz képest. A két vizes élőhelytípus közötti fajösszetétel és fajszámbeli különbség a Mustafapur vizes élőhely magas nitrát- és foszfátszintje miatt bekövetkezett eutrofizációnak tulajdonítható. Sajnos a Mustafapur vizes élőhelyet a fokozott emberi tevékenység miatt veszély fenyegeti. A természetes vizes élőhelyek védelme és fenntartható kezelése szükséges a biológiai sokféleség megmentéséhez a vizsgált területeken.

Kulcsszavak: vizes élőhely kezelés, természetvédelem, madárfajok sokfélesége, eutrofizáció

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Introduction

Urbanization has resulted in more and more natural land being replaced by buildings and roads (Ferenc *et al.* 2014) and has led to biodiversity loss (Grimm *et al.* 2008). Birds form an important indicator group of urban ecosystem health (Yang *et al.* 2020). Therefore, studying bird diversity is important for conservation and management activities in urban ecosystems (Wang *et al.* 2013). Wetlands increase biodiversity in urban areas by acting as networks of fragmented habitat to facilitate the movement of species in the environments (Blicharska *et al.* 2016, Hill *et al.* 2021, Krivtsov *et al.* 2022, Richardson *et al.* 2023). Unfortunately, more than 50% of wetlands around the world have been lost due to urbanization (Martin Jean 2006, Bhagyanathan & Dhayanithy 2023). According to Wetlands International (WI) South Asia, nearly 30% of the natural wetlands in India have been lost in the last three decades. Similarly, 70% of Bihar's wetlands including Patna have been lost in the last few decades. The loss and degradation of wetlands has negatively affected the waterbirds. Maintenance of parks including small waterbodies may help to protect biodiversity in urban ecosystems (Hagen *et al.* 2017). Artificial wetlands or waterbodies managed by humans can provide alternative or complementary habitats for waterbirds (Connor & Gabor 2006). Rajdhani Jalashay (a managed waterbody) of Patna, Bihar, India is one such waterbody. This study was conducted in Rajdhani Jalashay to document the avifaunal diversity that would serve as baseline data for upcoming studies as no comprehensive study on the ecology of this area has been done so far. For comparison, an unmanaged wetland called Mustafapur was also included in the study.

Methods

Rajdhani Jalashay (25.602583°N and 85.118781°E) is located in the center of Patna city, Bihar, India *(Figure 1)*. It is managed by the Government of Bihar and was established in 2019. The area of Rajdhani Jalashay is 0.03 km^2 and the perimeter is 744 m. This waterbody has an elliptical geometry and is surrounded by a gravel pathway. It has well-defined boundaries and is under tight security. This waterbody is recharged with groundwater with the help of a waterpump. Mustafapur wetland (25.59341°N and 85.040778°E) is located around 10 km away from Rajdhani Jalashay *(Figure 1)*. Mustafapur wetland has an area of 0.14 km^2 and a perimeter of 1.71 km. This waterbody is recharged with rainwater. The survey was conducted between November 2021 and January 2022. The average temperature was around 18–25 °C with the lowest dip recorded as 7 °C.

The tree species found in the Rajdhani Jalashay were *Saraca asoca, Mangifera indica, Bombax ceiba, Ficus religiosa, Ficus benghalensis, Senna sophera, Delonix regia, Cassia fistula* and *Adiantum* sp. Birds can be seen roosting on these trees preferably on *Bombax ceiba.* Herbaceous vegetation included species like, *Setaria faberi, Ageratum conyzoids, Amaranthus spinosus, Lantana camara, Solanum nigrum, Euphorbia prostrata, Parthenium hyterophorus and Cynodon dactylon.* Aquatic flora included species such as *Eichornia crassipes, Lemna minor, Azolla* sp. *and Hydrilla. Lemna minor* and *Azolla* sp., also known

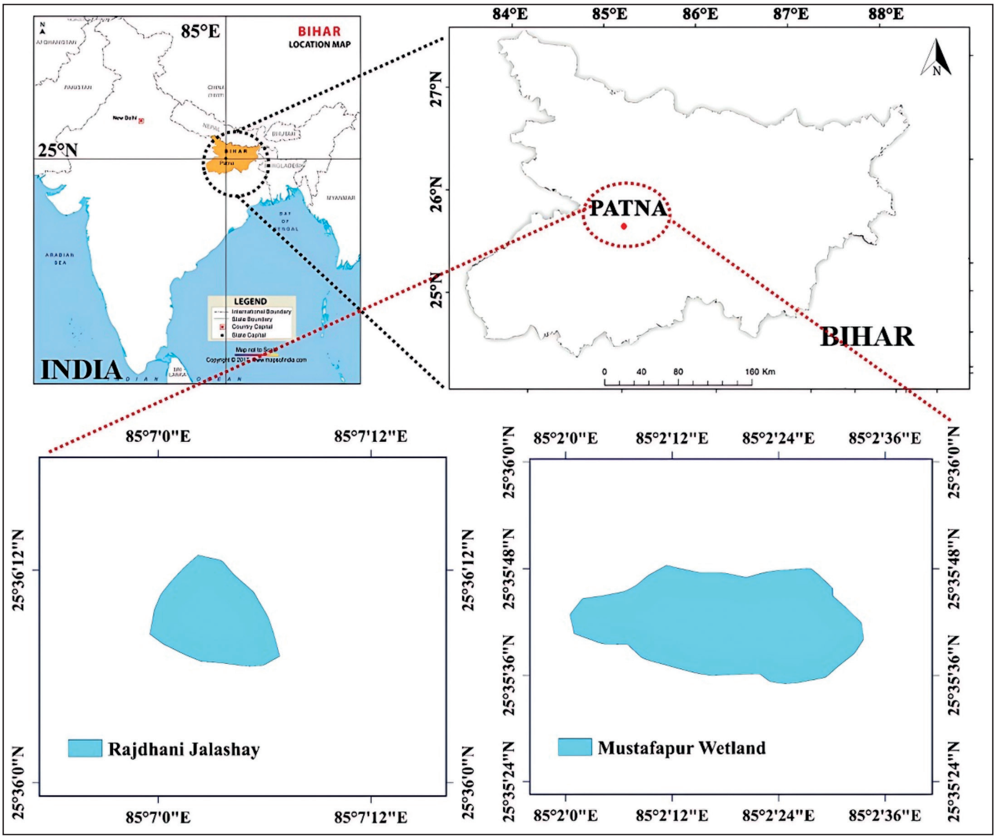

Figure 1. Map of the study *area*
1. ábra A vizsgálati terület térképe

as duckweeds are food source for most of the waterbirds. Rajdhani Jalashay supports both migratory and resident birds.

The tree species found in the Mustafapur wetland were *Ficus racemosa* and *Ficus religiosa.* Herbaceous vegetation includes *Cymbopogon martinii, Brachiara mutica, Pennisetum purpureum, Imperata cylindrica, Hymenachne amplexicaulis, Setaria viridis, Arundo donax, Phragmites karka, Phragmites australis, Typha domingensis* and *Actinoscirpus grossus.* Aquatic flora includes *Pistia stratiotes, Eichhornia crassipes, Nymphaea micrantha, Vallisneria natans, Spirodela polyrhiza, Limnocharis flava, Hydrilla verticillata, Monochoria vaginalis, Azolla pinnata, Ottelia alismoides, Salvinia natans, Eclipta prostrata, Lemna minor, Alternanthera philoxeroides, Elodea najas, Polygonum plebeium, Enydra fluctuans* and *Marsilea minuta.*

Bird species were recorded by using point count method and fixed route monitoring. In this method we walked along a 360° arc around the study area in both clockwise and anti-clockwise directions. The survey was conducted weekly between 7.30 am and 10.00 am. Birds were identified by direct sightings with the help of a field guide (Ali & Ripley 1983).

Water samples were collected in triplicates from four sites of both the wetlands during the post-monsoon season of 2022 following the standard protocols (APHA, 2012). Nitrate was estimated using Phenyl Disulphonic Acid method by spectrophotometric analysis (Trivedi & Goel 1986). Phosphate was determined using Stannous Chloride method by spectrophotometric analysis (APHA, 2012).

Shannon-Weiner Diversity Index (Shannon, 1948), Evenness index, Effective Number of species (ENS), Simpson's diversity index (Simpson, 1949), and Relative abundance were calculated to understand the difference in avifaunal diversity between the two wetlands.

Relative Abundance

Relative abundance of avian species was determined by using encounter rates that give crude ordinal scales of abundance (abundant, common, frequent, uncommon and rare) (Bibby *et al.* 1992) *(Table 1)*.

Student's t test and Kolmogorov-Smirnov tests were used for statistical comparisons in GraphPad Prism v9.0. Kolmogorov-Smirnov (non-parametric) test was used to compare the abundance data between the two sites.

Results

At Rajdhani Jalashay, a total of 73 species were recorded of which 14 species were winter visitors and one was a summer visitor. The recorded species were classified into 16 orders and 33 families. The most dominant order was Passeriformes followed by Anseriformes *(Table 2)*. The most dominant family was Anatidae. *Dendrocygna javanica* was observed to be the most abundant species. Two species Alexandrine Parakeet *(Psittacula eupatria)* and Ferruginous Duck *(Aythya nyroca)* were Near threatened. Four species Western Marsh Harrier *(Circus aeruginosus)*, Booted Eagle *(Hieraaetus pennatus)*, Crested Honey-buzzard *(Pernis ptilorhynchus)* and Eurasian Wigeon *(Mareca penelope)* were recorded for the first time in Rajdhani Jalashay. At Mustafapur wetland, 67 species were recorded with 11 species as winter visitors. No summer visitor was found. The recorded species were classified into 15 orders and 29 families. The most dominant order was Passeriformes followed by Anseriformes *(Table 3)*. The most dominant bird families were Anatidae along with Ardeidae. *Dendrocygna javanica* was observed to be the most abundant species. *Figure 2* represents a comparative assessment of waterbird abundance in both the wetlands. The Mustafapur wetland had a higher species richness

Table 1. Classification of bird species based on abundance score

1. táblázat A madárfajok osztályozása egyedsűrűségi mutatóik alapján

Abundance score	Local Occurance Rate (L.O.R)	Acronym
0–0.2	Rare	R
0.21–0.40	Uncommon	UC
0.41–0.80	Frequent	F
0.81–5.0	Common	C
>5	Abundant	A

Table 2. Status and relative abundance of bird species in Rajdhani Jalashay (*RJ*)
2. táblázat A madárfajok természetvédelmi és vonulási besorolása, valamint relatív egyedsűrűség kategóriája Rajdhani Jalashay területén

Order	Family	Species	IUCN status	Migratory status	R.A	L.O.R
Anseriformes (9 sp)	Anatidae (9 sp)	Cotton Pygmy-goose *(Nettapus coromandelianus)*	LC	WM	0.2	R
		Lesser Whistling-duck *(Dendrocygna javanica)*	LC	R	45.7	A
		Knob-billed Duck *(Sarkidiornis melanotos)*	LC	R	0.39	UC
		Ferruginous Duck *(Aythya nyroca)*	**NT**	**WM**	**0.2**	R
		Red-crested Pochard *(Netta rufina)*	LC	WM	0.2	R
		Garganey *(Anas querquedula)*	LC	WM	2.15	C
		Northern Shoveler *(Anas clypeata)*	LC	WM	1.37	C
		Eurasian Wigeon *(Anas penelope)*	LC	WM	0.2	R
		Gadwall *(Anas strepera)*	LC	WM	2.34	C
Apodiformes (1 sp)	Apodidae (1 sp)	Asian Palm Swift *(Cypsiurus balasiensis)*	LC	R	0.2	R
Cuculiformes (3 sp)	Cuculidae (3 sp)	Common Hawk Cuckoo *(Hierococcyx varius)*	LC	R	0.39	UC
		Asian Koel *(Eudynamys scolopaceus)*	LC	R	2.15	C
		Greater Coucal *(Centropus sinensis)*	LC	R	0.59	F
Columbiformes (4 sp)	Columbidae (4 sp)	Spotted Dove *(Spilopelia chinensis)*	LC	R	0.78	F
		Eurasian Collared Dove *(Streptopelia decaocto)*	LC	R	0.39	UC
		Yellow-footed Green Pigeon *(Treron phoenicoptera)*	LC	R	1.56	C
		Feral Pigeon *(Columba livia)*	LC	R	0.59	F
Gruiformes (3 sp)	Rallidae (3 sp)	Common Moorhen *(Gallinula chloropus)*	LC	R	1.17	C
		White-breasted Waterhen *(Amaurornis phoenicurus)*	LC	R	0.98	C
		Eurasian Coot *(Fulica atra)*	LC	R	1.56	C
Podicipediformes (1 sp)	Podicipedidae (1 sp)	Little Grebe *(Tachybaptus ruficollis)*	LC	R	0.78	F
Charadiformes (3 sp)	Charadriidae (1 sp)	Red-wattled Lapwing *(Vanellus indicus)*	LC	R	0.39	UC
	Scolopacidae (1 sp)	Common Sandpiper *(Actitis hypoleucos)*	LC	WM	0.59	F
	Jacanidae (1 sp)	Bronze-winged Jacana *(Metopidius indicus)*	LC	R	0.78	F

Order	Family	Species	IUCN status	Migratory status	R.A	L.O.R
Ciconiiformes (1 sp)	Ciconiidae (1 sp)	Asian Openbill Stork *(Anastomus oscitans)*	LC	R	0.2	R
Suliformes (2 sp)	Phalacrocoracidae (2 sp)	Little Black Cormorant *(Phalacrocorax sulcirostris)*	LC	R	0.98	C
		Indian Cormorant *(Phalacrocorax fuscicollis)*	LC	R	0.39	UC
Pelecaniformes (5 sp)	Ardeidae (5 sp)	Cattle Egret *(Bubulcus ibis)*	LC	R	0.78	F
		Little Egret *(Egretta garzetta)*	LC	R	0.59	F
		Purple Heron *(Ardea purpurea)*	LC	R	0.2	R
		Indian Pond Heron *(Ardeola grayii)*	LC	R	1.56	C
		Black-crowned Night Heron *(Nycticorax nycticorax)*	LC	R	0.2	R
Accipitriformes (5 sp)	Accipitridae (5 sp)	Black Kite *(Milvus migrans)*	LC	R	0.78	F
		Shikra *(Accipiter badius)*	LC	R	0.39	UC
		Crested Honey Buzzard *(Pernis ptilorhynchus)*	LC	R	0.2	R
		Booted Eagle *(Hieraaetus pennatus)*	LC	WM	0.2	R
		Western Marsh Harrier *(Circus aeruginosus)*	LC	WM	0.2	R
Bucerotiformes (1 sp)	Bucerotidae (1 sp)	Indian Grey Hornbill *(Ocyceros birostris)*	LC	R	0.78	F
Coraciiformes (3 sp)	Alcedinidae (1 sp)	White-throated Kingfisher *(Halcyon smyrnensis)*	LC	R	0.39	UC
	Meropidae (1 sp)	Asian Green Bee-eater *(Merops orientalis)*	LC	R	0.2	R
	Coraciidae (1 sp)	Indian Roller *(Coracias benghalensis)*	LC	R	0.2	R
Piciformes (3 sp)	Picidae (1 sp)	Black-rumped Flameback *(Dinopium benghalense)*	LC	R	0.98	C
	Megalaimidae (2 sp)	Coppersmith Barbet *(Megalaima haemacephala)*	LC	R	0.98	C
		Brown-headed Barbet *(Megalaima zeylanica)*	LC	R	0.78	F
Psittaciformes (3 sp)	Psittaculidae (3 sp)	Rose-ringed Parakeet *(Psittacula krameri)*	LC	R	0.59	F
		Plum-headed Parakeet *(Psittacula cyanocephala)*	LC	R	0.98	C
		Alexandrine Parakeet *(Psittacula eupatria)*	**NT**	**R**	**0.39**	UC

Order	Family	Species	IUCN status	Migratory status	R.A	L.O.R
Passeriformes (26 sp)	Sturnidae (4 sp)	Common Myna *(Acridotheres tristis)*	LC	R	1.37	C
		Indian Pied Myna *(Gracupica contra)*	LC	R	1.17	C
		Brahminy Starling *(Sturnia pagodarum)*	LC	R	0.39	UC
		Rosy Starling *(Pastor roseus)*	LC	R	0.39	UC
	Oriolidae (2 sp)	Golden Oriole *(Oriolus oriolus)*	LC	R	1.17	C
		Black-hooded Oriole *(Oriolus xanthornus)*	LC	R	0.78	F
	Corvidae (3 sp)	Rufous Treepie *(Dendrocitta vagabunda)*	LC	R	0.98	C
		Large-billed Crow *(Corvus macrorhynchos)*	LC	R	1.76	C
		House Crow *(Corvus splendens)*	LC	R	2.15	C
	Hirundinidae (1 sp)	Barn Swallow *(Hirundo rustica)*	LC	WM	0.2	R
	Turdidae (1 sp)	Orange-headed Thrush *(Geokichla citrina)*	LC	R	0.39	UC
	Leiothrichidae (1 sp)	Jungle Babbler *(Turdoides striata)*	LC	R	3.71	C
	Dicruridae(1 sp)	Black Drongo *(Dicrurus macrocercus)*	LC	R	0.59	F
	Muscicapidae (7 sp)	Verditer Flycatcher *(Eumyias thalassinus)*	LC	R	0.39	UC
		Asian Brown Flycatcher *(Muscicapa dauurica)*	LC	WM	0.39	UC
		Oriental Magpie Robin *(Copsychus saularis)*	LC	R	0.78	F
		Black Redstart *(Phoenicurus ochruros)*	LC	R	0.2	R
		Taiga Flycatcher *(Ficedula albicilla)*	LC	WM	0.39	UC
		Pale-chinned Blue Flycatcher *(Cyornis poliogenys)*	LC	R	0.2	R
		Brown Rock Chat *(Cercomela fusca)*	LC	R	0.2	R
	Motacillidae (2 sp)	White Browed Wagtail *(Motacilla maderaspatensis)*	LC	R	0.39	UC
		White Wagtail *(Motacilla alba)*	LC	WM	0.59	F
	Pyconotidae (1 sp)	Red-vented Bulbul *(Pycnonotus cafer)*	LC	R	1.17	C
	Cisticolidae(1 sp)	Common Tailorbird *(Orthotomus sutorius)*	LC	R	0.78	F
	Phyloscopidae (1 sp)	Greenish Warbler *(Phylloscopus trochiloides)*	LC	WM	0.59	F
	Nectariniidae (1 sp)	Purple Sunbird *(Cinnyris asiaticus)*	LC	R	0.39	UC

Abbreviations: WM-Winter Migrant, SM-Summer Migrant, R-Resident, IUCN-International Union for Conservation of Nature, LC-Least Concern, NT-Near Threatened, RA-Relative Abundance, L.O.R-Local Occurrence Rate

Table 3. Status and relative abundance of bird species at Mustafapur wetland
3. táblázat A madárfajok természetvédelmi és vonulási besorolása, valamint relatív egyedsűrűség kategóriája Mustafapur területén

Order	Family	Species	IUCN status	Migratory status	R.A	L.O.R
Anseriformes (7 sp)	Anatidae (7 sp)	Gadwall *(Anas strepera)*	LC	WM	2.94	C
		Garganey *(Anas querquedula)*	LC	WM	1.8	C
		Lesser Whistling-duck *(Dendrocygna javanica)*	LC	WM	42.97	A
		Red Crested Pochard *(Netta rufina)*	LC	WM	0.33	UC
		Northern Pintail *(Anas acuta)*	LC	WM	0.49	F
		Northern Shoveler *(Anas clypeata)*	LC	WM	0.49	F
		Eurasian Wigeon *(Mareca penelope)*	LC	WM	0.16	R
Apodiformes (1 sp)	Apodidae (1 sp)	Asian Palm-swift *(Cypsiurus balasiensis)*	LC	R	0.9	C
Cuculiformes (2 sp)	Cuculidae (2 sp)	Asian Koel *(Eudynamys scolopaceus)*	LC	R	0.16	R
		Greater Coucal *(Centropus sinensis)*	LC	R	0.49	F
Columbiformes (4 sp)	Columbidae(4 sp)	Eurasian Collared Dove *(Streptopelia decaocto)*	LC	R	0.33	UC
		Spotted Dove *(Spilopelia chinensis)*	LC	R	0.16	R
		Laughing Dove *(Spilopelia senegalensis)*	LC	R	0.65	F
		Rock Pigeon *(Columba livia)*	LC	R	0.82	C
Gruiformes (4sp)	Rallidae (4 sp)	Grey-headed Swamphen *(Porphyrio poliocephalus)*	LC	R	1.8	C
		Common Moorhen *(Gallinula chloropus)*	LC	R	1.23	C
		Common Coot *(Fulica atra)*	LC	R	2.45	C
		White-breasted Waterhen *(Amaurornis phoenicurus)*	LC	R	1.63	C
Podicipediformes (1 sp)	Podicipedidae (1 sp)	Little Grebe *(Tachybaptus ruficollis)*	LC	R	0.98	C

Order	Family	Species	IUCN status	Migratory status	R.A	L.O.R
Charadriiformes (6 sp)	Charadriidae(2 sp)	Red-wattled Lapwing *(Vanellus indicus)*	LC	R	1.06	C
		Grey-headed Lapwing *(Vanellus cinereus)*	LC	R	1.63	C
	Scolopacidae(2 sp)	Wood Sandpiper *(Tringa glareola)*	LC	R	0.08	R
		Common Sandpiper *(Actitis hypoleucos)*	LC	WM	0.49	F
	Jacanidae (2 sp)	*(Metopidius indicus)*	LC	R	1.96	C
		Pheasant-tailed Jacana *(Hydrophasianus chirurgus)*	LC	R	1.47	C
Ciconiiformes (1 sp)	Ciconiidae (1 sp)	Asian Openbill Stork *(Anastomus oscitans)*	LC	R	4.98	C
Suliformes (2 sp)	Phalacrocoracidae (2 sp)	Indian Cormorant *(Phalacrocorax fuscicollis)*	LC	R	2.94	C
		Little Black Cormorant *(Phalacrocorax sulcirostris)*	LC	R	3.27	C
Pelicaniformes (7 sp)	Ardeidae (7 sp)	Cattle Egret *(Bubulcus ibis)*	LC	R	0.65	F
		Little Egret *(Egretta garzetta)*	LC	R	0.9	C
		Great Egret *(Ardea alba)*	LC	R	0.33	UC
		Purple Heron *(Ardea purpurea)*	LC	R	0.57	F
		Indian Pond Heron *(Ardeola grayii)*	LC	R	0.33	UC
		Black-crowned Night Heron *(Nycticorax nycticorax)*	LC	R	0.57	F
		Cinnamon Bittern *(Ixobrychus cinnamomeus)*	LC	R	0.74	F
Accipitriformes (3 sp)	Accipitridae(3 sp)	Black Kite *(Milvus migrans)*	LC	R	0.82	C
		Western Marsh Harrier *(Circus aeruginosus)*	LC	WM	0.08	R
		Shikra *(Accipiter badius)*	LC	R	0.25	UC
Coraciiformes (3 sp)	Alcedinidae (1 sp)	White-throated Kingfisher *(Halcyon smyrnensis)*	LC	R	0.41	F
	Meropidae (1 sp)	Asian Green Bee-eater *(Merops orientalis)*	LC	R	0.57	F
	Coraciidae (1 sp)	Indian Roller *(Coracias benghalensis)*	LC	R	0.25	UC
Piciformes (1 sp)	Megalaimidae (1 sp)	Coppersmith Barbet *(Megalaima haemacephala)*	LC	R	0.49	F
Psittaciformes (2 sp)	Psittaciculidae (2 sp)	Plum-headed Parakeet *(Psittacula cyanocephala)*	LC	R	0.65	F
		Rose-ringed Parakeet *(Psittacula krameri)*	LC	R	0.49	F

Order	Family	Species	IUCN status	Migratory status	R.A	L.O.R
Passeriformes (23 sp)	Costicolidae (5 sp)	Rufescent Prinia *(Prinia rufescens)*	LC	R	0.25	UC
		Ashy Prinia *(Prinia socialis)*	LC	R	0.41	F
		Plain Prinia *(Prinia inornata)*	LC	R	0.82	C
		Common Tailorbird *(Orthotomus sutorius)*	LC	R	0.57	F
		Zitting Cisticola *(Cisticola juncidis)*	LC	R	0.08	R
	Motacillidae (4 sp)	Citrine Wagtail *(Motacilla citreola)*	LC	WM	0.33	UC
		White-browed Wagtail *(Motacilla maderaspatensis)*	LC	R	0.74	F
		White Wagtail *(Motacilla alba)*	LC	WM	0.65	F
		Rosy Pipit *(Anthus roseatus)*	LC	R	0.08	R
	Muscicapidae (2 sp)	Brown Rock Chat *(Cercomela fusca)*	LC	R	0.49	F
		Oriental Magpie Robin *(Copsychus saularis)*	LC	R	0.33	UC
	Pycnotidae (1 sp)	Red-vented Bulbul *(Pycnonotus cafer)*	LC	R	0.49	F
	Nectariniidae (1 sp)	Purple Sunbird *(Cinnyris asiaticus)*	LC	R	0.41	F
	Dicruridae (1 sp)	Black Drongo *(Dicrurus macrocercus)*	LC	R	0.98	C
	Leipthrichidae (1 sp)	Jungle Babbler *(Turdoides striata)*	LC	R	0.82	C
	Hirundinidae (1 sp)	Barn Swallow *(Hirundo rustica)*	LC	R	0.9	C
	Corvidae (3 sp)	Large-billed Crow *(Corvus macrorhynchos)*	LC	R	0.57	F
		House Crow *(Corvus splendens)*	LC	R	0.98	C
		Rufous Treepie *(Dendrocitta vagabunda)*	LC	R	0.33	UC
	Sturnidae (3 sp)	Common Myna *(Acridotheres tristis)*	LC	R	0.82	C
		Indian Pied Myna *(Gracupica contra)*	LC	R	0.65	F
		Bank Myna *(Acridotheres ginginianus)*	LC	R	0.98	C
	Passeridae (1 sp)	House Sparrow *(Passer domesticus)*	LC	R	0.57	F

Abbreviations: WM-Winter Migrant, R-Resident, IUCN-International Union for Conservation of Nature, LC-Least Concern, RA-Relative Abundance, L.O.R-Local Occurrence Rate

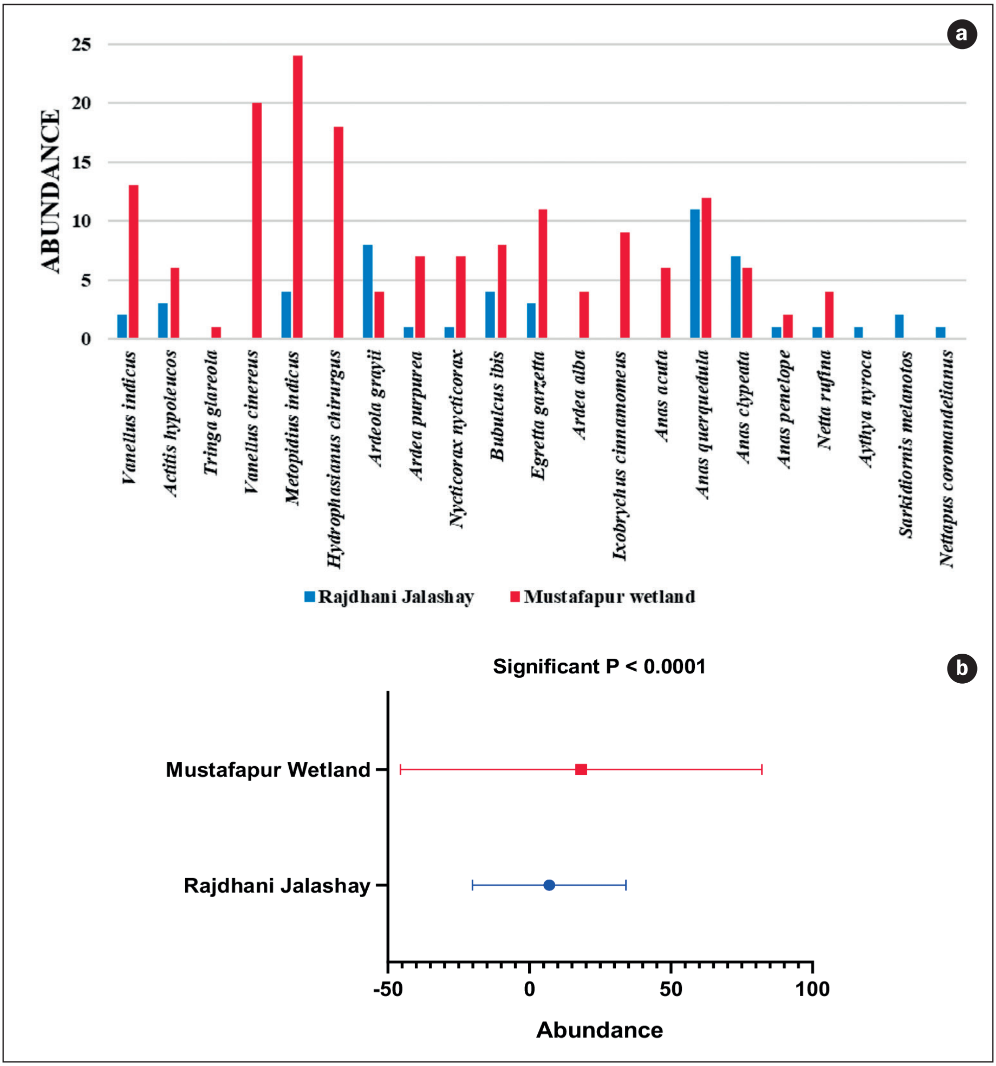

Figure 2. Comparison of abundance of waterbird species between Rajdhani Jalashay and Mustafapur wetland at Patna, Bihar. (a) Comparison of bird count between the two sites; (b) Statistical difference in abundance of birds between the two sites

2. ábra A madárfajok egyedsűrűségének összehasonlítása Rajdhani Jalashay és Mustafapur vizes élőhelyein (Patna, Bihar, India). (a) A két területen leszámolt madarak összehasonlítása; (b) Statisztikai különbség a két terület madárfajainak egyedsűrűségében

(n=21) compared to Rajdhani Jalashay (n=18) (Kolmogorov-Smirnov D=0.4823, P< 0.0001). The results indicate a notably higher abundance of most waterbird species in the unmanaged Mustafapur Wetland compared to the managed Rajdhani Jalashay. For instance, the Lesser Whistling-duck *(Dendrocygna javanica)* was 2.2 times more abundant at Mustafapur Wetland, while the Gadwall *(Anas strepera)* exhibited a threefold higher abundance, and the Asian Openbill Stork *(Anastomus oscitans)* was a remarkable 61 times more abundant.

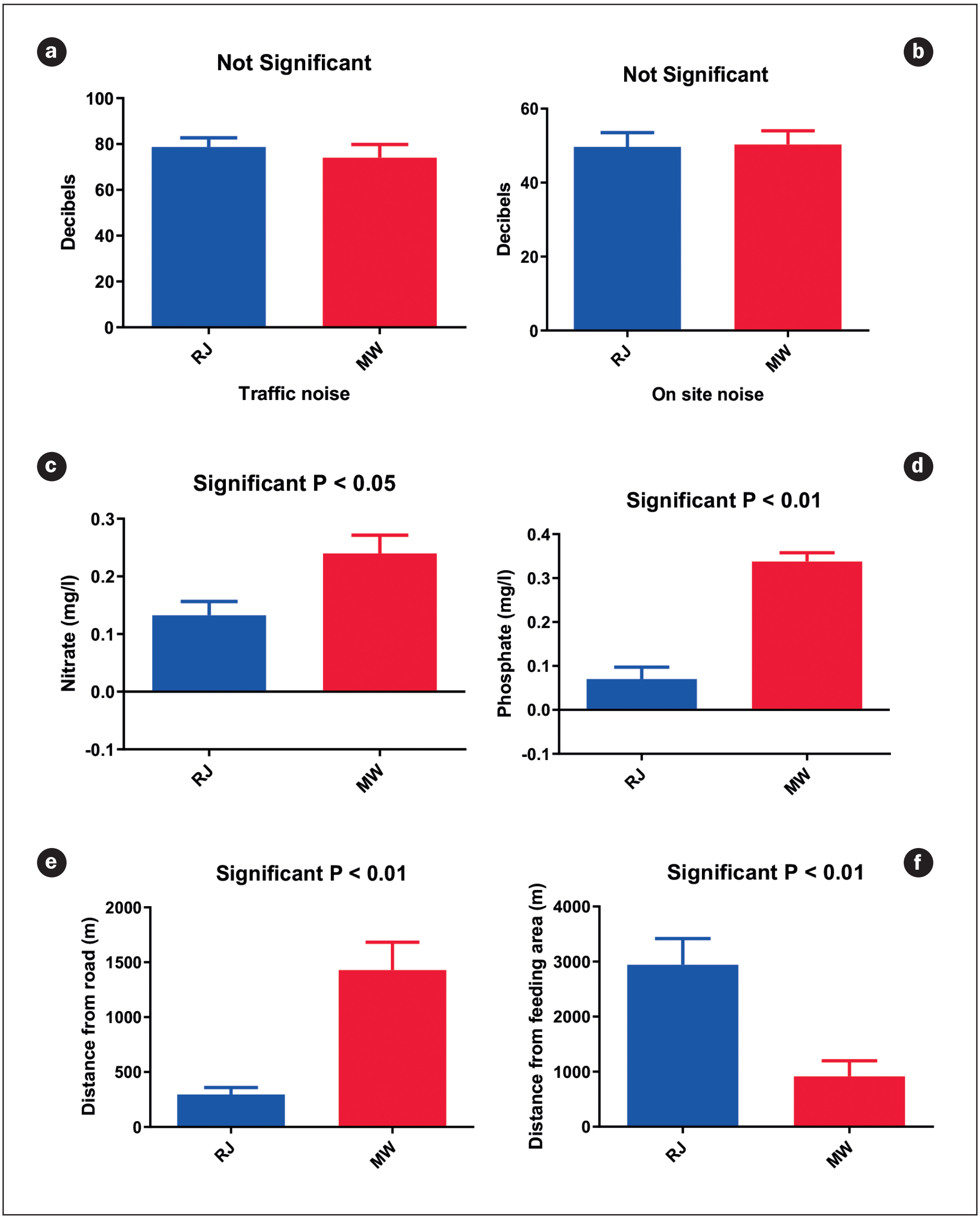

Figure 3. Comparison of Rajdhani Jalashay (*RJ*) with Mustafapur wetland (*MW*)

3. ábra A két vizes élőhely Rajdhani Jalashay (RJ) és Mustafapur (MW) tulajdonságainak összehasonlítása

Simpson's diversity index for Rajdhani Jalashay was calculated as 0.78. Shannon-Weiner's diversity index was 2.85. Species evenness of the community was 0.66 and Effective Number of Species (ENS) was 17.32.

Mustafapur wetland showed marginal higher values of the Simpson's diversity index (0.81), Shannon-Weiner's diversity index (2.86), Species evenness (0.69), and Effective Number of Species (17.59).

While the traffic and on-site noise level were non-significantly different between the two wetlands, distance from the road was higher for Mustafapur wetland (t=4.343, df=14, P=0.0007). More importantly, distance from adjoining feeding area was significantly less (t=3.641, df=14, P=0.0027) for Mustafapur wetland *(Figure 3)*. The nitrate level at the unmanaged wetland was found to be twice higher (t=2.725, df=6, P=0.0344), and the phosphate level was four times higher (t=7.867, df=6, P= 0.0002) as compared to the managed waterbody *(Figure 3)*.

Discussion

The number of resident species were greater as compared to migrants at both the wetlands. Resident species contribute the most to the diversity (59%) and density of waterbirds on artificial irrigation tanks (Bellio *et al.* 2009).

Wading birds are highly mobile and respond quickly to changes in habitat quality, thus serving as important indicator species for wetland systems (Beerens *et al.* 2015). Moreover, the total number of Lesser Whistling-duck, a resident bird was almost double (526) at Mustafapur wetland as compared to 234 at Rajdhani Jalashay. Similarly, Adhurya *et al.* (2019) reported high number of the species at Ambuja Wetland, West Bengal having high nutrient load.

The concentration of phosphate varied from 0.01–0.38 mg/l that would promote algal bloom. Higher nitrate and phosphate levels at the unmanaged wetland can be attributed to the inflow of sewage from adjacent residential areas and run-off from nearby crop fields resulting in eutrophication. Eutrophication is often produced by an excess of macronutrients derived from anthropogenic sources, which has been shown to promote growth of aquatic vegetation (O'Hare *et al.* 2018). Rosselli and Stiles (2012) and Murphy and Dinsmore (2018) have also attributed the higher aquatic bird richness and abundance at one of the smallest lakes studied, Colta Lake, to high eutrophication levels, expressed as high values of biochemical demand of oxygen and high concentrations of phosphates and nitrites. However, high levels of eutrophication may also trigger the proliferation of green algae and decline of macrophytes leading to a high-turbidity state of water, in which few species can survive (Scheffer *et al.* 1993). To address the eutrophication and excess nutrient issues in aquatic ecosystems, phytoremediation offers a promising solution (Liu *et al*. 2021). Aquatic plants like duckweeds, water lettuce *(Pistia stratiotes)*, and water lilies have demonstrated their ability to combat eutrophication by absorbing and assimilating excess phosphorus and nitrogen (Nahar & Hoque 2021). However, these plants can sometimes grow uncontrollably, potentially covering the water surfaces. To avoid such scenarios, regular monitoring is essential (Liu *et al*. 2021). Promoting public awareness is the cornerstone for mobilizing support and ensuring effective eutrophication management. Controlled eradication of excess flora when necessary is vital to prevent overgrowth. This integrated approach can effectively reduce eutrophication in the water bodies (Wang *et al.* 2022).

Each species of wetland-dependent bird has a unique and complex set of needs for wetland habitats that makes it difficult to generalize about how loss or degradation of wetlands affects bird populations. Wetland restoration efforts for aquatic birds should focus on protecting and creating habitat to maintain demographic and genetic connectivity and metapopulation viability (Hall & Beissinger 2017). Further, ecosystem-based approach is needed in wetland management with various targets (Ma *et al.* 2010). This requires integrated knowledge of the entire wetland ecosystem (including hydrology, geology, agrology, botany, aquatic biology, landscape ecology, engineering, and ornithology). Wetland restoration has been found to increase bird count and diversity (Proctor *et al.* 2022). Therefore, protection and sustainable management of natural wetlands is required that may help to restore the declining biodiversity especially of avifauna and other aquatic fauna and also support the livelihoods of the local population (Aslam *et al*. 2021).

Conclusion

This study shows that even in developed urban areas like Patna, certain habitats support significant numbers of bird species. Therefore, perennial flowering plants, fruit trees that provide nesting grounds for bird species, should not be cut and more trees should be planted to attract more birds. For better understanding the ecology of these waterbodies, it is recommended that the physicochemical parameters along with biological parameters of these sites should be monitored on a regular basis.

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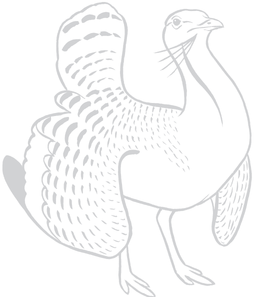

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Census and spatial distribution of White Stork *(Ciconia ciconia)* population in Kosovo in 2017 and 2018

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Abstract In this study, during 2017–2018, for the first time in Kosovo, research on the census, distribution and population dynamics of the White Stork was made. 61 new nests were found in the whole country territory and together with 22 known nests, the total population is recorded to 83 nests and 72 breeding pairs. In total, 461 chicks were raised in the successful nests. Breeding success for the country territory during the observation period of all breeding pairs was 3.18, and 3.19 of all breeding pairs that raised chicks. The mean breeding density for the entire country was 0.67 breeding pairs/100 km^2 in 2017 and 0.70 in 2018. For the potential feeding habitats, it was 2.19 (2017) and 2.28 (2018). The densest area, the river basin of Lepenci held 2.48 pairs for 100 km^2. 48.61% of all recorded White Stork nests were located on various poles.

Keywords: Kosovo, White Stork, population, census, spatial distribution

Összefoglalás Koszovó első országos szintű fehérgólya-felmérése 2017–2018-ban zajlott le. A korábban is ismert 22 fészek mellett 61 új fészek került elő. A teljes gólyaállomány 72 költőpár volt, amely összesen 461 fiókát repített ki. A fészkenkénti átlagos fiókaszám az összes költőpárra számítva 3,18, a sikeres párokra számítva 3,19 volt. Az állomány országos denzitása 2017-ben 0,67 pár/100 km^2, 2018-ban 0,70 pár/100 km^2, a potenciális táplálkozóterületekre számítva 2,19 (2017), illetve 2,28 (2018) volt. A legsűrűbb állomány a Lepenci folyó vízgyűjtőterületén él (2,48 pár/100 km^2). A fészkek 48,61%-a különféle oszlopokra épült.

Kulcsszavak: Koszovó, fehér gólya, állománynagyság, cenzus, térbeli eloszlás

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Introduction

Until today, seven International White Stork Censuses (IWC) have been carried out in the years 1934, 1958, 1974, 1984, 1994/1995, 2004/2005 and 2014/2015 (Denac 2010, Kaatz *et al*. 2017). Latest censuses showed that population trends of the White Stork are positive in many parts of its range for the first time in several decades, except for the large area of the states in the southern part of the Balkan Peninsula and Turkey (Schulz 1999).

Kosovo is a relatively small country and distinguished by rich biodiversity. Its geographical position, geological factors, hydrology, and climate are some of the factors that enabled Kosovo to have rich biological diversity, rich flora, fauna, and vegetation as well as the presence of relict, endemic and other important species (Maxhuni *et al.* 2014). Kosovo represents an interesting area in terms of resident and migratory bird fauna, as it is an important part of a major eastern European migration flyway connecting Europe and the Africa/Asia region (Maxhuni *et al.* 2014). Kosovo's fauna in general and especially bird fauna has not been studied sufficiently. So far in Kosovo 220 bird species are recognized and their number is assumed to be larger than 300 species (Maxhuni *et al.* 2018).

Even though White Stork is a common bird in Kosovo, there are no comprehensive studies of population and migration ecology. The earliest description of a Kosovarian stork nest is found in Marčetić and Andrejević's 1960 book (Ornithofauna of Kosovo). At that time, there were 26 localities recorded with a total number of 108 nests accounting for an annual average of 238 young. The total population were estimated to 450 White Stork individuals, but no information on nest location was recorded. An incomplete survey has been done by Pelle (1999), where only 4 breeding pairs were found. During extensive field research from 2006 to 2014, only 22 active nests have been found within 19 localities in the whole country and the nesting population size was estimated to be only 22 pairs, mentioning that data gathering can be effective only if it is continued by White Stork Census. This activity shows that Kosovo still has not all the information regarding its White Stork population (Maxhuni *et al.* 2014).

Detailed surveys have been carried out during the period 2017–2018, the period foreseen for this research study. The main goal of this study has been the first research in Kosovo on the census, spatial distribution, and population dynamics of the White Stork.

Materials and Methods

Nest detection

In addition to the 22 nests known from previous years (Maxhuni *et al.* 2016), new territories were searched in field surveys conducted throughout the country. Since some stork nests were in difficult or even impossible places to reach, such as electric poles, the number of

Figure 1. Stork nests on the poles: (a) and (b) recorded with a drone camera (© A. Mavriqi)
1. ábra Drónkamerás felvételek oszlopon lévő gólyafészkekről (© A. Mavriqi)

juveniles and adults in those nests was determined by images taken with drones *(Figure 1)*. Areas, where nests are located were marked on the map using GPS.

Phenology

Nest visits took place every 3–5 days, between 1st of March and 30th of April to detect arrivals and from 1st of August to 10th of September to detect White Stork departures. The date of the first arrival (return from migration) was recorded when at least one bird was observed in a nest in the area under investigation. Similarly, the date of departure (migration) was recorded as the last date the stork was observed in the nest.

Phenological data were calculated using the Mann-Whitney U test, which is used to determine whether two independent samples are selected from populations with the same distribution (Mann & Whitney 1947).

Census method

Fieldwork was equal over the whole period of this study, 2017–2018, and the effort on White Stork census has been carried out between June 1st and July 31st in both years of the survey. This is the period just before juvenile White Storks fledge. During this study, which at the same time is the first real White Stork census in Kosovo, the following parameters – majority of them recommended by Schulz (1999) – were recorded and calculated at each nest: uH (unoccupied nest); HPa (adult pairs), including HPo (pairs without young), HPx (pairs with an unknown number of young) and HPm1–5 (pairs with 1–5 young); JZG (number of young); JZa (JZG/Hpa – average number of fledge young related to HPa); JZm (JZG/HPm – the average number of fledged young related to HPm); StD (population density or "stork density" as HPa per 100 km^2) and StDBiol ("Biological" population density = number of HPa per 100 km^2 of potential feeding habitat).

Standard notation has been used for the description of the reproductive parameters of White Storks (Nowakowski 2003). The number of young has been recorded from the ground, preferably from a more elevated observation point, with the help of binoculars or a spotting scope (20–60 × magnification). Ground and vegetation under the nests have been checked for possible dead, thrown-out chicks.

The data calculations, obtained for each region where the stork is located, were made by following population parameters. We have used the surface area of Kosovo (10,887 km^2) for the calculation of surface-based population density (StD). The surface area of potential feeding habitats (non-irrigated arable lands, pastures, lands principally occupied by agriculture with significant areas of natural vegetation, natural grasslands) was used to calculate biological population density (StDBiol) both as the number of breeding pairs (Hpa) per 100 km^2 surface. Area of potential feeding habitats was calculated based on the CORINE Land Cover database (Copernicus Land Monitoring Service 2018).

Results

Phenology

During this research conducted from the early spring until autumn in 2017 and 2018, 83 stork nests were detected in different parts of Kosovo. According to the observations made in these nests, it was registered that the first partner of a pair arrived about 3–5 days earlier than the second partner. There were cases when both partners appeared at the nest simultaneously. The average arrival (return from migration) date of storks was recorded as 21 March in 2017 and 19 March in 2018, the average departure date of adults was recorded as 21 August in 2017 and 19 August in 2018. The first storks in both two years have reached the center of Kosovo, in Prelluzhe locality, in early March (11th, or 71st day of the 2017 year and 8th, or 68th day of the 2018 year), compared to others which arrived mostly between 22 and 26 March. The last arrivals reached the area on April 1 (92nd day of 2017) and April 2 (93rd day of the 2018 year) *(Figure 2)*.

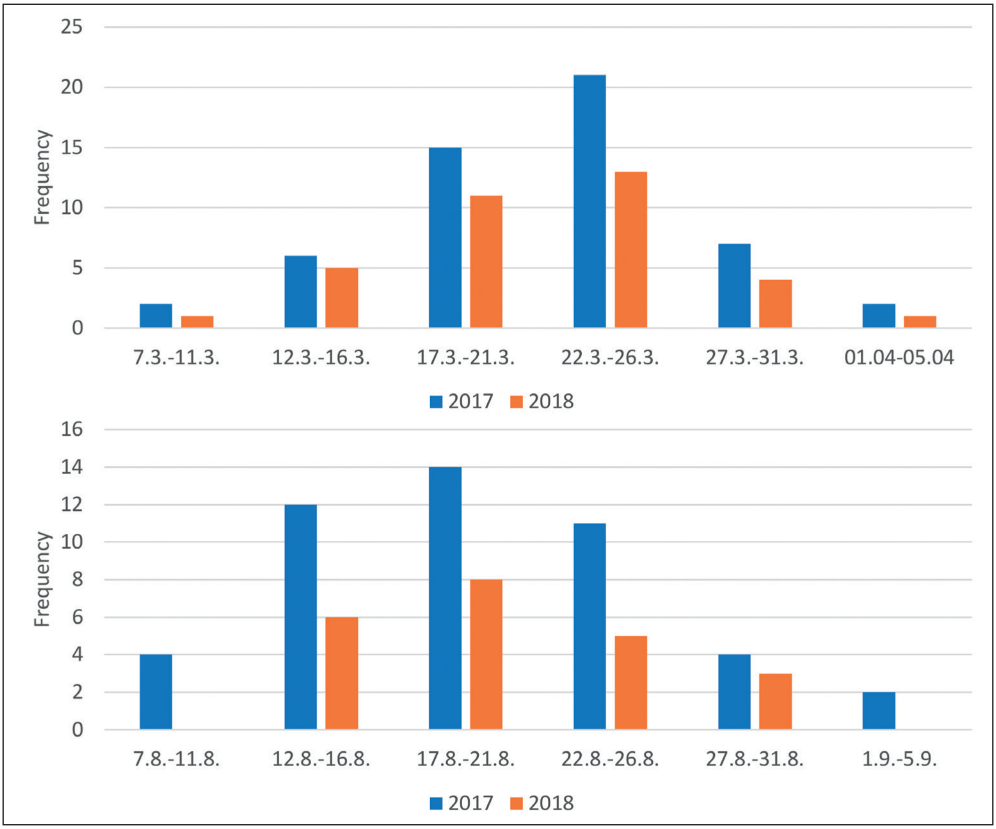

Figure 2. Frequencies of the White Stork arrivals from winter quarters to Kosovo and departures in 2017 and 2018

2. ábra A fehér gólyák tavaszi érkezési és őszi elvonulási időpontjainak megoszlása Koszovóban 2017-ben és 2018-ban

According to our observations, the variability in the arrival date of the second partner did not relate to a considerable extent to the departure date of the individuals from the nest.

Departure dates of adults were also not significantly related to the number of chicks in each nest *(Figure 2)*.

Distribution and population size

The distribution of White Stork nests identified until now in the whole country territory is presented in *Figure 3*. We confirmed the presence of a breeding pair when at least one

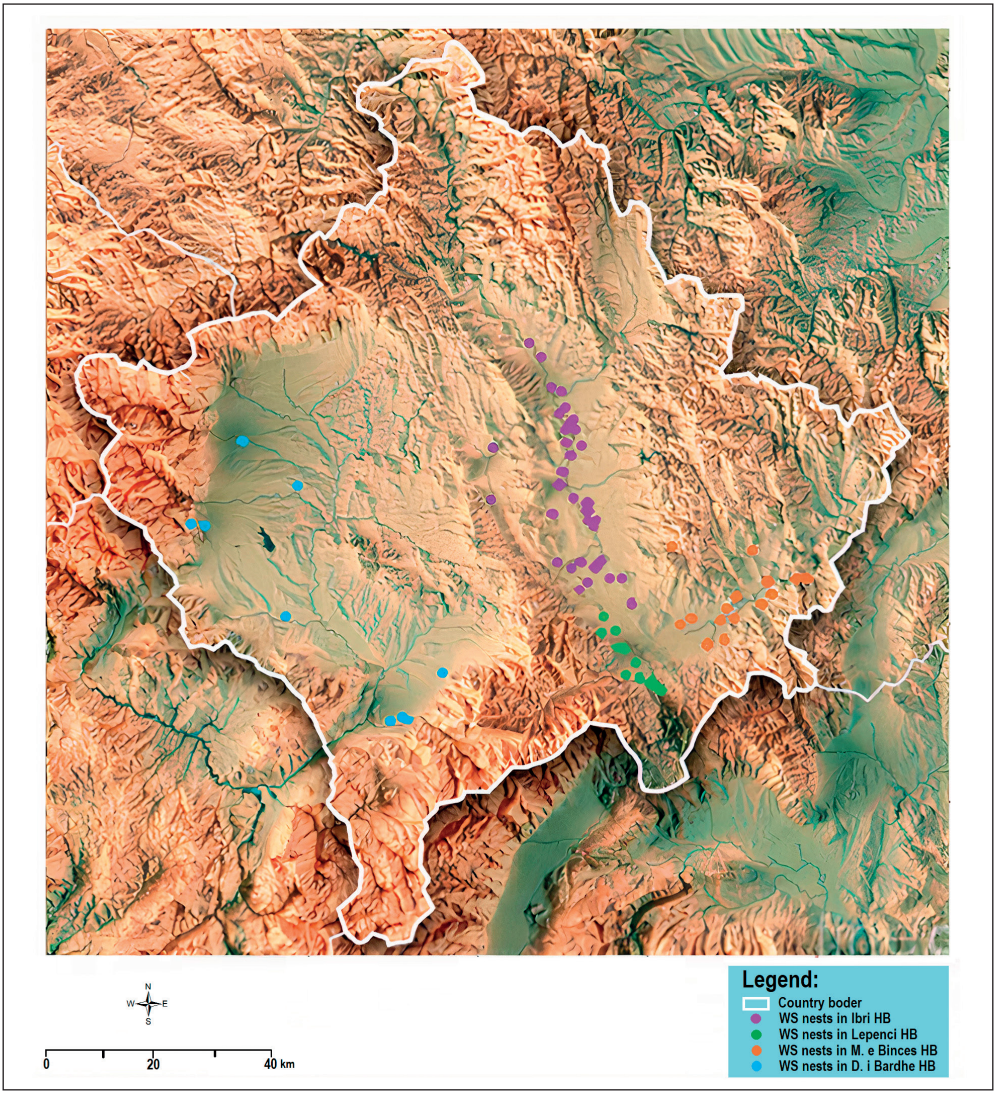

Figure 3. Distribution of White Stork nests (H) in the whole country territory
3. ábra A fehérgólya-fészkek (H) megoszlása az ország területén

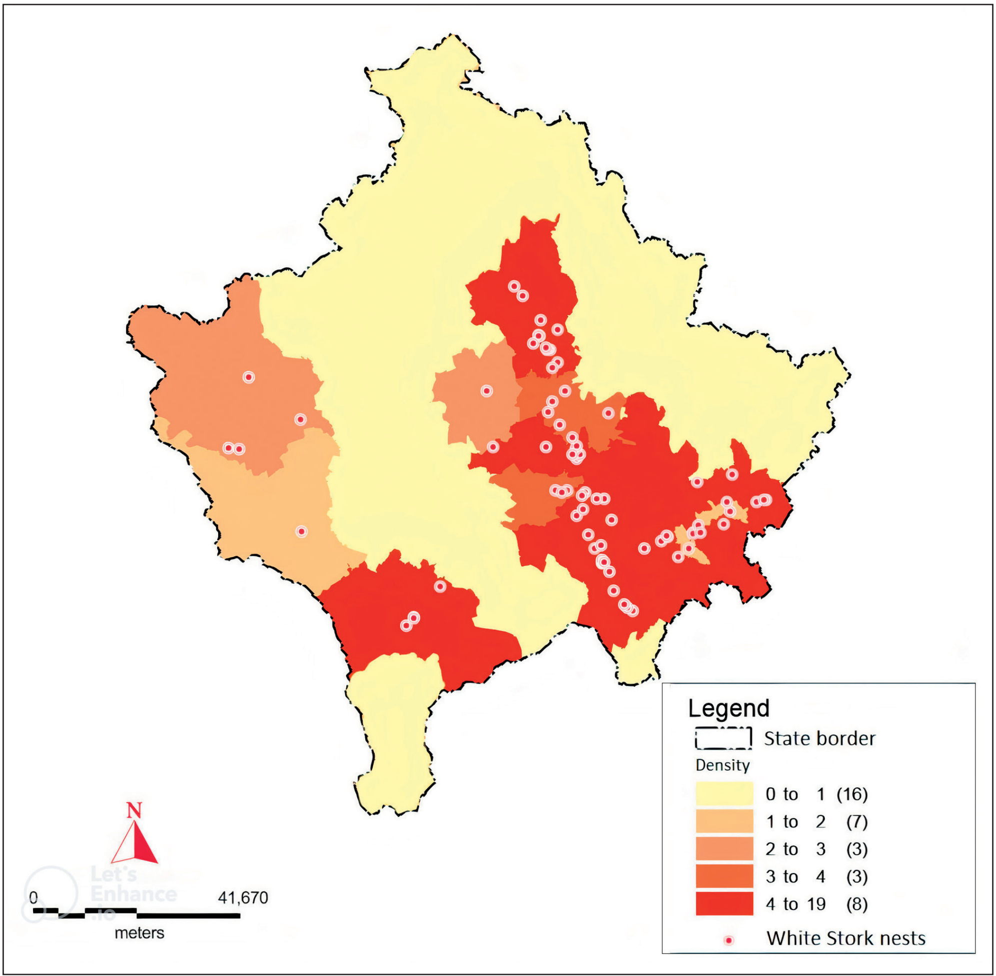

Figure 4. Distribution of densities of occupied White Stork nests
4. táblázat A foglalt fehérgólya-fészkek sűrűség szerinti megoszlása

individual is observed by constructing, defending, incubating, feeding chicks, or perching on the nest and counted the total number of fledglings when they were about 5–7 weeks of age.

During this research 61 new nests were found in the whole country territory and the total population is estimated to be 80 nests in 2017 and 83 nests in 2018 *(Figure 3, 4, Table 1)*. The highest number of nests per village (9) was recorded in Varosh village, the Municipality of Ferizaj *(Figure 7)*.

Nest distribution within hydrographic basins

According to the drainage of river basins, the majority of nests (57 nests) are found in the Black Sea hydrographic basin followed by the Aegean basin (17 nests) and Adriatic basin (9 nests) *(Table 2)*.

Table 1. White Stork cenzus results by localities in Kosovo (2017–2018)
1. táblázat A fehérgólya-felmérés településenkénti eredményei Koszovóban (2017–2018)

Municip.	**Locality**	**H**		**HE**		**uH**		**HPa**		**HPm**		**HPo**		**JZG**		**JZa**		**JZm**		**StD**	
		2017	**2018**	**2017**	**2018**	**2017**	**2018**	**2017**	**2018**	**2017**	**2018**	**2017**	**2018**	**2017**	**2018**	**2017**	**2018**	**2017**	**2018**	**2017**	**2018**
Vushtrri	Vushtrri	1	1	0	0	0	0	1	1	1	1	0	0	3	3	3	3	3	3	6.25	6.25
	Nedakovc	1	1	0	0	0	0	1	1	1	1	0	0	4	3	4	3	4	3	50.0	50.0
	Lumi i M.	-	1	-	0	-	0	-	1	-	1	-	0	-	2	-	2	-	2	-	50.0
	Prelluzhë	3	3	0	0	0	0	3	3	3	3	0	0	11	10	3.67	3.33	3.67	3.33	42.86	42.86
	Plemetin	4	4	1	0	0	0	3	4	3	4	0	0	10	14	3.33	3.5	3.33	3.5	60.0	80.0
	Bivolak	1	1	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Obiliq	Babimoc	1	1	0	0	0	0	1	1	1	1	0	0	4	3	4	3	4	3	12.50	12.50
	Obiliq	1	1	0	0	0	0	1	1	1	1	0	0	3	3	3	3	3	3	8.33	8.33
	Caravodicë	1	1	0	0	0	0	1	1	1	1	0	0	4	3	4	3	4	3	14.29	14.29
Fushë Kosovë	F. Kosovë	1	1	0	0	0	0	1	1	1	1	0	0	4	3	4	3	4	3	9.09	9.09
	Vrogoli	1	1	0	0	0	0	1	1	0	1	1	0	0	3	0	3	0	3	33.33	33.33
	Henc	-	1	-	0	-	0	-	1	-	1	-	0	-	4	-	4	-	4	-	50.0
Drenas	Drenas	1	1	0	0	0	0	1	1	1	1	0	0	3	2	3	2	3	2	25.0	25.0
	Nekoc	1	1	0	0	0	0	1	1	1	1	0	0	3	3	3	3	3	3	9.09	9.09
Graçanic	Lepi	1	1	0	0	0	0	1	1	1	1	0	0	5	4	5	4	5	4	20.0	20.0
	Suhadoll	1	1	0	1	0	0	1	0	1	0	0	0	3	0	3	0	3	0	14.29	0
Lipjan	Lipjan	5	5	0	0	0	0	5	5	5	5	0	0	17	16	3.4	3.2	3.4	3.2	50.0	50.0
	Topliçan	1	1	1	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	14,29
	Poturoc	1	1	0	0	0	0	1	1	1	1	0	0	3	3	3	3	3	3	50.0	50.0

Municip.	Locality	H		HE		uH		HPa		HPm		HPo		JZG		JZa		JZm		StD	
		2017	**2018**	**2017**	**2018**	**2017**	**2018**	**2017**	**2018**	**2017**	**2018**	**2017**	**2018**	**2017**	**2018**	**2017**	**2018**	**2017**	**2018**	**2017**	**2018**
Shtime	Davidovc	1	1	0	0	0	0	1	1	1	1	0	0	4	3	4	3	4	3	50.0	50.0
	Rashincë	1	1	0	0	0	0	1	1	1	1	0	0	3	2	3	2	3	2	16.67	16.67
	Muzeqinë	1	1	0	0	0	0	1	1	1	1	0	0	3	3	3	3	3	3	16.67	16.67
Ferizaj	Terrn	2	2	0	0	0	0	2	2	2	2	0	0	5	5	2.5	2.5	2.5	2.5	40.0	40.0
	Prelez i M.	1	1	0	0	0	0	1	1	0	1	1	0	0	0	0	3	0	3	33.3	33.3
	Surçinë	1	1	0	0	0	0	1	1	1	0	0	1	4	0	4	0	4	0	50.0	50.0
	Kosinë	1	1	0	0	0	0	1	1	1	1	0	0	3	3	3	3	3	3	14.29	14.29
	Softaj	1	1	0	0	0	0	1	1	1	1	0	0	5	4	5	4	5	4	50.0	50.0
	Lloshkobare	1	1	0	0	0	0	1	1	1	1	0	0	3	3	3	3	3	3	16.67	16.67
	Ferizaj	1	1	0	0	0	0	1	1	1	1	0	0	3	3	3	3	3	3	9.09	9.09
	Nikadin	1	1	0	0	0	0	1	1	1	1	0	0	2	2	3	2	3	2	25.0	25.0
	Varosh	9	9	0	1	1	1	8	7	8	6	0	1	28	22	3.5	3.14	3.5	3.67	114.3	100.0
Kaçanik	Rakaj	1	1	0	0	0	0	1	1	1	1	0	0	3	3	3	3	3	3	33.33	33.33
	Kovaqec	3	3	0	0	0	0	3	3	3	3	0	0	9	8	3	2.67	3	2.67	60.0	60.0
	Tushaj	1	1	0	0	0	0	1	1	1	1	0	0	3	3	3	3	3	3	33.33	33.33
	Kaçanik	1	1	0	0	0	0	1	1	1	1	0	0	3	3	3	3	3	3	6.25	6.25
Viti	Pozheran	3	3	0	0	1	1	2	2	2	2	0	0	7	7	3.5	3.5	3.5	3.5	20.0	20.0
	Radivojc	2	2	0	0	0	0	2	2	2	2	0	0	6	6	3	3	3	3	50.0	50.0
	Viti	1	1	0	0	0	0	1	1	1	1	0	0	3	3	3	3	3	3	11.1	11.11
	Mogillë	1	1	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Budrikë e E.	2	2	0	0	1	1	1	1	1	1	0	0	4	4	4	4	4	4	25.0	25.0
	Sadov. e Ç.	1	1	0	0	0	0	1	1	1	1	0	0	3	4	3	4	3	4	14.29	14.29

Municip.	Locality	H		HE		uH		HPa		HPm		HPo		JZG		JZa		JZm		StD	
		2017	**2018**	**2017**	**2018**	**2017**	**2018**	**2017**	**2018**	**2017**	**2018**	**2017**	**2018**	**2017**	**2018**	**2017**	**2018**	**2017**	**2018**	**2017**	**2018**
Partesh	Partesh	1	1	0	0	0	0	1	1	1	1	0	0	3	3	3	3	3	3	12.5	12.5
	Pasjan	1	1	0	0	0	0	1	1	1	1	0	0	3	4	3	4	3	4	6.67	6.67
Gjilan	Lladovë	1	1	0	0	0	0	1	1	1	1	0	0	2	2	2	2	2	2	33.33	33.33
	Velekincë	1	1	0	0	0	0	1	1	1	1	0	0	3	3	3	3	3	3	20.0	20.0
	Livoq i E.	1	1	0	0	0	0	1	1	1	1	0	0	3	3	3	3	3	3	12.5	12.5
	Shillovë	1	1	0	0	0	0	1	1	1	1	0	0	4	3	4	3	4	3	11.11	11.11
	Bresalc	2	3	0	0	0	0	2	3	2	2	0	1	6	6	3	2	3	3	10.53	15.79
Pejë	Pejë	1	1	0	0	0	0	1	1	1	1	0	0	3	3	3	3	3	3	4.0	4.0
	Qallopek	1	1	0	0	0	0	1	1	1	1	0	0	5	4	5	4	5	4	25.0	25.0
Deçan	Pobergjë	1	1	0	0	0	0	1	1	1	1	0	0	3	4	3	4	3	4	7.14	7.14
	Drenoc	1	1	0	0	0	0	1	1	1	1	0	0	3	3	3	3	3	3	16.67	16.67
Gjakovë	Gjakovë	1	1	0	0	0	0	1	1	1	1	0	0	4	3	4	3	4	3	4.35	4.35
Prizren	Prizren	4	4	0	0	0	0	4	4	4	4	0	0	14	13	3.5	3.25	3.5	3.25	14.81	14.81
Total:		**80**	**83**	**2**	**2**	**5**	**5**	**73**	**76**	**71**	**72**	**2**	**4**	**237**	**224**	**3.25**	**2.95**	**3.34**	**3.11**	**0.67**	**0.70**

Table 2. White Stork nest distribution on hydrographic basins, municipalities in the years 2017–2018
2. táblázat A fehérgólya-fészek megoszlása közigazgatási egységenként és vízgyűjtő területenként 2017–2018-ban

Flows into	River basin	Rivers	Municipality	No. of localities	No. of nests	Total localities	Total nests	No. of nests/ 100 km^2
Black Sea	Ibri	Sitnica	Vushtrri	6	11	28 (51.85%)	38 (45.78%)	0.95
			Ferizaj	6	7			
			F. Kosovë	3	3			
			Lipjan	3	7			
			Shtimje	3	3			
			Graçanicë	2	2			
		Sitnica (2) Llapi (1)	Obiliq	3	3			
		Drenica	Drenas	2	2			
	Morava e Binçes	Morava e Binçes	Viti	6	10	13 (20.07%)	19 (22.89%)	1.21
			Partesh	2	2			
			Gjilan	5	7			
Aegean Sea	Lepenci	Nerodimja	Ferizaj	3	11	7 (12.96%)	17 (20.48%)	2.48
		Lepenci	Kaçanik	4	6			
Adriatic Sea	Drini i Bardhë	Lumbardhi i Pejës	Pejë	2	2	6 (11.11%)	9 (10.84%)	0.19
		Lumbardhi i Deçanit	Deçan	2	2			
		Lumbardhi i Prizrenit	Prizren	1	4			
		Ereniku	Gjakovë	1	1			
		Total:		**54**	**83**			**0.76**

Comparing the data from the three hydrographic basins is possible to see that the Ibri hydrographic basin is the most important. It contains the highest number of identified nests – 38 (45.78%) followed by Morava e Binçes with 19 nests (22.89%), Lepenci 17 nests (20.48%), and the last one Drini i Bardhe with only 9 nests (10.84%) *(Table 2)*.

About 21.69% of the whole breeding population was found only in Ferizaj municipalities. The mean standard density of active White Stork nests per municipality has been found to be significantly changing from one municipality to another and indicated that Ferizaj municipality holds the largest breeding population over the country (18 nests or about 22%). While at the same time, mean standard density of active White Stork nests per river basin indicate that Lepenci River Basin holds the densest breeding population (2.48 pairs/100 km^2, compared to the value of 0.70 calculated for the entire country).

Population density

During this first national White Stork census, the Kosovarian population was estimated to be 71 breeding pairs in 2017 and 72 in 2018 with a mean breeding density of 0.67 (0.70 in 2018) breeding pairs/100 km^2 of country territory (StD).

Table 3. Population and breeding parameter analysis on hydrographic basins
3. táblázat Populációs és költési eredmények vízgyűjtő területenként

River basin	**H**		**HPa**		**HPm**		**HPo**		**JZG**		**JZa**		**JZm**		**StD**	
	2017	**2018**	**2017**	**2018**	**2017**	**2018**	**2017**	**2018**	**2017**	**2018**	**2017**	**2018**	**2017**	**2018**	**2017**	**2018**
Ibri	36	38	34	36	33	34	2	2	107	102	76.9	72.53	76.9	72.53	0.85	0.90
M. e Binçes	18	19	15	16	15	15	0	1	47	48	21.5	19.81	21.5	20.34	0.96	1.02
Lepenci	17	17	15	15	14	14	0	1	51	44	37.5	36	37.5	36	2.19	2.19
Drini i Bardhë	9	9	9	9	9	9	0	0	32	30	21.5	20.25	21.5	20.25	0.19	0.19
Total	**80**	**83**	**73**	**76**	**71**	**72**	**2**	**4**	**237**	**224**	**3.25**	**2.95**	**3.34**	**3.11**	**0.67**	**0.70**

The highest breeding density (breeding pair/100 km^2) was recorded in the southeast part of Kosovo, in the locality Varosh, with a maximum of 114.29 breeding pairs/100 km^2 in 2017 and 100.0 in 2018. The lowest density occurs in the northern and western part of the country, located along the Drini i Bardhe river. The number of nests varies according to the hydrographic basins within Kosovo. Ibri basin is the most important. It contains the highest number of identified nests 38 (45.78%) followed by Morava e Binçes with 19 nests (22.89%), Lepenci 17 nests (20.48%), and the last one Drini i Bardhe with only 9 nests (10.84%).

The Biological population density (StDBiol), calculated by the total area of non-irrigated arable lands, pastures, lands principally occupied by agriculture with significant areas of natural vegetation and natural grasslands in the country (3,336.9 km^2), was 2.19 pairs/100 km^2 grassland in 2017 and 2.28 in 2018.

The lowest density of stork nests (0.19 nests/100 km^2) is within the Dukagjini Plain in the Drini i Bardhe river valley, while the highest nest density is in the Lepenci river valley (2.48 nests/100 km^2) and Morava e Binçes valley (1.21 nests/100 km^2). The average density of nests across the country was found to be quite low, only 0.76 nests/100 km^2. On the other hand, in this first national stork census conducted in Kosovo, the average breeding density (StD) was calculated as 0.67 breeding pairs per 100 km^2 in 2017 and 0.70 in 2018 *(Table 3)*.

Nest locality preferences

The majority (48.61%) of all recorded White Stork nests were located on various poles. Within this percentage, nests on overhead electricity line poles accounted for 82.35% of the total, whereas only 17.65% of nests were on communication line poles or those that were not in use any longer.

White Stork nests placed on the electricity pylons are considered to be at high risk of electrocution, collision or fire.

There are some recent focal activities to erect artificial nest platforms mostly in places where they are in a very dangerous situation.

After the poles, trees come with a ratio of 19.44% as nesting places. In addition, chimneys (9.72%), mobile phone antennae (8.33%), roofs (6.94%), and the top of mosques (6.94%) are among the preferred nesting places *(Figure 5, 6, Table 4)*.

Reproductive Success

73 out of 80 nests occupied by nesting couples were detected in 2017 and 76 out of 83 nests in 2018. In two years, two nests were used by individuals

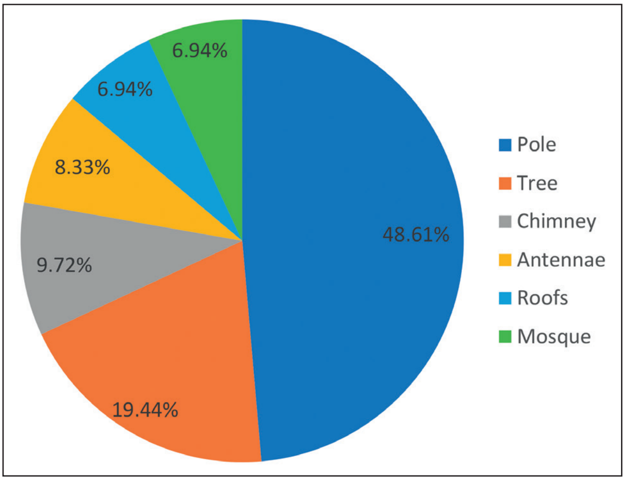

Figure 5. White Stork nest placements in Kosovo
5. ábra A fehérgólya-fészkek aljzat szerinti megoszlása Koszovóban

Figure 6. White Stork nests in various places
6. ábra Különböző helyekre épült fehérgólya-fészkek

Table. 4. Breeding success of the White Stork related to nest location in Kosovo
4. táblázat Költési eredmények a különféle fészekaljzatokon Koszovóban

Nest location	**HPa**		**HPm**		**HPo**		**JZa**		**JZm**	
	2017	**2018**	**2017**	**2018**	**2017**	**2018**	**2017**	**2018**	**2017**	**2018**
Pole	33	36	32	35	1	2	3.22	3.03	3.22	3.08
Tree	16	16	15	14	0	2	3.06	2.65	3.06	2.65
Chimney	7	7	7	7	0	0	2.72	2.22	2.72	2.22
Roofs	5	5	5	5	0	0	3.12	3.04	3.12	3.04
Antennae	6	6	6	6	0	0	3.08	3.14	3.08	3.14
Mosque	6	6	6	5	1	0	3	2.57	3	2.57
Total:	73	76	71	72	2	4	3.25	2.95	3.34	3.11

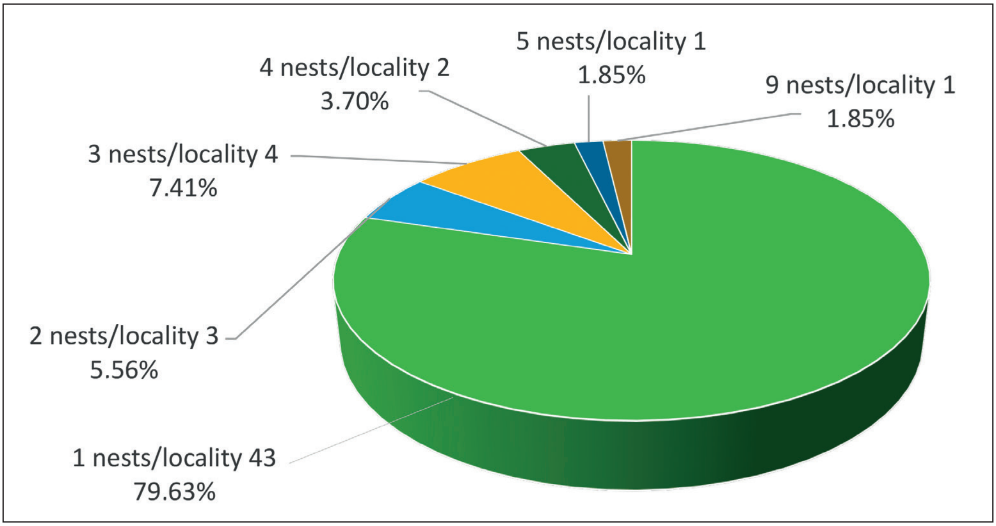

Figure 7. The distribution of the localities (54) by the number of nests (%)
7. ábra A települések megoszlása (%) az ott található gólyafészkek száma alapján

alone. It was found that five slots were not used in these years. 71 couples used the nests in 52 different areas in 2017 and 72 of them in 54 locations in 2018 were successful (HPm). Successful couples raised a total of 461 offspring, 237 in 2017 and 224 in 2018.

According to these data, the frequency distribution of the offspring size in 2017 and 2018 was calculated *(Figure 9)*. Accordingly, broods with three (HPm3) nestlings made up the highest proportion of nests with breeding success (52.94%) on average, was 39 in 2017 and 37 in 2018. Broods with four (HPm4) nestlings were also high, 18 in 2017 and 19 in 2018 while the broods with two (HPm2) nestlings was 11 in 2017 and 13 in 2018. The data about number of chicks per nests (HPm1 – HPm5) are in *Figures 8*.

During this census, the highest figures (HPa, StD) and the highest breeding success (JZm, JZa) were recorded in the areas along the Sitnica, Lepenci, and Morava e Binçes River.

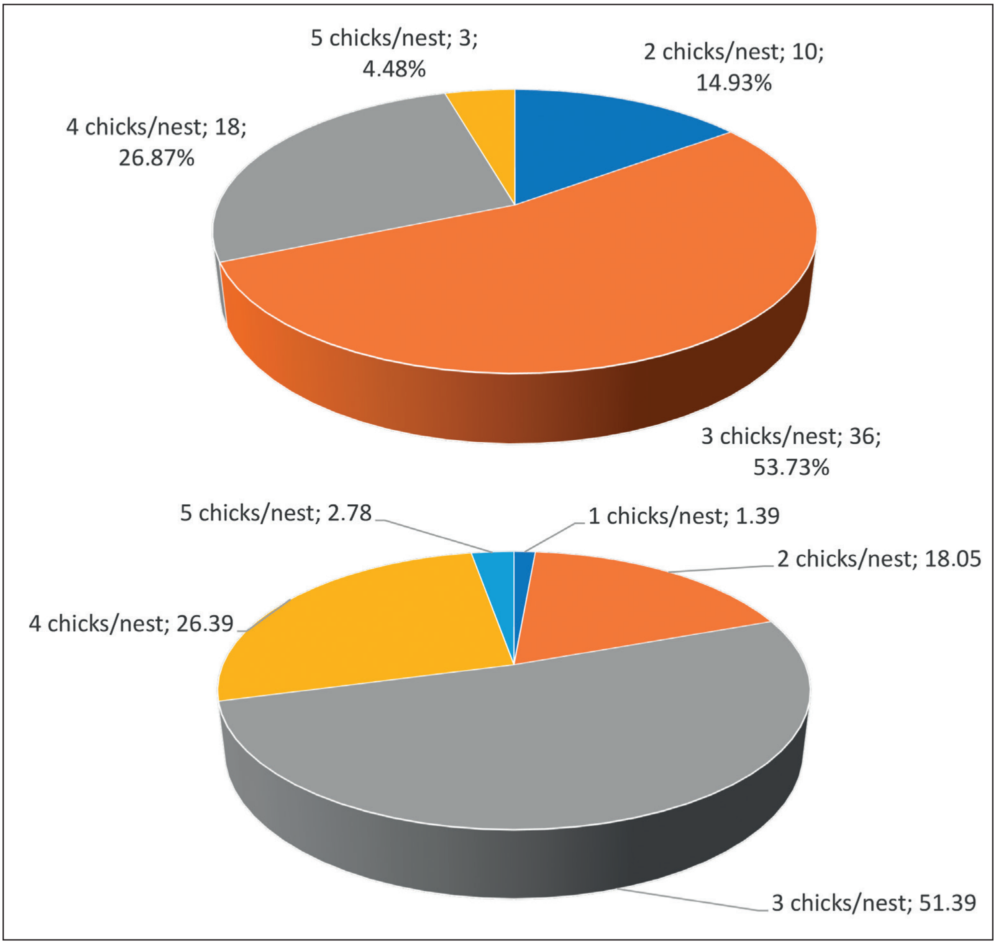

Figure 8. The nest distribution by the number of chicks / nests (2017 and 2018)
8. ábra A fészkek fiókaszám szerinti megoszlása (2017 és 2018)

Discussion

Phenology

The average dates of arrival of storks in Kosovo can be compared with Kosicki *et al.* (2004) for the storks in Poland. The first partner of a pair in our case arrived about 3–5 days earlier than the second partner. The difference of less than 7 days between the sexes were found from Barbraud *et al.* (1999) for the return date in France.

Distribution of nests

Based on the results carried out for the first time in 2014, when 22 nests were present (Maxhuni *et al.* 2016), during this research made in 2017–2018 with more search effort

61 new nests were found in the whole country territory and together with those 22 nests the total population is estimated to be 83 nests. This number is quite higher compared to the neighboring countries such as Montenegro where, according to Jovičevič and Saveljič (2012), is present only one nest and in Albania 4 nests (Bego *et al.* 2016). Our number of nests are lower comparing to Macedonia where 817 nests are present (Thomsen & Lachman 2013), while in Serbia there are 1,220–1,370 breeding pairs, where more than 77% of the population are in Vojvodina province (Puzovič *et al.* 2015).

In 54 localities, within 16 municipalities 83 nests were found with the mean number of nests/localities of 1.53. This mean number is very similar to those in Romania (Mestecaneanu *et al.* 2017), where this number was 1.85 and higher than those in Cluj County where this value was only 1.36 (Kosa 2015).

The highest concentration of breeding pairs along the Sitnica river can be explained due to favorable feeding conditions in the upper and central part of the basin, also by the fact that covering the surface of this hydrographic basin is among larger, excluding Drini i Bardhe river basin and, particularly in the temporarily flooded meadow and pastures that follow the river along both banks.

Population density

The average breeding density (StD) in Kosovo – 0.67 breeding pairs per 100 km^2 in 2017 and 0.70 in 2018 – is lower than in neighboring countries. Among them, in Slovenia the breeding density was 0.95–1.18 nests/100 km^2 (Denac 2010) in a period of 12 years (1999–2010), in Romania 4.33 (Kósa 2007), in Northern Croatia 7.55 (Mužinić & Hackenberger 2015). Exceptionally, the percentage of nests without nestlings (hPo) was lower than in many European countries (Gyalus *et al*. 2022).

During the breeding season, it has been proven that suitable feeding areas exist in many places along the Sitnica River Basin and near the nests; more or less the same results were found in Pomerania (Ożgo & Bogucki 1999), where the most visited habitats were meadows, grasslands and fields.

The reason for irregular distribution of White Stork nests per river basin might be the differences in food diversity and abundance (Tryjanowski & Kuveniak 2002, Tsachalidis & Goutner 2002). In addition, the distance to possible feeding sites (Johst *et al*. 2001), altitude and distance to the nearest river (Onmuş *et al*. 2012), differences in habitat structure and use (Moritzi *et al*. 2001, Nowakowski 2003).

Nest Location Preference

It has been determined that the stork nests built on trees were found only in three different tree species, consisting of oak, black locust, and lime tree. Similarly, the oak tree as a most common place of nest building has been found also in Lithuania (Vaitkuvienė & Dagys 2015). However, since nests built on buildings (chimney or roofs) are generally not welcome and storks are not allowed nesting there, the occupation rate of nests in buildings is lower than for pole nests, often because storks are not allowed to nest.

The oldest stork nest in Kosovo was estimated to be about 40 years old, the largest number of nests were between 6–10 years old. Even though the nests are in different areas, there was no significant difference in productivity between the old nests. While the number of nests on chimneys and trees has increased in the last 15–20 years compared to other areas with more nests, it has been determined that it has decreased (48.61%) in chimneys and trees. Similarly, the number of nests in chimneys is decreasing in many European countries. One reason for this is the modified shape of chimneys where the newer types are opened on the top in contrast with the ones that were earlier, with holes on the sides. Sometimes the top is cone-shaped, especially aiming to deter storks not to built the nest there (Gyalus *et al.* 2018).

During the last fifteen years, some changes have been observed in Kosovo in nest site preferences, birds moving from buildings to electricity pylons (Maxhuni *et al.* 2016) where the storks show the adaptability to the new conditions of life. This process has differed significantly in various parts of the country.

A higher nest location may provide a better and more secure landing and takeoff site for White Storks. Thus, some White Stork pairs trying to build nests on houses in villages may be disturbed by homeowners and build their nests on pylons (Onmuş *et al.* 2012).

Considering that overhead electricity line poles have been available across the countryside for many years (since 1960s), probably the recent increase in nesting on electricity poles is most likely a consequence of a gradual change in White Stork nesting behaviour in an increasing population. A similar tendency of White Storks increasingly nesting on overhead electricity line poles and gradually abandoning their former traditional nest sites in trees and on roofs of buildings has been observed over the last decades in several other European countries (Janaus & Stipniece 2004, Tryjanowski *et al.* 2009, Denac 2010, Onmuş *et al.* 2012). In Kosovo also, the decrease of nests in trees is present during the period from 2006 to now, while the proportion of nests on electricity line poles and cellsite antenae increased. Similarly, in other European countries such as Estonia, the proportion of nests in trees decreased from 68% in 1984 to less than 10% in 2008, while the proportion of nests on electricity line poles increased from 12% to 72% (Ots 2009). In Slovenia, the last White Stork nest in a tree was recorded in 2008 (Denac 2010). This same tendency has also been observed in Poland, both in the entire country, where the proportion of nests on electricity line poles increased from 4% in 1974 to 37% in 1995 (Jakubiec & Guziak 1998).

Nest position is known to have an important role in breeding success (Vergara & Aguirre 2006) and nest replacement or relocation may require caution as White Storks have high nest fidelity (Chernetsov *et al.* 2006, Vergara *et al.* 2006). In our case, especially in 2018, it has been observed in some cases that the placement of platforms on electric poles has resulted in the reduced success of the breeding of those nests, delaying the process of their reproduction and hatching the youngs.

Reproductive Success

Breeding success for the Kosovo stork population during our study, which was 3.19 per successful pair is a bit higher than the estimated JZm values needed to keep the population stable (Burnhauser 1983, Lakeberg 1995). Although this value cannot be generalized since it is obtained in only two years (2017 and 2018), it is slightly higher than in other European countries where their breeding success has remained more or less unchanged. It was higher than in 2016 in Eastern Romania: 2.25 nestlings per nest (Fasolă-Mătăsaru 2018). Our data are more or less similar with those in Hungary (Lovászi 2022) where the breeding success in 2017 was 2.72 and in 2018 very similar to us: 3.15. The mean breeding success in Slovenia over the period 1999–2010 was 2.6 young per successful pair (Denac 2010). In Poland, which holds the largest population of White Storks (BirdLife International 2004), breeding success in various regions varied between 2.5 and 3.0 young per successful pair in the 1990s and early 2000s (Nowakowski 2003, Daniluk *et al*. 2006, Kuźniak 2006). In France, the mean breeding success was 2.5 young per successful pair in 2003 and 2004 (Massemin-Challet *et al*. 2006). In Slovakia, the mean breeding success during the period of 1978–2002 was 3.05 young per successful pair (Fulin *et al*. 2009). Considerably higher breeding success was recorded in Turkey, which holds one of the highest populations of White Stork (BirdLife International 2004), with 4.2 young per successful pair in central Turkey in 2004 (Göcek 2006) and 3.8 young per successful pair in northern Turkey in 2010 (Yavuz *et al*. 2012).

Our results related to the number of nestlings of birds (*Figure 8*) are in accordance with studies made in many countries like in Poland (Nowakowski 2003), Greece (Kominos & Galanali 2013) and in Romania (Mestecaneanu *et al*. 2017) with dominant proportion of HPm3 type broods, while in Cluj County (Romania) 4 young storks were the most common (Kósa & Papp 2015).

According to the results of our research, it is shown that the Kosovo White Stork population, which presumably belong to the south-eastern peripheral subpopulation (Stumberger & Velevski 2001), comparing with results from 1950 (Marčetić & Andrejevič) where 116 breeding pairs of White Storks were registered (hPa), shows decline since then. Similar declines were noted in the Macedonian Skopje basin (Micevski *et al*. 1992) and Albania (Peja & Bego 1999) but with lack of data about this situation in Serbia, Montenegro, and other surrounding countries. It is evident that in the countries of the southern Balkans we are facing negative population trends in the whole range of the species (Štumberger & Velevski 2001).

The availability of high-quality foraging sites close to the nest is one of the factors determining the breeding success of the White Storks (Kósa 2007). Habitat and food availability, in particular the food supply for adults feeding nestlings, and the breeding success of White Storks heavily depends on land use patterns and farming practices (Struwe & Thomsen 1991, Johst *et al*. 2001, Tryjanowski & Kuzniak 2002). Apart from a decrease in suitable habitats such as wetlands, possible reasons for the decrease in the number of storks include low rainfall, agricultural activities, and deaths during migration and in wintering areas.

In the case of the White Stork population air temperature and precipitation may influence breeding output in two ways: first, directly, because rainy days with low temperature are dangerous for eggs and small nestlings and indirectly by affecting potential food resources available to storks (Dawson & Bortolotti 2000, Pasinelli 2001, Tryjanowski & Kuzniak

2002, Gyalus *et al*. 2022). Then, reduced food availability and severe weather constitute stress factors often associate with parasite infections (Newton 1998).

A decrease in nestling survival when temperature falls may be due to a decrease in small prey availability since invertebrates are the main food intake during the first weeks of life and they are very sensitive to temperature (Djerdali *et al*. 2008). In our case, during the period 2017–2018 there was not any extreme weather conditions and we did not find the mortality scale in any cases.

White Stork arriving in Kosovo and other parts of Balkan and Europe in early spring, when the snow has not melted yet. Contrary to the study of Nowakowski and Wasilewska (2016), no relationship was found between breeding success and temperature because the average temperature in April in the study area was 10.9 °C, while in the work of Nowakowski and Wasilevska (2006) were 4.9 °C.

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Geographic variations of song and rain calls of the Chaffinch across the ranges of three subspecies

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Abstract We analyze the variability of the Chaffinch's *(Fringilla coelebs)* song and rain calls in 20 populations localized along a transect of about 3,000 km, crossing the territory of European Russia between the White Sea, Crimean Peninsula and the Caucasus Mountains. Three subspecies of Chaffinch inhabit this area: European *(F. c. coelebs)*, Caucasian *(F. c. caucasicus)*, and Crimean *(F. c. solomkoi)*. The results of cluster analysis based on song show that the populations of Crimea and southeastern Dagestan stand out the most. All other populations fall clearly into two clusters corresponding to the European and Caucasian subspecies. In most of the European subspecies vast range in Russia, the "buzzing" dialect of the rain call is widespread. Only in the extreme northwest of Russia, it is replaced by a whistling dialect. In most of the Caucasus and in the Ciscaucasia, Chaffinches also emit exclusively whistling sounds, but of a completely different structure. In the Western Caucasus, Chaffinches perform also a whistling call having a unique two-syllable structure. The Crimean peninsula is inhabited by whistling Chaffinches as well, although the frequency modulation of its call is different from that of Caucasian subspecies. We discuss the spatial distribution of song types and of rain calls dialects within the ranges of subspecies and in the contact zones between them.

Keywords: vocal dialects, population bioacoustics, contact zones, *Fringilla coelebs*

Összefoglalás Az erdei pinty énekének és esőhívó hangjának variabilitását elemeztük 20 populációban, melyek egy 3000 km-es transzekt mentén találhatóak, átszelve Oroszország európai részét a Fehér-tenger, a Krím-félsziget és a Kaukázus között. Az erdei pinty *(Fringilla coelebs)* három alfaja él ezen a területen: az európai *(F. c. coelebs)*, a kaukázusi *(F. c. caucasicus)* és a krími *(F. c. solomkoi)*. Az éneken alapuló klaszteranalízis eredményei azt mutatják, hogy a krími és a délkelet-dagesztáni populációk térnek el leginkább. Az összes többi populáció egyértelműen két különböző klaszterbe esik, amelyek az európai és kaukázusi alfajoknak felelnek meg. Az európai alfaj hatalmas oroszországi elterjedési területének nagy részén az esőhívó hang „zümmögő" dialektusa jellemző. Csak Oroszország legészaknyugatibb részén váltja fel a fütyülő dialektus. A Kaukázus és Ciszkaukázus nagy részén az erdei pintyek kizárólag fütyülő hangokat is kiadnak, de ezek teljesen más szerkezetűek. A Nyugat-Kaukázusban az erdei pintyek egyedi, kétszillabusos szerkezetű fütyülő hangot is használnak. A Krím-félszigeten fütyülő erdei pintyek is élnek, bár ezek hangjainak frekvencia modulációja különbözik a kaukázusi alfajétól. Az énektípusok és az esőhívó hang dialektusainak térbeli eloszlását az alfajok elterjedési területén belül és a köztük lévő kontaktzónában tárgyaljuk.

Kulcsszavak: ének dialektusok, populáció bioakusztika, érintkezési zónák, erdei pinty

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Introduction

For many years, ornithologists and bioacousticians have been fascinated by geographical variations in songbirds singing. Many reasons contribute to the interest in this subject, including the problems of speciation and taxonomy (Payne 1986, Alström & Ranft 2003). Song is known as a key factor in reproductive isolation between closely related songbird species under sympatric conditions (Qvarnström *et al.* 2006, Kenyon *et al.* 2017). The song of songbirds has an innate basis, however, for its full development a young bird must hear and remember the singing of adults of its species. Therefore, the structural features of the song are independently transmitted from generation to generation, both through genetic inheritance and through vocal learning (Catchpole & Slater 2008). This results in a complex spatial variation of the song, which is studied at different levels: from local populations to the whole range of the species or a significant part of it (Mundinger 1982, Martens 1996, Podos & Warren 2007, Pitocchelli 2011, Petrusková *et al.* 2015, Kaluthota *et al.* 2016).

The Chaffinch *(Fringilla coelebs)* inhabits a huge range stretching from the British Isles and North Africa to the Baikal Lake in Central Siberia. The geographical variability of the Chaffinch's song has been known for a long time (Promptov 1930, Marler 1952) and has attracted much attention from researchers (Slater *et al.* 1980, Conrads 1986, Lynch & Baker 1993, 1994, Lachlan & Slater 2003). Nevertheless, the number of studies analyzing the variability of the song of this species in an area comparable to the size of its range remains limited (Slater *et al.* 1984, Böhner & Westel-Wozniak 1995, Yablonovka-Grishchenko & Grishchenko 2007, Astakhova 2012).

In this article, we analyze the variability of the Chaffinch song along a transect of about 3,000 km, crossing from north to south the territory of European Russia between the White Sea, Crimean Peninsula and the Caucasus Mountains. Three subspecies of Chaffinch inhabit this vast area: European *(F. c. coelebs)*, Caucasian *(F. c. caucasicus)*, and Crimean *(F. c. solomkoi)*. We consider the variations of the song within the ranges of these subspecies and focus in more detail on the patterns occurring on the borders between them.

The rain call is a special acoustic signal of the Chaffinch, which is often emitted by males during the breeding season. Along with the song, the rain call is the subject of close attention of researchers. Several dialects of rain call have been described in Central and Eastern Europe. Some dialects occupy a limited area; others have a very wide distribution (Baptista 1975, Bergmann 1993, Sorjonen 2001, Ivanitskii *et al.* 2021). All the subspecies studied by us have clearly distinct rain call dialects, and the European and Caucasian Chaffinch has two dialects, so we also consider the degree of correspondence between spatial variability of the population repertoires of song types and rain calls.

Materials and Methods

From 2017 to 2022, we recorded 1,061 Chaffinches in 20 populations representing three subspecies. The distance between the northernmost (White Sea) and the southernmost (Dagestan) recording points is about 3,000 km. Our recordings were made on a Marantz

Table 1. The recording areas, number of male recorded, song types, and endemic song types found

1. táblázat A mintavételi területek, a hímek, a daltípusok és az endemikus daltípusok száma

	recording areas	coordinates	number of males recorded	number of song types found	number of endemic song types
1	the city of Kandalaksha (White Sea)	67°09′N 32°25′E	48	23	5
2	Belomorskaya Biological Station (White Sea)	66°32′N 33°06′E	18	16	0
3	Pinezhsky Nature Reserve (Arkhangelsk Region)	64°54′N 42°41′E	44	19	1
4	the city of Sortavala (Karelia)	61°42′N 30°42′E	130	31	1
5	Piytsieki village (Karelia)	62°01′N 32°06′E	71	29	0
6	Pryazha village (Karelia)	61°41′N 33°36′E	38	26	0
7	Darwinsky Nature Reserve (Rybinsk Reservoir)	58°43′N 37°47′E	99	29	2
8	Zvenigorodskaya Biological Station	55°42′N 36°45′E	112	27	1
9	the city of Moscow	55°43′N 37°35′E	71	20	1
10	Gornensky Forestry (Rostov region)	47°50′N 40°14′E	35	11	6
11	the city of Rostov-on-Don	47°15′N 39°43′E	37	27	6
12	Alexandrovsky forestry (Rostov region)	46°44′N 39°07′E	41	22	5
13	Novopokrovskaya village (Krasnodar Region)	45°56′N 40°41′E	46	18	1
14	Western Kalmykia	46°04′N 41°55′E	27	17	3
15	Crimean Peninsula	44°48′N 34°32′E	90	34	26
16	Utrish village (Abrau Peninsula, Black Sea coast)	44°45′N 37°23′E	31	34	3
17	Djanhot village (Black Sea coast)	44°46′N 38°16′E	25	27	3
18	the city of Kislovodsk (Ciscaucasia)	43°53′N 42°43′E	25	13	0
19	Dombai village (Northern Caucasus)	43°16′N 41°37′E	23	19	3
20	Samursky National Park (Dagestan)	41°51′N 48°30′E	50	28	28

PMD 660 digital audio recorder with a Sennheiser ME 66 condenser microphone equipped with a K6 preamplifier. The list of location studied, their geographic coordinates, the number of males recorded, the number of song types and the number of endemic song types found in each location are presented in *Table 1*. The positions of all the locations on the geographical map are shown in *Figure 1*.

The vocal session of the Chaffinch consists of distinct songs separated by clear pauses. Each individual song belongs to a certain type (i.e. a stereotypical acoustic construction that is repeated many times in the singing of a given male, in the singing of several males from a given population or even from other populations) (Slater *et al.* 1980, Conrads 1986). We identify song types by visual inspection of sonograms. We consider different renditions of song as belonging to the same song type if they have the same set of syllable

Figure 1. The recording points: 1 – the city of Kandalaksha; 2 – Belomorskaya Biological Station; 3 – Pinezhsky Nature Reserve; 4 – the city of Sortavala (Karelia); 5 – Piytsieki village (Karelia); 6 – Pryazha village (Karelia); 7 – Darwinsky Nature Reserve; 8 – Zvenigorodskaya Biological Station; 9 – the city of Moscow; 10 – Gornensky forestry (Rostov region); 11 – the city of Rostov-on-Don; 12 – Alexandrovsky forestry (Rostov region); 13 – Novopokrovskaya village (Krasnodar Region); 14 – Western Kalmykia; 15 – Crimean Peninsula; 16 – Utrish (Abrau Peninsula); 17 – Dzhankhot village; 18 – the city of Kislovodsk; 19 – Dombai village; 20 – Samursky National Park (Dagestan). The sharp angle of the black triangle identifies the exact location of the recording point

1. ábra A mintavételi pontok: 1 – Kandalaksha városa; 2 – Belomorskaya Biológiai Állomás; 3 – Pinezhsky Természetvédelmi Terület; 4 – Sortavala városa (Karélia); 5 – Piytsieki falu (Karélia); 6 – Pryazha falu (Karélia); 7 – Darwinsky Természetvédelmi Terület; 8 – Zvenigorodskaya Biológiai Állomás; 9 – Moszkva városa; 10 – Gornensky erdészet (Rosztov régió); 11 – Rostov-on-Don városa; 12 – Alexandrovsky erdészet (Rosztov régió); 13 – Novopokrovskaya falu (Krasnodar régió); 14 – Nyugat-Kalmykia; 15 – Krím-félsziget; 16 – Utrish (Abrau-félsziget); 17 – Dzhankhot falu; 18 – Kislovodsk városa; 19 – Dombai falu; 20 Samursky Nemzeti Park (Dagesztán). A fekete háromszögek hegyes szöge jelöli a felvételi pontok pontos helyét types performed in the same sequence. Two obviously similar songs were assigned to the same type, even if they differed in one type of syllable. Songs ending with different flourish have always been classified as different types. The number of repetitions of the same syllables performed in a row within a song usually varies even in one male; however, we do not consider this variability when determining song types. The song types in the Chaffinch are strictly stereotyped and reliably differ from each other, therefore, their identification on the sonogram usually does not constitute a problem. The individual repertoire of a male Chaffinch includes from one to six (usually 2–3) song types; in a local and fairly large settlement of Chaffinches, usually several dozen song types could be recorded (Slater *et al.* 1980).

The spectrograms were created in Syrinx 2.5s (software developed by John M. Burt; University of Washington, Department of Psychology, Seattle, WA 98195, USA) with settings FFT = 512 and Blackman window. We used the software packages STATISTICA V. 8.0 (StatSoft, Inc.USA) and PAST V. 2.13 (Hammer *et al.* 2001) for statistical data processing. For each population, we calculated the variety of song types and the number of males performing them (in percentage of the total number of males studied in this population). We used cluster analysis with the unweighted pair-group average as combining algorithm and the Jacquard coefficient (for a variety of song types) and the Bray-Curtiss metrics (for the number of performing males) as a similarity measure.

Results

A total of 179 song types have been identified in 20 populations. The number of song types found in one population varied from 11 to 34, with an average of 23.5±6.7. More than half of the song types (54.2%) were performed in one population, while 38 song types were recorded in five or more populations, and one song type was found in 10 populations, localized across a space of more than 2,000 km from Kandalaksha to Rostov-on-Don *(Figure 2)*.

The results of cluster analysis are presented in *Figure 3*. Two different clustering methods revealed a very similar pattern. The results of the analysis of the simple similarity of population repertoires and numerical ratios of males performing different song types show only few differences. Among all the populations studied, the Crimean and Dagestan populations stand out the most. In Crimea, we identified 34 song types, of which eight song types were found in the nearest population of Utrish (Abrau Peninsula) and five from the latter were identified in the Dzhankhot population localized 60 km to the south-west from the Utrish. All the other 26 Crimean song types were endemic.

The population from southeastern Dagestan is largely removed from other populations of the Caucasian subspecies studied. This can be explained by that the Samursky National Park is a rather isolated forest area, bounded from the east by the Caspian Sea and from the north, west and south it is surrounded by arid mountains, steppe areas and cultivated lands. All 28 song types recorded in Dagestan turned out to be endemic and were not found in any of the populations from the Caucasus or from the Ciscaucasia. In particular, no shared song types were found with the nearest populations of Kislovodsk and Dombai, located 580 km from

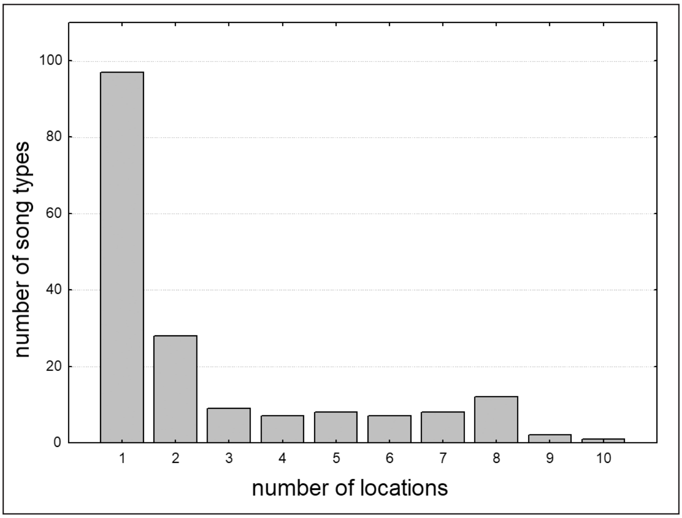

Figure 2. Frequency of the song types performance. The horizontal axis is the number of localities in which song types were performed; the vertical axis is the number of song types.

2. ábra Az énektípusok gyakorisága. A vízszintes tengely mutatja a helyszínek számát, ahol az énektípusokat énekelték; a függőleges tengely mutatja az énektípusok számát

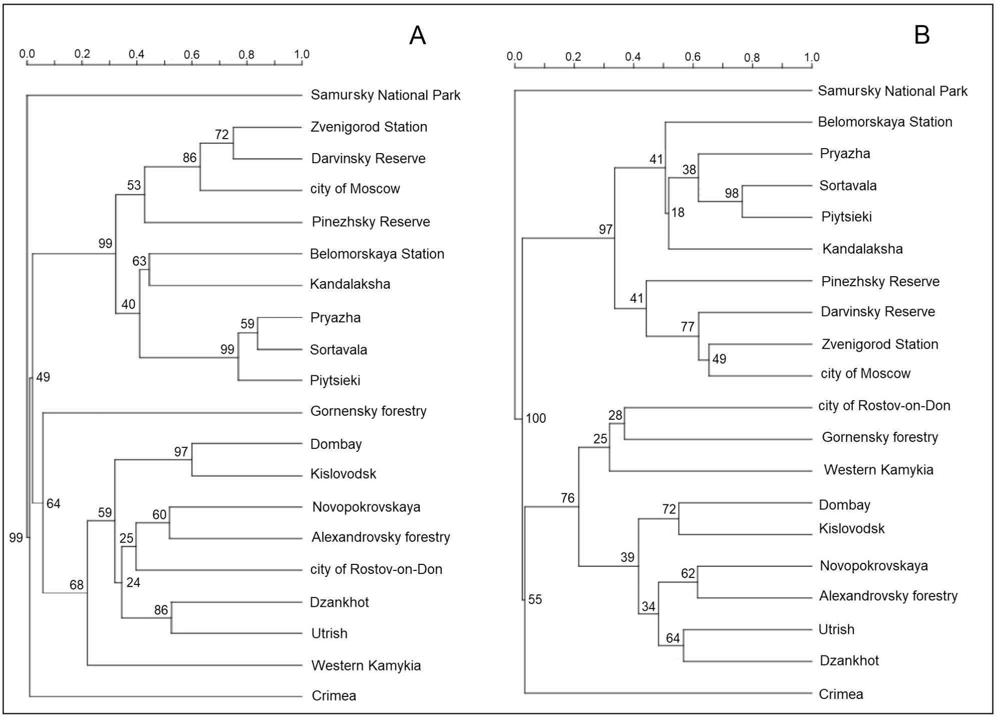

Figure 3. Similarity of the song types repertoires of the 20 populations studied. A – according to the presence/absence of song types in the repertoire of the population; B – according to the number of males performing this song type (in percentage of the total number of male recorded in the population)

3. ábra Az énektípus repertoárok hasonlósága a 20 vizsgált populációban. A – az énektípus a populáció repertoárjában való jelenlétének/hiányának megfelelően; B – az énektípust előadó hímek számának megfelelően (a populációban felvett hímek teljes számának százalékában) the Samursky forest while 10 shared song types were found between Dombay and Rostov-on-Don, separated by comparable distance 480 km.

All other populations studied fall clearly into two large clusters corresponding to the European and Caucasian subspecies. Three clusters with good bootstrap support are distinguished within the European subspecies. One of them unites three populations found relatively close to each other: the city of Moscow, Zvenigorodskaya station, and the Darwinsky Reserve located about 270 km from Moscow. In another cluster, three points in Karelia are united with almost absolute bootstrap support. The distance between them is about 90–150 km. Kandalaksha and Belomorskaya stations are connected to the third cluster, but with less support. These populations are separated from Karelia by a distance about 600 km, and they are about 65 km from each other. Finally, the population of the Pinezhsky Reserve occupies a separate position in the cluster of the European subspecies. It is separated from the nearest White Sea population by a distance of 450 km.

There are also three groups with good bootstrap support within the Caucasian cluster *(Figure 3)*. The first one combines the populations of Dombay and Kislovodsk, located 100 km from each other, with 12 shared song types. Second cluster includes population of the Utrish and Dzhankhot with 21 shared song types and the distance between them 60 km. The third cluster unites the Chaffinch populations of the Alexandrovsky Forestry and Novopokrovskaya, localized 150 km from each other with 14 shared song types.

Exactly the same distance of 150 km separates Gornensky and Alexandrovsky forestry, but only two shared song types were found between them. These two forestries are inhabited by different subspecies (the European subspecies in the Gornensky forestry and the Caucasian subspecies in the Alexandrovsky forestry). The city of Rostov-on-Don is located just in the middle between these two forestry and it has 14 song types shared with the Alexandrovsky forestry and six song types shared with the Gornensky forestry. For comparison, the cities of Rostov-on-Don and Dombay are located 500 km from each other and have 10 shared song types. Thus, the population of Rostov-on-Don, from the point of view of the song type distribution, tends more to Caucasian subspecies.

It is important to note that many song types of the Chaffinch are present unchanged even in populations that are very remote from each other. For example, in the population repertoires of the city of Moscow and the Darwin Reserve, separated by 280 km, 19 shared song types were found; in the repertoire of Moscow and the Pinezhsky Reserve, the distance between which is 1,100 km, nine shared song types were identified. Even in the populations of Moscow and Kandalaksha, separated by a distance of 1,300 km, seven shared song types were found. A similar situation occurs within the Caucasian subspecies. For example, 11 shared song types were found between Novopokrovskaya and Dombay. These two points are 300 km away from each other, and Chaffinches live here in completely different conditions: in the broad-leaves forests on the plain of the Ciscaucasia (Novopokrovskaya) and in mountain coniferous forests at an altitude of 1,600 m above sea level (Dombay).

Let us now consider the relationship between the distribution of song types and the rain calls of Chaffinch. In most of the European subspecies vast range in Russia, the “buzzing” (“wrüt”) dialect of the rain call is widespread *(Figure 4A)*. Only in the extreme north-west of Russia (in Karelia), it is replaced by a whistling dialect *(Figure 4B)*. In most of the Caucasus

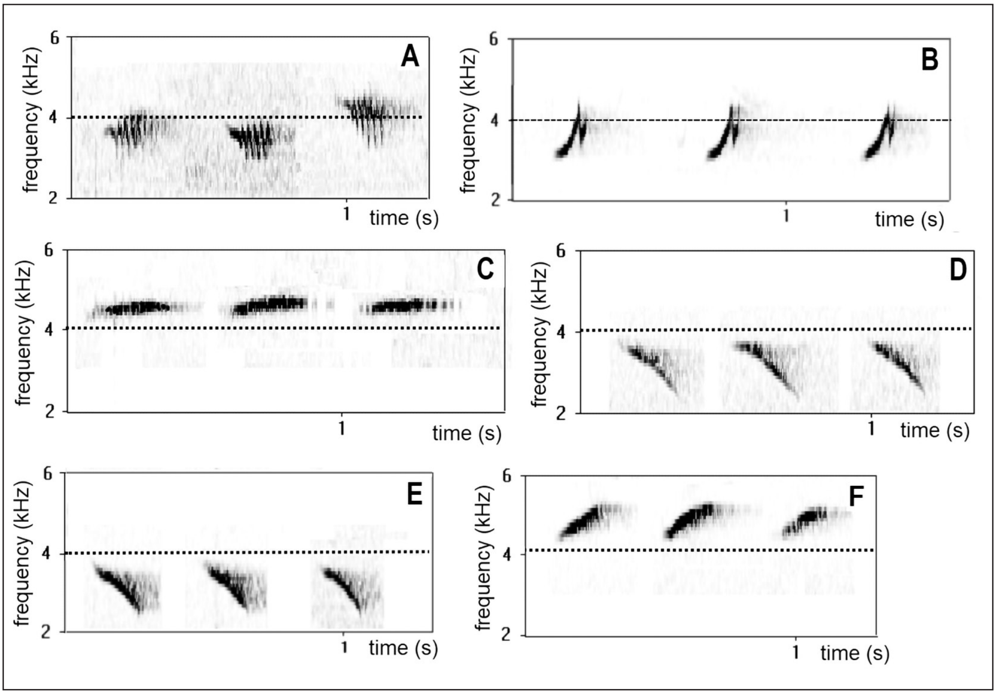

Figure 4. Example sonograms of rain calls: A – buzzing ("wrüt") dialect; B – north-western ("hüid") dialect; C – Crimean dialect; D – central and eastern Caucasus dialect; E and F – western Caucasus dialect

4. ábra Példák esőhívó hangok szonogramjára: A – zümmögő („wrüt") dialektus; B – északnyugati („hüid") dialektus; C – krími dialektus; D – közép- és kelet-kaukázusi dialektus; E és F – nyugat-kaukázusi dialektus

and in the Ciscaucasia, Chaffinches also emit exclusively whistling calls; however, the structure of the latter is sharply different from that of the northern one *(Figure 4C)*. In the Western Caucasus, Chaffinches perform also a whistling call having a unique two-syllable structure *(Figure 4E, F)*. Finally, the Crimean peninsula is inhabited by whistling chaffinch as well, although the frequency modulation of its call *(Figure 4D)* is quite different from that of Caucasian subspecies (Ivanitskii *et al.* 2021).

According to our observation, in Kandalaksha and at the Belomorskaya station all the chaffinches whistle while in the Pryazha they buzz. Sortavala and Piytsieki are located in the mixing zone of these call dialects. The Chaffinches found here use both buzzing and whistling calls, as well as a variety of intermediates between them. Thus, the border between the dialects of the rain calls in Karelia is expressed quite clearly, which cannot be said about the song types distribution. Between Pryazha and Kandalaksha, belonging to different rain call dialects and located 600 km from each other, 12 shared song types were found, which is about half of their population repertoires.

The situation looks different in the contact zone of the European and Caucasian subspecies in the Rostov-on-Don region. The population of Rostov-on-Don looks transitional between the European and Caucasian subspecies, which is also confirmed by the distribution of rain call types in this region. According to our observations, both buzzing (European subspecies) and whistling (Caucasian subspecies) Chaffinches are found in the city in approximately equal proportions. Thus, there is a clear boundary here between both the population repertoires of song types and the dialects of the rain call.

The Kerch Strait clearly separates the Crimean and West Caucasian dialects of rain calls. In Crimea (including Feodosia and Koktebel as an easternmost recording points), Chaffinches emit monosyllabic repetitive whistling signals with descending frequency modulation. In the western Caucasus (including Utrish and Dzhankhot as a westernmost recording points), the rain calls have a two-syllable structure and sound like a fairly regular alternation of whistling signals with descending and ascending modulation. Finally, throughout the rest of Caucasus (to the east of the Sochi), as well as throughout the Ciscaucasia, Chaffinches emit a typically "Caucasian" dialect: monosyllabic whistling signals with flat or slightly increasing frequency modulation (Tsvelykh & Yablonovska-Grishchenko 2012, Ivanitskii *et al.* 2021).

Discussion

All researchers who studied the distribution of Chaffinch song types over large areas pay attention to the similarity of repertoires even in the most remote populations (Slater *et al.* 1984, Simkin & Steinbach 1988, Yablonovska-Grishchenko & Grishchenko 2007, Astakhova 2012). Our results also reveal an extremely wide distribution of many song types within the ranges of the European and Caucasian subspecies *(Figure 5)*.

Thus, in the Chaffinch, cultural continuity ensures the transfer of vocal models (song types) over a distance of 1,300 km. It is not known, however, how long does it take for the song types to spread over such a distance. For example, the spread of a new variant of the White-throated Sparrow *(Zonotrichia albicolis)* song from west to east across Canada was observed; this variant replaced the existing song over approximately four decades (Otter *et al.* 2020). Obviously, it is necessary for this that the song types, spreading to new areas, would remain unchanged in the original area of their distribution. The song types are known to persist in populations of some species for decades (Harbison *et al.* 1999, Goodale & Podos 2010, O'Loghlen *et al.* 2013, García *et al.* 2015, Jäckel *et al.* 2022). We have described the survival of many of the Chaffinch song types for 38 years (from 1982 to 2020) in the population of the Zvenigorodskaya Station (Ivanitskii *et al.* 2023). It is quite possible that such a high temporal stability is one of the important prerequisites for the widespread distribution of song types in this species of songbirds.

Thus, although the number of shared song types found between any two localities undoubtedly decreases with increasing distance between the latter, many of Chaffinch song types are distributed almost throughout the range of the European and Caucasian subspecies at least within the borders of the Russian Federation. Our conclusion about the song type's spatial consistency within the subspecies ranges and the sharp change when crossing the boundaries between them is supported by the data of Astakhova (2012). Of the 15 Chaffinch song types recorded by her in Moscow, 12 were found on the Curonian Spit of the Baltic Sea about 1,100 km from Moscow, while of the 16 song types recorded in Crimea – about

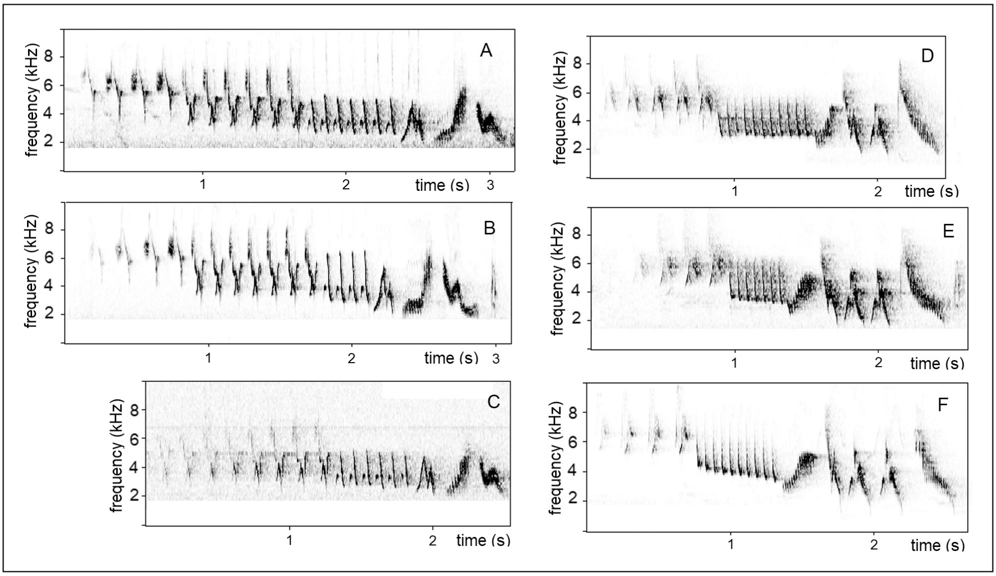

Figure 5. Example sonograms of European (A, B, C) and Caucasian (D, F) song types with a broad geographical distribution: A – Kandalaksha; B – the city of Sortavala (Karelia); C – Pinezhsky Nature Reserve; D – Alexandrovsky forestry (Rostov region); E – Western Kalmykia; F – the city of Kislovodsk

5. ábra Példák a széles elterjedésű európai (A. B, C) és kaukázusi (D, F) énektípusok szonogramjára: A Kandalaksha városa; B – Sortavala városa (Karélia); C – Pinezhsky Természetvédelmi Terület; D – Alexandrovsky erdészet (Rosztov régió); E – Nyugat-Kalmykia; F – Kislovodsk városa

the same distance from Moscow – only one song type was found to be shared with Moscow population.

The distances to which the rain calls spread over are also very large. For example, the Caucasian dialect occupies almost the entire Ciscaucasia and the entire Caucasus (with the exception of its western part). The distance of distribution of this dialect from west to east is about 700 km. The Caucasian and Crimean subspecies are separated by the narrow Kerch Strait (from 4.5 to 15 km wide), which does not look an important obstacle to the spread of song types and rain calls. As a result, the rain call of Chaffinches in the Western Caucasus looks like a very orderly alternation of Crimean and Caucasian calls. Thus, on the border between the Caucasian and Crimean subspecies, there is an active unilateral penetration of Crimean vocal models (both song types and rain calls) to the east of the Kerch Strait, while there is no reverse movement.

As for the buzzing ("wrüt") rain call dialect, it is the only dialect in most of the vast area inhabited by the European subspecies from north-western Germany (Bergmann 1993) to Krasnoyarsk (Ivanitskii *et al.* 2021) at a distance of over 5,000 km. The exact mechanisms that allow song types and rain calls to move hundreds and thousands of kilometers remain unknown and need further research. It is possible that the continuous distribution of the Chaffinch and its high abundance almost everywhere throughout the range (Payevsky 2020) largely contributes to the transmission of vocal models over long distances.

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Vocal interaction between Eurasian Eagle-Owl *(Bubo bubo)* and canines (Carnivora, Canidae)

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Abstract We recorded vocal interaction in the natural environment of an Eurasian Eagle-Owl *(Bubo bubo)* with canines Gray Wolves *(Canis lupus)*, Red Foxes *(Vulpes vulpes)* and domestic dogs *(Canis familiaris)*. Vocalization was recorded using Olympus digital voice recorders. The calls of the male Eurasian Eagle-Owl were recorded by us in the frequency range of 200–420 Hz. The howl of a Gray Wolf was recorded in the frequency range from 300 to 1,100 Hz. Red Fox barking was recorded in the frequency range from 750 to 1,000 Hz. Barking of domestic dogs was recorded in the frequency range from 250 to 1,500 Hz. The vocalization of the Eurasian Eagle-Owl had an independent character inherent in the biology of the species. The Eurasian Eagle-Owl, with its cries, involuntarily provoked the entry of canines into joint vocal interaction, which can be explained by the high social activity of the latter. Co-vocalizations of the Eurasian Eagle-Owl and canines were noted in winter, spring and autumn, but mainly in spring (50%). The increased use of autonomous voice recorders, which record spontaneous vocalizations emitted by animals over long periods, will allow us to better document and study the importance of such interspecific interactions.

Keywords: *Bubo bubo, Canis lupus, Vulpes vulpes, Canis familiaris*, vocalization, predators

Összefoglalás Vokális kölcsönhatást vettünk fel az uhu *(Bubo bubo)* természetes élőhelyén szürke farkasokkal *(Canis lupus)*, vörös rókákkal *(Vulpes vulpes)* és kutyákkal *(Canis familiaris)*. A vokalizáció rögzítését Olympus digitalis hangfelvevővel végeztük. Az általunk felvett hím uhu hangok 200–400 Hz frekvencia között voltak. A szürke farkas üvöltése 300–1100 Hz közötti frekvenciatartományban, a vörös róka ugatása 750–1000 Hz közötti frekvenciatartományban, a kutya ugatása 250–1500 Hz közötti frekvenciatartományban lett felvéve. Az uhu vokalizációjának független jellege volt a faj biológiájából következően. Az uhu a kiáltásaival akaratlanul arra késztette a kutyaféléket, hogy közös vokális interakcióhoz csatlakozzanak, ami az utóbbiak magas szociális aktivitásával magyarázható. Az uhu és a kutyafélék együttes hangadása ősztől tavaszig, de leginkább tavasszal (50%) lett rögzítve. Az automatikus hangfelvevők növekvő használata, amelyek hosszú időszakon keresztül veszik fel az állatok spontán vokalizációját, lehetővé teszi számunkra, hogy jobban dokumentáljuk és tanulmányozzuk ezeknek a fajok közötti kölcsönhatásoknak a fontosságát.

Kulcsszavak: *Bubo bubo*, *Canis lupus*, *Vulpes vulpes*, *Canis familiaris*, vokalizáció, ragadozók

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Introduction

Acoustic communication plays an important role in the life of birds (Kumar 2003), including birds of prey (Catchpole & Slater 2008). Birds of prey use vocal signals for various purposes. The vocal activity of birds can change under the influence of habitat conditions: season, meteorological factors, and biotic connections. But the biological characteristics of the bird itself are of significant importance: sex, age, physiological state. The vocalization of birds of prey is more often aimed at attracting sexual partners or is a signal for conspecifics to protect the territory. Among conspecifics, males often give vocal signals in order to mark the boundaries of their territories. More often, interspecific co-vocalizations between owls are known in the literature (Mikkola & Mikkola 2022). Acoustic communication in nature can be recorded between different types of predators. Vocal interactions can also occur between birds and mammals (Caro 2005, Aubin & Mathevon 2020). This happens very rarely and needs special attention from scientists. The relationship between predatory owls (Strigidae) and mammals, in particular species from the canine family (Canidae), is of great interest, because representatives of these taxa are among the most actively vocalizing. Nevertheless, there are very few facts of joint voice interactions in literary sources. In particular, co-vocalizations between the Great Horned Owl *(Bubo virginianus)* and the Gray Wolf *(Canis lupus)* were noted in Yellowstone National Park (Domken *et al.* 2021). In addition, during the reproductive period of wolves in the Iberian Peninsula, V. Palacios and B. Marty-Domken noted territorial calls and aggressive behavior of the Tawny Owl *(Strix aluco)* towards researchers who imitated the vocalization of a predator (Domken *et al.* 2021).

A number of works are devoted to the study of the vocalization of a rare bird of prey – the Eurasian Eagle-Owl *(Bubo bubo)* (for simplicity referred to as Eagle Owl in the text (Penteriani 1999, 2001, 2002, Delgado & Penteriani 2007, Lapshin *et al.* 2018), but so far in the literature available to us no joint vocal activity of this large owl with mammals was noted. There is an opinion that when the cry of an owl or the howl of a wolf is heard in the forest, all other birds and animals calm down. This is well explained from the standpoint of the suppression of the activity of smaller competing species of owls. In most forests of Eurasia, these two species of predators can be at the top of the vocal hierarchy among birds and mammals, respectively. However, the existence of vocal relationships between these predators is unknown, so this is of undoubted relevance from the standpoint of competitive relationships.

Therefore, the purpose of this study was to characterize the joint vocal activity of the Eagle Owl with predatory mammals: Gray Wolf, Red Fox *(Vulpes vulpes)*, domestic dog *(Canis familiaris)* in Mordovia (Middle Volga region). The main objectives of this study were to describe the cases of co-vocalizations of animals and to assess the influence of situational parameters (temperature, wind strength, cloudiness and atmospheric pressure) on them. The latest data are of great importance for understanding and predicting the frequency of registration of such interspecies interactions. We predict that canines show a specific vocal reaction to the calls of the Eagle Owl.

Material and Methods

Study site

Voice activity of the animals was recorded year-round in various districts of the Republic of Mordovia (53º38’ – 55º11’N and 42º11’ – 46º45 ’E) *(Figure 1)* in 2016–2023. The research covered the following districts: Bolshebereznikovsky, Chamzinsky, Dubensky, Atyashevsky,

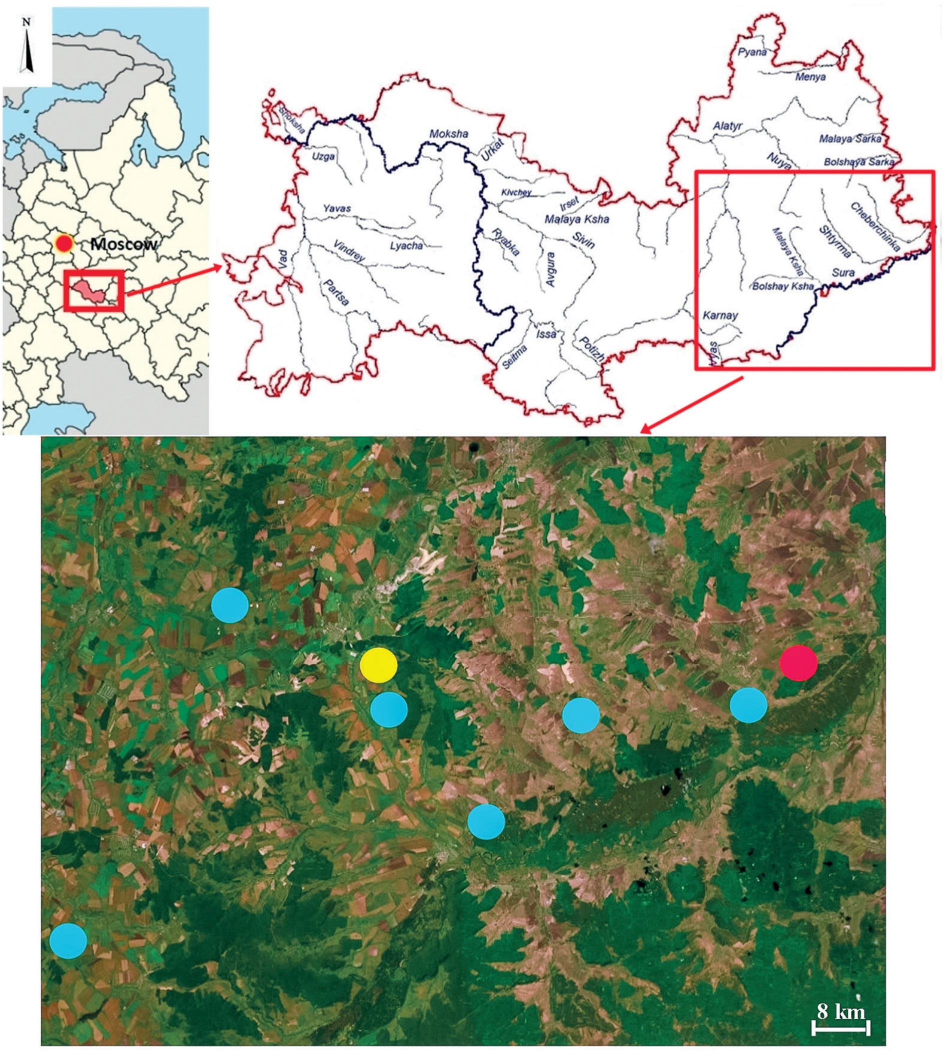

Figure 1. Map of the Republic of Mordovia with co-vocalizations registration points of Eagle Owl (red circle – with a Gray Wolf, yellow circle – with a Red Fox, blue circle – with a domestic dog)

1. ábra Mordvinföld térképe az uhuval történő közös hangadás felvételi pontjaival (piros kör – egy szürke farkassal, sárga kör – egy vörös rókával, kék kör – egy kutyával)

Table 1. Number of audio recordings containing the calls of different animal species
1. táblázat A felvételek száma, melyek a különböző állatfajok hangjait tartalmazzák

Species	**Districts**											
	Bolshebereznikovsky	**Chamzinsky**	**Dubensky**	**Atyashevsky**	**Ardatovsky**	**Kovylkinsky**	**Kadoshkinsky**	**Kochkurovsky**	**Ruzaevsky**	**Lyambirsky**	**Romodanovsky**	**Saransk**
B. bubo	87	12	63	8	11	7	5	15	–	–	–	21
C. lupus	4	2	3	1	3	–	–	3	–	–	–	–
V. vulpes	6	4	2	2	2	1	1	3	2	1	1	1
C. familiaris	90	52	84	17	11	5	6	24	12	6	11	44
B. bubo and *C. lupus*	–	–	1	–	–	–	–	–	–	–	–	–
B. bubo and *V. vulpes*	–	1	–	–	–	–	–	–	–	–	–	–
B. bubo and *C. familiaris*	2	2	1	–	–	–	–	1	–	–	–	–

Ardatovsky, Kovylkinsky, Kadoshkinsky, Kochkurovsky, Ruzaevsky, Lyambirsky, Romodanovsky and suburbs of the city of Saransk *(Table 1)*. The distance between the research points ranged from 4 to 190 km. The climate of the region is continental with pronounced seasons throughout the year. The average annual air temperature varies from 3.5 to 4.0 °C. The average annual precipitation in the territory is 480 mm.

Data collection

The material for this article was the audio recordings of the vocalization of the animals obtained using Olympus VN-416PC, VN-406PC, VN-712PC autonomous recording units, as well as direct recordings on the ground. The sampling frequency of these voice recorders is 8–44.1 kHz. Bitrate 5–320 kbps. The recommended recording mode is WMA 5 kbps (mono), the recording level is high. The frequency range is from 70 to 19,000 Hz. Recording media: Internal flash memory – 4 GB + memory card up to 32 GB if needed. This technique of recording vocalization was developed and tested by us earlier on different animal species (Andreychev 2019, Andreychev *et al.* 2020, 2022). Voice recorders were placed in a camouflage device made from a sawn-off tree branch with a cavity inside for a recorder. Then they were placed on the edge of the forest, where Eagle Owls live. The distance between the recorders was at least 4 kilometers. This minimum distance for placing voice recorders was chosen because in our previous studies (Andreychev *et al.* 2017, Lapshin *et al.* 2018) it was proved that the vocalization of the Eagle Owl in the absence of wind extends to this distance from the calling Eagle Owl. If an Eagle Owl vocalize between the two recorders, its sound is recorded by both recorders. Moreover, on the voice recorder where the loud recording was received, it indicates the proximity of a screaming bird. We used this circumstance when searching for nests. Voice recorders were installed in the daytime for 3–5 days. The maximum duration of continuous operation of voice recorders was about 140 hours. By the time the previous recording was finished, we would arrive and move the recorder to a different location. More than 10,000 h of audio recordings were processed each year. Most of them were made during the spring-summer period (more than 7,000 h/1 year).

Data analysis

Initially, the received audio recordings from voice recorders were converted in the Sony Sound Forge Audio Studio 7.0 (2003) program from WMA to WAV format and divided into short audio recordings of 70 hours each. The obtained audio records were processed with the use of the Avisoft-SASLab Pro 5.3.2-16 (2023) and Audacity 2.1.1 (2015) programs. With the help of these acoustic programs, it is possible to quickly identify animal calls.

The duration of individual periods of vocalization was determined. The possible influence on vocal activity of weather conditions (temperature (°C), wind speed (m/s) and direction of the wind, precipitation in the form of rain or snow, cloud cover (%), atmospheric pressure (mm Hg)) was revealed. To characterize the climatic conditions, we used data from a weather station Bolshie Berezniki (http://rp5.ru; http://nuipogoda.ru).

Data analysis was performed using MS Excel (Microsoft Corporation, Redmond, Washington, DA, USA). For proportions, 95% confidence interval (CI) was calculated using Quantitative Parasitology software, Qpweb version 1.0.15 (https://www2.univet.hu/qpweb/qp10/index.php).

Results

During the research period, 610 expeditions were carried out, 892 sound recordings were obtained and processed, with a total length of more than 82,000 hours. For all the time, 29 records were identified with co-vocalizations of the Eagle Owl with other animal species. Of these, 8 records (27.6%) of Eagle Owl calls with mammals *(Figure 2)* and 21 records of Eagle Owl calls with different species of birds (Ural Owl *Strix uralensis*, Tawny Owl, Long-eared Owl *Asio otus*, Tengmalm's Owl *Aegolius funereus*, Hooded Crow *Corvus cornix*, Common Raven *Corvus corax*, European Cuckoo *Cuculus canorus*, Common Crane *Grus grus*, European Nightjars *Caprimulgus europaeus*). Of the total number of co-vocalizations of the Eagle Owl, 6 records (20.7%) were registrations of the calls of the Eagle Owl with domestic dogs, 1 case each with a Gray Wolf and a Red Fox *(Figure 2)*. The frequency of registration of joint voice activity with domestic dogs can be explained by the fact that the nests of some pairs of Eagle Owls in the region were located in ravine-gully systems near settlements within about 1 km. Therefore, joint vocal interactions of the Eagle Owl and dogs are often noted. Even before the use of voice recorders, we often heard screaming owls at their characteristic pace against the background of barking dogs in the village. The frequency range of the calls of the male Eagle Owl is 200–420 Hz (328±34 Hz), the female is 400–550

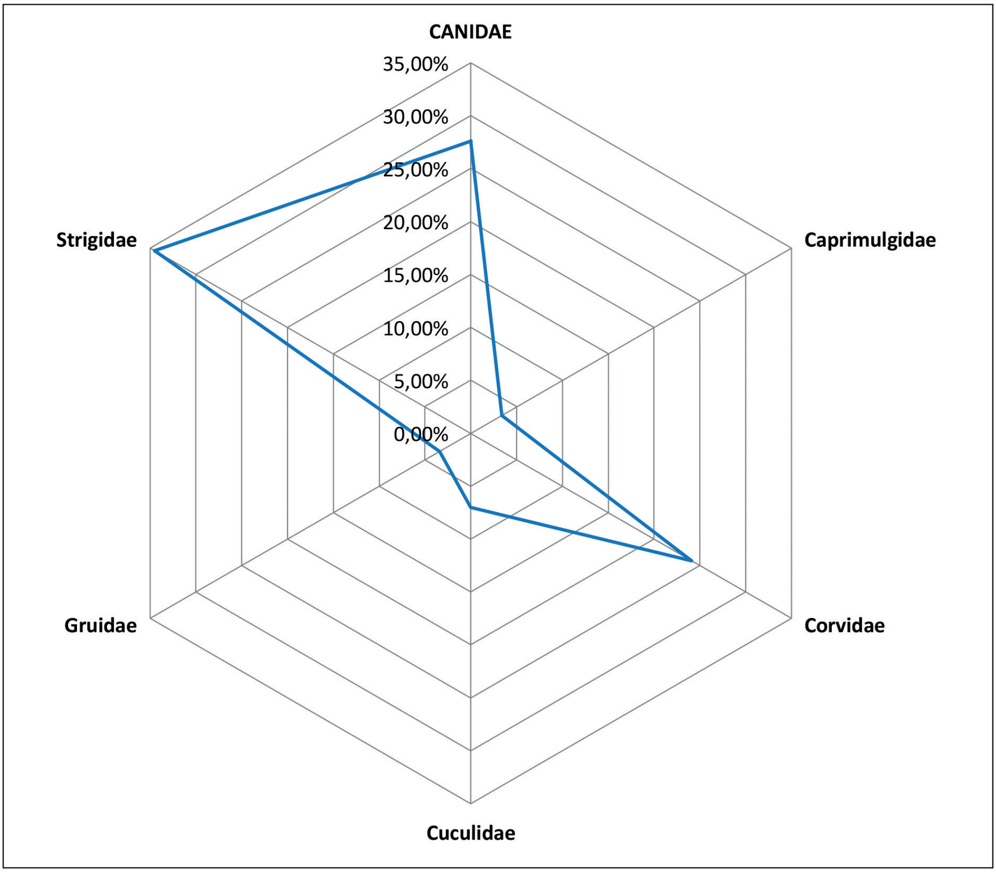

Figure 2. Ratio of co-vocalizations of Eagle Owl with other animals from different families of mammals and birds

2. ábra Az uhu együttes hangadásának aránya más állatokkal különböző emlős és madár családokból

Hz (455±18 Hz). The duration of the Eagle Owl's call is about 0.7 s, the frequency of calls usually varies with a frequency of 1 call in 5–10 s.

The vocal interaction between the Eagle Owl and the Gray Wolf was noted in the vicinity of the village Purkaevo (Dubensky district) October 17, 2016. Co-vocalizations was recorded from 23:56 to 23:59. The male Eagle Owl was the first to enter into joint vocal interaction, 20 seconds after the next call of the Eagle Owl, the Gray Wolf howled, which lasted 4 minutes. The howl of a Gray Wolf was recorded in the frequency range from 300 to 1,100 Hz *(Figure 3)*. The interval between continuous series of howls was 15 seconds. The Eagle Owl continued to scream against the background of the howl of the Gray Wolf. After the Gray Wolf stopped howling, the Eagle Owl continued to call for several minutes. Probably the Gray Wolf entered into acoustic interaction with the Eagle Owl under the influence of the latter on him as an irritant. Similarly, the Eagle Owl can be provoked to respond to the imitation of his calls by the accountant.

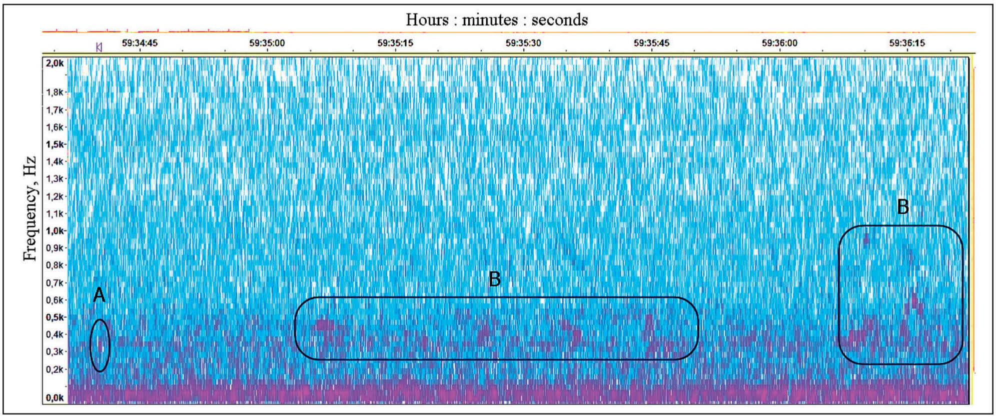

Figure 3. Spectrograms of the calls of the Eagle Owl (A) and Gray Wolf (B)
3. ábra Uhu (A) és szürke farkas (B) hangjainak spektrogramja

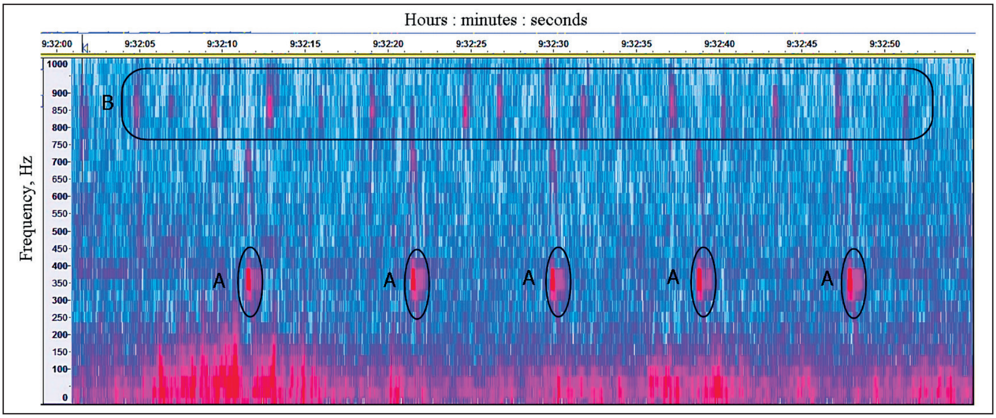

Figure 4. Spectrograms of the calls of the Eagle Owl (A) and Red Fox (B)
4. ábra Uhu (A) és vörös róka (B) hangjainak spektrogramja

Co-vocalizations of the Eagle Owl and Gray Wolf were observed in the temperature range from 0 to +3 °C. Joint calls were recorded at wind from 1 to 2 m/s, cloudiness from 10 to 20%, pressure from 764 to 766 mm Hg.

Joint calls of the Eagle Owl and Red Fox were noted in the vicinity of the village Ivanova Polyana (Chamzinsky district) March 3, 2020. Co-vocalizations were recorded from 19:49 to 19:52. This time interval indicates that the Red Fox was not at the hole during the barking. This is known from our previous studies using camera traps (Andreychev *et al.* 2015). The Red Fox and the Eagle Owl called simultaneously without interruption. Thirty-nine calls of Red Fox and twenty-six calls of Eagle Owl were recorded. Red Fox barking was recorded in the frequency range from 750 to 1,000 Hz *(Figure 4)*. Co-vocalizations were observed in the temperature range from +1 to +3 °C. Joint calls were recorded at wind from 1 to 3 m/s, cloudiness from 10 to 30%, pressure from 754 to 756 mm Hg.

Joint calls of an Eagle Owl and a domestic dog were noted in the vicinity of the village Bolshie Berezniki near the Bolshebereznikovsky boarding school for the elderly and

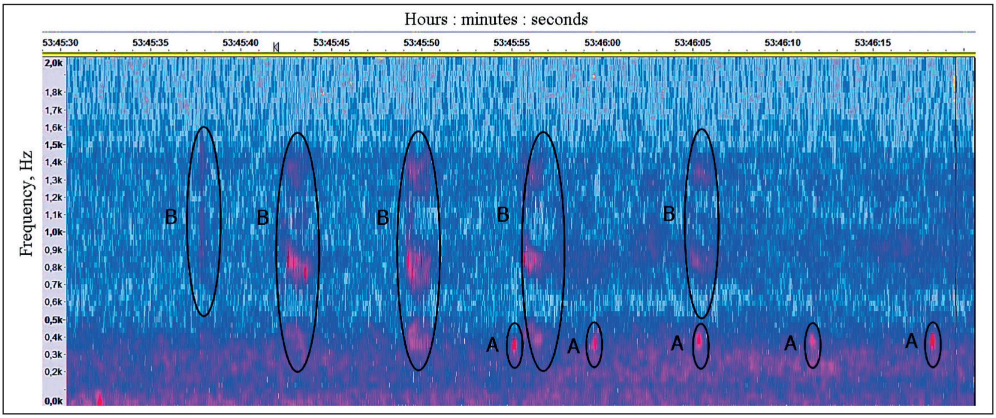

Figure 5. Spectrograms of the calls of the Eagle Owl (A) and domestic dog (B)
5. ábra Uhu (A) és kutya (B) hangjainak spektrogramja

disabled (Bolshebereznikovsky district), village Parakino (Bolshebereznikovsky district), village Picheury (Chamzinsky district), village Makolovo (Chamzinsky district), village Nikolaevka (Dubensky district), village Bulgakovo (Kochkurovsky district). We recorded dogs barking in the frequency range from 250 to 1,500 Hz *(Figure 5)*. Vocal interaction was recorded on January 18, 2018, February 3, 2020, March 4, 2020, March 10, 2022, March 16, 2022, and September 9, 2018. Eagle Owls and domestic dogs showed vocal activity together at 18:10, 20:05, 20:17, 21:02, 21:38, and 03:20. It should be noted that the voice activity of the Eagle Owl and dogs is independent. For example, when an Eagle Owl called during the barking of dogs, they did not stop barking when they heard it. Another situation was when the dogs barked in the village against the background of the calls of the Eagle Owl, which continued its vocalization. It seemed that each animal showed its vocal activity, not paying attention to other cries. Joint calls were observed at an average temperature of +2 ± 7.3 °C (CI = -18 ± 1 °C). Joint calls were recorded at an average wind strength of 1 ± 1.4 m/s (CI = 0–4 m/s), cloud cover of 20 ± 6.9% (CI = 10–30%), pressure of 754 ± 4.63 mm Hg (CI = 728–764 mm Hg).

Co-vocalizations of the Eagle Owl and canines were noted in winter, spring and autumn, but mainly in spring (50%). At the same time, the share of recordings with calls from the total number of recordings by season was taken into account. The predominance of co-vocalizations in the spring period is primarily due to the pre-incubation and incubation periods of the Eagle Owl. After comparing the intervals of values of environmental factors (temperature, pressure, cloudiness, wind strength) during the registration of co-vocalizations and all manifestations of factors during the years of research, it was revealed that duets of the Eagle Owl and canines are recorded in a certain tolerant range. In particular, in relation to the temperature factor, co-vocalizations was recorded of +3 ± 7.6 °C (CI = -18–+11 °C), while the range of annual temperatures varied from -26 to +34 °C. The atmospheric pressure factor during co-vocalizations were recorded of 756 ± 5.11 mm Hg (CI = 728–764 mm Hg), while the range of pressure fluctuations in the year varied from 714 to 783 mm Hg. The cloudiness factor during co-vocalizations were recorded of 20 ± 6.5% (CI

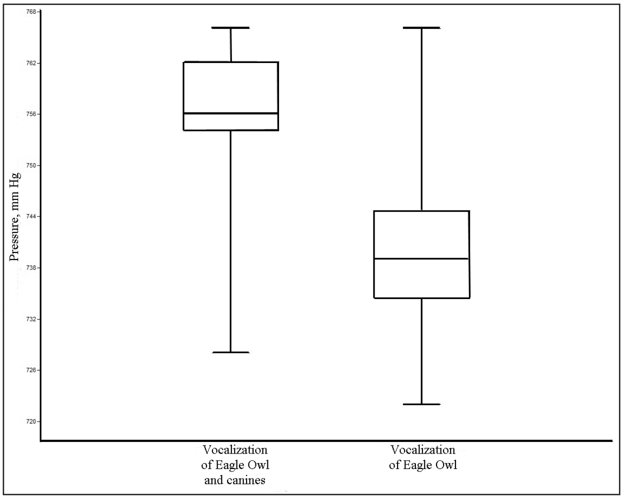

Figure 6. Ranges of atmospheric pressure in which vocalization was recorded for the Eagle Owl and canines and for the Eagle Owl alone

6. ábra A légnyomás tartománya, amelyben az uhu és a kutyafélék, illetve csak az uhu vokalizációja rögzítésre került

Note: 'strip on box' is the median, the boundaries of the box are 25–75% quantiles, whiskers – minimum and maximum values.

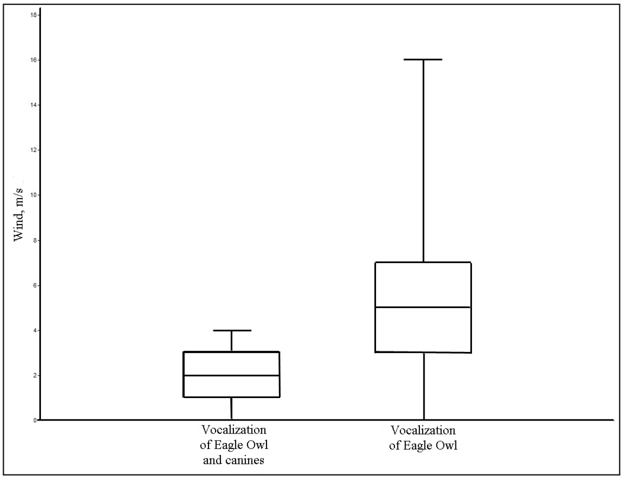

Figure 7. Ranges of wind speed in which vocalization was recorded for the Eagle Owl and canines and for the Eagle Owl alone

7. ábra A szélsebesség tartománya, amelyben az uhu és a kutyafélék, illetve csak az uhu vokalizációja rögzítésre került

Note: 'strip on box' is the median, the boundaries of the box are 25–75% quantiles, whiskers – minimum and maximum values

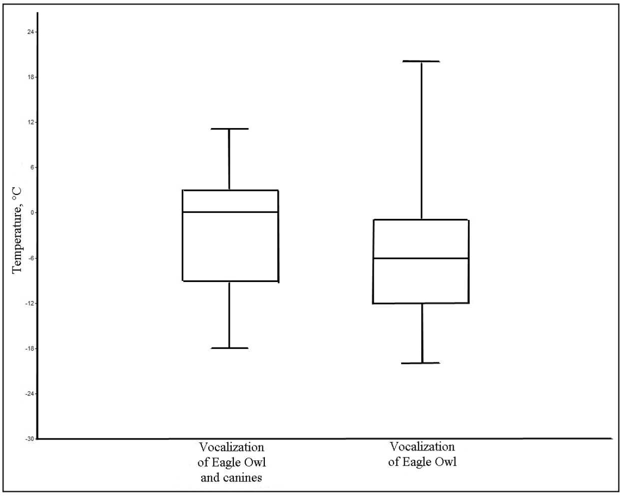

Figure 8. Ranges of temperature in which vocalization was recorded for the Eagle Owl and canines and for the Eagle Owl alone

8. ábra A hőmérséklet tartomány, amelyben az uhu és a kutyafélék, illetve csak az uhu vokalizációja rögzítésre került

Note: 'strip on box' is the median, the boundaries of the box are 25–75% quantiles, whiskers – minimum and maximum values.

= 10–30%), while the cloudiness varied from 0 of 100% throughout the year. The wind during co-vocalizations were recorded of 2 ± 1.1 m/s (CI = 0–4 m/s), while the wind varied from 0 of 17 m/s throughout the year. It should be noted the values of the parameters of meteorological conditions (atmospheric pressure *(Figure 6)*, wind *(Figure 7)* and temperature *(Figure 8)*), at which the co-vocalizations of the Eagle Owl with canines, and exclusively the vocalization of the Eagle Owl, was recorded. This may have practical implications for science in subsequent studies.

Discussion

In our work, we have received the answer of a Gray Wolf with a howl to the call of an Eagle Owl. It was like imitating the «hu-hu-hu» of an Eagle Owl. It is known that wolves respond to the howl of their conspecifics or the wailer on the hunt. They can also respond to other sources of sound, such as a horn (Palacios *et al.* 2017, Domken *et al.* 2021). This can be explained by the similar acoustic structure of all these sounds, namely, they are long and harmonic with a close frequency range. They use howling to communicate over long distances. In particular, wolves use vocalizations to transmit information about pack members, their location, or boundaries of spatial subunits (Harrington & Asa 2003, Palacios *et al.* 2007, Zaccaroni *et al.* 2012, Watson *et al.* 2018). The howl of wolves shows plasticity according to the situations (Theberge & Theberge 2022). According to the literature, the main frequency of Gray Wolf howling is usually in the range from 150 to 1,300 Hz in adults (Tooze *et al.* 1990, Feddersen-Petersen 2000, Zaccaroni *et al.* 2012, Root-Gutteridge *et al.* 2014, Sadhukhan *et al.* 2019).

The registration of the calls of the Eagle Owl and the wolf in the autumn period indicates that they cannot be attributed to reproductive vocalization. With regard to the Great Horned Owl and the Gray Wolf, the researchers recorded vocal interaction at the end of August, i.e. also not during the breeding season (Domken *et al.* 2021). They make the assumption that the wolves were young, because they are characterized by a high probability of responding to acoustic stimulation (Harrington & Mech 1979). Another important message is that wolves show the greatest vocal activity throughout the year in August, October, and July (Nowak *et al.* 2007). It is also known that during the day the maximum vocalization of wolves is recorded from 22:00 to 00:00 (Theuerkauf *et al.* 2003). This explains the time interval for recording the joint vocal activity of the wolf and the Eagle Owl in our work. For the Eagle Owl, on the contrary, the nighttime vocal activity is noticeably weaker than the evening one (Lapshin *et al.* 2018, Palacios *et al.* 2022), which indicates a discrepancy between the daily acoustic activity of the two species and explains the rarity of joint duets in nature. However, the wolf and the Eagle Owl are forced to interact in an acoustic signal environment, since their vocal activity can be timed to coincide with sunset and sunrise (Lapshin *et al.* 2018, Palacios *et al.* 2022). Thus, these two predators are quite active in terms of vocalization not only in relation to conspecifics, but also to other competitor species. This circumstance is decisive in the formation of a joint vocal repertoire between species.

Darden and Dabelsteen (2006) believe that Swift Fox *(Vulpes velox)* bark when threatened. This is in good agreement with our results on the co-vocalizations of the Red Fox and the Eagle Owl, since the Eagle Owl called often in the spring day, and the fox joined him. The calls of the Eagle Owl in this case can be considered provocative vocalization of the fox, because no response calls from another Red Fox were noted. These calls were directed precisely at the calls of an Eagle Owl. The fox probably perfectly heard the Eagle Owl, because it is known that the absolute hearing sensitivity of the Red Fox is one of the best among mammals and varies in the range from 51 Hz to 48 kHz (Isley & Gysel 1975, Malkemper *et al.* 2015). In its natural habitat, the fox made sounds with a lower frequency in the presence of Eagle Owl calls. In comparison, the frequency of the sounds of unselected Red Foxes 2 times higher (Mukhamedshina *et al.* 2019). The influence of Eagle Owl calls on the vocalizations of foxes and wolves is similar. For the Red Fox, as for the Gray Wolf, social contacts play an important role in their ecology (White & Harris 1994).

As for the entry of canines into joint vocal interaction with the Eagle Owl, this can be explained by their provocation by its calls. Canids are socially active animals, so they tend to interact not only with conspecifics, but also with other species. The frequency range of dog barking recorded by us is consistent with the data of Feddersen-Petersen (2000).

Thus, the joint vocal activity of the Eagle Owl and carnivorous mammals from the canine family has different reasons for its occurrence. The Eagle Owl is invulnerable to wild canines (Gray Wolf and Red Fox). Although they may be its competitors in the same territories, primarily for rodents and hares. Therefore, the vocalization of the Eagle Owl occurs mainly in spring and autumn in the traditional manner reported earlier (Lapshin *et al.* 2018), regardless of the presence and vocalization of wolves, and especially foxes. With regard to domestic dogs, the Eagle Owl does not pay any attention to their barking, which is actually confirmed by the greater frequency of joint vocal interactions. Our results serve as a starting point for further study of the relationship between the Eagle Owl and canines based on acoustic activity.

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Population trend and breeding productivity of some migrant passerines in Hungary

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Abstract This study aimed to monitor the demographic changes of some closely related species based on bird ringing data from the CES (Constant Effort Sites) program in Hungary between 2007 and 2018, and to explore the reasons for these demographic changes. The CES program tracks breeding bird populations with standard methods. The studied species breeding in Hungary were from genera *Sylvia*, *Curruca,* and *Phylloscopus*. Among these species, the trends of some forest birds, like Eurasian Blackcap *(Sylvia atricapilla)*, Lesser Whitethroat *(Curruca curruca)*, Common Chiffchaff *(Phylloscopus collybita)* and Willow Warbler (*Ph. trochilus)* showed no substantial changes, and one of the open-habitat species, the Barred Warbler *(Curruca nisoria)* – a long distant migrant – showed decreasing trends. The Garden Warbler *(Sylvia borin)* – a trans-Saharan migrant but forest dweller – also experienced population declines. Short-distance migrants maintained stable populations. Common Whitethroat productivity displayed an increasing trend to compensate for population decline. Upon examining the Eurasian Blackcap, this study detected a strong relationship between the number of adult birds, productivity, and the number of adults captured the following year.

Keywords: CES program, *Sylvia*, *Curruca*, *Phyllsocopus*, annual capture, demographic changes

Összefoglalás Kutatásunk célja, hogy kimutassuk néhány rokon faj demográfiai változását és ennek okait a CES programban 2007–2018 között gyűjtött gyűrűzési adatok alapján. A CES (Constant Effort Sites) program célja a hazai költőállományok hosszútávú monitorozása standard módszerek segítségével. A vizsgálatban résztvevő fajok a *Sylvia, Curruca* és *Phylloscopus* nemekbe tartozó Magyarországon költő fajok közül kerültek ki. Az ide tartozó erdei fajok – mint a barátposzáta *(Sylvia atricapilla)*, a kis poszáta *(Curruca curruca)*, a csilpcsalpfüzike *(Phylloscopus collybita)* és a fitiszfüzike *(Ph. trochilus)* – állományai nem változtak kifejezetten. Az elsősorban nyílt élőhelyekhez kötődő fajok közül a Szaharától délre telelő, hosszútávú vonuló karvalyposzáta *(Curruca nisoria)* és a szintén hosszútávú vonuló, de elsősorban erdei élőhelyeken fészkelő kerti poszáta *(Sylvia borin)* populációi csökkenő tendenciát mutatnak, ezzel szemben a rövid távú vonulók állományai stabilak vagy enyhén növekednek. A mezei poszáta produktivitása az évek során emelkedik, ezzel némileg ellensúlyozni tudja az egyedszámban bekövetkezett csökkenést. A barátposzáták esetében összefüggéseket találtunk az adult egyedek, a produktivitás és a következő évi adult egyedek száma között, ami sűrűségfüggő szabályozásra utal.

Kulcsszavak: CES program, *Sylvia*, *Curruca*, *Phyllsocopus*, éves fogás, demográfiai változások

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Introduction

Birds are the most abundant terrestrial vertebrates and the most studied group; the distributions, breeding ranges, habitat requirements, behaviours and migration routes of most species are well known (e.g. Cody 1985, Furness & Greenwood 1993, Csörgő *et al.* 2009, Haraszthy 2019, Keller *et al.* 2020, Szép *et al.* 2021). For this reason, their roles as indicator species in biodiversity monitoring are growing because their absence, presence, abundance or behaviour reflect environmental factors and changes (Báldi *et al.* 1999, Standovár 2000, Winkler 2000, Newton 2008).

Recently, more ornithological studies have focused on surveys covering the largest region possible to detect the local demographic changes and their causes and to gather data from the entire distribution-range level of a species (Gregory *et al.* 2008). Integrated international monitoring programs should collect such large data amounts from the whole distribution area of a species (Keller *et al.* 2020, Szép *et al.* 2021). Only a large amount of data can more precisely determine which parameters strongly influence population sizes in breeding grounds, wintering grounds and during migration (Goodenough *et al.* 2009).

Hungarian researchers use various methods for programs covering different periods and goals. The Common Bird Census (MMM) program employs observation-based methods (Szép & Nagy 2002, 2006, Szép *et al.* 2012) linked to the Pan European Common Bird Monitoring program (Gregory *et al.* 2003, 2005, PECBMS 2023). This method provides a large amount of data on species diversity, breeding population and abundance of a given area, even large areas, but is unsuitable for individual identification.

The AH (Actio Hungarica) and the CES (Constant Effort Sites) programs use standardised mark-recapture methods. The CES program focuses on the breeding season, and the AH focuses on the autumn and spring migration.

The CES program links directly to the program launched by the BTO (British Trust for Ornithology) and is now also active in many European countries and North America (MAPS) (Desante *et al.* 1995).

Each method can answer different questions and goals. Harmonising long-term systems and analysing them to detect population changes and understand their causes is indispensable.

The population trends of passerines show considerable variation between species (Sanderson *et al.* 2006, Szép *et al.* 2012, 2021, BirdLife International 2023) and geographical scales (Stanbury *et al.* 2017, Keller *et al.* 2020). According to the literature, the annual cycle, diet, habitat selection, migratory strategies, and environmental factors on the breeding or wintering grounds and along the whole migration route strongly influence songbird population dynamics (Wesołowski *et al.* 2006, Ockendon *et al.* 2014).

When considering changes in a songbird population, especially in migratory species, it is challenging to determine whether the most crucial effects occur at the breeding sites, wintering sites or migratory routes (Goodenough *et al.* 2009). Studies cannot focus on a single factor in the complex system that affects the population, because changes are driven by a combination of all factors, including abiotic, biotic, interspecific, and intraspecific effects. However, some may be more prominent during certain periods. For example, the presence or absence of food during the breeding period can strongly influence clutch size and breeding numbers, which affects productivity in a given year. Food availability depends on several factors: for insectivorous species during the breeding period, it primarily depends on weather conditions, especially spring temperatures and rainfall (Jones *et al.* 2003).

Examining population changes in a species requires a separate analysis of the effects at breeding sites, during migration routes and wintering grounds. Long-term changes are primarily determined by breeding success, which depends on habitat quality and the processes in the breeding area. Then, wintering grounds influence population size through survival rates (Ockendon *et al.* 2014), to which migration losses must be added. However, these losses can be compensated by higher productivity during the breeding season up to a specific limit. Weather conditions may also affect those trends locally (Gyurácz *et al.* 2016).

This study aimed to obtain information about the population dynamics of some passerines breeding in Hungary and to explore the reasons for those trends.

The closely related species have similar environmental requirements, but their habitat selection on breeding grounds and migration strategies vary, leading to differing changes to particular environmental factors (Cramp 1992, Csörgő *et al.* 2009, Haraszthy 2019); thus, we can use them as bioindicators (Winkler 2000).

The study included eight related passerine bird species, two of which – Eurasian Blackcap *(Sylvia atricapilla)* and Common Chiffchaff *(Phylloscopus collybita)* – are short-distance migrants. All other species winter south of the Sahara. Among these are forest bird species like Garden Warbler *(Sylvia borin)*, Lesser Whitethroat *(Curruca curruca),* Wood Warbler *(Phylloscopus sibilatrix)*, and Willow Warbler *(Ph. trochilus*)*,* and species connected to open habitats like Barred Warbler *(Curruca nisoria)* and Common Whitethroat *(C. communis)*. Most of these species are abundant enough to indicate local and regional environmental changes.

Material and Methods

We analysed capture data from Hungarian Constant Effort Sites (CES) (Baillie 1990, Halmos & Karcza 2004), an international bird ringing program in the breeding season, through which it is possible to check local breeding population demographics (Baillie & Schaub 2009). The Hungarian CES Program began in 2004. The birds were captured with mist nets, a suitable method to estimate population size, relative abundance, species composition (Dunn & Ralph 2004, Halmos & Karcza 2004), and demographic parameters like productivity and apparent survival rates (Kiss *et al.* 2020, Gyurácz *et al.* 2022).

Only a few ringing sites participated in the CES program in its first three years, and the biometrics data were only identified from 2007 onwards. Therefore, this study uses data spanning 12 years (2007 to 2018). The CES program covers the breeding period from 15 April to 13 July. Nine visits occur during the season, with a minimum five-day gap between visits. The ringing starts at sunrise and ends at noon (Halmos & Karcza 2004).

Ringing data were collected from 16 CES ringing sites spread over Hungary *(Figure 1)*. The sites included in this study were those that provided continuous data for at least 10 years during the study period (2007–2018). The numbers, locations, types, and lengths of

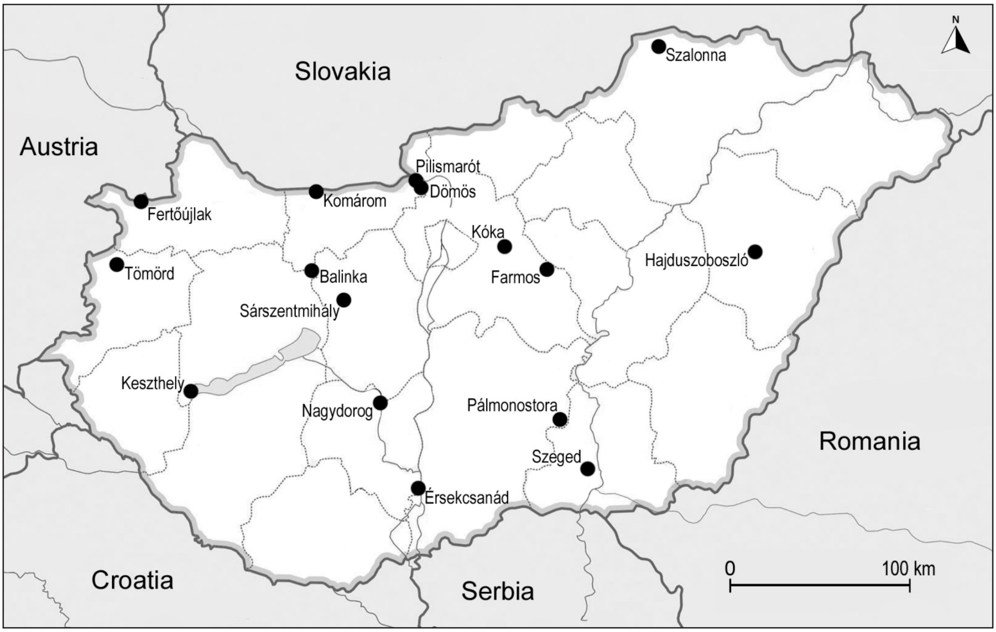

Figure 1. Study sites (bird ringing sites)
1. ábra Vizsgálati területek (gyűrűzőállomások)

mist nets at sites were constant between years, but each site used different amounts of mist nets. In order to ensure comparability the data was standardised per unified net surface and period. The captures were standardised to the number of birds caught by a net surface of 1,000 m^2 within 54 hours (six hours per day for nine days) on each site.

The CES protocol also includes the measurement of biometric data of the ringed individuals, according to Svensson (1992). However, in this study, we only used the age and sex data of birds. In the breeding season, we can determine age and sex in all studied species based on brood patch, cloaca shape or plumage features. We classified the first-year birds (hatched in the actual calendar year) as juveniles and signified them as “1y”. Birds hatched in earlier years were determined as adults and denoted as “1+”.

Based on the data obtained, we determined the population trends of birds ringed as juveniles or adults and their productivity, considering the proportion of the first-year birds to the total captures. Apparent survival rate was previously analysed in Kiss *et al.* (2020).

We tested whether the studied species showed similar trends and what behaviours influenced these trends. Furthermore, this study examined the relationships between productivity and the number of adults from the same year and the following years.

Generalized linear modelling (GLM) with identity link function was used to analyse the species trend slopes. Spearman’s correlation was used to quantify the relationship between productivity and the number of adults. The significance level was set at $P < 0.05$.

A hierarchical cluster analysis (with Euclidean distance) was used to detect similarities between the productivity of the studied species in consecutive years. All data analyses were conducted using the Past program version 4.03 (Hammer *et al.* 2001).

Results

A total of 5,997 individuals of the studied species were ringed in the study period, including 4,400 Eurasian Blackcap, 67 Garden Warblers, 143 Barred Warblers, 296 Lesser Whitethroats, 193 Common Whitethroats, 22 Wood Warblers, 816 Common Chiffchaffs, and 60 Willow Warblers. This study excluded the Wood Warbler from further investigations due to the small amount of data collected on the species. For more detailed capture data by ringing station, see the Appendix.

The annual number of adult Garden Warblers ($r = –0.60$, $P < 0.05$) and Barred Warblers ($r = –0.74$, $P < 0.01$) decreased significantly. The remaining species showed no substantial changes. The annual number of juveniles of the studied species showed no clear trend over the study period *(Table 1, 2)*.

The productivity of Common Whitethroats showed a significantly increasing trend between 2007 and 2018, while the productivity of the other species did not change substantially and can be considered stable *(Table 3)*.

Two main groups are observable based on the cluster analysis using the yearly productivity data for each species *(Figure 2)*. The Common Chiffchaff and the Eurasian Blackcap are

Table 1. Standardised capture data of the adult birds (2007–2018) and generalized linear modelling (GLM) results. Species name abbreviations comprise the first three letters of the genus and the species name (HURING code)

1. táblázat Az adult madarak sztenderdizált éves fogási adatai (2007–2018) és az általánosított lineáris modell (GLM) eredményei. A fajnevek rövidítésénél a HURING kódokat alkalmaztuk

	PHYTRO	**PHYCOL**	**SYLATR**	**SYLBOR**	**CURCUR**	**CURNIS**	**CURCOM**
2007	13.40	96.62	901.86	26.67	70.19	53.34	69.33
2008	7.69	63.01	872.32	20.14	95.73	42.07	125.49
2009	4.17	83.57	791.72	16.67	36.82	84.89	37.10
2010	13.82	147.39	1018.12	31.03	72.83	64.16	42.86
2011	14.20	90.70	572.97	15.11	65.03	11.86	39.54
2012	18.96	73.79	1069.39	12.50	60.20	37.34	46.34
2013	11.79	87.56	830.37	37.50	72.30	25.31	45.11
2014	2.34	90.27	728.79	12.50	73.63	13.76	21.15
2015	5.34	114.92	923.47	18.58	71.69	26.92	68.89
2016	17.98	113.78	883.46	12.50	51.22	13.94	26.07
2017	16.11	89.09	734.61	2.78	96.96	4.17	49.99
2018	7.91	109.96	627.09	2.78	92.68	17.46	24.76
Slope	0.09	1.55	–13.51	–1.72	1.37	–4.98	–4.10
SE	0.48	1.88	12.21	0.73	1.50	1.44	2.12
Intercept	–178.22	–3021.00	28023.00	3488.6	–2683.00	10060.00	8305.40
SE	974.72	3792.00	24572.00	1471.5	3014.30	2904.00	4266.80
G	0.04	0.68	1.22	5.56	0.84	11.92	3.74
p(slope=0)	0.85	0.41	0.27	**0.02**	0.36	**0.01**	0.05

Table 2. Standardised annual capture of juveniles (2007–2018) and generalized linear modelling (GLM) results. Species name abbreviations comprise the first three letters of the genus and the species name (HURING code)

2. táblázat A fiatal madarak sztenderdizált éves fogási adatai (2007–2018) és az általánosított lineáris modell (GLM) eredményei. A fajnevek rövidítésénél a HURING kódokat alkalmaztuk

	PHYTRO	**PHYCOL**	**SYLATR**	**SYLBOR**	**CURCUR**	**CURNIS**	**CURCOM**
2007	2.78	68.62	747.53	0.00	15.06	25.32	0.00
2008	27.88	146.31	712.45	2.78	33.37	4.17	14.42
2009	0.00	84.26	759.07	4.86	8.33	4.65	0.00
2010	0.00	154.93	282.55	0.00	23.44	9.38	0.00
2011	0.00	195.50	755.11	0.00	23.40	5.13	5.13
2012	0.00	78.65	705.11	0.00	13.18	4.17	11.32
2013	13.68	146.32	438.23	0.00	12.33	4.17	5.13
2014	2.34	220.55	859.01	0.00	33.33	0.00	2.78
2015	4.69	96.55	499.26	0.00	6.73	8.33	10.90
2016	4.17	108.98	631.30	0.00	25.32	2.56	11.11
2017	0.00	68.34	617.07	0.00	23.40	6.73	12.82
2018	2.78	90.95	636.35	0.00	40.86	6.73	5.56
Slope	–0.62	–1.51	–6.46	–0.21	0.90	–0.76	0.58
SE	0.69	4.41	13.98	0.12	0.90	0.50	0.43
Intercept	1254.40	3162.50	13637.00	416.08	–1796.70	1531.80	–1160.00
SE	1394.10	8884.10	28124.00	240.31	1805.40	1012.90	864.01
G	0.80	0.12	0.21	2.99	1.01	2.27	1.82
p(slope=0)	0.37	0.73	0.65	0.08	0.31	0.13	0.18

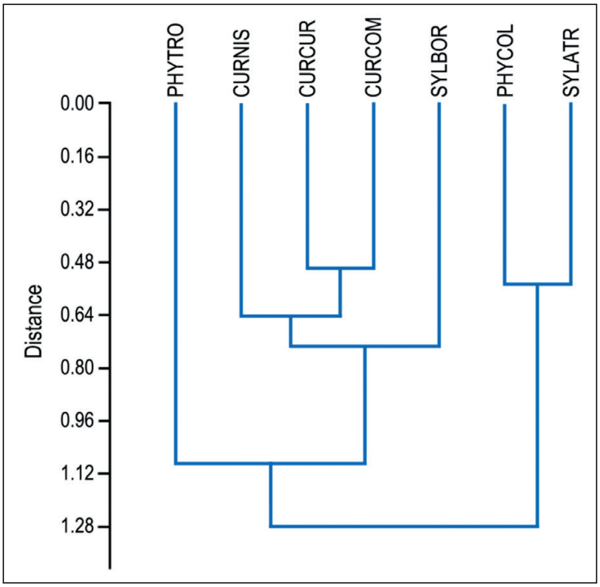

Figure 2. Dendrogram of the studied species' productivity (cluster analysis, Euclidean distance, P = 0.05). Species name abbreviations consist of the first three letters of the genus and the species name (HURING code)

2. ábra A vizsgált fajok produktivitásának hasonlósági vizsgálata klaszterezéssel (Euklideszi távolság, P = 0,05). A fajnevek rövidítésénél a HURING kódokat alkalmaztuk

Table 3. The productivity of the examined species in the study period (2007–2018) and generalized linear modelling (GLM) results. Species name abbreviations comprise the first three letters of the genus and the species name (HURING code)

3. táblázat A vizsgált fajok produktivitásának alakulása a vizsgált időszakban (2007–2018) és az általánosított lineáris modell (GLM) eredményei. A fajnevek rövidítésénél a HURING kódokat alkalmaztuk

	PHYTRO	**PHYCOL**	**SYLATR**	**SYLBOR**	**CURCUR**	**CURNIS**	**CURCOM**
2007	0.17	0.42	0.45	0.00	0.18	0.32	0.00
2008	0.78	0.70	0.45	0.12	0.26	0.09	0.10
2009	0.00	0.50	0.49	0.23	0.18	0.05	0.00
2010	0.00	0.51	0.22	0.00	0.24	0.13	0.00
2011	0.00	0.68	0.57	0.00	0.26	0.30	0.11
2012	0.00	0.52	0.40	0.00	0.18	0.10	0.20
2013	0.54	0.63	0.35	0.00	0.15	0.14	0.10
2014	0.50	0.71	0.54	0.00	0.31	0.00	0.12
2015	0.47	0.46	0.35	0.00	0.09	0.24	0.14
2016	0.19	0.49	0.42	0.00	0.33	0.16	0.30
2017	0.00	0.43	0.46	0.00	0.19	0.62	0.20
2018	0.26	0.45	0.50	0.00	0.31	0.28	0.12
Slope	0.00	–0.01	0.00	–0.01	0.00	0.02	0.02
SE	0.02	0.01	0.01	0.01	0.01	0.01	0.01
Intercept	2.42	16.16	–4.21	18.96	–8.36	–33.50	–34.72
SE	47.53	18.43	16.74	11.22	12.67	27.31	11.50
G	0.01	0.71	0.08	2.84	0.46	1.52	9.18
p(slope=0)	0.96	0.40	0.78	0.09	0.50	0.22	**0.01**

Table 4. Relationship between the annual capture of adults and annual productivity (Spearman correlation) Species name abbreviations comprise the first three letters of the genus and the species name (HURING code)

4. táblázat Az öregek éves fogása és az éves produktivitás közti kapcsolat. A fajnevek rövidítésénél a HURING kódokat alkalmaztuk

	number of adults /productivity in the same year		**productivity in a year / number of adults in the following year**	
	Spearman r	**P-value**	**Spearman r**	**P-value**
PHYTRO	-0.54	0.07	-0.56	0.07
PHYCOL	-0.43	0.17	-0.01	0.98
SYLATR	-0.86	**0.00**	0.72	**0.01**
SYLBOR	0.18	0.57	0.40	0.23
CURCUR	0.20	0.54	0.01	0.98
CURNIS	-0.41	0.18	-0.25	0.45
CURCOM	-0.16	0.62	-0.03	0.94

grouped together, separated from other species. The separation of the Willow Warbler in the second main group deserves mention.

The comparison of productivity and the number of adults in the following year resulted in a significant relationship in Eurasian Blackcaps: productivity decreases as the number of adults increases *(Table 4)*, suggesting density-dependent regulation. Higher productivity in a given year ensures more adults in the following year. Thus, more fledged birds return to breed. This study observed no significant relationship between productivity and adult catch number in the other species.

Discussion

Reproductive success and the survival rate during migration and overwintering largely determine the population size of a species, suggesting that the population size peaks after the breeding season and then declines steadily until the following season. However, environmental factors like habitat conditions over the lifecycle or local weather conditions can strongly influence this basic model (Newton 1998).

Songbird population changes show much variation within their distribution area, but main trends based on long-term studies can be determined (Reif 2013, Hanzelka *et al.* 2015, Buchanan *et al.* 2016, Brlík *et al.* 2021, Reif *et al.* 2022, Wesołowski *et al.* 2022, Virkkala *et al.* 2023). Based on our current results, the annual number of adult Garden Warblers and Barred Warblers showed a decreasing trend during the study period. The decline is significant in Garden Warblers, with 80% of the population having disappeared since the 2000s. This decline occurred throughout the country in all habitat types (Csörgő & Gyurácz 2021). With some minor exceptions, the breeding range of Garden Warblers has remained the same, but their populations show a slight decline everywhere in Europe (PECBMS 2023). According to Johnston *et al.* (2016), this decline is linked to the survival of adult birds.

Garden Warblers and Barred Warblers are long-distance migrants with wintering areas beyond the Sahara (Csörgő *et al.* 2009). Many detailed studies have pointed out the declines of Afro-Palearctic migrant birds, but the temporal pattern of these decreases was disproportionate (John 1992, Sanderson *et al.* 2006, Wesołowski *et al.* 2010). Migratory species, especially long-distance migratory birds, are at high risk because they must adapt to the changed environmental conditions at the breeding grounds, along the migratory route, in wintering areas, and stopover sites (Newton 2008). They are mostly obligatory migrants, meaning the routes and timing of the migration and the wintering grounds are genetically encoded (Morelli *et al.* 2022). Such species have less plastic behaviour and, with a few exceptions (e.g. Jonzén *et al.* 2006), cannot adapt quickly enough to the changed circumstances. They still winter in locations where they survived the last ice age (Berthold 2001). Long-distance migrant declines occur mainly along their migration routes or in wintering grounds. For the trans-Saharan migrants, the main threat may be the expanding Sahara Desert, which forces them to fly greater distances without food and water, and droughts in the Sahel (Hagemeijer & Blair 1997, Marchant *et al.* 1997).

Most long-distance migrants are insectivorous or mixed-feeders, and their food availability peak is influenced by local habitat and climatic conditions to which they cannot adapt as quickly as obligate migrants. Climate change shifts the peak availability of prey in wintering areas and stopover sites (Both *et al.* 2009). The number of migratory songbird species with strong links between population fluctuations and climatic conditions in the Sahel region of West Africa is remarkably high (Newton 2004a).

We can quantify migration and overwintering loss by apparent survival rate. The returning rate of the first-year bird is low, i.e., most young birds hatched in a given year will not return from the wintering area. This survival may be much higher for second and third-year birds (Kiss *et al.* 2020). Migration losses cannot be recovered after the return to breeding areas because the return time often does not coincide with the peak in food availability, which affects breeding success and clutch size (Both *et al.* 2006).

Common Whitethroat productivity showed a rising trend during the study period, suggesting that the carrying capacity of the habitat in the breeding area and subsequent higher productivity are high enough to compensate for wintering loss, resulting in a moderately growing European population (PECBMS 2023). Common populations decreased considerably across Europe by the 1960s, possibly due to African drought (Zwarts *et al.* 2015). Populations have since recovered in several areas (Birdlife International 2023) thanks to favourable climatic conditions, especially in northern and western European countries (Balmer *et al.* 2013, Sovon Vogelonderzoek Nederland 2018, Kalyakin & Voltzit 2020).

The migration route, its length, and the habitat in the breeding areas greatly determine population sizes. The more diverse and heterogeneous a habitat, the more species and individuals it supports and the more resilient the community. Thus, forests – which are in a more natural state – are less disturbed habitats in which the birds can better adapt to habitat and structural changes like forest fragmentation and forest management (Angelstam *et al.* 2004, Wesołowski *et al.* 2010, Bakermans *et al.* 2012, Czeszczewik *et al.* 2015). Forest management considerably influences changes in forest species populations. The increasing proportion of forests is one of the reasons why the nesting population of the Eurasian Blackcap is stable or moderately rising in Hungary (Csörgő & Gyurácz 2021) and increasing across Europe (BirdLife International 2023).

The Barred Warbler and especially the Common Whitethroat are connected to open habitats (including farmlands and shrublands); they forage on fields and nest in shrubs along the edges. Numerous detailed studies in recent decades have reported on declining farmland songbird populations, including Tucker and Heath (1994), Siriwardena *et al.* (1998), Pitkänen & Tiainen (2001), Gregory *et al.* (2004), Newton (2004b), Wretenberg *et al.* (2006), Reif *et al.* (2008) and Báldi and Batáry (2011). Agricultural intensification is the main reason behind the large-scale decrease (Verhulst *et al.* 2004, Németh 2017). Such intensification comprises large homogeneous fields, increased isolation of habitat patches due to the conversion of previously unused land to production, lack of bushes on field edges, the application of a large number of pesticides, chemicals and fertilisers, heavy mechanisation or overgrazing (Hallmann *et al.* 2014, Traba & Morales 2019, Valavanidis 2021). Population changes of the Barred Warbler can vary immensely from area to area. This study observed a slight decrease in the breeding population; however, based on the

Hungarian Monitoring of Common Birds programme, the population east of the Tisza River shows an increasing trend (Csörgő & Gyurácz 2021). European research also indicates a stable population (PECBMS 2023).

Our results show no significant trend in the remaining species, either in the numbers of adults or juveniles.

The comparison of productivity based on the cluster analysis shows a clear distinction between certain species groups. The Common Chiffchaff and Eurasian Blackcap, predominantly overwintering in the Mediterranean, are separated from all other species, which overwinter mainly or exclusively south of the Sahara. According to Gregory *et al.* (2007), the populations of short-distance or partial migrants like the two species mentioned above are stable, because they are exposed to fewer risks and have more plastic behaviour. Short-distance or partial migrants are mostly facultative migrants whose migration strategies are affected by weather events. Thus, they respond quicker to changes to the environment or local food resources (Berthold 2001). Weather parameters also influence peak food availability. Facultative migrants adapt to such changes by arriving earlier and laying eggs sooner, providing them with a remarkable advantage compared to long-distance migrants (Mitrus 2003, Czeszczewik 2004, Wesołowski & Maziarz 2009). Consequently, their populations are more stable or can increase. However, early returns or remaining in place also exposes them to dangers like sudden temperature drops and snowy winters (Gregory *et al.* 2007).

The ratio of adults and productivity shows an interesting pattern in the Eurasian Blackcap. This study found that productivity decreased with more adults returning. Higher productivity can compensate for the loss of migration and wintering when fewer adults return, suggesting density-dependent population regulation. Following a period of high productivity over several years, fewer adult birds returning in the spring are often observed, indicating density-independent regulation during migration and wintering (Newton 1998). Temperature is the most crucial factor determining Eurasian Blackcap density (Knaus 2020). In addition to abundance, the success of juveniles also contributes to species productivity. Our previous studies at the Tömörd Bird Ringing Station showed that temperatures at the beginning of the breeding season influenced Eurasian Blackcap fledgling success. Milder spring weather resulted in increased fledging success, while cooler spring weather increased the mortality of first-year birds (Kiss *et al.* 2016). The proportion of overwintering Eurasian Blackcaps has increased in northern and central Europe over the last decade, especially in urban and peri-urban areas. Earlier spring arrivals have been observed in northern and western Europe (Lundberg & Edholm 1982, Fransson 1995, Hüppop & Hüppop 2011). In addition, the migratory routes of migrants are shorter, which has also resulted in earlier breeding (Aymí *et al.* 2020).

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Appendix

Standardised annual capture (mean ± SD) of the studied species in the ringing stations during the CES sessions (2007–2018)
A vizsgált madárfajok sztenderdizált fogásszámának éves átlaga és szórása az egyes gyűrűzőállomásokon a CES időszakban (2007–2018)

	PHYTRO	PHYCOL	SYLATR	SYLBOR	CURCUR	CURNIS	CURCOM
Dömös	0	15.3 ± 12.4	185.7 ± 52.1	0.3 ± 1.2	0.7 ± 1.6	0.3 ± 1.2	0.7 ± 1.6
Balinka	0.6 ± 1.9	6.8 ± 9.4	149.5 ± 47.6	0	0	0	0.6 ± 1.9
Érsekcsanád	1.1 ± 3.8	16.3 ± 10.9	201.9 ± 44.5	1.5 ± 2.9	4.1 ± 4.4	0.4 ± 1.3	11.1 ± 10.8
Farmos	0	0	0.8 ± 1.2	0.2 ± 0.7	0.4 ± 0.9	0	0.8 ± 1.6
Fertőújlak	1.7 ± 3.0	1.1 ± 2.6	10.1 ± 8.7	0.6 ± 1.9	0	0	1.7 ± 4.1
Hajdúszoboszló	0	6.3 ± 4.9	56.5 ± 34.9	1.6 ± 1.9	6.2 ± 7.4	0	0,5 ± 1.7
Keszthely	2.3 ± 2.6	12.0 ± 6.0	29.9 ± 13.8	1.8 ± 3.8	1.6 ± 2.2	0	2.1 ± 2.4
Kóka	0.4 ± 1.4	28.0 ± 13.6	185.9 ± 53.0	0.3 ± 1.2	0.4 ± 1.4	1.1 ± 2.9	4.9 ± 10.5
Komárom	0	0	68.5 ± 47.9	0	0	0	0
Nagydorog	1.3 ± 2.2	27.2 ± 13.8	94.4 ± 23.0	1.4 ± 2.1	1.9 ± 2.1	5.5 ± 4.5	3.9 ± 3.3
Pálmonostora	0	0.3 ± 1.2	0.7 ± 1.6	0	0.3 ± 1.2	0	1.7 ± 2.1
Pilismarót	0.3 ± 1.2	2.3 ± 3.2	176.3 ± 42.9	0.3 ± 1.2	4.0 ± 4.2	2.3 ± 3.6	0.7 ± 1.6
Sárszentmihály	0	2.9 ± 4.6	14.9 ± 28.6	0	0	0	5.0 ± 6.1
Szalonna	2.8 ± 2.7	32.6 ± 16.4	172.3 ± 36.4	2.8 ± 2.7	57.6 ± 20.6	21.4 ± 19.5	4.9 ± 6.1
Szeged	0.2 ± 0.6	0	0.3 ± 0.8	0.2 ± 0.6	0.2 ± 0.5	0	0.5 ± 1.2
Tömörd	5.2 ± 6.3	67.0 ± 36.4	118.8 ± 34.5	8.0 ± 3.7	15.8 ± 6.4	8.7 ± 6.4	17.5 ± 12.1

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Long-term population changes of the Moustached Warbler *(Acrocephalus melanopogon)* in a Central Hungarian wetland habitat

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Abstract In recent years, the breeding populations of many migratory songbird species have declined in the Carpathian Basin. However, there may be significant differences between different geographical regions, as most species have a much higher chance of successful breeding in protected areas. This is also the case for the Moustached Warbler, one of the most habitat-specialist passerine. It colonises only perennial, unharvested reedbeds, therefore its conservation management is essential. We studied the population changes of this species between 2001 and 2022 at Lake Kolon in Izsák, based on bird ringing data from 10–24 July. Data of 12,817 ringed and 5,075 recaptured birds were used in the analyses. The annual capture rate decreased significantly during the study period. The proportion of juveniles was higher at higher water levels during the whole breeding season. In contrast, when looking at winter and first and second broods separately, water level had no effect on the juvenile/adult ratio. This is because the birds compensate for unsuccessful first broods by increasing the proportion of second and replacement broods. If the first broods are successful, the ratio of second and replacement broods will be lower. As reed management is practically non-existent in this area, the perennial reedbeds provide suitable nesting conditions for the species. Changes in the wintering sites may be responsible for the declining trend. Protection of the area is of particular importance for the conservation of the species.

Keywords: reed management, precipitation, Passerine migration, bird ringing

Összefoglalás Az utóbbi években számos vonuló énekesmadár-faj fészkelő állománya csökkent a Kárpát-medencében. Jelentős eltérések lehetnek azonban különböző földrajzi régiók között, mivel a védett területeken a legtöbb faj esélyei jóval magasabbak a sikeres költésre. Ez jellemző a fülemülesitkére is, amely egyike a legspeciálisabb élőhelyigényű énekesmadaraknak. Csak többéves, aratatlan nádas-gyékényesekben telepszik meg, így ezek természetvédelmi kezelése elengedhetetlen a faj számára. Munkánk során 2001 és 2022 között az izsáki Kolon-tónál vizsgáltuk meg a faj állományváltozását a július 10–24. között gyűrűzési adatok alapján. Az elemzések során 12 817 gyűrűzött és 5075 visszafogott madár adatát használtuk fel. A vizsgált időszakban az éves fogásszám szignifikánsan csökkent. A teljes költési szezon alatti magasabb vízszint esetén a fiatalok aránya magasabb volt, mint ellenkező esetben. Ezzel szemben a téli, valamint az első és második költések időszakát külön vizsgálva, a vízszint nem volt befolyással a fiatal/öreg arányra. Ennek az az oka, hogy a madarak a másod- és pótköltések arányának növelésével kompenzálják a sikertelen első költéseket. Ha az első költések sikeresek, akkor a másod- és pótköltések aránya alacsonyabb lesz. Mivel nádgazdálkodás ezen a területen gyakorlatilag nincs, így a sokéves nádas megfelelő fészkelési feltételeket biztosít a faj számára. A trendszerű állománycsökkenés hátterében a telelőhelyeken történt változások állhatnak. A terület védelme kiemelten fontos a faj megóvása érdekében.

Kulcsszavak: nádgazdálkodás, csapadék, énekesmadár vonulás, madárgyűrűzés

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Introduction

The Moustached Warbler *(Acrocephalus melanopogon)* is a member of the striped reed warbler group (Leisler *et al.* 1997). It has three subspecies. One of the two distribution areas of the nominate race *(A. m. melanopogon)* is contiguous from the Danube Delta to the Don River. Breeding birds winter on the western and southern coast of Asia Minor and the southern Balkan Peninsula. The other population has a patchy distribution in northern Morocco and Tunisia, on the Mediterranean coast and inland areas of the Iberian Peninsula, in patches on the Balearic Islands and Sardinia, Corsica, Sicily, the Rhone, the Appennine Peninsula along the Po and Arno rivers, the Carpathian Basin, the Balkan Peninsula, and the interior of Asia Minor (Dyrcz 2006). Occasional breeding occurs in the Czech Republic (Hudec *et al.* 1995). In Switzerland, an isolated small population has developed in the last decade (Volet & Burkhardt 2006). The European population size is estimated to be between 76,100 and 124,000 pairs, but this still needs validation (Birdlife International 2016). The largest European populations are found in the Danube Delta, southern Azerbaijan, the lower Don River, Hungary and Austria (Keller & Sokolov 2020).

The subspecies *A. m. albiventris* is found along the coast of the Sea of Azov, the lower Don river and adjacent areas of southeastern Ukraine and southern Russia, while *A. m. mimicus* nests in southern and eastern Turkey, Iraq, southern Russia along the lower Volga River, northern Iran and as far east as eastern Kazakhstan (Dyrcz 2006).

It is a species with special habitat requirements, as it colonises only perennial, unharvested reedbeds (Csörgő 1995, Vadász *et al.* 2008a), which is the main reason for its patchy distribution (Keller & Sokolov 2020).

Western populations are resident or short-distance migrants and typically spend the winter in the Mediterranean. Eastern populations winter in the Levant, Mesopotamia, southeastern Afghanistan, Pakistan (Indus Valley) and northwestern India (Dyrcz 2006).

The first individuals return from wintering grounds in late February, with a migration peak only in mid-March. The earliest nesting species among reed warblers. In the Carpathian Basin, the first clutches are laid between April and May, the second between late May and early July (Haraszthy 2019). After the breeding period, the dispersal movements of the birds starts late July and the migration finishes as late as early November (Kovács & Konyhás 2004, Németh & Králl 2009).

In several Mediterranean countries (Spain, France, Italy, Turkey), the population is in decline (Birdlife International 2016). The Tuscan population has declined by about 40% since 1990 (Keller & Sokolov 2020), but in Europe is classified as a species with stable population by the IUCN (International Union for Conservation of Nature), as there are no specific surveys or population change data from the eastern part of its range (Birdlife

International 2016). In Russia, a slight northern expansion of the population has been observed (Keller & Sokolov 2020).

A significant part of the European population is found in the Carpathian Basin, with about 10% in Hungary (Keller & Sokolov 2020). Its distribution is patchy. The most important nesting sites are Lake Fertő with 10,000–20,000 pairs (Vadász *et al.* 2011) and Lake Kolon in Izsák with 800–1,000 pairs (Biró & Morvai 2016). Other important nesting sites are Lake Velencei (BirdLife Hungary 2018a), Kis-Balaton (BirdLife Hungary 2018b), Kunkápolnási-mocsár (Kovács & Konyhás 2004) and Ócsai-turjánvidék (Csörgő *et al.* 2016). It also occurs in lowland saline lakes, in the Slovakian Párizsi-mocsár (Trnka 2003) and sporadically in backwaters and fishponds (Haraszthy 2019).

In Hungary, it was still considered a common species in the 1980s (Keve 1984). Its population was estimated at 1,000–1,200 pairs between 1979 and 1993 and in 1998 (Magyar *et al.* 1998, Kovács & Konyhás 2004), and at 3,000–5,000 pairs between 2005 and 2007 (Hadarics & Zalai 2008). Recent estimates suggest that this number may be around 2,500–3,500 pairs, but the trend at the national level is unknown (Csörgő & Gyurácz 2021).

During our work, we estimated the local population change of the species based on data from Lake Kolon in Izsák between 2001 and 2022. We aimed to know whether the population change was related to the current water level of Lake Kolon as one of the most important environmental conditions that could affect the population of the species. Given that it is possible to determine the age of the birds (Svensson 1992, Demongin 2016), we also examined the difference in the number of annual captures between the different age groups as well as the ratio of juveniles and adults.

Material and Methods

The data was collected at Lake Kolon, located in the Kiskunság National Park. It declared protected in 1975, and its current extent is 3,057.9 hectares. Lake Kolon is one of the country's most extensive freshwater wetlands and marshes. Usually, during the spring high water level, water depths can reach 1.5 m in some places, especially in the north, but during the year, water level fluctuations can reach 1 m. Bird ringing were carried out here between 2001 and 2022, in the period of 10–24 July each year, using standard methods. The survey was carried out on the Lower Matyó embankment, which crosses the lake in an east-west direction, using 133 Japanese type mist-nets (each 2.5 m high and 12 m long) divided into 4 blocks. The study area covers the entire cross-section of the lake. On both sides of the embankment, a narrow band of reedbeds, while on the embankment, grey willows *(Salix cinerea)* can be found. Shrub encroachment has been prevalent on the western side of the study area in recent times. Here, this process has also occurred in small areas of the reedbeds. The quality of the reed is not uniform across the study area. The east side of the lake has a lower thinner dense reed, while the west side has a thinner thicker reed.

A total of 12,817 birds were ringed during the study period. Of these, 5,075 different individuals were recaptured 6,763 times at the ringing site during the same period. Age determination was possible for 12,746 ringed birds (4,142 adults and 8,604 juveniles).

Chi-square test was used to compare the number of annual captures, while linear regression was used to establish the trend. Multiple regression analyses were used to examine the relationship between water level data and annual captures in winter (January–March), during the first brood (April–May), during the second brood (June–July) and between January and July. Each breeding period was defined based on published data (Haraszthy 2019). For investigating the association between the number of juvenile per pair and average water level, we used Spearman's correlation. Provided that trapping efficiency was constant (including numbers, types and location of nets) in each year, the proportion of juveniles captured should constitute a valid index of annual changes in breeding productivity (Peach *et al.* 1996, Dunn & Ralph 2004). Given that the species is monogamous (Dyrcz 2006) and the fact that dispersal movements have not yet started, it was possible to estimate the number of juveniles per pair. Capture probability was also similar for the two sexes as both males and females are involved in the incubation (Haraszthy 2019). For this reason, the number of adult birds caught in a given year was divided by two, and the number of juvenile birds caught in that year was then divided by this value. For statistical analyses, the program Past 3.14 was used (Hammer *et al.* 2001).

Results

The number of annual captures was significantly different ($\chi^2 = 1079.6$, $P < 0.001$), with the fewest birds caught in 2009 and in the period 2020–2022, while the most birds caught in 2001. Both the number of birds caught ($R^2 = 0.251$, $P = 0.017$) and recaptured ($R^2 = 0.377$, $P = 0.002$) significantly decreased over the study period *(Figure 1, 2)*.

On average, adults accounted for 32.9% of total catches and juveniles for 67.1%, but there were significant differences between years ($\chi^2 = 606.4$, $P < 0.001$). The proportion of adults was lowest in 2006, while at one point, in 2020, it exceeded that of juveniles *(Figure 3)*.

The average number of juveniles per two adults (pairs) was 4.75 (SD = 2.44), with the lowest value (1.85) in 2020 and the highest (10.33) in 2006 *(Figure 4)*. No significant trend over time was detected ($P > 0.05$).

Water levels of Lake Kolon during the winter, first and second broods did not affect the annual numbers of either adults ($F = 0.275$, $P = 0.89$) or juveniles ($F = 2.08$, $P = 0.13$) *(Table 1)*.

There was a significant positive correlation between the annual average water level and the juvenile/adult ratio: when the water level decreased, the juvenile/adult ratio also decreased and vice versa ($R^2 = 0.321$, $P = 0.005$) *(Figure 5)*.

Discussion

The populations of most migratory bird species have been declining in Hungary in recent years (Szép *et al.* 2021), but the decline we have showed for Moustached Warbler in Lake Kolon is much more severe than even that of long-distance migratory reed warbler species (Szép *et al.* 2012, 2021). In just over two decades, the number of birds captured has declined by 90%.

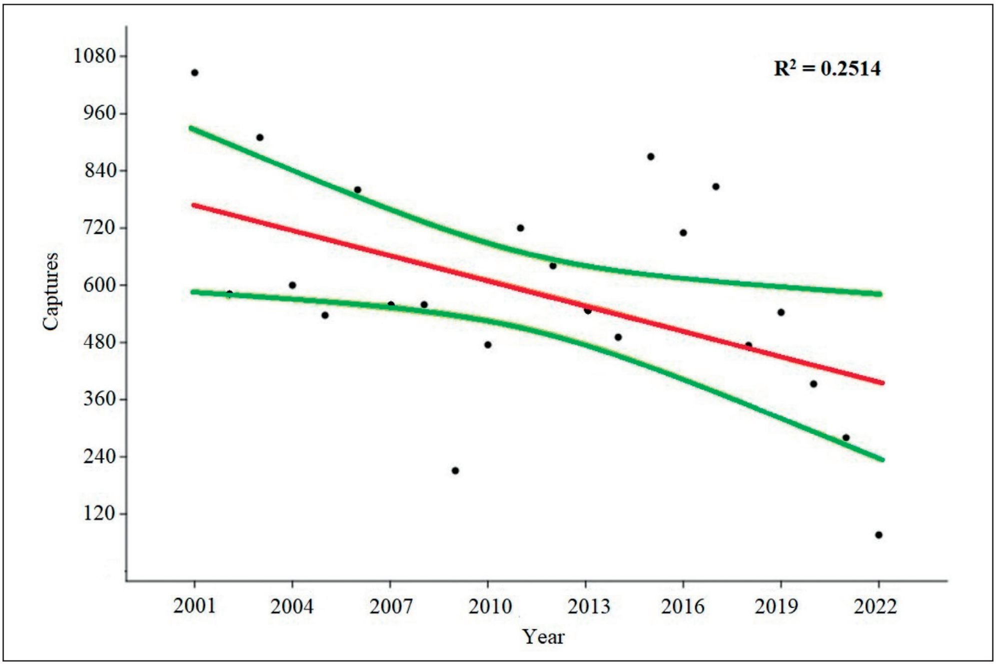

Figure 1. Changes in the number of ringed birds between 2001 and 2022
1.ábra A gyűrűzött madarak számának változása 2001 és 2022 között

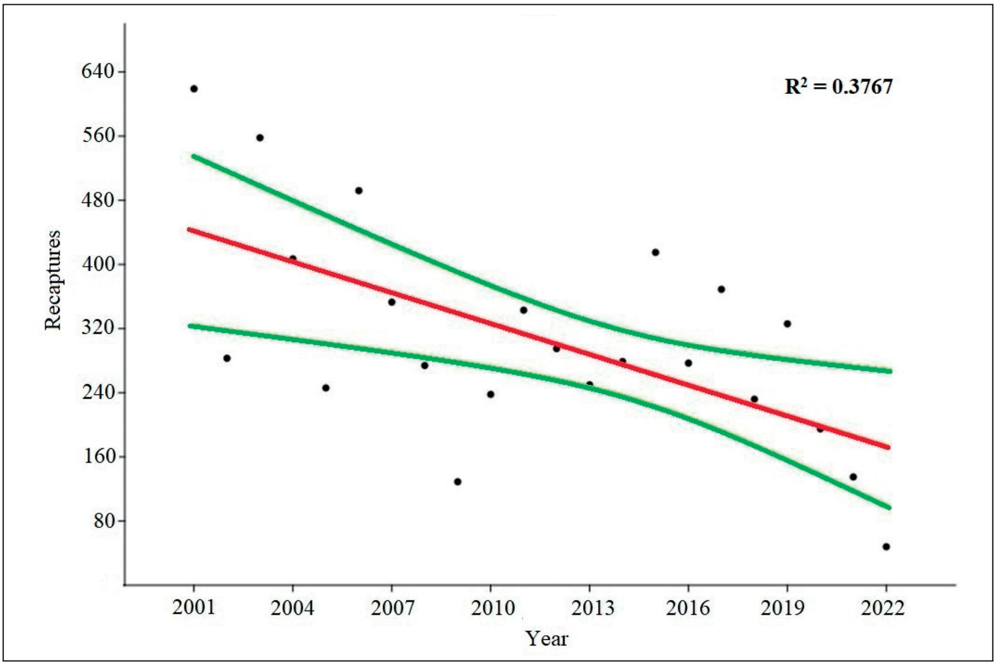

Figure 2. Changes in the number of recaptured birds between 2001 and 2022
2. ábra A visszafogott madarak számának változása 2001 és 2022 között

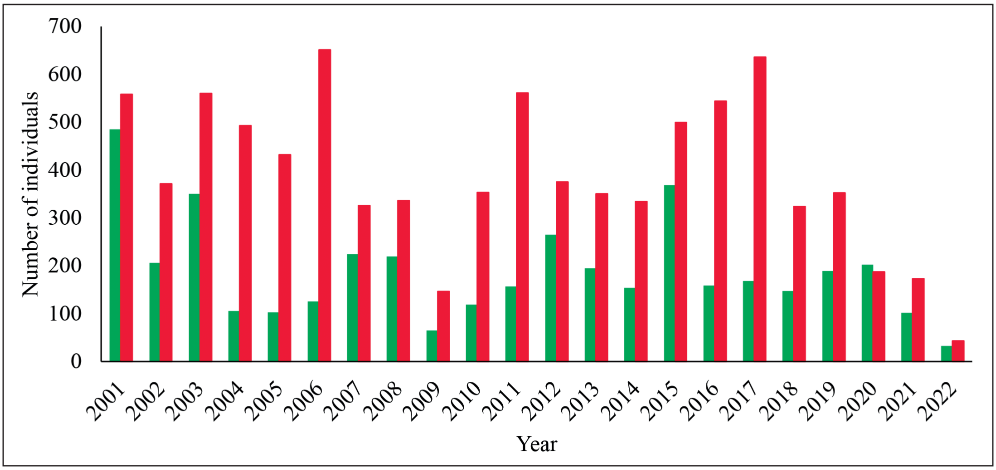

Figure 3. The number of adults (green bar) and juveniles (red bar) captured during the study period
3. ábra A vizsgálati időszakban fogott öreg (zöld oszlop) és fiatal (piros oszlop) fülemülesitkék számának változása

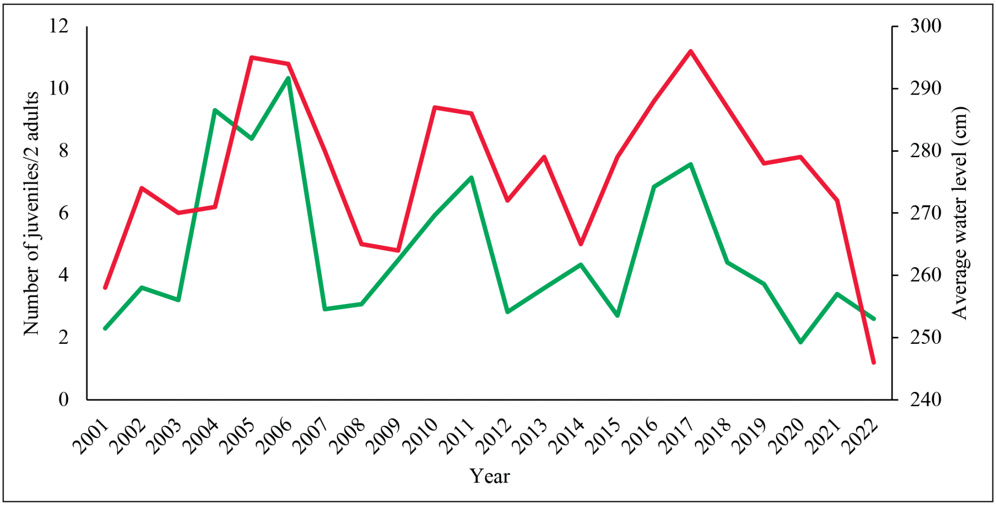

Figure 4. Distribution over time of the number of young per two birds (pairs) (green line) and the annual average water level of Lake Kolon (red line)
4. ábra A két madárra (pár) jutó fiatalok számának időbeli eloszlása (zöld vonal) és a Kolon-tó átlagos éves vízszintje (piros vonal)

Due to its special habitat requirements, the species may be threatened by several factors. The fragmentation and removal of old, perennial reedbeds with a small area of old reedbeds used by the species is still ongoing in both breeding and wintering areas. Burning and intensive management of these habitats (industrial reed cutting) negatively affect the presence of the species, as freshly emerged annual reedbeds are unsuitable for it (Báldi & Moskát 1995, Poulin *et al.* 2002, Trnka & Prokop 2006). Climate change-induced extreme weather events, such as cooling during the first brood or high temperatures during the second brood can

Table 1. The relationship between water level of Lake Kolon and captures of adult and juvenile birds

1. táblázat A Kolon-tó vízszintje és a fogásszám közti összefüggés vizsgálatának eredményei az öreg és fiatal madarak esetében

	Variable	Coefficient	S.E.	t	p	R^2
Adults	winter	17.19	41.21	0.417	0.681	0.006
	1. brood	11.12	21.911	0.507	0.618	0.014
	2. brood	9.84	45.034	0.332	0.744	0.039
	Jan. – Jul.	-39.39	93.068	-0.423	0.677	0.021
Juveniles	winter	-35.18	53.939	-0.652	0.523	0.172
	1. brood	-18.60	28.68	-0.648	0.525	0.259
	2. brood	-21.96	38.744	-0.567	0.578	0.291
	Jan. – Jul.	83.37	121.82	0.684	0.503	0.291

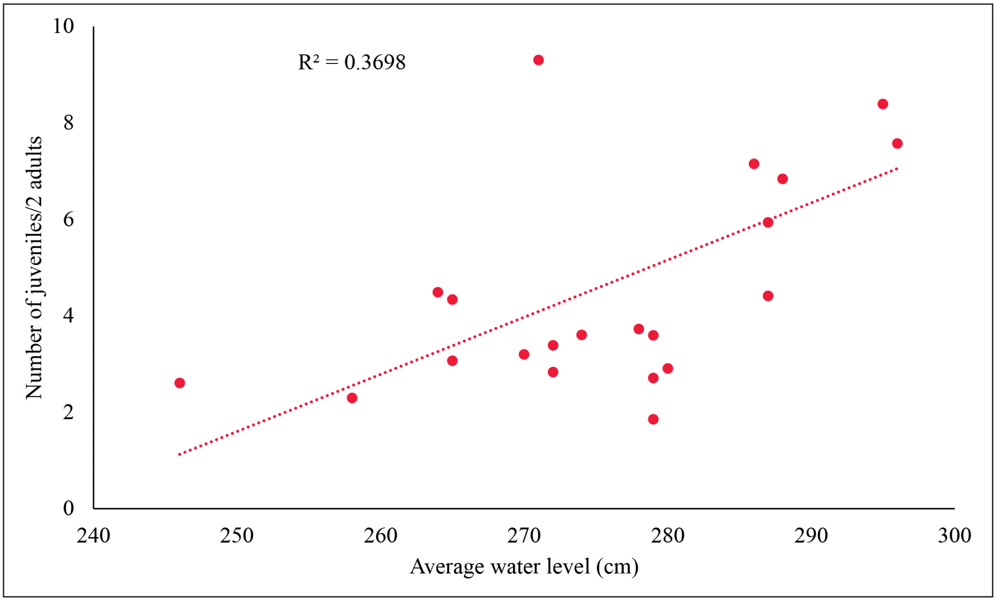

Figure 5. Correlation between the number of young per two birds (pairs) and the annual average water level of Lake Kolon

5. ábra A két madárra (pár) jutó fiatalok száma és a Kolon-tó átlagos éves vízszintje közötti összefüggés (korreláció)

also reduce breeding success and survival of individuals. These threats are common, but not uniform throughout the species' range.

In the Carpathian Basin, the larger breeding sites of Moustached Warblers are protected. The managers of the most important nesting sites pay special attention to the conservation of the species. Reed management activities are minimal in the approximately 1,000 hectares of Lake Kolon. Between 20 and 60 hectares are cut each year, which should not significantly affect the number of individuals of the species in the area.

Males return to the area and usually occupy territory in or near the same place where they successfully bred the previous year. The second year birds also show a high site fidelity. Males are more territorial than females (Vadász *et al.* 2008b). They breed twice a year, with additional breeding occassions. The first breeding occurs very early. This may be compromised by recurrent cold or rising water levels. In a study in southern Spain, an increase in water level during the breeding period negatively affected the population of the species, as higher water levels destroyed nests (Alambiaga *et al.* 2021). For our own data, a significant positive correlation between water level and juvenile/adult ratio was found when the water level of the whole breeding season and the average annual water level was considered. In contrast, water level had no influence when considering the winter and the first and second breeding seasons separately. The reason for this is that birds compensate for unsuccessful first broods by increasing the proportion of second and subsequent broods, if the conditions changes for the better (Haraszthy 2019).

During the breeding season, it is important to ensure adequate water cover in the habitat. At Lake Kolon, water level control is carried out according to the possibilities offered by precipitation conditions. During high water levels, it is possible to drain excess water, but unfortunately, as the area has no surface water recharge, there is no way to supply water in drought years. The Moustached Warblers feed at the lowest part of the reedbed or from the water surface (Dyrcz 2006). The water level measured in the channel, which is the data available, does not accurately reflect the water cover conditions within the marsh. Due to the specific micro-relief of the marsh, a drop of a few centimetres in the water level in the channel can cause drying out of a significant part of the inner marsh, and therefore the annual fluctuation of the water level can cause significant fluctuations in the annual breeding success in addition to other reasons not studied yet (e. g. nest predators, parasitic insects) (Haraszthy 2019). The presence or absence of water in the area mainly determines the number of pairs starting to breed (Németh Á. pers. obs.).

In conclusion, among the factors affecting the area, reed management certainly does not influence the local decline of the species, and weather factors can only affect it through drought. As similar fluctuations in the population of this species have been observed in a wetland in southern Spain, changes in migration routes and wintering sites may be the underlying causes, as is the case for so many long- and short-distance migratory bird species (Alambiaga *et al.* 2021, Petras & Vrezec 2022).

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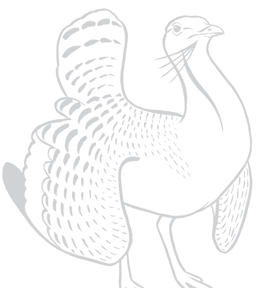

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Breeding of the Common Crane (*Grus grus* L.) in Hungary since the 19th century to modern times

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Abstract In the present study, I summarized the data on Common Crane *(Grus grus)* nesting published in the Hungarian ornithological literature from the mid-19th century to the present day. Based on these data, it can be observed that the crane was never a frequent nesting species in Hungary. It probably nested regularly until the early 19th century, then occasionally until the 1910s, after which, apart from two occasional reports, no nesting data were available until 2015. From this year onwards, it started nesting again in the Transdanubian region. In the examined period, 55.6% of the nests (n=25) originated from the Transdanubian region, 37.0% from the Tiszántúl region, and 7.4% from the Duna-Tisza area. The observations recorded during the nesting period showed a strong correlation with the spatial distribution of confirmed nests. 82.6% of the observations recorded (n=23) were from the Transdanubian region, 13.0% from the Tiszántúl region, and 4.3% from the Duna-Tisza region.

The distribution of nesting data between regions varies not only spatially but also temporally. The nesting data from the Duna-Tisza area and Tiszántúl region date back to the 19th century, with the exception of one report, while the most recent nesting data are from the Transdanubian region (Vas and Veszprém counties).

Keywords: crane nesting, breeding biology, brood rearing, nesting habitat, breeding success

Összefoglalás Jelen tanulmányban a 19. század közepétől napjainkig összegeztem a magyar ornitológiai szakirodalomban közölt darufészkelésre vonatkozó megfigyelési adatokat. Ezek alapján megállapítható, hogy a daru sohasem volt gyakori fészkelő faj Magyarországon, de a 19. század elejéig valószínűleg rendszeresen, majd az 1910-es évekig esetenként költött, ezt követően két eseti adatközlést leszámítva 2015-ig nincs fészkelési adata. Ettől az évtől újra költ a Dunántúlon. A vizsgált időszakban a fészkelések (n=25) 55,6%-a a Dunántúlról származik, a Tiszántúl részesedése 37,0%, a Duna-Tisza közéé 7,4%. A fészkelési időszakban regisztrált megfigyelések az igazolt fészkelések területi megoszlásával szoros korrelációt mutatnak. A regisztrált megfigyelések (n=23) 82,6%-a a Dunántúlról származik, a Tiszántúl részesedése 13,6%, a Duna-Tisza közéé 4,3%.

A fészkelési adatok megoszlásában az egyes régiók között nem csupán térbeli, hanem időbeli eltérés is tapasztalható. A Duna-Tisza közéről és a Tiszántúlról származó fészkelési adatok, egy közlést leszámítva, a 19. századból származnak, míg az elmúlt időszak fészkelési adatai a Dunántúlhoz (Vas és Veszprém vármegye) köthetők.

Kulcsszavak: darufészkelés, költésbiológia, fiókanevelés, fészkelőhely, költési siker

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Introduction

The species has a breeding range in the boreal and temperate regions of the Palaearctic faunal range, from Scandinavia (70°N) and north-eastern Europe through Russia (Indigirka, Kolyma) to the Far East (northern China). Currently, only sporadic nests are known south of the latitude (35°N) crossing the northern parts of France and Ukraine border (Turkey, Armenia and Azerbaijan) (Archibald & Meine 1996, Ellis *et al.* 1996, Hartwig 1997). It has patchy occurrences in the Balkan region and in Asia Minor. It formerly extended southwards through Spain, the northern regions of Italy, the northern parts of the Alps and the Carpathian Basin (Glutz von Blotzheim 1986, Schepers 2020). In the 19th century, hunting pressure and habitat loss led to the almost complete disappearance of nesting populations in central and southern Europe (eastern England, Spain, Italy, Greece, Austria, Duna-Delta) (Johnsgard 1983, Snow & Perrins 1998, Prange 2005). Since the 1960s, following the strengthening of the main nesting area (Deinet *et al*. 2013, Schepers 2020), new breeding data were recorded in several countries on the southern and western edges of the nesting periphery (Bobek *et al.* 2003, Salvi 2003, 2010, 2017, Repel *et al.* 2009, Prowse 2010, Deinet *et al.* 2013, Kever *et al.* 2018, Tichackova & Lumpe 2018, Van Der Ven 2018, Schepers 2020, Carys 2021, Jeremy 2021).

In the first half of the 18th century from Hungary, Marsigli (1726), and in the 19th century, Frivaldszky (1891) mentioned it as a nesting species. Concerning the time before the large-scale river regulations and drainages, several authors (Nagy 1917, Berzsenyi 1918, Hankó 1933, Fallon-Kund 1937, Keller 1937, Bertóti 1948) mentioned it as a regular nester in the Berek of Balaton, the Hanság of Fertőmellék and the Sárrét. According to Chernel (1903), the crane used to breed in many areas in Hungary in the past in the large swamps. According to Schenk (1917), it could not have been a frequent nester even in undisturbed, large areas of habitat otherwise potentially suitable for nesting.

Material and Method

This study is based on the data of nesting observations (n=25) (Lovassy 1887, 1907, Szomjas 1913, Láposi 1914, Nagy 1917, Schenk 1917, Berzsenyi 1918, Zeyk 1920, Nagy 1926, Csath, 1938, Schenk 1938a, 1938b, Sterbetz 1958, Bérczy *et al*. 1972, Keve 1978, Kaufman *et al*. 2017a, 2017b, 2018, 2021, Szekeres *et al*. 2021, Szekeres & Heffenträger 2021, Faragó *et al*. 2022, Fellner 2022, Szekeres & Németh 2022, Fellner, Z. pers comm. 2023) and observations recorded during the nesting period (n=23) (Vasvári 1921, Keller 1937, Tarján 1942, Sőregi 1958, Keve 1978, Kaufman *et al*. 2017a) from the 19th century to the present day, as known from the Hungarian ornithological literature.

I plotted the definite nesting and the hypothetical data for historical Hungary and the present territory of our country on a point map (ArcGIS 10.3). The correlation of the two data sets was performed using a two-sample t-test.

Results

Confirmed nesting sites

There is no detailed literature review on the nesting data of the crane in Hungary dating back to the 19th century, so only the works of Schenk (1917) and Berzsenyi (1918) are cited in connection with earlier nesting (e.g. Hadarics & Zalai 2008, Kaufman *et al*. 2017a, Haraszthy 2019, Végvári 2021a), noting that the last nesting record of the species before 2015 was from the 1910s, from the Nagyberek near Fonyód. In addition to these publications, earlier nesting data are known as well (Lovassy 1888, Szomjas 1913, Vasvári 1921, Nagy 1926, Sterbetz 1958, Pelle 1967, Ocsovszky 1964, Keve 1978), which can be used to clarify the knowledge on the species' historical nesting areas. Based on the known nesting data from the last two centuries (n=25), the crane was not a common nesting species in Hungary even at the beginning of the period under investigation, but it was a regular nester until the 1910s.

Except for one known nesting site (1870s, Mosorini Marshes, now Mošorin, Serbia), all data come from within our present borders, from nine counties (Bács-Bodrog: 3.7%, Békés: 18.5%, Csongrád-Csanád: 11.1%, Hajdú-Bihar: 3.7%, Pest: 3.7%, Somogy: 7.4%, Szabolcs-Szatmár-Bereg: 3.7%, Vas: 22.2%, Veszprém: 22.2%). The most dominant area

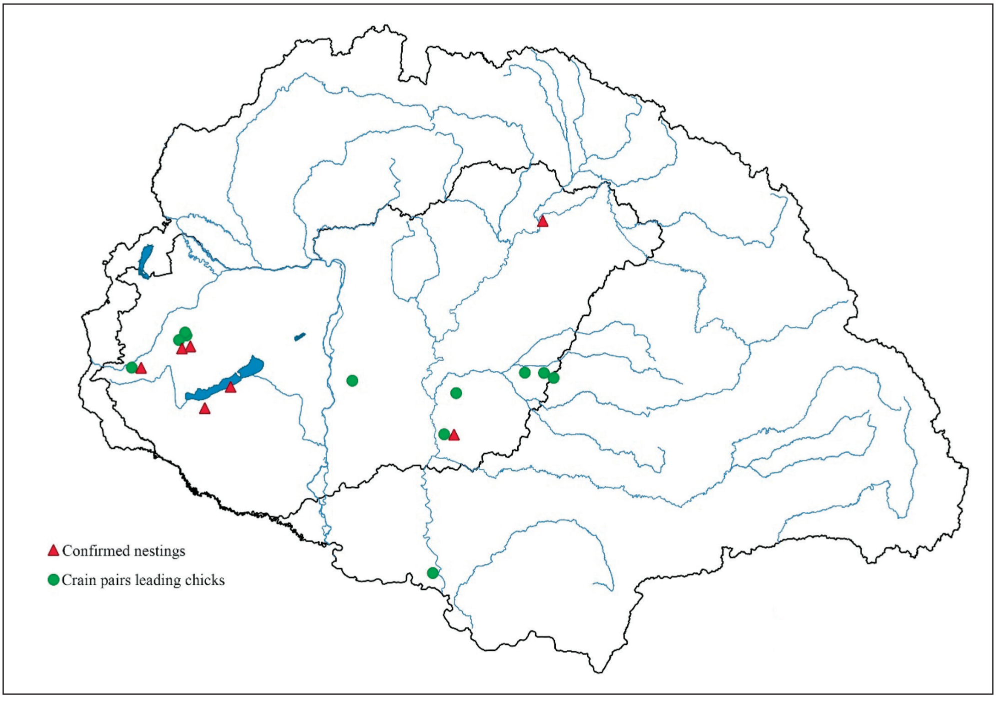

Figure 1. Geographical distribution of crane nests (n=12) and crane pairs (n=13) leading chicks in the Kingdom of Hungary and in the present territory of Hungary from the mid-1800s to the present

1. ábra Darufészkek (n=12) és csibéket vezető darupárok (n=13) földrajzi eloszlása a Magyar Királyság és Magyarország jelenlegi területén az 1800-as évek közepétől napjainkig is Transdanubia (55.6%), followed by nests from the Tiszántúl region (37.0%), while the smallest dataset comes from the Duna-Tisza area (7.4%). In the Transdanubian region, the western region (Marcal Basin, Rába floodplain) and the Nagyberek area on the southern shore of Lake Balaton are the dominant ones. The most recent nesting data also come from here, from the border area between the counties of Vas and Veszprém (Kaufman *et al.* 2017a, Kaufman 2018, 2021, Szekeres & Heffenträger 2021, Szekeres *et al.* 2021, Faragó *et al.* 2022, Fellner pers. comm. 2023).

The data (n=10) – with the exception of one publication (1956 Hódmezővásárhely [Sterbetz, 1958]) – for Duna-Tisza area and Tiszántúl region date from the 19th century *(Figure 1)*.

Known observations from the nesting season

The first known record, dated to June 15, 1875, comes from Ferenc Kovássy, who captured a full-grown specimen in Kócs-puszta in the area of Tiszafüred (Sőregi 1958). In 1884, Károly Antóny, a forester from Lubenyik (now Lubeník, Slovakia), shot a specimen on 18 May (Lovassy 1888). According to Vasvári (1921), Kálmán Bogyay saw three cranes flying towards Lake Kis-Balaton on 5 June 1921 in Zala County, near Komárváros. According to

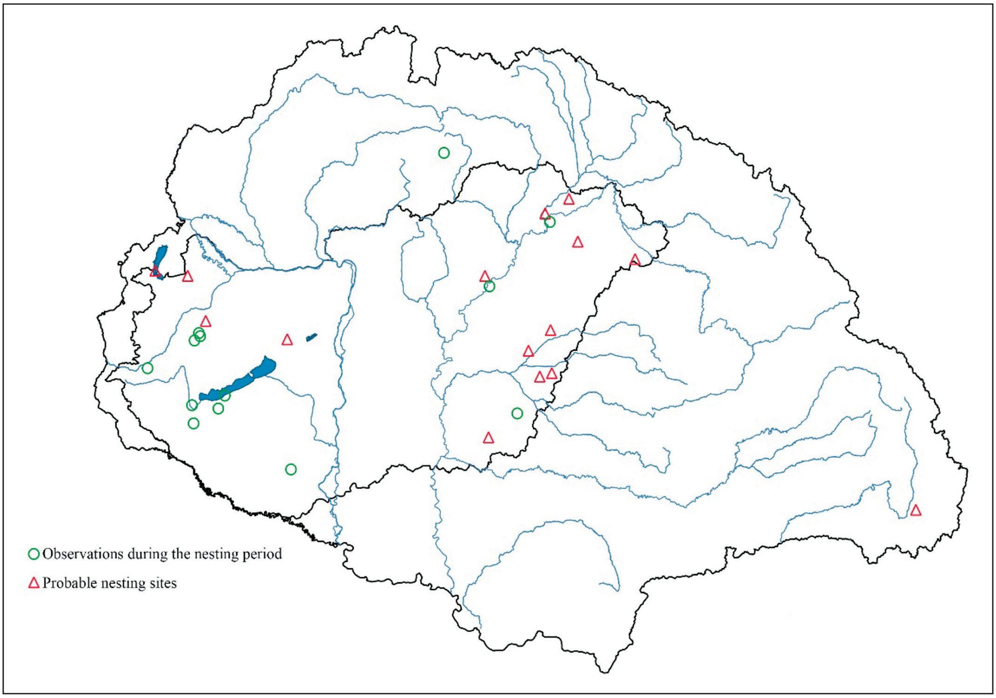

Figure 2. Geographical distribution of cranes (n=23) observed during the nesting period in the Kingdom of Hungary and the present territory of Hungary from the mid-1800s to the present day

2. ábra A fészkelési időszakban megfigyelt darvak (n=23) földrajzi eloszlása a Magyar Királyság és Magyarország jelenlegi területén az 1800-as évek közepétől napjainkig observations by some shepherds, 12 specimens were seen in May and June 1919 and 1920 in Ormánd (Baranya county). Sándor Ajtai-Kovách observed four specimens near Zalavár (Zala county) on 8 August 1937 (Keller 1937). The observation data from Ókígyós (today Szabadkígyós, Békés county) from 1940 is known for 5 specimens (Tarján 1942). The observations of Kálmán Bogyay are mentioned by Tarjáni (1978), who states that in 1905 Bogyay encountered cranes several times in the Nagyberek. László Bogdán saw cranes in the Fonyód area on 1 June 1971.

Subsequently, it was not until 2014 that the crane was observed again. In July 2014, a specimen was observed in the Marcal Basin trying to chase away a Marsh Harrier *(Circus aeruginosus)*, and another crane responded from the cover of tall vegetation. Based on this behaviour, Kaufman *et al*. (2017a) suggested that nesting was probable. Repeated attempts in the marshy area failed to conclude whether the pair was leading any chicks, so – as in 2016 – nesting was not confirmed (Kaufman *et al.* 2017b) *(Figure 2).*

The majority of the observations recorded during the breeding period also occurred in the Transdanubian region (82.6%), followed by the Tiszántúl regions (13.0%), while the Duna-Tisza area was the least significant (4.3%). The spatial distribution of observations recorded during the nesting period closely matches the distribution of nesting data (P=0.9201, df=24).

Discussion

Nesting

Over the last three decades, the number of individuals of nesting populations of the species has increased significantly in the nesting areas of the Crane: Scandinavia (Lundgren 1999, Lundgren & Lundin 2003, Lundgren 2018), Poland, the Baltic countries (Nowald *et al*. 1999, Budrys 2003, Ojaste *et al*. 2018), Finland, Ukraine (Gavris 1999, Veselskiy 2023), Russia (Markin 2003), Germany (Lerhmann & Mewes 2018, Schmitz Ornes 2018, Lehrmann & Nowald 2023, Schmitz-Ornés *et al.* 2023). European nesting populations of the species were estimated at 82,000–92,000 pairs in the 2000s (Schepers 2020), while BirdLife International estimated the number of nesting birds in 2015 at a minimum of 113,000 pairs, representing more than 225,000 reproductively mature specimens (Ashpole 2015). The nesting population size of the species had reached around 140,000–150,000 pairs by 2019. (Schepers 2020).

Several recent nesting records are known from the southern and western periphery of the nesting area (UK (Carys 2021), Belgium (Nowald & Prange 2013, Kever *et al*. 2018, Jeremy 2021), the Netherlands (Van Der Ven 2018), France (Salvi 2003, 2010, 2017), Czech Republic (Tichackova & Lumpe 2018), Slovakia (Repel *et al*. 2009). This nesting area expansion reached Hungary as well (Kaufman & Hencz 2015, Kaufman *et al*. 2017a, 2017b, Kaufman 2018, 2021, Haraszthy 2019, Szekeres & Heffenträger 2021, Szekeres *et al*. 2021, Végvári 2021a, Fellner 2022, Szekeres & Németh 2022).

In the last three decades or less, the migration phenology of European populations has changed, probably due to climate change. Previously, the entire population was migratory in Europe, spending the winter in the Iberian Peninsula and North Africa. Nowadays, migratory populations are travelling increasingly shorter distances as the wintering grounds shift northwards, and in some parts of Europe former migratory populations are overwintering in areas such as the British Isles, Belgium and even France or Germany (Fintha 1993, Végvári, 2009). From the northern nesting areas (Finland, Baltic States) the cranes arrived in our region along the so-called Baltic-Hungarian migration route and continued to their wintering grounds from Tunisia to Sakhalin, but the total size of the overwintering flocks is also increasing in Hungary. The Tiszántúl region of the country plays a more important role in the autumn migration, although cranes are also increasingly frequent autumn visitors in the west Hungarian region. The conditions of the eastern Hungarian region favour the species during migration, with its extensive feeding and roosting sites (large cornfields, drained fishponds) (Fintha 1993, Végvári & Tar 2002). Another factor in the polarisation between the two regions of the country is the choice of nesting site. Habitats suitable for nesting are typically available only in the Transdanubian area, so the plastic, adaptive migration strategy of the crane in response to changes in environmental factors, the spatial and temporal pattern of feeding and resting sites and nesting areas explain the polarisation of migration data and breeding occurrences between the eastern and western regions of the country.

The cranes preferred marshy, open nesting areas in Belgium (Kever *et al*. 2018), while in the UK they settled in reedbeds in the Norfolk Broads and flooded grasslands in Cambridgeshire (Bridge & Morgan 2018). For nests (n=126) surveyed in Germany, Mewes & Rauch (2012) found that a smaller percentage of nesting pairs (34%) chose this type of habitat, with more than half (56%) of breeding pairs nesting in the forest (willow, birch, and alder swamps).

During recent successful nesting events recorded in Hungary, cranes built their nests in open areas, but under the shelter of the lesser and the greater pond sedges *(Carex acutiformis, C. riparia)* providing sufficient cover (Kaufman & Hencz 2015, Kaufman *et al*. 2017a). The known nests from Hungary (Marcal Basin, Rába floodplain) (Kaufman *et al*. 2017a, Szekeres *et al*. 2022, Fellner pers. comm. 2023) were in open, marshy areas similar to the Belgian nesting sites.

For crane nesting, permanent water cover is required in the area (Leito *et al*. 2005), which – considering the average territory size of almost 250 ha (Mannson *et al*. 2013) – does not provide adequate habitat for even some pairs of cranes in the current state of the Marcal Basin and the Rába floodplain without habitat reconstruction intervention. In Belgium, cranes prefer to nest in a variety of peat bogs and shallow, islands with vegetation surrounded by water, and the recent reconstruction of the Hautes Fagnes area will help them to colonise as much as possible (Kever *et al*. 2018). In Hungary, conservation interventions to support wintering (for example the creation of feeding areas and roosting sites ensuring their tranquillity, the organisation of autumn flooding in drier years, and the appropriate timing of draining fish ponds) are a priority for conservation (Végvári 2009), but no interventions to support nesting have been implemented so far. Based on the above, we can expect to see nesting of the crane in Hungary in the coming years, but the lack of suitable nesting areas will limit the establishment of significant numbers of the species.

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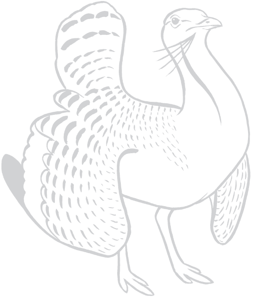

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Aspects of cranial adaptation in foot-propelled diving birds – foraging and visual fields of some piscivorous species

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Abstract The adaptation to an aquatic lifestyle has occurred several times during the evolution of birds. The transition from a terrestrial to an aquatic lifestyle requires enormous changes in morphology, physiology, and behaviour. In addition to many physical parameters, aquatic foraging is also a limiting factor, despite the fact that aquatic habitats are often rich in food and prey. Despite many previous studies (foraging, physiology, anatomy, ecology, etc.) and a large amount of data regarding piscivore foot-propelled diving birds, our knowledge on the possible relationships between cranial morphology, feeding mechanism, visual abilities and binocularity is still very limited. In this study, we attempt to achieve a deeper understanding of the visual abilities and foraging related attributes of 5 recent and 1 extinct species of foot-propelled diving birds. We attempted to measure the horizontal visual fields of these species using 3D visualization techniques. According to our model, the narrowest horizontal binocular field was measured in Anhinga *(Anhinga anhinga)*, and the widest was measured in the cases of Great Cormorant *(Phalacrocorax carbo)* and Goosander *(Mergus merganser)*. Our results support the prediction that binocular field variation among aquatic birds is primarily associated with foraging methods and activities.

Keywords: evolution, skull shape, cranial morphology, ecomorphology, morphometrics, anatomy, binocular vision, visual field, aquatic birds, piscivorous birds

Összefoglalás A vízi életmódhoz való alkalmazkodás több alkalommal kialakult a madarak evolúciója során. A szárazföldi életmódról a vízi életmódra való átállás óriási változásokat követel meg morfológiai, élettani és viselkedésbeli vonatkozásban is. Számos fizikai paraméter mellett a vízben való táplálékkeresés is korlátozó tényező, annak ellenére, hogy a vízi élőhelyek általában gazdagok táplálékban és zsákmányállatokban. Az elsősorban lábukat használó halevő búvármadarakkal kapcsolatban számos korábbi tanulmány (táplálkozás, fiziológia, anatómia, ökológia stb.) és a rengeteg adatmennyiség ellenére a koponyamorfológia, a táplálkozási mechanizmus, a látási képességek és a binokularitás közötti lehetséges összefüggésekről szóló ismeretek erősen korlátozottak. Jelen tanulmányban 5 recens és 1 kihalt faj vizuális képességeinek és táplálkozáshoz köthető tulajdonságainak kapcsolatát vizsgáltuk látótereik mérésével, 3D vizualizációs technológiák segítségével. A modell szerint a vizsgált fajok közül a legkeskenyebb binokuláris látómezővel a kígyónyakú madár *(Anhinga anhinga)*, a legszélesebbel pedig a nagy kárókatona *(Phalacrocorax carbo)* és a nagy bukó *(Mergus merganser)* rendelkeznek. Eredményeink erősítik azt az észrevételt, miszerint a vízimadarak binokuláris látómezejében való eltérések elsősorban az életmódbeli és a táplálék megszerzésében való különbségeknek köszönhetők.

Kulcsszavak: evolúció, koponyaalak, koponyasajátosságok, ökomorfológia, morfometria, anatómia, binokuláris látás, látómező, vízimadarak, halevő madarak

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Introduction

The transition from a terrestrial lifestyle to an aquatic requires tremendous changes in morphology, physiology and behaviour. Buoyancy is a major determinant of the locomotory cost in diving animals, especially in aquatic birds due their highly pneumatic skeletal system (Kato *et al.* 2006). For the success of living and feeding in aquatic environment, several bird clades chose different evolutionary traits to increase their locomotor performance, buoyancy control, and reduce drag forces at the same time (Fish 2016, Houssaye & Fish 2016, Gutarra & Rahman 2022). In addition to many physical parameters, foraging in water is also a limiting factor, despite the fact that aquatic habitats are often rich in food and prey (Dethier *et al.* 2003). Different foraging behaviours, swimming and diving abilities highly contribute to the coexistence of sympatric species in the same environment and in the vertical and horizontal partitioning of the habitat (Livezey & Humphrey 1982, Pöysä 1983a, 1983b, Johnsgard 1987, Hustler 1992. A central tenet of optimal foraging theory is that natural selection has produced predators that employ behavioural strategies which maximize foraging efficiency (MacArthur & Pianka 1966, Pyke *et al.* 1977). This assumes that predators have evolved phenotypes that maximize fitness in particular environments. Sensory systems play a key role in finding prey; vision is particularly the most important. The specific capacities of sensory organs are dictated by their adaptive significance and physiological trade-offs. For instance, the amphibious behaviour presents major sensory problems to seabirds since optical requirements in air are fundamentally different from those in water (Lythgoe 1979).

During the history of Earth, several primarily terrestrial clades of birds have returned to the water and adapted, on different levels, to live in an aquatic environment (Kelley & Pyenson 2015, Motani & Vermeij 2021) *(Figure 1)*. The aquatic adaptation of different lineages to similar physical parameters and challenges has resulted in similar external morphology (Lindgren *et al.* 2010, Motani & Vermeij 2021, Gutarra & Rahman 2022). The first known avialans adapted to foot-propelled swimming and diving are the members of the order Hesperornithiformes which includes a small and restricted group of marine toothed, foot-propelled diving birds (Panteleyev *et al.* 2004). These birds evolved and colonised the marine and freshwater ecosystems in the Cretaceous (Marsh 1880, Chiappe & Witmer 2002, Bell & Chiappe 2016). One of the most well-preserved species are known from numerous fossil remains, *Hesperornis regalis* (Bell & Chiappe 2022). There are many anatomical similarities with today's diving species, this bird also had a long flexible neck with long and narrow jaws but armed with sharp recurved teeth formed together a perfect tool to catch fast fishes (Cracraft 1982, Houde 1987, Witmer & Martin 1987, Padian & Chiappe 1998). Since the discovery of *Hesperornis* (Marsh 1880) several specimens have been found, therefore, the elements of the

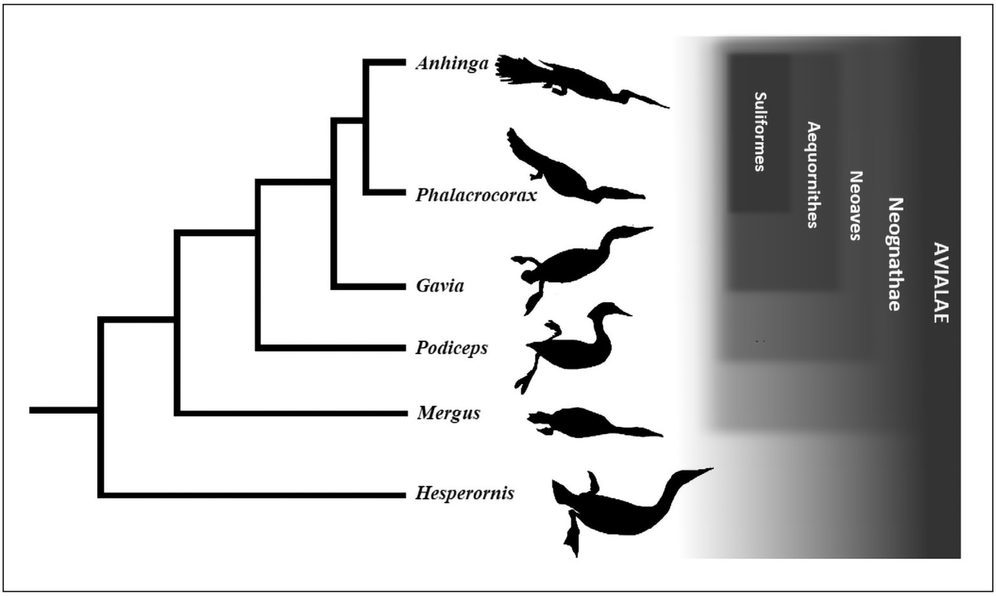

Figure 1. Foot-propelled diving bird lineages in Earth history (Braun & Kimball 2021)
1. ábra Lábbal úszó, víz alá bukó madárcsoportok a földtörténet során (Braun & Kimball 2021)

cranium are better known and paint a more accurate picture of the whole skull (Gregory 1952, Gingerich 1973, Bühler *et al.* 1988).

According to our current knowledge, the most of the main clades of modern birds evolved in the Middle to Late Cretaceous (Moen & Morlon 2014). Some species of modern clades already adapted to aquatic life, as the loon-like *Polarornis*, but its taxonomic position is still disputed (Mayr *et al.* 2018). After the Cretaceous-Paleogene mass extinction, birds diversified dramatically and conquered numerous empty ecological spaces (Brusatte *et al.* 2015). Through the following era, numerous foot-propelled piscivorous species appeared, including grebes (Kurochkin 1976, Zelenkov 2015), loons (Storer 1956, Mayr 2004), anhingas (Mayr *et al.* 2020), cormorants (Mayr 2015) and early anatids (Alvarez & Olson 1978, Zelenkov 2020).

The more advanced foot-propelled divers are characterised by an elongated body, caudally positioned hind limbs, with powerful pelvic and leg musculature to make them enable to pursuit hunt their underwater prey (Kristoffersen 2001, Clifton & Biewener 2018, Segesdi & Pecsics 2022).

Several studies discussed the various anatomical adaptations of these groups previously, but our understanding of the adaptation of cranial features and visual abilities are still limited (Martin 2007, 2012, 2014).

The study of the visual abilities of birds, as related to their ecology and evolution, has a long history, and over the past several years, huge amount of data has been collected, mainly quantified as visual fields (Martin 2014, Cerio & Witmer 2020). "In vivo" observations on field are difficult, time and access to living specimens of rare species is extremely limited. Studies with endangered species raise additional problems and difficulties, furthermore, comparison to extinct species is impossible. Performing ophthalmological studies and measures on living or dead specimens requires expensive infrastructure, technologies, specific training and experience. Modelling in a virtual area is a well-established practice. Some authors have even predicted static visual fields in extinct species using inverse perimetry (Stevens 2006) or used simple ray tracing method (Rinehart & Breton 2009).

Binocular field topography varies among species associated with controlling bill and legs, position changes during hunting, foraging activities (Martin & Wanless 2015), and feeding their offspring (Martin *et al.* 2005). In diving birds, binocularity enables accurate control of the bill, and their time to reach the prey items (Martin 2014). Binocular field topography represents an important trait for further understanding the evolution of avian vision and creates a broader picture of convergent evolution of distinct lineages.

Unfortunately, despite numerous studies and the enormous amount of data with regards to the feeding ecology of foot-propelled diving birds, our knowledge about the potential relationships between cranial morphology, feeding mechanism, visual abilities and binocularity is still limited.

In this preliminary study, our aim was to increase our understanding regarding the role of binocularity in foot-propelled fish-eating birds, and observe the differences in skull morphology that reflect on feeding habits. The virtual models allow us to predict and measure static visual fields in two dimensions within a virtual environment, and to give a rough estimation of binocularity in diving piscivorous birds.

Materials and Methods

Species and specimens

This study is based on skulls from 5 extant and 1 extinct species. All skulls are from adult specimens in the collection of the Eötvös Loránd University, Budapest, Hungary, Great Cormorant *(Phalacrocorax carbo)*, the collection of the Hungarian Natural History Museum Budapest, Hungary, Great Crested Grebe *(Podiceps cristatus)*, Goosander *(Mergus merganser)*, the digital archives of University of Wyoming, Laramie, USA, Common Loon *(Gavia immer)*, and the Natural History Museum of London, London, United Kingdom, Anhinga *(Anhinga anhinga)*. For the extinct bird *Hesperornis regalis*, a virtual model was created in Blender free 3D modelling software (Community 2018), following the previous studies as references (Gingerich 1973, Bühler *et al.* 1988) *(Figure 2)*.

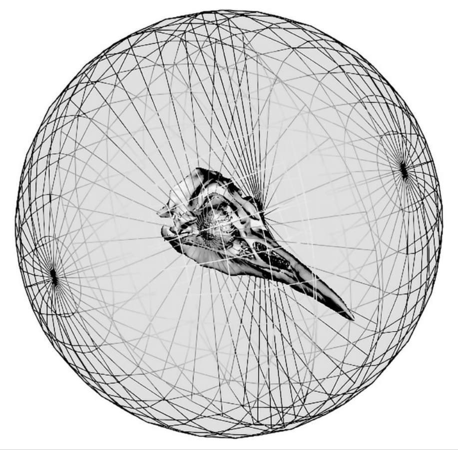

Figure 2. The 3D digital model of *Hesperornis regalis* that we used in our study. The parameters of the skull was based on previous studies as references (Gingerich 1973, Bühler *et al.* 1988)

2. ábra A *Hesperornis regalis* koponyájának 3D modellje, amelyet jelen tanulmányunkban használtunk. A koponya paramétereihez korábbi tanulmányokat használtunk referenciaként (Gingerich 1973, Bühler *et al.* 1988)

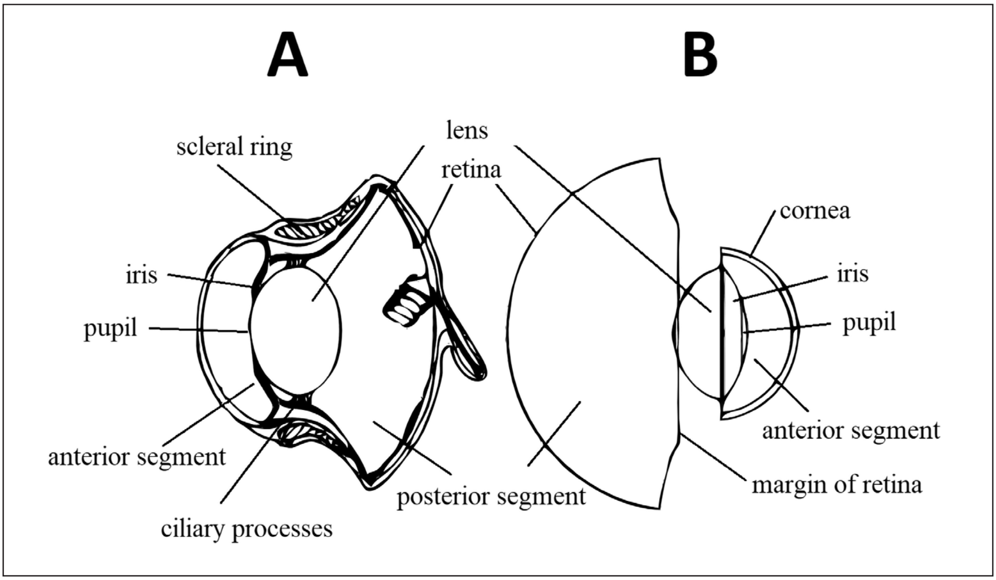

Figure 3. A) Simplified cross section of an avian eyeball with anatomical dimensions in *caudal* view (Schmitz 2009). B) Schematic eyeball used for the model (Cerio & Witmer 2020)

3. ábra A) A madárszem egyszerűsített keresztmetszeti ábrája az anatómiai dimenziókkal *alsó* nézetben (Schmitz 2009). B) Sematikus szem, amely modellként szolgált (Cerio & Witmer 2020)

For the study, larger extant species from different clades were deliberately chosen that feed almost exclusively on fish in their adult age. Information of foraging behaviour was gathered from primary literature (Cramp 1978, del Hoyo *et al.* 1992).

No birds were killed in order to obtain their skull; all either died of natural causes or whilst in captivity.

Models and procedures

We attempted to depict horizontal sections through the visual fields. For our measures, we captured the skulls in dorsal view at the plane of optic axes and used schematic eyeballs to calculate the visual fields, and to estimate the binocular sections. Schematic eyeballs utilize several simplifying assumptions to estimate the optical performance of the visual apparatus (Cerio & Witmer 2020). Some of these assumptions are known to be slightly inaccurate but are nonetheless useful approximations for assessing optical performance, and can provide theoretical estimates of the peripheral limits of visual fields (Martin 2007). Despite the aspects of inaccuracy, these schematic eyeballs are good enough to estimate the size of the visual areas that are mathematically consistent with behavioural measurements. Gross morphology of the eyeball was based on previous studies (Ritland 1982, Schmitz 2009, Cerio & Witmer 2020) *(Figure 3)*. Due to the aim of this recent study, we were counting in every situation with slightly converged eyes in a relaxed position without the scientific data of eye movements. The skulls were standardised and fixed at the tip of the bill (90°) and at the cross section of optic axis of left eye and the right eye (0°).

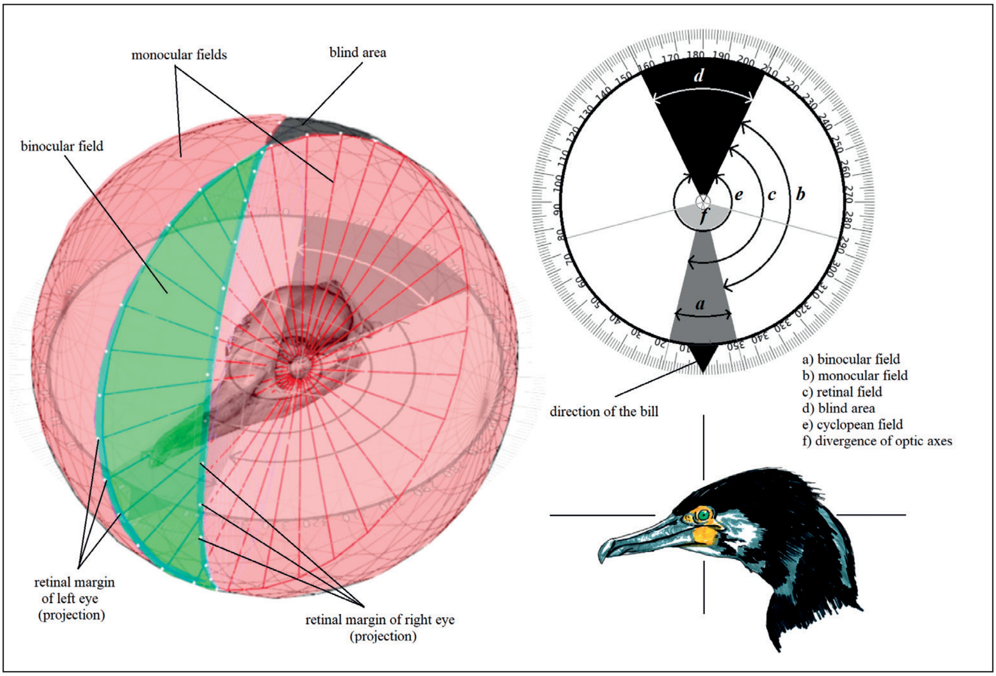

Figure 4. Visual fields in Great Cormorant. Perspective views of orthographic projection of the retinal margin boundaries of the two eyes in slightly converged, relaxed position. In the diagram the bird's head is positioned at the centre of a transparent sphere with the bill tips and field boundaries projected onto the surface of the sphere (without the positions of *pecten* and optical axes)

4. ábra A nagy kárókatona látómezeje. Perspektivikus nézet a retina széleinek ortografikus kivetítésével, ahol a szemek kissé konvergált, nyugalmi állapotban vannak. Az ábrán a madár feje egy átlátszó gömb közepén helyezkedik el, a csőr végével és a látómező határaival a gömb felületére vetítve (a *pecten* és az optikai tengelyek megjelölése nélkül)

Visual fields of foot-propelled diving birds were measured in a horizontal plane when the eyes are in a standard relaxed position and slightly converged *(Figure 4)*.

Results

According to our model, the narrowest horizontal binocular field was measured in Anhinga, and the widest was measured in the cases of Great Cormorant and Goosander. The results of Common Loon, Great Crested Grebe and *Hesperornis* were ranged between the previously mentioned species. Obviously, the species with wider binocular fields have narrower monocular fields and greater blind areas *(Table 1, Figure 5)*.

The visual field scores showed that foraging behaviour and environmental conditions were important predictors. In poor visibility conditions, swamps and lakes with dense vegetation, a wide binocular field is less important for the Anhinga. Even slower prey items do not require better depth perception either.

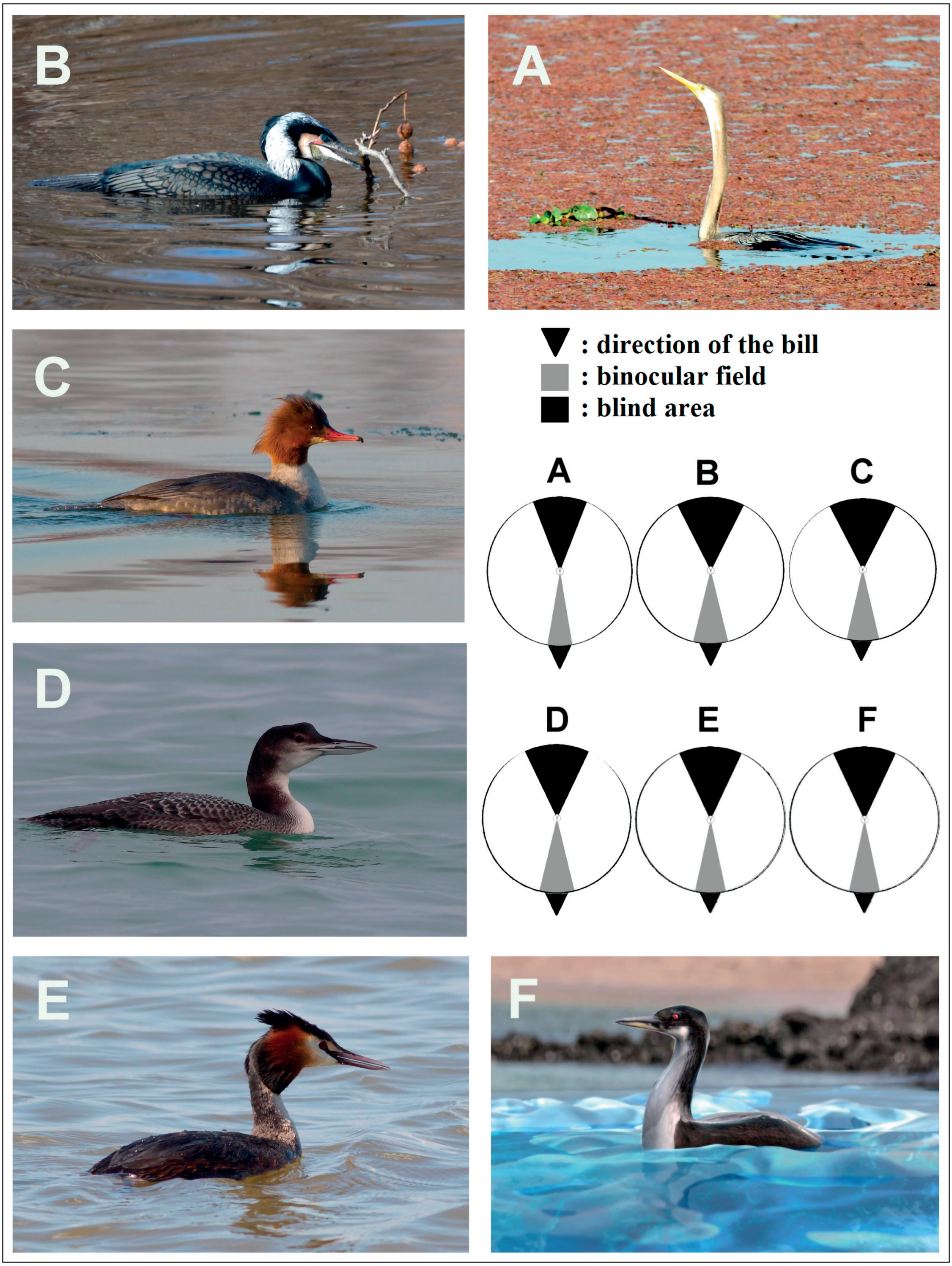
B
A
C
▼ : direction of the bill
▨ : binocular field
■ : blind area
A
B
C
D
E
F
D
E
F

Figure 5. Horizontal sections through the visual fields of birds with slightly converged eyes in a relaxed position: *Anhinga* (A), *Phalacrocorax* (B), *Mergus* (C), *Gavia* (D), *Podiceps* (E), *Hesperornis* (F) (Photos: *Anhinga*: Tibor Csörgő; *Phalacrocorax*: Dániel Baráth; *Mergus, Gavia, Podiceps*: József Mészáros; *Hesperornis*: 3D digital image modelled and rendered in Blender by the authors)

5. ábra A madarak látómezejének vízszintes metszete, ahol a szemek kissé konvergált, nyugalmi állapotban vannak: *Anhinga* (A), *Phalacrocorax* (B), nagy bukó *Mergus* (C), *Gavia* (D), *Podiceps* (E), *Hesperornis* (F)
(Fényképek: *Anhinga*: Csörgő Tibor; *Phalacrocorax*: Baráth Dániel; *Mergus, Gavia, Podiceps*: Mészáros József; *Hesperornis*: 3D digitalis kép Blenderben modellezve és renderelve a szerzők által)

Moreover, in better visual conditions, binocularity plays a more important role in the pursuit of relatively small and fast prey items (Common Loon, Great Crested Grebe, Goosander). Furthermore, it has a greater role in feeding from the bottom during pecking and fishing from the upper layer of the water column (Great Cormorant, Goosander) *(Figure 5)*.

In our model, the scores of Great Crested Grebe and the extinct *Hesperornis* were the same on each level *(Table 1)*.

Table 1. Comparison of visual field parameters in horizontal section
1. táblázat A látómező paramétereinek összehasonlítása vízszintes metszetben

	Anhinga	**Great Cormorant**	**Goosander**	**Common Loon**	**Great Crested Grebe**	***Hesperornis***
binocular field	20°	28°	28°	26°	24°	24°
monocular field	148°	140°	139°	140°	143°	143°
retinal field	168°	168°	167°	166°	167°	167°
blind area	44°	52°	54°	54°	50°	50°
cyclopean field	316°	308°	306°	306°	310°	310°
divergence of optic axes	140°	124°	126°	126°	130°	130°

Discussion

In our study, the binocular field of Anhinga was the smallest. Despite the evidence of obvious similarities with cormorants, in other respects than orbital region, the shape of the bill and certain muscles associated with these regions, features of the skull are very different due to the extreme elongated skull (Marugán-Lobón *et al.* 2022). These are consequences of different lifestyle and hunting methods. Their adaptation to obtain fish evolved on different directions, while ecological ranges of the species may overlap, both appear to be most proficient in quite different habitats. The cormorant exhibits a far greater degree of specialization for active pursuit of fish and the skull is adapted for precise and powerful prehension. The Anhinga has achieved proficiency in an aquatic environment through adaptations, which emphasize slow, prowling progression under water (Owre 1967). Prey is usually approached by stealth and pierced with a thrust of the mandibles. Far less buoyant, an adaptation which facilitates its remaining submerged while moving slowly, it does not remain long in the water after prey is secured (Owre 1967, Dostine & Morton 1989). Although these bird are not fast swimmers, they are very effective ambush aquatic hunters, relying on their quick necks and sharp bills to catch prey. They target slower-moving species of fish and stalk them underwater, finally striking out with their long neck and spearing the prey with the beak (Hustler 1992), then bring the prey above water and manipulate it in order to swallow the fish head first in ideal direction (Owre 1967). The binocular field is long and narrow, and the central placement of the bill suggests that vision is used to guide the bill position during visual foraging (Hayes *et al.* 1991).

The binocular field of Great Cormorant is wider than in the case of Anhinga. The visual fields of cormorants are associated with visually guided pecking or lunging at prey. The bill tip projection falls centrally or within the lower half of the binocular area. The binocular field is relatively long and narrow, the maximum binocularity occurs at or above the projection of the tip of the bill (Martin *et al.* 2008, White *et al.* 2008). Great cormorants eat almost exclusively fish less than 20 cm in length and occasionally eat larger fishes and crustaceans and molluscs (Jepsen *et al.* 2018, Lyach *et al.* 2018). Fish are taken mostly in shallow water less than 20 m deep, but they hunt throughout the whole water column, from the surface to the bottom, depending on the attributes of their prey. They dive in and pursue fish under the water using their vision, eating small fish underwater and bringing larger fish to the surface to swallow (Lehikoinen *et al.* 2017). Great cormorants may forage alone or in flocks, varying regionally and possibly with subspecies. Great cormorants eat a wide variety of fish species, but may rely primarily on only a few species that are abundant locally, often bottom-dwelling ones. In those areas where Great Cormorants are sharing habitat with the swifter pursuit hunter Double-crested Cormorants *(Nannopterum auritum)*, they eat more bottom-dwelling fish species (Ross 1977).

In our study, the Goosander showed similar attributes to cormorants. Foraging behaviour, rather than diet, is the primary driver of binocular field size and binocular shape associated with the horizontal plane among the Anatidae (Cantlay *et al.* 2023). Goosanders are skilled diving predators, eating mainly slower and smaller fish species. Their serrated bills are well suited for capturing small and slippery preys. Similarly to cormorants, a hooked *rostrum* is ideal for fishing in upper water column. Clear water is preferred for feeding because these birds hunt primarily by sight (Wood & Hand 1985, Brewer *et al.* 1991). Mergansers are usually foraging in shallow water, but they will hunt wherever prey is abundant. Other merganser species forage in several different ways as they float at the surface and looking underwater column as they go, they dive in deep or shallow water to search for prey (Munro & Clemens 1939). Mergansers diving to obtain fish, therefore, had lesser mean angular separation sizes (the bill tip is furthest from the maximum binocular field width) compared to their relatives, as they are dependent upon visual discrimination of food items in the bill (Lisney *et al.* 2013, Cantlay *et al.* 2023).

Common Loons are visual predators, locating fish by sight and diving deep to catch them. The binocular field is similar to the Great Cormorant and Goosander but a bit narrower. These swift-swimmer birds' binocular field is projecting to tip of the bill as they are targeting schooling fishes with higher speed. They generally hunt in water 2 to 4 m deep. Because they rely on sight, clear water is critical to Common Loons (Barr

1996, McIntyre & Barr 1997), and they do not fish at night. The prey consists of small or medium sized fish, including cod, herring, sprat, sculpins, and occasionally, other small vertebrates and invertebrates. Food is usually swallowed underwater, their oesophagus is relatively elastic. When they find a suitable prey species in abundance, they will fully exploit it (del Hoyo *et al.* 1992).

The diet of Great Crested Grebe consists mainly of large fish, but also includes insects and other invertebrates. Larger prey item does not requires broad binocular field. These birds catch their prey by diving under the surface of the water, similarly to loons, but they forage the most during dawn and dusk, probably because this is when their prey are closest to the surface (Newbrey *et al.* 2012). This makes the fish easier to detect visually and also reduces diving distance (Ulenaers *et al.* 1992, Gwiazda 1997). Large sized grebes are fast and aggressive hunters. At higher speed, these birds spear larger fishes with their long bill (Cramp 1978).

In our model, the results were exactly same in the case of *Hesperornis* and Great Crested Grebe. The skull is elongated with a long rostrum similar to that seen in large grebe and loon species *(Figure 6)*. These similarities make them an example for mosaic

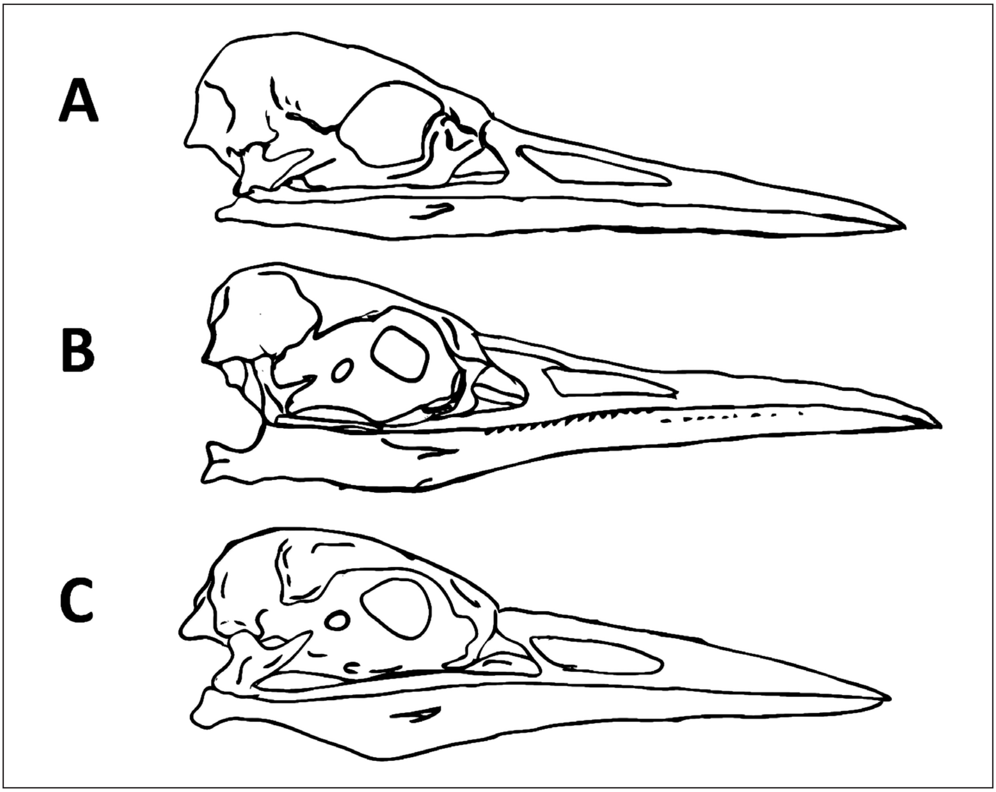

Figure 6. Convergent attributes on the skulls of Common Loon *(Gavia immer)* (A), Great Crested Grebe *(Podiceps cristatus)* (B) and *Hesperornis regalis* (C) (lateral view)

6. ábra Konvergens tulajdonságok a jeges búvár *(Gavia immer)* (A), búbos vöcsök *(Podiceps cristatus)* (B) és a *Hesperornis regalis* (C) koponyáin (oldalnézet) evolution (Bell & Chiappe 2016).This elongation is due primarily to the length of the premaxilla (Bell & Chiappe 2022). The dentary and maxillae of hesperornithiforms bear small recurved teeth set in a groove (O'Connor 2019). The retention of teeth in birds is a conserved character with similar molecular and developmental mechanisms inherited from their non-avian reptilian ancestors. The number, shape, and arrangement of teeth in the jaws of *Hesperornis* have trophic implications, with the increased number of teeth in the dentary having been related to a piscivorous diet (Wu *et al.* 2021). The distinct and delicately hooked cranial terminus of the premaxilla, which may have been emphasized by the shape of the keratinous beak, may have also been useful for the retention or capture of larger fish. In addition to many other similar characteristics that they share with grebes, the absence of teeth in *premaxilla* suggests that these fast swimming underwater hunters may spear occasionally larger fishes with their long bill. Several other features of the skull of *Hesperornis* have been used to support interpretations of a diving lifestyle. The large size of the auricular *fossae*, the reduced dorsal pneumatic recess, and the flattened cerebellar *fossa* as traits shared with modern diving birds. The latter two of these features was noted as possibly associated with the expansion of the dural sinuses (Elzanowski & Galton 1991), a convergent feature found in modern diving birds (Jessen 2001). Unless the few exceptions, it is interesting to note that among modern diving birds, foot-propelled species are generally found in shallow, primarily freshwater environments, while pelagic marine divers are primarily wing-propelled birds (Houde 1987). This represents a dichotomy between shallow and deep-water diving, with wing-propelled divers typically engaging in much deeper dives than foot-propelled divers (Bell *et al.* 2019).

A number of species of waterfowl are active and feed at night, while others, such as the pursuit-diving mergansers, appear to be limited to foraging under brighter conditions (del Hoyo *et al.* 1992, Lisney *et al.* 2013).

The maximum width of the binocular field is in a range of bird species equal only 20–30 degrees. Thus, it has been proposed (Martin & Katzir 1999) that the essential function of binocularity in birds may lie in the provision in each eye of an optic flow-field, which expands symmetrically about a target point in front of the head.

It can be suggested that this width represents an optimal trade-off that provides sufficient optic flow-field information to ensure accurately controlled rapid approaches towards objects during foraging, while at the same time, maximising the width of the peripheral, and hence cyclopean, visual field within constraints imposed by each eye's optical design (Martin 2007). In the case of aquatic piscivore birds, not only the food but the hydrodynamic demands and the drag forces affect the cranial morphology (Harrison 1957, Pecsics *et al.* 2017).

In an attempt to deeper understand the complexity of aquatic birds' foraging behaviour and visual fields, we must take into account not just the comparative anatomical descriptions but the newer advanced methods and modelling techniques. However, besides the significance of the latter sources, the importance of traditional field observations must not be forgotten.

Our results support the prediction that binocular field variation among aquatic birds is primarily associated with foraging methods and activities rather than phylogeny. The variation in binocular field characteristics probably reflect the different perceptual challenges experienced by different species when foraging in aquatic environments. In future studies should rather examine the differences of closely related species that may have effect on the cranial morphology of these birds. With a larger sample size (including more species) and using parameters of soft tissues of the eye will create a more complex vision regarding the evolution of those features which are supporting underwater foraging.

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Description of representatives of the family Phasianidae from Mátraszőlős 3 (Nógrád county, Hungary) by means of recent finds of Badenian age

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Abstract The article reviews of the Galliformes fo from the Mátraszőlős 3 site in Hungary from the Middle Miocene. A total of 200 bones have so far been recovered from site at Mátraszőlős 3, of which the identification of 95 bones will be discussed in this article, including anatomical differences between species. Within the fossil record, *Palaeocryptonix hungaricus* (Jánossy 1991) and three species of *Palaeortyx* have been identify (*P. phasianoides* Milne-Edwards, 1869*, P. gallica* Milne-Edwards, 1869 and *P. brevipes* Milne-Edwards, 1869). Only one bone of *P. brevipes* was recovered. As the appearance of the members of the family can be traced back to the early Oligocene, while the majority of the species are of Neogene origin, the study contributes to a better understanding of the distribution of extinct pheasant speciesin the Carpathian Basin.

Keywords: Mátraszőlős 3, Phasianidae, Palaeortyx, middle Miocene, Hungary, birds, fossils

Összefoglalás A cikk a magyarországi középső-miocén korabeli Mátraszőlős 3-as lelőhelyről előkerülő leletanyag feldolgozását mutatja be. Ezen publikációban a tyúkalakúak (Galliformes), azon belül a fácánfélék (Phasianidae) család képviselői kerülnek bemutatásra. Mátraszőlős 3-as lelőhelyről eddig összesen 200 db csont került elő, melyek közül 95 db határozását ezen cikk tárgyalja, a fajok közti anatómiai eltérésekre is kitérve. A leleteken belül a *Palaeocryptonix hungaricus* Jánossy, 1991 illetve 3 *Palaeortyx* fajt sikerült azonosítani (*P. phasianoides* Milne-Edwards, 1869, *P. gallica* Milne-Edwards, 1869, és *P. brevipes* Milne-Edwards, 1869), ezek körül egynek *(P. brevipes)* csupán 1 db csontja került elő. Mivel a család tagjainak megjelenése az eocénig vezethető vissza, ugyanakkor a fajok többsége a neogénből származik, a cikk hozzájárul ahhoz, hogy részletesebb képet kapjunk a Kárpát-medence kihalt fácánféléinek elterjedéséről.

Kulcsszavak: Mátraszőlős 3, Phasianidae, Palaeortyx, középső-miocén, Magyarország, madarak, fossziliák

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Introduction

The village of Mátraszőlős is located in the south-eastern part of Nógrád County, in the Zagyva valley in Hungary. The village and its surroundings are well known and researched in the Hungarian geological and palaeontological literature from several points of view. So far, three sites have been excavated in the vicinity of the settlement. These are the following:

Mátraszőlős (1): This site was already known in the 1940s (Noszky 1940, Horusitzky 1942), but only in 1998 János Hír succeeded in finding vertebrate remains. The following year, site No. 2 was found nearby. The bird material was determined by Erika Gál and Jenő Kessler: aff. *Anhinga* sp., *Bucephala* aff. *cereti*, *Clangula* sp., *Mergus* sp., Anatidarum sp. indet., *Porzana* aff. *estramosi*, *Rallus* sp., Rallidae gen *et* sp. indet., Charadriiformes gen *et* sp. indet., Passeriformes sp. (*Chloris-Pyrrhula* + *Parus* size), (Gál *et al*. 1998–1999, then in the revision *Anas* cf. *velox*, *Clangula matraensis*, *Mergus minor* and *Gallinago* cf. *veterior* instead of Anatidarum indet), *Palaeortyx* cf. *gallica* (instead of Charadriiformes gen. *et* sp.!), Pteroclidae sp. indet., *Rallicrex polgardensis* (replacing *Rallus* sp., and from this in 2012 *Rallicrex litkensis*), *Porzana matraensis*, Cuculidae gen. *et* sp. indet. (replacing Passeriformes ind.), Aves indet. (Kessler 2009a, 2009b). From the previously undetermined remains, the following taxa have been identified by redescription: *Phalacrocorax* sp. indet.; *Rallicrex litkensis* and various Passeriformes (Kessler & Hír 2012a, Kessler & Hír 2012b).

Mátraszőlős (2): *Proardeola walkeri* Harrison, 1979*, Megapaloelodus goliath* Miller, 1944*, Mionetta consobrina* Milne-Edwards, 1867 cf. *Miogallus altus* Milne-Edwards, 1869; *Columbidae* gen. *et* sp. indet.; *Turdicus minor* Kessler *et* Hír, 2012b*,* cf. Turdidae gen. *et* sp. indet., Passeriformes indet. (Gál *et al*. 2000), *Palaeortyx* sp. *(P. prisca/ phasianoides)* (Kessler 2009b). From the previously unidentified remains, the following results were obtained from the re-description: Ardeidae gen. *et* sp. indet. cf. *Miogallus altus;* Columbidae gen. *et* sp. indet.; *Turdicus matraensis* Kessler & Hír, 2012; Passeriformes indet. (Kessler & Hír 2012a, Kessler & Hír 2012b).

Most taxa from this find suggest an aquatic or marshy habitat. And the large flamingo *(Megapaloelodus)* is a specialised species of shallow water environment. Some of the galliform species, the warblers and the undetermined cuckoo and thrush, are associated with woody environments, while the quail and the bush hen, with open grassland.

Mátraszőlős (3): the area around the sites was re-examined in spring 2008, when, in addition to the re-exploration of Mátraszőlős 2, it was possible to sample Mátraszőlős 3. This is located about 20 m from the Mátraszőlős 2 site. The swan species *Cygnopterus neogradensis* (Kessler& Hír 2009) and the material of *Palaelodus ambiguus/crassipes, Tadorna minor;* Anatidae gen. *et* sp. indet. *Miocorvus larteti, Turdicus minor*; Aves indet. were also found here (Kessler & Hír 2009, Kessler 2010). The species list indicates a typical wetland, where the small crow and thrush may have lived in the riparian zone. The waterfowl all indicate very typical habitats: the swan, the little flamingo and the shoveler.

All three of these materials are in the possession of the Pásztó City Museum.

Description

The order Galliformes is one of the best represented groups of birds in the fossil record. The main reasons for this are that it contains a large number of species and individuals, which have poor flight ability (apart from quail) and occur in relatively open habitats. They are the preferred prey of many predators. They have skeletal features and dimensions that facilitate their identification, but the considerable homologation makes it much more difficult to distinguish between genera and species, especially in the smaller and medium-bodied specimens, and their classification is often highly controversial. Because of their sexual dimorphism, their size is highly variable (males are larger). In terms of distribution, pheasants, partridges and quails are found in Eurasia, Africa, Australia and New Zeland mostly in grassy, shrubby areas and nesting on the ground.

Most of the fossil remains come from Europe. The earliest representatives from the Eocene and Oligocene of France are *Paraortyx* species (*Paraortyx lorteti, P. brancoi* (Gaillard, 1908)) and ?*Piriortyx* species Brodkorb, 1964 (*Pirortyx major* (Gaillard, 1939)), and from the Miocene of France, the Czech Republic and Hungary (Mátraszőlős, Rudabánya, Sümeg, Tardosbánya) are *Palaeortyx* species, *Palaeocryptonyx hungaricus* from the Miocene of Hungary (Rátka), *Miogallus* species *(M. altus, M. medius)* from the Miocene of France, Germany, Hungary and Spain, *Alectoris* species *(A. bavarica, A. prisca, A. edwardsi, A. donnezani)* from the Miocene of Germany and France, and *Francolinus capeki* and *Gallus beremendensis* from the early Pleistocene of Romania and Hungary. The turkeys live in Central America and are medium to large in size. The earliest finds are from the Miocene of the USA *(Rhegminornis calobates, R. kimballensis)*. One of the largest genus and species of the order is the family Phasianidae, not only in terms of recurrent taxa, but also in terms of fossil extinct taxa. There are various representatives (partridges, pheasants, quails, peacocks, and allies) and these representatives are present continuously from the Early Miocene to the Holocene. In the Carpathian Basin, they are represented by 3 extinct genera, 11 extinct species and 1 extinct subspecies, in addition to 7 extant taxa. It is important to note that 3 of the extinct taxa and 1 subspecies were present in the area over a fairly wide time span and represent 3 body size types at several sites. Chickens, partridges and quails: chicken by the chicken of Beremendi (*Gallus beremendensis* Jánossy, 1976) and a new species *Pliogallus csarnotanus* (Kessles & Horváth 2022) (from Beremend and Csarnóta) in the Pliocene and Early Pleistocene, partridges by the Betfia frankolin (*Francolinus capeki* (Lambrecht, 1933)) also in the same time range and the partridge subspecies (*Perdix perdix jurcsaki* Jánossy, 1976) also described from Betfia, which occurred as late as the Middle Pleistocene, and quail, an endemic species of an extinct genus (*Palaeocryptonyx hungaricus* Jánossy, 1991) present in the area from the Upper Miocene to the Lower Pleistocene. Its absence in the Upper Pliocene is presumably explained only by identification problems (Kessler 2013, Mayr & Smith 2013, Kessler & Horváth 2022).

From the Mátraszőlős sites, as shown above, only the gallus-like find *Palaeortyx* sp. *(P. prisca/phasianoides)* (Kessler 2009b) from Mátraszőlős 2 is known so far. Thus, the new Mátraszőlős 3 material with a significant number of finds is of particular importance. It will be presented in this paper. In processing this material, we were greatly assisted by the 2005 study by Cécile Mourer-Chauviré and Ursula Göhlich (2005), in which they provide a detailed description of the anatomical differences of these taxa.

From site at Mátraszőlős 3, almost all skeletal parts are represented among 205 relatively well preserved bones, although many are fragmentary, but by definition the limb bones are best represented. The vast majority of these belong to the genus *Palaeortyx* and only five to *Palaeocryptonyx.* The former taxon is presumably represented by 3 species: *P. phasianoides, P. gallica* and *P. brevipes*. Their discussion is presented in the taxonomy chapter.

Abbreviations: MN6-MN8 – Middle Miocene; †-extinct/fossil species-subspecies; A-total lengths; B-partial lengths; C-breadth of proximal epiphysis; D-thickness of proximal epiphysis; E-breadth of diaphysis; E1-partial breadth of diaphysis; F-breadth of distal epiphysis; G-thickness of distal epiphysis; H-height of distal epiphysis; Hungarian Institute of Geology and Geophysics (HIGG)

Anatomical terminology: after Lambrecht (1933), Baumel *et al.* (1979), Gilbert *et al.* (1981), Kessler (2013)

Method of measurement: after von den Driesch (1976), Kessler (2013). The recent comparative material included the partridge (*Coturnix coturnix* (L. 1758)) *(Figure 1/5–7)* and the Rock Partridge (*Alectoris graeca* (Meisner, 1804)) *(Figure 2/9–10, 12–13)*.

Figure 1. *Palaeocryptonyx hungaricus* Jánossy, 1991 – Mátraszőlős 3. 1. left *coracoideum*, proximal end, lateral view; 2. left *coracoideum*, proximal end, medial view; 3. right *ulna*, proximal end, ventral view; 4. right *ulna*, proximal end, dorsal view; 5. *Coturnix coturnix* (L. 1758) extant, left *coracoideum*, proximal end, lateral view; 6. *Coturnix coturnix* (L. 1758) extant, – right *ulna*, ventral view; 7. *Coturnix coturnix* (L. 1758) extant, – right *ulna*, dorsal view

1. ábra *Palaeocryptonyx hungaricus* Jánossy, 1991 – Mátraszőlős 3. – 1. baloldali hollócsőrcsont, proximális vég, laterális nézet; 2. baloldali hollócsőrcsont, proximális vég, mediális nézet; 3. jobboldali singcsont, proximális vég, ventrális nézet; 4. jobboldali singcsont, proximális vég, dorzális nézet; 5. *Coturnix coturnix* (L. 1758) recens, baloldali hollócsőrcsont, proximális vég, laterális nézet; 6. *Coturnix coturnix* (L. 1758) recens, – jobboldali singcsont, ventrális nézet; 7. *Coturnix coturnix* (L. 1758) recens, – jobboldali singcsont, dorzális nézet

Systematics

Ord. Galliformes (Temminck, 1820)
Fam. Phasianidae (Vigors, 1825)
†*Palaeocryptonix* Depéret, 1892
†*Palaeocryptonix hungaricus* Jánossy, 1991 *(syn: Eurobambusicola turolicus* Zelenkov, 2016)

Location and age: Mátraszőlős 3; Middle Miocene (MN6–8)
Material: 1 *coracoideum* proximal fragment *(Figure 1/1–2)*; 1 *ulna* proximal fragment *(Figure 1/3–4)* and 2 *maxilla (Figure 2/1–2);* 3 *phalanx ungularis*
Dimensions (in mm): *coracoideum*: C-4.97, D-5.72, F-2.94; *ulna*: B-4.74, C-5.33; E-3.18; *phalanx ungularis (Figure 2/7–8, 11)*: A-4.28–9.19, B-3.49–3.64;

This species is a quail-sized pheasant. It was fairly common in the Carpathian Basin in the late Miocene and early Pliocene. Only one almost complete skeleton has been found from the Upper Miocene in northern Hungary (Rátka). There is no previous information on the *phalanx ungularis*, but its size certainly places it in a smaller size range (Kessler 2019). Mlíkovskỳ also assigns this species and genus to the genus *Alectoris donnezani* (Depéret, 1892) (Mlíkovskỳ 2002). At the same time, N. Zelenkov, examining the collection in the HIGG Museum, assigns it to the species *Eurobambusicola turolicus* (Zelenkov 2016, Kessler 2009b, 2013).

†*Palaeortyx* Milne-Edwards, 1869
† *Palaeortyx brevipes* Milne-Edwards, 1869 / syn. † *Palaeoperdix* (Milne-Edwards, 1871) / **† *Palaeortyx grivensis* Lydekker, 1893** / *Coturnix † gallica* (Mlíkovskỳ, 2002).

Location and age: Mátraszőlős 3; Middle Miocene (MN6–8)
Material: 1 *tarsometatarsus* distal fragment
Dimensions (in mm): E-2.9, F-5.5, G-6.8

It is a slightly larger representative of the genus *Palaeortyx* than the recnt quail. It is easily distinguished from *Palaeocryptonix*. Its distribution outside the Carpathian Basin is type locality of the Grive Saint-Alban (Upper Miocene, MN8) and the Măluşten of eastern Romania (MN15) (Kessler 2019).

† *Palaeortyx gallica* Milne-Edwards, 1869 / syn. *P. intermedia* Ballmann, 1969 / *Coturnix † gallica* (Mlíkovskỳ 2002)

Location and age: Mátraszőlős 3; Middle Miocene (MN6–8)
Material: 2 *tarsometatarsus* distal fragment and 5 *tarsometatarsus* proximal fragment; 1 almost complete bone; *ulna* 1 proximal fragment and 1 distal fragment; *humerus* distal fragment.
Dimensions (in mm): *tarsometatarsus*: A-ap.31, C-6.8–7.22, D-5.18–6.5, E-2.5, F-7, G-4 *(Figure 4/18–19)*; *ulna*: C-6.31, E-4.01–4.61, F-7.08, G-4.83 *(Figure 3/7–8)*; *humerus*: E-4.77, F-8.58, G-5.22, H-7.21 *(Figure 3/3)*.

This species is slightly larger in size than *P. brevipes*, but much smaller than *P. phasianoides.* In *P. gallica* the *tarsometatarsus* has an anatomical marker that makes it easy to distinguish

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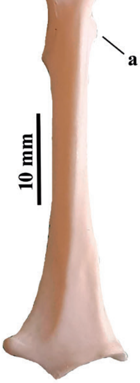

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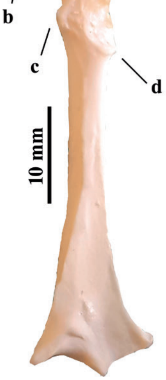

from other species. This is the *fossa parahypotarsalis (Figure 4/18–19)*, a notch on the lateral side of the bone, located on the proximal epiphysis of the *tarsometatarsus*. The humeral features are similar in character to those of *P. phasianoides*, except that they have a smaller range. Since a distal epiphysis fragment remains, the *processus supracondylaris dorsalis* is not broken off, so it can be seen to be protruding and branching.

Its geographic distribution is broadly similar to that of *P. brevipes*.

†*Palaeortyx phasianoides* Milne-Edwards, 1869 /syn. † *Palaeoperdix longipes* (Milne-Edwards, 1869) / *Coturnix † longipes* (Mlíkovskỳ, 2002)
Location and age: Mátraszőlős 3; Middle Miocene (MN6–8)
Material: 31 *tarsometatarsus* (18 proximal fragments, 8 distal fragments and 5 completely intact bone); *femur* (5 proximal and 1 distal epiphysis fragment); 4 *tibiotarsus* distal fragment; 3 *maxilla*; 6 *mandibula*; 5 *coracoideum* proximal fragment; 3 *ulna* proximal fragment; 3 *humerus* (1 proximal and 2 distal epiphysis; fragments); 4 *femur* (3 proximal and 1 distal epiphysis fragments); 9 *carpometacarpus* (1 completely intact bone, 3 proximal epiphysis fragments and 5 distal epiphysis; fragments); 3 *phalanx proximalis digiti majoris*.
Dimensions (in mm): *tarsometatarsus (Figure 4/8)*: A-37.57–ap.41, C-7.79–8.73, D-6.24–8.06, E-3.15–3.59, F-8.26–8.91, G-6.11–6.91; *tibiotarsus*: E-4.42, F-7.02–7.28, G-6.68–6.71; *maxilla*: B-8.30, C-7.30; *mandibula*: B-5.29–7.08, C-6.48–9.02; *coracoideum (Figure 2/3–6)*: A-ap.43, B-ap.40, C-4.87–6.38, D-5.72–9.73, E-2.94–4.66; *ulna (Figure 3/5–6)*: B-8.12, C-7.36; *humerus (Figure 3/1–2, 4)*: A-50, B-20.25, C-16.23, D-15.21, E-6.16, F-11.51–12.19, G-6.54–6.74, H-8.04; *femur (Figure 4/4–5)*: C-9.33–11.39, D-7.69–10.02, E-4.75–5.64, F-11.52, G-8.96; *carpometacarpus (Figure 4/1–2)*: A-ap.32.07, B-28.09,

Figure 2. *Palaeocryptonyx hungaricus* Jánossy, 1991 – Mátraszőlős 3. – 1. *maxilla*, upper view; 2. *maxilla*, lower view; *Palaeortyx phasianoides* Milne-Edwards, 1869 – Mátraszőlős 3. – 3. right *coracoideum*, dorsal view; 4. right *coracoideum*, ventral view; 5. right *coracoideum*, proximal end, dorsal view; 6. right *coracoideum*, proximal end, ventral view; *Palaeocryptonyx hungaricus* Jánossy, 1991 – Mátraszőlős 3. – 7. claw bone, lateral view; 8. claw bone, plantar view; *Alectoris graeca* (Meisner, 1804) extant, – 9. *maxilla*, upper view; 10. *maxilla*, lower view; *Palaeocryptonyx hungaricus* Jánossy, 1991 – Mátraszőlős 3. – 11. claw bone, lateral view; *Alectoris graeca* (Meisner, 1804) extant, – 12. right *coracoideum*, dorsal view, a – *processus procoracoidalis*; 13. right *coracoideum*, ventral view, b – *processus acrocoracoidalis*, c – *cotyla scapularis*, d – *facies articularis humeralis*

2. ábra *Palaeocryptonyx hungaricus* Jánossy, 1991 – Mátraszőlős 3. – 1. *maxilla*, felső nézet; 2. *maxilla*, alsó nézet; *Palaeortyx phasianoides* Milne-Edwards, 1869 – Mátraszőlős 3. – 3. jobboldali hollócsőrcsont, dorzális nézet; 4. jobboldali hollócsőrcsont, ventrális nézet; 5. jobboldali hollócsőrcsont, proximális vég, dorzális nézet; 6. jobboldali hollócsőrcsont, proximális vég, ventrális nézet; *Palaeocryptonyx hungaricus* Jánossy, 1991 – Mátraszőlős 3. – 7. karomcsont, laterális nézet; 8. karomcsont, plantáris nézet; *Alectoris graeca* (Meisner, 1804) recens, 9. *maxilla*, felső nézet; 10. *maxilla*, alsó nézet; *Palaeocryptonyx hungaricus* Jánossy, 1991 – Mátraszőlős 3. – 11. karomcsont, laterális nézet; *Alectoris graeca* (Meisner, 1804) recens, – 12. jobboldali hollócsőrcsont, dorzális nézet, a – *processus procoracoidalis*; 13. jobboldali hollócsőrcsont, ventrális nézet, b – *processus acrocoracoidalis*, c – *cotyla scapularis*, d – *facies articularis humeralis*

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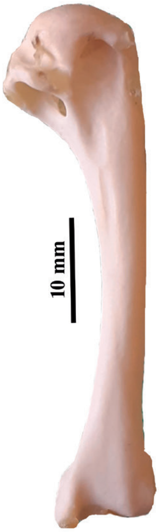

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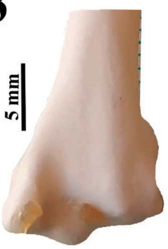

C-8.14–10.14, D-4.92–6.04, E1-3.55–2.94, F-6.26–7.71, G-3.46–4.49; *phalanx proximalis digiti majoris (Figure 4/3)*: A-13.73–16.05, C-4.69–5.28, E-6.03–6.62, F-5.54–5.99.

The largest extinct species of pheasant at the locality. Most of the bones in the Mátraszőlős 3 fossil belong to this species. If the size range of *tarsometatarsus* is observed, it can be noticed that there are 2 different size classes within this species. This is most likely due to sexual dimorphism, i.e. the smaller size range bones are assumed to belong to a female (A-37.57, C-7.79, D-6.24, E-3.15 F-8.28, G-6.11), while the larger ones belong to a rooster (A-ap.41, C-8.73, D-8.06, E-3.59, F-8.9. These are differences of a few mm. What distinguishes them from *P. gallica* is that the *parahypotarsal* indentation of the fossa on the proximal epiphysis of the tarsometatarsus is less marked. The range of tibiotarsal dimensions and the thickness/height of the distal epiphysis, as well as the *pons supratendineus*, make it certain that it belongs to this species. The *incisura intercondylaris* is rounded. The *maxilla* and *mandibula* are almost equal in size, morphologically all two are characterized by a short and broad beak tip with a broad and semicircular beak notch and a small tip in the middle. Also in the *coracoideum*, there is some difference between the thickness of the proximal epiphysis and the width of the diaphysis, which may also be due to the sex difference. In the *ulna*, the *olecranon* is rounded and slightly conical and the *cotyla dorsalis* is elongated and conical. The proximal and distal epiphysis; of the *humerus* are spectacularly larger than those of any other member of the genus *Palaeortyx*. In the distal epiphysis, the *processus supracondylaris dorsalis* is broken off. In the *carpometacarpus*, the most visible anatomical stamp is the strongly developed *processus intermetacarpalis*. The *facies articularis metacarpalis* is straight and wavy, the strongly and irregularly prominent arc of the *margo dorsalis* is slightly wavy, and the *facies articularis phalangealis* is a strongly prominent dorsal process. In the *femur*, the *fovea lig. capitis* and the *facies articularis acetabularis* are also clearly visible.

Figure 3. *Palaeortyx phasianoides* Milne-Edwards, 1869 – Mátraszőlős 3. – 1. right *humerus*, proximal end, caudal view; 2. right *humerus*, proximal end, cranial view; *Palaeortyx gallica* Milne-Edwards, 1869 – Mátraszőlős 3. – 3. right *humerus*, distal end, caudal view; *Palaeortyx phasianoides* Milne-Edwards, 1869 – Mátraszőlős 3. – 4. right *humerus*, distal end, cranial view; 5. right *ulna*, proximal end, dorsal view; 6. right *ulna*, proximal end, ventral view; *Palaeortyx gallica* Milne-Edwards, 1869 – Mátraszőlős 3. – 7.right *ulna*, distal end, dorsal view; 8. right *ulna*, distal end, ventral view; *Alectoris graeca* (Meisner, 1804) extant, 9. right *humerus*, caudal view; 10. right *humerus*, distal end, caudal view; 11. right *ulna*, proximal end, dorsal view; 12. right *ulna*, dorsal view; 13. right *humerus*, distal end, cranial view

3. ábra *Palaeortyx phasianoides* Milne-Edwards, 1869 – Mátraszőlős 3. – 1. jobboldali felkarcsont, proximális vég, caudális nézet; 2. jobb oldali felkarcsont, proximális vég, craniális nézet; *Palaeortyx gallica* Milne-Edwards, 1869 – Mátraszőlős 3. – 3. jobboldali felkarcsont, disztális vég, caudális nézet; *Palaeortyx phasianoides* Milne-Edwards, 1869 – Mátraszőlős 3. – 4. jobboldali felkarcsont, disztális vég, craniális nézet; 5. jobboldali singcsont, proximális vég, dorzális nézet; 6. jobboldali singcsont, proximális vég, ventrális nézet; *Palaeortyx gallica* Milne-Edwards, 1869 – Mátraszőlős 3. – 7. jobboldali singcsont, disztális vég, dorzális nézet; 8. jobboldali singcsont, disztális vég, ventrális nézet; *Alectoris graeca* (Meisner, 1804) recens – 9. jobboldali felkarcsont, caudális nézet; 10. jobboldali felkarcsont, disztális vég, caudális nézet; 11. jobboldali singcsont, proximális vég, dorzális nézet; 12. jobboldali singcsont, dorzális nézet; 13. jobboldali felkarcsont, disztális vég, craniális nézet

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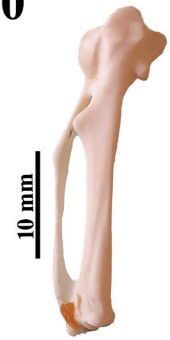

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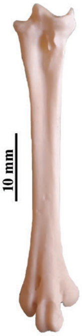

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***Palaeortyx* sp. indet.:**

Location and age: Mátraszőlős 3; Middle Miocene (MN6–8)

Materials: 1 *carpometacarpus* proximal fragment

Dimensions (in mm): C-8, D-ap. 6, E-5, E1-ap. 3.

Morphologically different from *P. phasianoides*, (and also in size, much smaller than *P. phasianoides*). The shape of the *trochlea carpalis* is different, but this is due to the fact that this part of *P. phasianoides* is wider and the *facies artic ulnocarpalis* is more prominent. The *processus extensorius* is also different, being slightly shorter and curved upwards in *P. phasianoides*, whereas in this bone it is straight and blunt. Unlike *P. phasianides*, this bone does not have a more developed *processus intermetacarpalis*, so both in size and morphology it can be excluded as a smaller specimen of *P. phasianoides*. The *fovea subalularis* is also different, as this bone lacks a small notch, whereas this is also observed in *P. phasianoides* and *P. gallica.*

Figure 4. *Palaeortyx phasianoides* Milne-Edwards, 1869 – Mátraszőlős 3. – 1. right *carpometacarpus*, ventral view; 2. right *carpometacarpus*, dorsal view; 3. right *phalanx proximalis digiti majoris*, dorsal view; 4. left *femur*, proximal end, caudal view; 5. left *femur*, distal end, cranial view; 6. right *tibiotarsus*, distal end, cranial view; 7. right *tibiotarsus*, distal end, caudal view; 8. left *tarsometatarsus*, dorsal view; *Alectoris graeca* (Meisner, 1804) extant, 9. right *carpometacarpus*, ventral view; 10. right *carpometacarpus*, dorsal view; 11. right *phalanx proximalis digiti majoris*, dorsal view; *Palaeortyx brevipes* Milne-Edwards, 1869 – Mátraszőlős 3. – 12. right *femur*, dorsal view; *Alectoris graeca* (Meisner, 1804) extant, 13. left *femur*, proximal end, caudal view; 14. left *femur*, distal end, cranial view; 15. right tibia, distal end, cranial view; 16. right *tibiotarsus*, distal end, caudal view; 17 – left *tibiotarsus*, dorsal view; *Palaeortyx gallica* Milne-Edwards, 1869 – Mátraszőlős 3. – 18. right *tarsometatarsus*, dorsal view; 19. right *tarsometatarsus*, dorsal view – a. – *fossa parahypotarsalis*

4. ábra *Palaeortyx phasianoides*, Milne-Edwards, 1869 – Mátraszőlős 3. – 1. jobboldali kézközépcsont, ventrális nézet; 2. jobboldali kézközépcsont, dorzális nézet; 3. jobboldali kézujjperc, dorzális nézet; 4. baloldali combcsont, proximális vég, caudális nézet; 5. baloldali combcsont, disztális vég, craniális nézet; 6. jobboldali lábszárcsont, disztális vég, craniális nézet; 7. jobboldali lábszárcsont, disztális vég, caudális nézet; 8. baloldali csüd, dorzális nézet; *Alectoris graeca* (Meisner, 1804) recens, 9. jobboldali kézközépcsont, ventrális nézet; 10. jobboldali kézközépcsont, dorzális nézet; 11. jobboldali kézujjperc, dorzális nézet; *Palaeortyx brevipes* Milne-Edwards, 1869 – Mátraszőlős 3. – 12. jobb oldali csüd, dorzális nézet; *Alectoris graeca* (Meisner, 1804) recens, 13. baloldali combcsont, proximális vég, caudális nézet; 14. baloldali combcsont, disztális vég, craniális nézet; 15. jobboldali lábszárcsont, disztális vég, craniális nézet; 16. jobboldali lábszárcsont, disztális vég, caudális nézet; 17. baloldali csüd, dorzális nézet; *Palaeortyx gallica* Milne-Edwards, 1869 – Mátraszőlős 3. – 18. jobb oldali csüd, dorzális nézet; 19. jobb oldali csüd, dorzális nézet, a – *fossa parahypotarsalis*

Conclusions

By examining the material from site 3 at Mátraszőlős, I concluded that three species of the genus *Palaeortyx, P. phasianoides, P. gallica* and *P. brevipes,* were found. These 3 species are well distinguishable both in size and anatomy, although most of their anatomical characters are similar. In terms of size, *P. phasianoides* falls within the pheasant size range, *P gallica* is a smaller size, and *P. brevipes* falls within an even smaller size range. Of the *Palaeortyx* species, *P. phasianoides* was probably a common and frequent species, as evidenced by the large number of bones found in this find.

Based on the identification of recent finds from Mátraszőlős 3 and the large number of these finds, it is concluded that presumably a relatively large, continuous, dry grassland and forest area was typical of the Middle Miocene (Erdei *et al.* 2011). This is in line with the ecological characteristics of the period, as we know that the Middle Miocene was characterised by a warm subtropical climate, with a high number of both forest and open areas inhabited by a large number of species and individuals. It is important to note that species indicative of warmer climatic conditions are also known to have been present, such as the anhingas, boobies, flamingos and tropical swift (Gál *et al*. 2000, Kessler 2009b, Kessler & Hír 2012a, Kessler & Hír 2012b).

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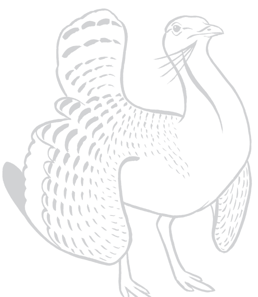

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Ectoparasitic aspects in Red-footed Falcon *Falco vespertinus* breeding colonies in the Po valley (Italy)

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Abstract Ectoparasite fauna of *Falco vespertinus* breeding colonies was investigated in a system of artificial nests in the Po valley (Parma province), Italy, during four subsequent breeding seasons (2019–2022). Conservation actions regarding *Falco vespertinus* led to a great increase in its presence in the area. This rise was believed to coincide with an increase in the prevalence of hematophagous ectoparasites breeding in the nests, with a potential negative impact on the attractiveness of the breeding site. Ectoparasites collected from the nestlings' bodies almost entirely belonged to a single species, Diptera *Carnus hemapterus,* with a quite variable prevalence in different years. Maximum ectoparasite load was consistently linked to younger than two weeks old chicks. *Carnus hemapterus* may pose a threat to less resilient specimens of *Falco vespertinus* because it feeds on live tissues, increases metabolic expenditure, and can introduce blood parasites. Nonetheless, this species is part of the ecosystem shared with the falcon and might have a conservational value itself. We propose that higher occurrence of this ectoparasite might be linked to diet parameters, especially the availability of small mammals and the lingering of prey remnants in the nests, as well as to the age of the parasitized nestlings. These findings might have important implications for the conservation of this rare *Falco* species.

Keywords: artificial nests, chicks, ectoparasites, *Carnus hemapterus*, age, diet

Összefoglalás A kék vércse *(Falco vespertinus)* telepek ektoparazita faunáját vizsgáltuk az olaszországi Pó-völgyben (Parma tartomány), mesterséges költőládákban, négy egymást követő költési időszakban (2019–2022). A természetvédelmi intézkedések nagymértékben növelték a kék vércsék jelenlétét a területen. Ez az emelkedés vélhetően egybeesik a fészkekben szaporodó vérszívó ektoparaziták mennyiségének növekedésével, ami potenciálisan negatív hatással lehet a kolónia vonzerejére. A fiókák testéről gyűjtött ektoparaziták szinte mindegyike a *Carnus hemapterus* (Diptera) fajba tartoznak, évente változó prevalenciával. A maximális ektoparazita fertőzés a kéthetesnél fiatalabb fiókákra volt jellemző. A *Carnus hemapterus* veszélyt jelenthet a kék vércsék kevésbé ellenálló példányaira. Mivel vérrel táplálkozik, megterheli az anyagcserét, és egysejtű vérélősködőket terjeszthet. Mindazonáltal ez a faj a vércsével együtt része az ökoszisztémának, és maga is természetvédelmi értéket képviselhet. Feltételezzük, hogy ennek az ektoparazitának a gyakoribb előfordulása összefüggésbe hozható a táplálkozási paraméterekkel, különösen a kisemlősök elérhetőségével, a zsákmánymaradványok fészkekben való felhalmozódásával, valamint a fiókák életkorával. Ezek a megállapítások jelentős hatással lehetnek e ritka sólyomfaj megőrzésére.

Kulcsszavak: költőláda, fióka, ektoparazita, *Carnus hemapterus,* életkor, táplálék

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Introduction

The Red-footed Falcon *(Falco vespertinus)* is classified as a near-threatened species on the IUCN Red List (IUCN 2022) and as a globally threatened Species of European Conservation Concern (SPEC 1) (BirdLife International 2017). Habitat degradation, soil sealing, pesticide spraying, loss of nesting sites, and the conversion of grasslands to agricultural fields are the main reasons behind the moderately rapid decline affecting its global population from the 1970s (Huber *et al.* 2008, BirdLife International 2018, Calabrese *et al.* 2020). The Red-footed Falcon usually exploits rookeries and solitary corvid nests (i.e. *Pica pica*, *Corvus cornix*) for breeding (Palatitz *et al.* 2009, Chavko & Krištín 2017), and has become a regular migrant and a breeding resident in the Italian rural landscapes since 1995 (Brichetti & Fracasso 2003, Sgorlon *et al.* 2013). As of 2015, over 90% of the Italian population bred in the alfalfa crops in the Parma province of the Emilia-Romagna region (Nardelli *et al.* 2015), two of the largest breeding colonies of this species in Italy (Ferrarini & Gustin 2022). Here the Red-footed Falcon can enjoy agricultural areas in a dry continental climate free of pesticides and rich in prey (Fior & Gustin 2012). To foster the presence of this rare raptor species in the area, many measures are implied, such as the regular monitoring of its occurrence patterns, the maintenance of artificial nests, and the nestlings' ringing for research purposes. The employment of nest-boxes is particularly useful, as they can be placed in accessible locations to better enable behavioural, ecological or conservation research (Bragin *et al.* 2017).

Nonetheless, crowded avian rookeries are often linked to the increase in ectoparasite abundance and infestation intensity (Liker *et al.* 2001). Moreover, nest-boxes are cleaned only once a year (prior to the beginning of the breeding season) (Calabrese *et al.* 2020) allowing organic matters to linger in the residual nest-material, providing an abundant food supply in an already micro-climatically suitable environment for ectoparasites (Fehérvári *et al*. 2015, Soltész *et al.* 2018, Castaño-Vázquez *et al.* 2022). Nest-dwelling ectoparasites are a community of species showing a plethora of eating and behavioural habits: most larvae are saprophagous or hematophagous and live in the nest substrate (Soltész *et al.* 2018).

The goal of this study is to analyse, for the first time, the ectoparasite fauna of *Falco vespertinus* in Italy, assessing prevalence, distribution, and role in the host species well-being during four subsequent breeding seasons.

Material and Methods

Study area

The sites where the colonies bred were labelled as: (a) Strada del Lazzaretto (Municipality of Trecasali, 44°88'82,64''N-10°28'22,64''E); (b) Bertinelli (Municipality of Trecasali, 44°89'91,99''N-10°27'73,29''E); (c) Calza (Municipality of Busseto, 44°97'55,44''N-10°11'72,58''E); (d) Crociletto (Municipality of Roccabianca, 44°97'89,22''N-10°17'68,22''E); (e) Boarini (Municipality of Roccabianca, 44°97’91,67”N-10°18’19,44”E); (f) Boni (Municipality of Trecasali, 44°53’33,22”N-10°17’45,20”E).

The study was conducted during the summers of 2019 to 2022 during the annual monitoring activities in a system of artificial nest-based *Falco vespertinus* colonies in Northern Italy. Examined clutches came from nest-boxes that have been routinely monitored to assess breeding success since the late 1990s, located on *Quercus robur, Platanus acerifolia*, and *Populus nigra* rows in the Po valley (Parma province) (30 m a.s.l.). The study area was identified dividing into three main sectors the 580 km^2 of farmed landscape, which also features six Natura 2000 sites and two natural reserves (Fior & Gustin 2012, Calabrese *et al.* 2020).

Field methods

On an annual basis, during the reproductive season (May-August), falcons were followed to their nests, stopping at previously known nesting sites to check for potential occupation, and their nestlings are ringed (Calabrese *et al.* 2020). Both the ringing activities and the ectoparasite collection are performed between the first week after hatching and just prior fledging, to have most nests occupied by chicks suitable for the study. Egg-laying period for this species is usually between the last ten days of April and mid-May, followed by approximately 23 days of incubation (Cramp & Simmons 1980). Nestlings from every nest-box are ringed using a metal ring with an alphanumeric code. For this study, ectoparasites were collected from every chick (even the ones too young to be ringed) through a visual examination of body and plumage, focusing on bald areas such as axillas, groin, goiter, and inner wings. All detectable ectoparasites were collected and then stored in 70% alcohol for later analytical purposes. Potential ectoparasites remaining in the nest were disregarded. Data coming from these activities were later organized in a dataset indicating: date and time, GI of the site, nest-box identification number, ring codes, age of the nestling, ectoparasite presence, weight, tarsus, and collected samples (e.g. unhatched eggs, pellets, prey remnants found in the nest-box). A specific age estimate was defined for each chick, being alternatively <7 days, 7–10 days, 10–12 days, 12–15 days, 15–20 days, 20–25 days old (i.e. between hatching and fledging ages). From the inside of some of the nest-boxes was collected unhatched eggs, pellets, and prey remnants (mainly *Microtus savii* specimens and the hardened forewing (*elytra*) of beetles (mainly *Pentodon bidens punctatus*). Stereomicroscopic observation was used to determine ectoparasite sex-ratio relying on sexual dimorphism cues. Male specimens showed easily detectable genitalia at the end of the abdomen while female specimens were characterized by a pronounced physogastry and the absence of abdominal sternites (Grimaldi 1997).

Ectoparasite abundance estimation

At a later stage, collected ectoparasites were individually examined by stereomicroscope for identification. Ectoparasites were counted as a comprehensive total and as the total number for each nest-box. Sex identification was based on anatomical differences between female and male specimens as described in Grimaldi (1997). Mean values, standard deviation, minimum, and maximum for each clutch were then estimated. Resulting data were interpolated with the ringing datasets to obtain yearly ectoparasitic prevalence. To verify if the observed frequency distribution differs from sets arose by chance was used the Pearson's chi-squared test (χ^2). Data management was performed with R 4.2.1. (R Core Team 2022) with the packages *MASS* (Venables & Ripley 2002), *ggplot2* (Wickham 2016), *tidyr* (Wickham & Girlich 2022), and *dplyr* (Wickham *et al.* 2022).

Result

A total of 557 Red-footed Falcon nestlings coming from the artificial nests in the province of Parma were ringed between 2019 and 2022. Of these, 318 belonging to 112 clutches were also inspected to determine their ectoparasitic load. Among the 112 inspected clutches, 50 had parasitized nestlings (44.6%). Ectoparasites were stored per individual host in

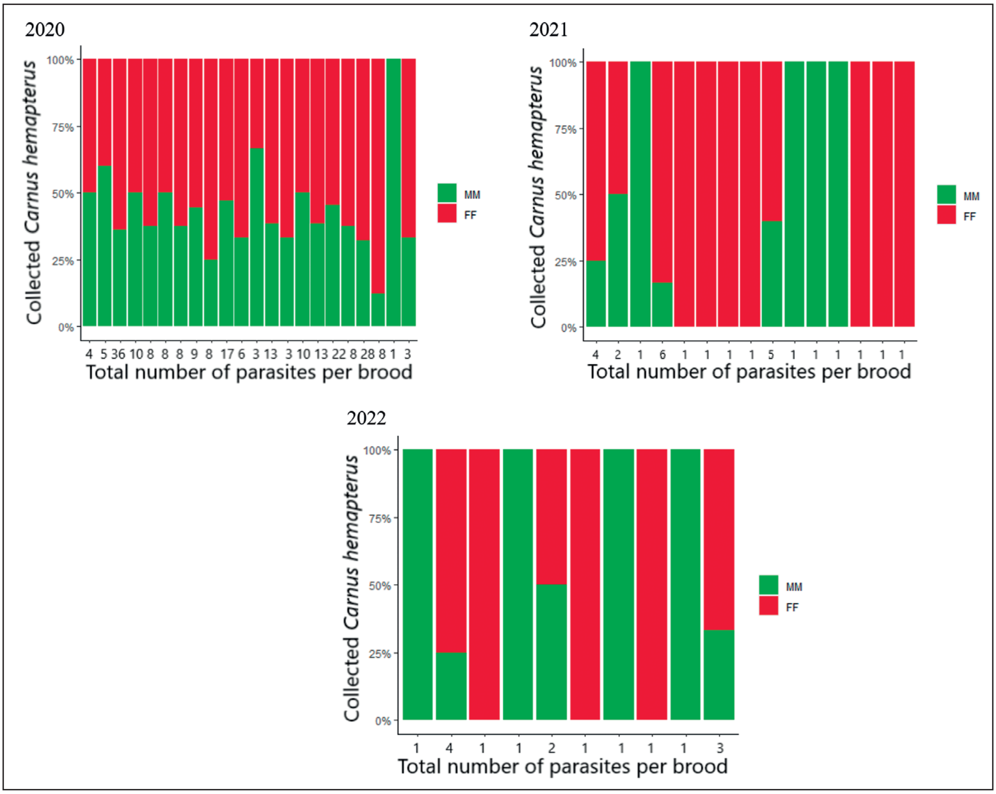

Figure 1. *Carnus hemapterus* sex-ratios per clutch (FF: females; MM: males). 100% FF or MM specimens means there was only one parasite in the whole clutch. Data for 2019 were not available

1. ábra *Carnus hemapterus* ivararányok az egyes fészekaljakban (FF: nőstények; MM: hímek). A 100% hím vagy nőstény ivararányok esetében csak egyetlen parazita volt a teljes fészekaljon. A 2019. évre az adatok nem elérhetőek

Table 1. Yearly ectoparasite prevalence from 2019 to 2022. Total number of inspected nestlings, per individual host, and per clutch prevalence are shown. Collected *Carnus hemapterus* specimens refer both to those collected from the overall inspected nestlings and to those coming from nestlings of known age only

1. táblázat Az ektoparaziták éves prevalenciája 2019 és 2022 között. A vizsgált fiókák teljes száma, valamint az egyedenként és fészekaljanként számított prevalencia. A begyűjtött *Carnus hemapterus* példányok száma az összes vizsgált fiókáról, illetve az ismert korú fiókákról

Year	**Infested nestlings**	**Inspected nestlings**	**Per host prevalence (%)**	**Per brood prevalence (%)**	**Collected *Carnus hemapterus***	***Carnus hemapterus* collected from nestlings of known age**
2019	3	50	6	19	3	/
2020	71	81	87.7	91.7	302	231
2021	23	107	21.5	37.5	28	28
2022	14	80	17.5	31.3	16	16

the years 2019 and 2021–2022 and per brood in 2020. Yearly ectoparasite prevalence and abundance details are available in *Table 1*. Collected ectoparasites belonged to the hematophagous Dipteran species *Carnus hemapterus* apart from the occasional finds of one specimen of *Laemobothrion* sp. and eight *Degeeriella rufa* (Phthiraptera) in two different nestlings in 2021.

Ectoparasites were mainly located on bald areas of the axilla and inner wing. Once disturbed, they scattered on the nestling's body moving towards the goiter and groin. Areas from which they were collected often exhibited skin lesions, bruises, and clotted blood related to their hematophagy. Disregarding potential ectoparasites left inside the nest, the range of *Carnus hemapterus* abundance was usually from 1 to 3 specimens for clutch, rarely from 4 to 8 *(Table 2, Figure 2)*. The lowest percentage of parasitized nestlings and clutches was recorded for the 2019 breeding season, followed by a substantial increase in 2020 and a subsequent overall reduction for the years 2021 and 2022 *(Table 1)*. The overall prevalence of ectoparasites in the year 2020 was highly significantly greater than the prevalence for the other three breeding seasons (Pearson's Chi-squared test, $\chi^2 = 28.053$, df = 3, P < 0.001). No significant difference among sexes could be detected for the overall number of collected ectoparasites (Pearson's Chi-squared test, $X^2 = 0.762$, df = 2, P = 0.6835), although the number of collected females was steadily higher than the number of collected males each year *(Table 3, Figure 1)*.

Table 2. Frequency distribution of *F. vespertinus* broods across infestation intensity classes over the years

2. táblázat A kék vércse fészekaljak gyakorisági eloszlása a fertőzés intenzitási osztályok között az évek során

Year	**Range of *C. hemapterus* abundance**	**Number of infested broods**
2019	1–3	3
2020	1–3	4
	4–8	9
	9–12	3
	13–18	3
	20–40	3
2021	1–3	12
	4–8	3
2022	1–3	8
	4–8	2

In 2019, the collected sample was rather small if compared to the following breeding seasons and the inspected nestlings were all over 15 days old (i.e. already in the molting phase). Nestlings' age seems to be particularly important for *C. hemapterus* host choice, and these two variables turned out to be highly statistically significant dependent (Pearson's Chi-squared test, P < 0.001) for the overall four breeding seasons *(Table 4, Figure 3)*. *Figure 3* shows the yearly age-prevalence relationship for the clutches of known age. Results show that concentrations of *C. hemapterus* were highest for nestlings under 7 days of age and remained generally high for

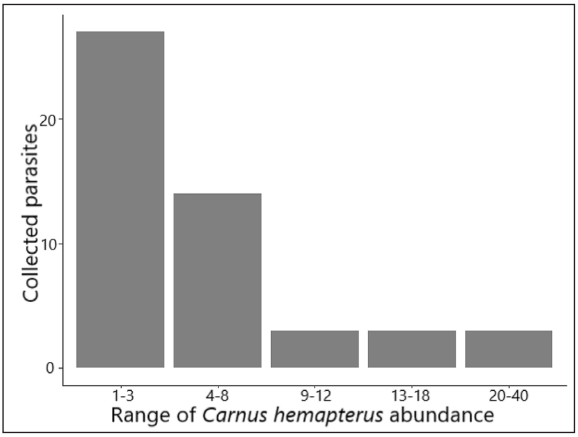

Figure 2. Frequency distribution of *Falco vespertinus* broods across infestation intensity classes during the 2019, 2020, 2021, and 2022 breeding seasons (N=50 broods)

2. ábra A kék vércse fészekaljak gyakorisági eloszlása fertőzöttség intenzitási osztályok között a 2019-es, 2020-as, 2021-es és 2022-es költési időszakban (N=50 fészekalj)

Table 3. *Carnus hemapterus* sex ratio (MM/[FF+MM]) and abundance per brood from 2020 to 2022 (sexing data from the year 2019 were not available). (FF: females; MM: males)

3. táblázat *Carnus hemapterus* ivararány (MM/[FF+MM]) és abundancia fészekaljanként 2020 és 2022 között (2019-es ivar adatok nem álltak rendelkezésre). (FF: nőstény; MM: hím)

Year	**FF (per brood range)**	**MM (per brood range)**	**Sex ratio (MM/[FF+MM])**	**Mean abundance per brood (FF, MM)**	**St. deviation of mean abundance per brood (FF, MM)**
2020	139 (0–23)	92 (1–13)	0.398	10.5 (6.3, 4.2)	8.4 (5.4, 3.1)
2021	19 (0–5)	9 (0–2)	0.321	1.9 (1.3, 0.6)	1.6 (1.3, 0.6)
2022	9 (0–3)	7 (0–1)	0.438	1.6 (0.9, 0.7)	1.0 (0.9, 0.5)

Table 4. Pearson's Chi-squared test results and rough data for the comparison between age ranges and the corresponding number of infested nestlings found in the four breeding seasons (from 2019 to 2022)

4. táblázat Pearson-féle Chi-négyzet teszt eredménye és a nyers adatok a korosztályok fertőzöttségének összehasonlítására a négy költési időszakban (2019-től 2022-ig)

Age range	**Infested nestlings**			
< 7 days	19			
7–10 days	23			
10–12 days	17			
12–15 days	14			
15–20 days	28	**Chi²**	***df***	***P-value***
20–25 days	10	23.845	5	0.0002325

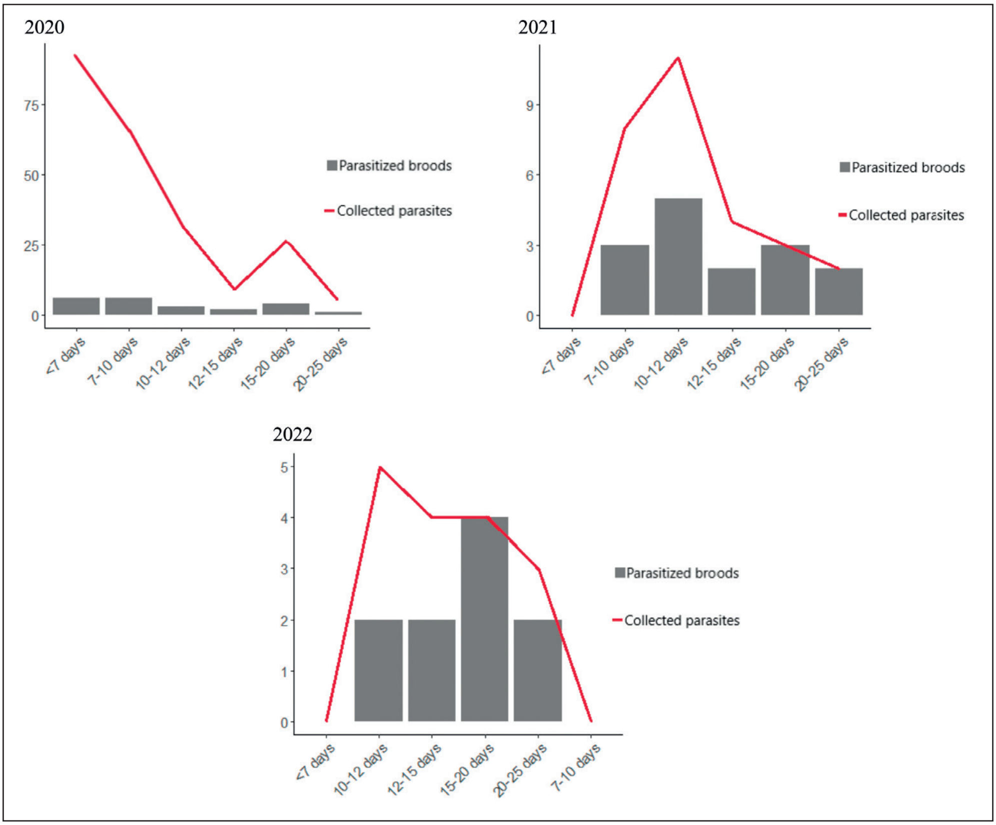

Figure 3. The number of infested broods and the number of *Carnus hemapterus* individuals per host-age categories. Year 2019 was disregarded due to the reduced sample size

3. ábra A fertőzött fészekaljak száma és a begyűjtött *Carnus hemapterus* legyek egyedszáma a három év során, a fiókák korosztálya szerint csoportosítva. A 2019-es évet a kis mintaelemszám miatt kihagytuk

individuals in the pre-molting phase (aged from 15 days under) tending to decrease in the following age groups, sharply in 2020 and 2021, gradually in 2022 *(Figure 3)*. Maximum abundance was recorded in the <7 days old age group for the year 2020 and in the 10–12 days old age group for the years 2021 and 2022. Please note that in both seasons 2021 and 2022 average nestlings' age was a little higher if compared to 2020 (i.e. no <7 days old nestlings in 2021, and no <7 days old nor 7–10 days old nestlings in 2022).

Discussion

In this study, we analyzed the prevalence and abundance of ectoparasites on *Falco vespertinus* nestlings in the Italian Po valley (Parma province). High ectoparasite loads on nestlings can impair their health condition and growth rate (Hoi *et al.* 2010, Cantarero *et al.* 2013, Romano *et al.* 2021), increase physiological stress by inducing costly immune and inflammatory responses (Martínez-Padilla *et al.* 2004, Tomás *et al.* 2008, Cantarero *et al.* 2013), raise the mortality rate (Richner *et al.* 1994) or indirectly decrease their fitness through the transmission of blood parasites (Poiani 1993, Richner *et al.* 1994, Martínez-De La Puente *et al.* 2013). Given these negative impacts, ectoparasite abundance and spatial distribution might affect the attractiveness of a breeding site and the behavioural and social dynamics in the host population (Møller 1993, de Lope & Møller 1993, Møller & Erritzøe 1996, Cantarero *et al.* 2013, Veiga & Valera 2020). Therefore, parasitic drivers may be a key ecological variable for the reproductive success of a rare species such as the Red-footed Falcon, as already showed in colonies of this species in Hungary (Piross *et al.* 2015, Soltész *et al.* 2018).

Almost all specimens collected from *F. vespertinus* nestlings in the Italian Po valley belonged to a single species, *Carnus hemapterus*, an ectoparasite of the *Carnidae* family with Holarctic distribution (Sabrosky 1987, Grimaldi 1997), known to parasite the nestlings of at least 45 bird species breeding in cavities or sheltered nests (Capelle & Whitworth 1973, Grimaldi 1997). *C. hemapterus* ecology is poorly known but it is believed that females lay their eggs in the debris of the nest where the saprophagous pupae winter in diapause, enjoying the humid microclimate and feeding on organic matter (Grimaldi 1997, Valera *et al.* 2006, Soltész *et al.* 2018). Hematophagous adults appear in the nest synchronizing with hatching and, once a suitable host is found, gather on bald skin areas, and lose their wings to move more easily between feathers (Grimaldi 1997). To feed, they tear the epidermis and suck the blood coming from the open wound (Bequaert 1942). Male adult flies remain in their winged phase longer than females, thus being able to colonize new hosts and new clutches for reproductive purposes (Capelle & Whitworth 1973, Grimaldi 1997, Roulin 1998).

C. hemapterus is the easiest-found ectoparasite in various raptor species breeding in nest-boxes (Dawson & Bortolotti 1997, Fargallo *et al.* 2001, Kal'avský & Pospíšilová 2010, Sumasgutner *et al*. 2014, Podofillini *et al.* 2018, Levesque-Beaudin *et al.* 2020) including the Red-footed Falcon (Fehérvári *et al.* 2015, Soltész *et al.* 2018).

Many studies on *Falco tinnunculus* show similar prevalence to the ones obtained here (Fargallo *et al.* 2001, Kal'avský & Pospíšilová 2010, Sumasgutner *et al.* 2014). *Carnus hemapterus* prevalence is expected to vary broadly both within and between years and is usually related to habitat parameters (e.g. vegetation structure, plant architecture) and date of inspection (Veiga *et al.* 2020). In accordance with our results (mean: 1.1) other studies on *Falco naumanni* show a usually low *Carnus hemapterus* load, frequently setting at 1–3 to around 6 parasites per nestling (Romano *et al.* 2021)

However, it is important to note that during the 2020 breeding season some individuals had up to 12 ectoparasites actively blood-feeding on their bodies during the inspection, setting at a higher load than expected (mean: 10.5). We consistently found female-biased sex ratios, regardless of the year of inspection and age of the host; however, no significant difference in collected amount could be detected among sexes for the overall four breeding seasons. The reason for this apparent sex-ratio unbalance could be that females in this species are wingless and bigger than males (Grimaldi 1997), so their detection tends to be easier. However, *Carnus hemapterus* sex-ratios per clutch were not significantly dissimilar in the overall four breeding seasons Václav *et al.* (2016) suggest that *C. hemapterus* could be a threat not only for the damage caused to tissues (skin tearing) but may also be a vector for *Plasmodium* and *Haemoproteus* infestations. Despite this, however, *C. hemapterus* does not seem to have significant effects on nestlings' health, development, or mortality rate, proving that they easily survive significant blood losses (Dawson & Bortolotti 1997). Most studies likewise exclude a negative effect on parents' fitness, apparently being able to meet the energy needs of a parasitized offspring thanks to high food availability at the breeding site (Dawson & Bortolotti 1997, Fargallo *et al.* 2001, Kal'avský & Pospíšilová 2010, Soltész *et al.* 2018, Castaño-Vázquez *et al.* 2022).

Peaks of *C. hemapterus* abundance often coincide with the first two weeks of age of the nestling both in *Falco sparverius* (Dawson & Bortolotti 1997, Lesko & Smallwood 2012) and in *Falco tinnunculus* (Kal'avský & Pospíšilová 2010, Sumasgutner *et al.* 2014). Similar results have also been obtained for other bird species such as *Tyto alba* (Roulin 1998) and *Sturnus vulgaris* (Liker *et al.* 2001). The reasons behind this trend have been long debated but are most probably related to plumage molting (from downy to flight feathers) as an increased darker plumage density and layering may result in a less hospitable environment for the flies (Kirkpatrick & Colvin 1989). Moreover, nestlings tend to be more mobile as they grow and start spending most of their time standing up, thus making themselves less easily reachable for mostly wingless parasites (Dawson & Bortolotti 1997). Further, they physically eliminate most ectoparasites through preening (Piross *et al.* 2020) and have stronger immune defenses (Roulin 1998, 1999). Nest-box cleaning activities can be an unsustainable long-term cost, even though nestlings coming from clean nest-boxes are more likely to develop into a fledged offspring (Fehérvári *et al.* 2015, Romano *et al.* 2021). Difficult accessibility of the nests (i.e. fixed on trees several meters above the ground) and financial limitations (i.e. need for a self-propelled aerial platform) made it unfeasible to determine if more frequent cleaning activities in these colonies influence overall ectoparasitic prevalence. However, many studies analyzing the differences in ectoparasite loads in recently cleaned *Falco vespertinus* nest-boxes and in nest-boxes left intact for longer periods express conflicting opinions on the need for maintenance since some pupae can survive in the interstices of the nest (Dawson & Bortolotti 1997) and these ectoparasites easily re-colonize recently cleaned nest-boxes (Lesko & Smallwood 2012, Podofillini *et al.* 2018). Therefore, we hypothesized that increasing the frequency of these activities and/or the substitution of nest materials could be of no use, besides being highly expensive and time-consuming.

Conclusion

Carnus hemapterus prevalence has significantly risen from the 2019 breeding season to 2020 in the *Falco vespertinus* colonies in the province of Parma. This increase was steadily reduced in the following two years. *C. hemapterus* has high transmissibility in avian colonies since winged adults are very mobile (Podofillini *et al.* 2018, Soltész *et al.* 2018). Given that *F. vespertinus* is mainly limited by the lack of suitable nesting sites, if nest-boxes are available they are quickly occupied disregarding their state of cleanliness (Kotymán *et al.* 2015).

As a result, nest-box maintenance activities do not seem to have a direct effect on *F. vespertinus* nesting choices. Not having historical records on nestlings' growth parameters in the Parma colonies, although only in 2015 reproductive success was found to be lower than average (Calabrese *et al.* 2020), it is not possible to determine whether the 2020 increase in parasite load had direct negative effects nor whether it led to an increase in infestations or disease transmission. However, *C. hemapterus* feeds on live tissues, increases the metabolic expenditure of the host, and tends to be more prevalent in individuals with poor immune defenses, so it is conceivable that it may pose a threat to weaker and younger *F. vespertinus* individuals (Piross *et al.* 2020), especially if we consider that ectoparasite abundance was found to be significantly dependent on host age (higher the abundance the younger the host). In a context of a global ecological niche, these parasites still fall within the natural balance related to the Red-footed Falcon and could be elements to be preserved themselves. Still, reproductive success was consistently high in the 2019–2022 period, so it is conceivable that potential negative impacts remained limited. To understand the parasite-host relationship in these colonies it may be useful to determine if, as hypothesized, a higher parasite load is linked to a more mammal-based diet related to the overall abundance of micro-mammals in the foraging habitat. The 2020 breeding season was characterized by a higher-than-usual availability of *Microtus savii* and most inspected nest-boxes were rich in prey remnants infested by various fly species; this year was indeed the one when ectoparasite infestation was the highest and the difference in collection between this year and the other three was highly significant, hence a connection between diet and parasite load could be suggested. Indeed, the Red-footed Falcon is a short-grass specialist and can feed upon different food resources (e.g. *Amphibia, Hexapoda, Mammalia, Reptilia*), so differences in ectoparasite prevalence could result from different foraging behaviours in subsequent breeding seasons, adapted to the local abundance of prey in the available foraging patches (i.e. alfalfa crops and fallow land) during the chick-rearing season. It might be interesting to define the parameters affecting the variability in ectoparasite abundances such as host measurements and expression of begging traits (e.g. body mass, forearm length, size, and colour of the flange, cere, and cape) that are reported to change under higher ectoparasitic loads in Lesser Kestrels *(Falco naumanni)* (Romano *et al.* 2021); average concentrations of attractant stimuli (e.g. odour, heat, carbon dioxide emission) in bigger breeding colonies; food availability and foraging preferences; climatic conditions (e.g. humidity, rainfall patterns) before and during the breeding season (Castaño-Vázquez *et al.* 2022).

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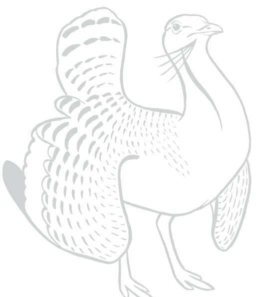

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Records of avian deformities in Nepal

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Abstract Avian deformities have been recorded in a variety of bird species all over the world. However, they have not been studied in Nepal, although there are increasing sightings of these deformities. Injuries, genetic mutations, environmental factors, infections, radiation, and other factors can cause deformities. In our study, we collected data from numerous field trips, conversations with bird watchers and experts, and social media posts in Nepal. We reported 24 cases of avian deformities in 16 different bird species across 12 districts in Nepal, suggesting that certain abnormalities persist in a high proportion of previously unstudied birds. We discovered different types of color abnormalities (6 cases of leucism, 3 albinism, 4 partial leucism, 1 brown mutation, 1 melanism, and 3 unidentified color aberration), 5 cases of avian keratin disorder (AKD), and 1 case of both leucism and AKD. The majority of these cases affected corvids and other birds frequently living and nesting near human settlements, indicating that causative agents such as anthropogenic toxicants and environmental degradation could be important contributors. There is a scarcity of research on avian deformities and diseases in Nepal, thus more research on avian abnormalities, such as the pathophysiology of AKD and genetic studies, should be performed.

Keywords: avian deformity, avian keratin disorder (AKD), albinism, leucism, melanism, environmental degradation

Összefoglalás Számos madárfajnál észleltek már változatos fizikai (testi) elváltozásokat a világ különböző részein. Nepálban azonban még nem vizsgálták ezeket, bár egyre gyakoribbak a megfigyelések ott is. Ezeket az elváltozásokat sérülések, genetikai mutációk, környezeti tényezők, fertőzések, sugárzás és egyéb tényezők okozhatják. Tanulmányunkhoz számos terepbejárásból, madármegfigyelőkkel és szakértőkkel folytatott beszélgetésekből, valamint a közösségi médiában közzétett bejegyzésekből gyűjtöttünk adatokat. Nepál 12 körzetében 16 madárfajnál összesen 24 elváltozásról számoltunk be, ami arra utalhat, hogy bizonyos rendellenességek a Nepálban föllelhető madárfajok populációiban nagy arányban és tartósan jelen lehetnek. A rendellenességek érintették a színezetet (6 esetben leucizmust, 3 esetben albinizmust, 4 esetben részleges leucizmust, 1 esetben barna mutációt, 1 esetben melanizmust és 3 esetben nem azonosított színelváltozást), 5 esetben madárkeratin-deformitást (MKD) és 1 esetben együttesen leucizmust és MKD-t. Ezek az esetek többségében varjúféléknél és egyéb olyan madárfajoknál fordultak elő, amelyek gyakran találhatóak meg települések közelében. Ez azt sugallja, hogy az antropogén tényezők, mint például a mérgező anyagok és a környezeti degradáció, fontos szerepet játszhatnak a rendellenességek feltűnésében. Nepálban kevés a madárdeformitásokkal és -betegségekkel kapcsolatos kutatás, ezért több olyan vizsgálatra lenne szükség, mint például az MKD patofiziológiája és a betegségek genetikai hátterének feltárása.

Kulcsszavak: albinizmus, környezeti degradáció, leucizmus, madárrendellenesség, madárkeratin-deformitás (MKD), melanizmus

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Introduction

Avian species have been observed with different malformations that manifest as deformities developed during their embryonic stage or after hatching (Pourlis 2011). Relatively, birds are affected by severe physical defects more than other vertebrates because of the physiological needs of powered flight. And, birds with physical abnormalities merely survive longer in wild (Reynolds 2021). Habitat conditions and health of bird are reflected in the malformations. These anomalies have increased understanding whether normal or abnormal growth in avian species and by extension, other animals and people. The utilization of abnormality data might be a viable bio-monitoring technique for determining changes in environmental circumstances significant enough to have an influence on biology (Pourlis 2011).

Deformities have been recorded in a wide range of birds which can be caused by injuries, genetic defects, environmental factors, diseases, radiation, and unknown reasons (Rutz *et al.* 2004, Pourlis 2011, Zylberberg *et al.* 2018). Early lethal conditions, beak deformities, feather abnormalities, skeletal abnormalities, ocular malformations, and sublingual oral fistulas are primary malformations observed in avian species (Pourlis 2011, Reynolds

Table 1. List of bird species recorded with deformity in Nepal
1. táblázat A Nepálban található azon madárfajok, amelyeknél rendellenes egyed észlelése történt

S.N.	Common Name	Scientific Name	IUCN Redlist	National Redlist	Migratory Status	Individuals Recorded
1	House Crow	*Corvus splendens*	LC	LC	R	5
2	House Sparrow	*Passer domesticus*	LC	LC	R	3
3	Eurasian Coot	*Fulica atra*	LC	LC	WM	1
4	Eurasian Cuckoo	*Cuculus canorus*	LC	LC	SM	1
5	Steppe Eagle	*Aquila nipalensis*	EN	VU	WM	1
6	Fulvous-breasted Woodpecker	*Dendrocopos macei*	LC	LC	R	1
7	Siberian Stonechat	*Saxicola torquatus*	LC	LC	R	1
8	Jungle Babbler	*Turdoides striata*	LC	LC	R	1
9	Red-vented Bulbul	*Pycnonotus cafer*	LC	LC	R	1
10	Barn Swallow	*Hirundo rustica*	LC	LC	R	2
11	Large-billed Crow	*Corvus macrorhynchos*	LC	LC	R	1
12	Rufous Treepie	*Dendrocitta vagabunda*	LC	LC	R	1
13	Great Barbet	*Megalaima virens*	LC	LC	R	1
14	Common Myna	*Acridotheres tristis*	LC	LC	R	2
15	Rufous-bellied Niltava	*Niltava sundara*	LC	LC	R	1
16	Indian Pond Heron	*Ardeola grayii*	LC	LC	R	1

Abbreviations: LC= Least Concern; EN= Endangered; VU= Vulnerable; R= Resident; SM= Summer Migrant; WM= Winter Migrant

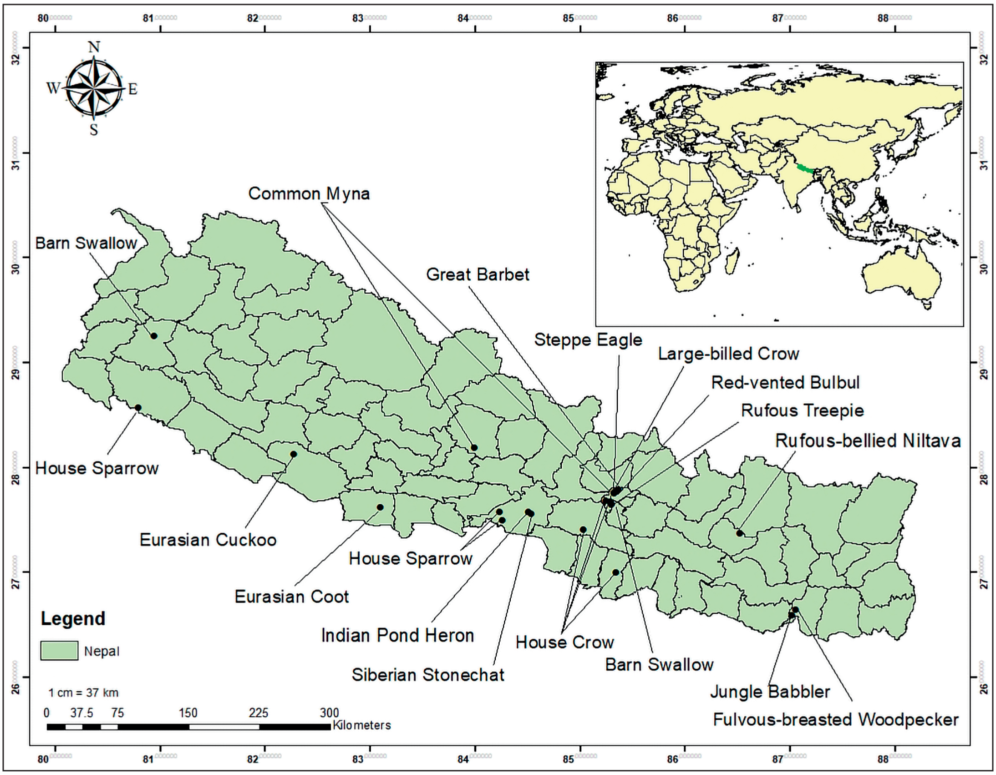

Figure 1. Avian deformities recorded from Nepal
1. ábra Nepálban észlelt rendellenességek madaraknál

2021). While there are varied avian deformities documented across the world, the proper documentation of birds with deformities in Nepal is merely obtained. Birds with deformities have been sighted opportunistically in varied locations and in varied species in Nepal. This study presents records of avian deformities in Nepal and is the first attempt to unveil avian deformity data for Nepal.

Material and Methods

The opportunistic sightings records of avian deformities were gathered (Zylberberg *et al.* 2021) in Nepal. Avian deformities in this study were focused on beak deformities and feather color abnormalities since these can be identifiable with high certainty by visual observations and photographic records. The sighting records were gathered during various field visits, communication with bird watchers and researchers, and collected from social media posts. The species name, taxonomy, and conservation status were determined using Inskipp *et al.* (2016) and the IUCN Red List of Threatened Species (2023).

Results

Altogether, 24 cases of avian deformities in 16 species have been recorded in our study. The cases of deformities were found to be the highest in *Corvus splendens* (n=5), followed by *Passer domesticus* (n=3), then both *Hirundo rustica* and *Acridotheres tristis* (n=2) *(Table 1)*. The highest number of recorded deformity was leucism (n=6), whilst the least were melanism and brown mutation (n=1).

The majority of the records (n=13) were noted in resident birds, while two deformity records were in winter migrants including the globally endangered Steppe Eagle *(Aquila nipalensis)*, and one deformity record was in summer migrants. Partial leucistic Steppe Eagle was also recorded.

Altogether the deformities were recorded from 12 districts of Nepal (see *Table 2* for detail). The majority of records were obtained from the Kathmandu Valley, which may be due to a greater number of bird watchers and researcher resident to the area *(Figure 1)*.

1. *Corvus splendens* House Crow

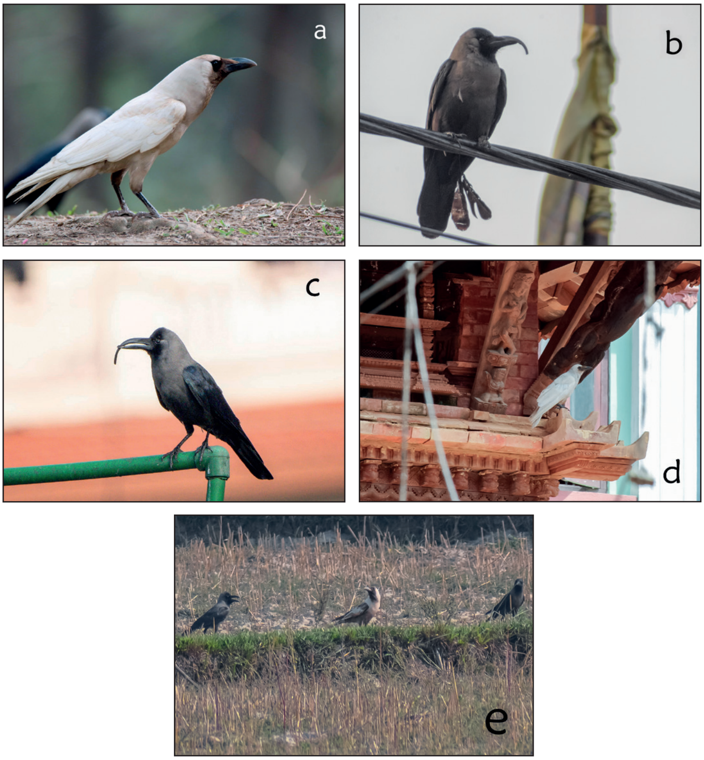

Figure 2. Avian deformities recorded in *Corvus splendens*. **a.** Leucism ©Aditya Pal **b.** Avian Keratin Disorder (AKD) ©Nikeet Pradhan **c.** AKD ©Sudeep K.C. **d.** Leucism ©Mohan Bikram Shrestha **e.** Mutation Brown ©Nikeet Pradhan

2. ábra *Corvus splendens* elváltozásai. **a.** Leucizmus ©Aditya Pal **b.** Madárkeratin-deformitás (MKD) (AKD) ©Nikeet Pradhan **c.** AKD ©Sudeep K.C. **d.** Leucizmus ©Mohan Bikram Shrestha **e.** Barna mutáció ©Nikeet Pradhan

2. *Passer domesticus* House Sparrow

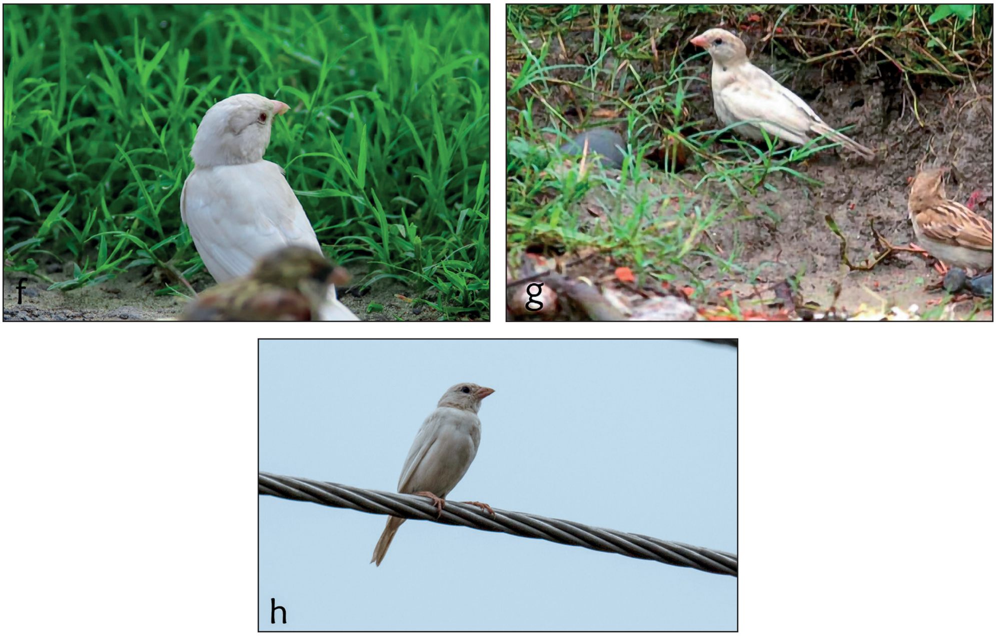

Figure 3. Avian deformities recorded in *Passer domesticus*. **f.** Albinism ©Kul Raj Chaudhary **g.** Unidentified color aberration (albinism or leucism) ©Manesh Limbu and Asbin Gurung **h.** Leucism ©Ram Krishna Mahato

3. ábra *Passer domesticus* elváltozásai. **f.** Albinizmus ©Kul Raj Chaudhary **g.** Nem meghatározható elváltozás (albinizmus vagy leucizmus) ©Manesh Limbu and Asbin Gurung **h.** Leucizmus ©Ram Krishna Mahato

3. *Hirundo rustica* Barn Swallow

Figure 4. Avian deformities recorded in *Hirundo rustica*. **i.** Unidentified color aberrations (albinism or leucism) ©Arend Van Riessen **j.** Unidentified color aberrations (albinism or leucism) ©Surat Pariyar

4. ábra *Hirundo rustica* elváltozásai. **i.** Nem meghatározható elváltozás (albinizmus vagy leucizmus) ©Arend Van Riessen **j.** Nem meghatározható elváltozás (albinizmus vagy leucizmus) ©Surat Pariyar

4. *Acridotheres tristis* Common Myna

Figure 5. Avian deformities recorded in *Acridotheres tristis.* **k.** AKD ©Mohan Bikram Shrestha **l.** Partial Leucism ©Sundar Oli

5. ábra *Acridotheres tristis* elváltozásai. **k.** MKD ©Mohan Bikram Shrestha **l.** Részleges leucizmus ©Sundar Oli

5. *Fulica atra* Eurasian Coot

Figure 6. Albinism recorded in *Fulica atra* ©Anil Chaudhary

6. ábra *Fulica atra* albinizmusa ©Anil Chaudhary

6. *Cuculus canorus* Eurasian Cuckoo

Figure 7. Leucism and AKD recorded in *Cuculus canorus* ©Suman Ghimire

7. ábra *Cuculus canorus* leucizmusa és MKD-ja ©Suman Ghimiref

7. *Aquila nipalensis* Steppe Eagle

Figure 8. Partial leucism recorded in *Aquila nipalensis* ©Ashish Shrestha

8. ábra *Aquila nipalensis* részleges leucizmusa ©Ashish Shrestha

8. *Dendrocopos macei* Fulvous-breasted Woodpecker

Figure 9. Leucism recorded in *Dendrocopos macei* ©Nikeet Pradhan

9. ábra *Dendrocopos macei* leucizmusa ©Nikeet Pradhan

9. *Saxicola torquatus* Siberian Stonechat

Figure 10. Leucism recorded in *Saxicola torquatus* ©Ram Krishna Mahato

10. ábra *Saxicola torquatus* leucizmusa ©Ram Krishna Mahato

10. *Turdoides striata* Jungle Babbler

Figure 11. Leucism recorded in *Turdoides striata* ©Deven Kharel

11. ábra *Turdoides striata* leucizmusa ©Deven Kharel

11. *Pycnonotus cafer* Red-vented Bulbul

Figure 12. AKD recorded in *Pycnonotus cafer* ©Mohan Bikram Shrestha

12. ábra *Pycnonotus cafer* MKD-ja ©Mohan Bikram Shrestha

12. *Corvus macrorhynchos* Large-billed Crow

Figure 13. Albinism recorded in *Corvus macrorhynchos* ©Mohan Bikram Shrestha

13. ábra *Corvus macrorhynchos* albinizmusa ©Mohan Bikram Shrestha

13. *Dendrocitta vagabunda* Rufous Treepie

Figure 14. AKD recorded in *Dendrocitta vagabunda* ©Arend Van Riessen

14. ábra *Dendrocitta vagabunda* MKD-ja ©Arend Van Riessen

14. *Megalaima virens* Great Barbet

Figure 15. Partial leucism recorded in *Megalaima virens* ©Bikash Singh Lama

15. ábra *Megalaima virens* részleges leucizmusa ©Bikash Singh Lama

15. ***Ardeola grayii*** **Indian Pond Heron**

Figure 16. Melanism recorded in *Ardeola grayii* ©Sugam Tamrakar

16. ábra *Ardeola grayii* melanizmusa ©Sugam Tamrakar

16. ***Niltava sundara*** **Rufous-bellied Niltava**

Figure 17. Partial leucism recorded in *Niltava Sundara* ©Mohan Bikram Shrestha

17. ábra *Niltava Sundara* részleges leucizmusa ©Mohan Bikram Shrestha

Discussion

Abnormal bill morphology in wild birds is extremely unusual, with a 0.5% incidence rate, and a broad epizootic of beak malformations compatible with AKD has been recorded in dozens of avian species throughout the world (Pomeroy 1962, Harrison 2011, Handel & Hemert 2015, Zylberberg *et al.* 2016). Beak deformities such as crossed mandibles, upper mandibles decurved, lower mandible upcurved, upper mandible upcurved and/or lower mandible decurved, elongation, lateral curvature, and locked bills have all been documented in various avian species over the world (Pourlis 2011). Wild bird species with malformed beaks are becoming more frequent, and the occurrence of these severe deformities in populations is routinely utilized to diagnose underlying environmental health concerns (Hemert & Handel 2010). In our study, 6 cases of AKD with upper mandible decurved and crossed mandible were recorded in Nepal, and all the records were found in urban areas with anthropogenic disturbances, suggesting that the major cause could be environmental degradation by humans (Leveau 2021).

Aberrations of feather color or morphology can impact only a single feather or even the entire body, altering the overall appearance of the bearer. These occurrences are more frequently documented as compared to the common opinion, birds with color anomalies do not always die to natural predators and may often live for a long period (Pourlis 2011, van Grouw 2012). Melanins (eumelanin and pheomelanin) are one of the primary pigments that contribute to plumage color production (Calhim *et al.* 2014, Laczi *et al.* 2019a), hence play important roles, for example, in communication (Bókony *et al.* 2003), camouflage

Table 2. Types of deformity observed in the bird species recorded
2. táblázat A madárfajoknál megfigyelt deformitás típusai

S.N.	Common Name	Scientific Name	Deformity Observed	Recorded Location	Recorded Date
1 (a)	House Crow	*Corvus splendens*	Leucism	Kirtipur, Kathmandu (27°40′45.03″N 85°17′18.67″E)	26 April 2018
1 (b)	House Crow	*Corvus splendens*	AKD	Hetauda, Makawanpur (27°25′0.30″N 85° 1′58.32″E)	6 May 2023
1 (c)	House Crow	*Corvus splendens*	AKD	Chandragiri, Kathmandu (27°41′11.16″N 85°14′29.28″E)	6 May 2023
1 (d)	House Crow	*Corvus splendens*	Leucism	Tokha, Kathmandu (27°46′9.35″N 85°19′43.73″E)	31 August 2019
1 (e)	House Crow	*Corvus splendens*	Brown Mutation	Ramoli Bairita, Rautahat (27° 0′27.65″N 85°20′39.08″E)	10 May 2023
2 (f)	House Sparrow	*Passer domesticus*	Albinism	Hulaki, Kailali (28°34′18.0″N, 80°47′12.0″E)	30 June 2022
2 (g)	House Sparrow	*Passer domesticus*	Unidentified color aberration	Meghauli, Chitwan (27°34′44″N, 84°13′42″E)	28 June 2020
2 (h)	House Sparrow	*Passer domesticus*	Leucism	Madi, Chitwan (27°30′13.92″N, 84°15′36.56″E)	25 September 2019
3 (i)	Barn Swallow	*Hirundo rustica*	Unidentified color aberration	Batsala Devi Mandir, Lalitpur (27°30′13.92″N, 84°15′36.56″E)	21 August 2021
3 (j)	Barn Swallow	*Hirundo rustica*	Unidentified color aberration	Dipayal silgadhi, Doti (29°15′31.88″N, 80°56′32.43″E)	14 April 2023
4 (k)	Common Myna	*Acridotheres tristis*	AKD	Tokha, Kathmandu (27°45′17.99″N, 85°19′38.00″E)	8 June 2020
4 (l)	Common Myna	*Acridotheres tristis*	Partial Leucism	Pokhara, Kaski (28°11′26.64″N, 83°59′23.34″E)	26 May 2023
5	Eurasian Coot	*Fulica atra*	Albinism	Jagdishpur reservoir, Kapilvastu (27°37′27″ N, 83°05′39″ E)	11 January 2019

S.N.	Common Name	Scientific Name	Deformity Observed	Recorded Location	Recorded Date
6	Eurasian Cuckoo	*Cuculus canorus*	Leucism and AKD	Ghorahi, Dang (28°07′54″ N, 82°16′18″ E)	1 February 2017
7	Steppe Eagle	*Aquila nipalensis*	Partial Leucism	Chobhar, Kathmandu (27°39′42.46″N, 85°17′42.21″E)	25 February 2017
8	Fulvous-breasted Woodpecker	*Dendrocopos macei*	Leucism	Koshi Tappu Wildlife Reserve, Sunsari (26°38′50.70″N, 87° 2′55.98″E)	14 December 2022
9	Siberian Stonechat	*Saxicola torquatus*	Leucism	Kumroj Community Forest, Chitwan (27°33′37.39″N, 84°31′51.40″E)	3 February 2020
10	Jungle Babbler	*Turdoides striata*	Leucism	Koshi Tappu Wildlife Reserve, Sunsari (26°36′4.13″N, 87° 0′50.24″E)	7 April 2022
11	Red-vented Bulbul	*Pycnonotus cafer*	AKD	Tokha, Kathmandu (27°46′5.99″N, 85°19′30.32″E)	31 July 2021
12	Large-billed Crow	*Corvus macrorhynchos*	Albinism	Tokha, Kathmandu (27°46′35.93″N, 85°20′21.31″E)	23 October 2022
13	Rufous Treepie	*Dendrocitta vagabunda*	AKD	Batsala Devi Temple, Lalitpur (27°39′14.14″N, 85°17′45.27″E)	5 April 2018
14	Great Barbet	*Megalaima virens*	Partial Leucism	Muhan pokhari, Kathmandu (27°47′30.06″N, 85°22′15.17″E)	19 January 2021
15	Indian Pond Heron	*Ardeola grayii*	Melanism	Bachhauli, Chitwan (27°34′40.60″N, 84°30′26.42″E)	8 December 2020
16	Rufous-bellied Niltava	*Niltava sundara*	Partial Leucism	Thade, Okhaldhunga (27°22′35.56″N, 86°31′15.30″E)	6 June 2022

(Surmacki *et al*. 2021) or thermoregulation (Margalida *et al*. 2008). There are common types of color aberrations found in birds which are: albinism (a total lack of both melanins or other pigments in all feathers, eyes, and skin; e.g. Mahabal *et al*. 2016, Laczi *et al.* 2019b), leucism (a total lack of pigments from parts of the plumage or the entire plumage, e.g. Gayen *et al.* 2022, Alby *et al.* 2023), brown (reduction only of eumelanin content, e.g. van Grouw *et al.* 2011), dilution (reduction of melanin content, e.g. Morrow & Morrow 2014), ino (strong qualitative reduction of both melanins with color change, Bende *et al*. 2019), and melanism (abnormal deposit of melanin in skin and/or feathers, e.g. Uy *et al*. 2016). Leucism was the most recorded color anomaly in our study compromising 26% (n=6) and melanism was the least recorded at 4% (n=1) out of the total 24 cases. Albinism was recorded at 13% (n=3). Albinos are less well-documented because their lack of melanin in the eyes could cause them to be extremely sensitive to light and have a restricted depth of vision and are prone to cancer due to a lack of UV-protecting melanin, which explains their seeming scarcity in the environment (Miller 2005, van Grouw *et al.* 2016). Many of the defects in wild avifauna that are easily recognized phenotypically have been primarily reported as being easily detectable, whereas many other genotypic malformations which are less detectable are not recorded in our study.

Species with bigger populations (e.g. *Passer domesticus*) may have more individuals with unique phenotypes owing to a higher likelihood of mutations, as well as a higher chance of encountering specimens of the species (Gross 1965, Sage 1963). Detecting such abnormalities in rarer species may be more fascinating evidence of environmental degradation, genetic degeneration owing to inbreeding, and so on.

The specimens g, i, and j have been observed with unidentified color aberration. However, it cannot be ascertained whether it is albinism or leucism as it is not clearly visible whether the eye is red or brown, however, red eyes would be served as a distinctive trait of albinism vs. total leucism. So, a further diagnostic is lacking to ascertain the deformity

The majority of cases were corvids and other birds that often dwell and nest near human settlements and are thus more likely to be identified in the early days following fledging (van Grouw *et al.* 2016). The majority of avian defect cases were observed in Nepal's settlement region, implying that causative agents such as anthropogenic toxicants and environmental degradation are key factors.

Documented avian deformities record in a few instances in Nepal. These records are the baseline highlighting for the subject of further studies in Nepal.

Conclusion

In Nepal, there are very few records of these avian deformities. There is still little information on the prevalence, incidence, or causes of congenital abnormalities in Nepal's wild birds. As a result, more research on avian anomalies has to be done in Nepal. Lack of knowledge of the underlying physiological changes that result from the primary factors that produce beak deformities and feather color highlights the need for more research into the pathophysiology of avian keratin disease as well as genetic studies in Nepal.

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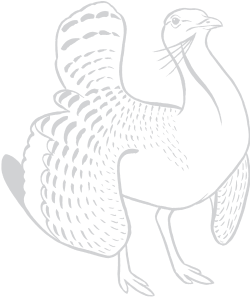

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First record of brown plumage aberration in Indian Pied Starling *(Gracupica contra)* from India

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Abstract Brown aberration in black plumage is defined by the progressive reduction of eumelanin in birds. The present report describes an observation of plumage with brown aberration in Indian Pied Starling *(Gracupica contra)* from the agricultural landscape of Shokliya village, Rajasthan, India. The observed individual exhibited browning in all the areas of the plumage that are normally black in this species, including the head, wing feathers, and tail feathers. However, feathers with no pigmentation remained white and unaffected. Genetic and dietary factors are thought to be major factors responsible for such aberrations in birds, but more research is needed to determine the exact reasons.

Keywords: brown plumage, Asian Pied Starling, Indian Pied Myna, colour aberration, phenotypic variation

Összefoglalás A fekete tollazat barna aberrációját az eumelanin fokozott csökkenése okozza a madaraknál. Tanulmányunkban egy barna aberrációval jellemezhető tollazatról adunk ismertetést az indiai Rádzsasztánban, Shokliya falu mezőgazdasági területén megfigyelt szarkaseregélynél *(Gracupica contra)*. A megfigyelt egyed a tollazata valamennyi olyan területén barnulást mutatott, amely e fajnál általában fekete, beleértve a fejet, a szárnytollakat és a farktollakat. A pigmentálatlan tollak fehérek maradtak. A tollazat efféle eltéréseiért felelős elsődleges okoknak a genetikai és táplálkozási tényezőket tartják, de a pontos okok meghatározásához további kutatásokra van szükség.

Kulcsszavak: barna tollazat, szarkaseregély, színaberráció, fenotípusos változatosság

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Introduction

Plumage aberrations in birds have long captured the attention of ornithologists and researchers due to their intriguing nature and potential insights into genetic and physiological processes (Hill & McGraw 2006, Guay *et al*. 2012, Price-Waldman & Mary 2021). Numerous instances of such aberrations have been documented in the avian world, e.g. brown, albino, melanistic, ino and leucistic plumage in the House Sparrow (Grouw 2012, Gokulakrishnan *et al*. 2019), leucism in the Greater Coucal (Alby *et al.* 2023) and Coppersmith Barbet (Gayen *et al.* 2022), etc. shedding light on the complex mechanisms governing plumage development and pigmentation (Sage 1962, Guay *et al.* 2012, Mahabal *et al*. 2015, 2016, Grouw 2021). The prevalence of aberrant plumage, estimated to exceed 1% of total bird populations, underscores the importance of these occurrences (Sage 1963).

Among the diverse array of described plumage aberrations, the phenomenon of brown plumage aberration has gained significant attention. Brown plumage is characterized by a qualitative reduction of eumelanin (Zbyryt *et al.* 2021).

Notes and Observations

This study reports a new record of brown plumage aberration in the Indian Pied Starling *(Figure 1)*. On 16th July 2023, an individual with brown aberrant plumage was observed and documented in Shokaliya village (26°12'24.7"N 74°52'22.8"E) of Rajasthan, India. Agriculture is the dominant land use in this area. The Indian Pied Starling, recognized for its predominantly black plumage adorned with distinctive white patches, is aptly named the pied starling (Grimmett *et al.* 2011).

Figure 1. Indian Pied Starling *(Gracupica contra)* side profile (left) and in flight (right)
1. ábra Szarkaseregély *(Gracupica contra)* oldalprofilban (balra) és repülés közben (jobbra)

In this case, the head region (including forehead, crown, malar, nape, supercilium and throat), flight feathers (including primaries and secondaries), and tail region, which are of shiny black colour, exhibited an unprecedented light brown hue, starkly contrasting with the bird's usual appearance. However, the white feathers, which typically exhibit no pigmentation anomalies, remained unaffected, retaining their natural appearance. This observation marks the first recording of a brown plumage aberration in the Indian Pied Starling.

In conclusion, the documented case of brown plumage aberration in the Indian Pied Starling underscores the fascinating variability and complexity of avian plumage abnormalities.

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Variation in small mammal food resource niche metrics of Western Barn Owl *(Tyto alba)* at the nesting pair and local population level

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Abstract In the present study, we investigated food resource niche parameters and the degree of specialization of two local Western Barn Owl *(Tyto alba)* populations in two different demographic phases as the crash (2015–2016) and outbreak (2019–2020) of the Common Vole *(Microtus arvalis)*. The study was conducted in two parts of the Transdanubian region of Hungary, namely in Duna-Drava National Park (DDNP) in the south-eastern part, and in Fertő-Hanság National Park (FHNP) in the north-western part. For the analysis, we used food consumption data of 20–20 randomly selected breeding pairs from the DDNP population, while 14 and 17 breeding pairs in FHNP population in the crash and outbreak periods, respectively. Since the small mammal consumption of owls represented 99.3% of the total number of individuals, only data of small mammals as main food resource were taken into account during the analysis. Based on a trait-based framework which taking into account the resemblance between resources, Rao's quadratic entropy metrics was used to estimate the food resource niche breadth at local owl populations and the breeding pair level. The small mammal resource utilization of owls was dependent on populations. The niche breadth of DDNP population was significantly smaller than FHNP population. The estimated niche overlap at the individual level was significantly different between the two populations. The calculated value of specialization of barn owl populations was significantly higher in north-western than south-eastern population. The niche breadth of the owl population living in the DDNP was significantly higher during the crash period. In contrast, the estimated niche breadth of the population living in FHNP did not differ significantly between the two demographic phases. Based on our result, the applied trait-based framework of resource niche pattern analysis demonstrated that the differences of niche breadth were explored in more detail by this method between the local Barn Owl populations of different geographical region.

Keywords: food resource, small mammal traits, estimation of niche parameters, *Tyto alba*

Összefoglalás Jelen tanulmányban két helyi gyöngybagoly *(Tyto alba)* populáció táplálékforrás niche paramétereit és specializálódási fokát vizsgáltuk a mezei pocok *(Microtus arvalis)* különböző demográfiai, mint az összeomlás (2015–2016) és gradáció (2019–2020) fázisban. A vizsgálat a Dunántúl régió két részén, nevezetesen a délkeleti részén a Duna-Dráva Nemzeti Park (DDNP), valamint az északnyugati részén a Fertő-Hanság Nemzeti Park (FHNP) területén valósult meg. Az elemzéshez a DDNP populációból 20–20 véletlenszerűen kiválasztott, míg az FHNP populációból összesen 14, illetve 17 költőpár táplálékfogyasztási adatait használtuk fel az összeomlás, illetve gradáció időszakban. Mivel a baglyok kisemlős fogyasztása az összes meghatározott egyedszám 99,3%-át tette ki, az elemzés során csak a kisemlősök, mint fő táplálékforrás adatait vettük figyelembe. A források közötti hasonlóságot figyelembe vevő tulajdonság alapú keretrendszer alapján Rao kvadratikus entrópia mérőszámát használtuk az táplálékforrás niche szélességének becslésére a lokális bagolypopulációk és az egyes költőpárok szintjén. A baglyok kisemlős forrás hasznosítása populációfüggő volt. A DDNP populációban a niche szélesség szignifikánsan kisebb volt, mint az FHNP populációban. A becsült niche-átfedés az egyedek szintjén szignifikánsan különbözött a két populáció között. A gyöngybagoly populációk specializációjának számított értéke szignifikánsan magasabb volt az északnyugati, mint a délkeleti populációban. A DDNP területén élő bagolypopuláció niche szélessége szignifikánsan nagyobb volt az összeomlás időszakban. Ezzel szemben az FHNP területén élő populáció becsült niche szélessége nem különbözött szignifikánsan a két demográfiai fázis között. Eredményeink alapján az alkalmazott táplálékforrás niche mintázat elemzés jelleg-alapú keretrendszere azt mutatta, hogy ezzel a módszerrel részletesebben feltártuk a niche szélesség különbségeit a különböző földrajzi régiók helyi gyöngybagoly populációi között.

Kulcsszavak: táplálékforrás, kisemlős jellegek, niche paramérek becslése, *Tyto alba*

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Introduction

The Western Barn Owl, *Tyto alba* (Scopoli, 1769) is the most widespread medium-sized nocturnal raptor species on Earth that inhabits mostly open areas, including synanthropic habitats, agricultural lands, natural and semi-natural grasslands in temperate ecosystems (Mikkola 1983, Tylor 1994, Roulin 2020). This owl species is common in semi-arid grasslands, fragmented farmlands, irrigated fields and vineyard agroecosystem in Mediterranean region (Charter *et al*. 2009, 2017, Wendt & Johnson 2017, Huysman & Johnson 2021a, 2021b), while its hunting territories are also include a wide variety of open areas, such as arid and semi-arid plains, palm plantations, rice fields and urban areas in the subtropical and tropical zone (Lenton 1984, Goodman *et al*. 1993, Bonvicino & Bezerra 2003, Hafidzi & Na Im 2003, Delgado-V & Cataño-B 2004, Saufi *et al*. 2020).

Although the Western Barn Owl have a wide food spectrum, especially due to the consumption of many potentially alternative preys in different geographical regions (Herrera 1974, Janžekovič & Klenovšek 2020, Romano *et al*. 2020), this owl species was characterized as a small mammal specialist nocturnal raptor, because it has adapted mainly to the hunting and consumption of nocturnal small mammals (Rodentia and Eulipotyphla) in its range (Taylor 1994, Romano *et al*. 2020). Studies on feeding habits and trophic niche breadth, and overlap variation of the Western Barn Owl at the level of intra- and interspecific feeding ecology are well known from several literature sources along its European (Pezzo & Morimando 1995, Bontzorlos *et al*. 2005, Kitowski 2013, Petrovici *et al*. 2013, Milchev 2016), North American (Marsk & Marti 1984, Marti *et al*. 1993, Jiménez *et al*. 2020), and South American (Trejo *et al*. 2005, Nanni *et al*. 2012) distribution range in temperate ecosystems. It is important to highlight the studies that evaluated the trophic niche pattern of the Western Barn Owl based on geographical variation or trends (Korpimäki & Marti 1995, González-Fischer *et al*. 2011, Milana *et al*. 2016), or along different gradients such as vegetative (Trejo & Lambertucci 2007), longitudinal-latitudinal (Leveau *et al*. 2006), and urban-rural (Teta *et al*. 2012, Hindmarch & Elliott 2015) gradients or in comparison of different landscape structures (Milchev 2015, 2022), focusing on the importance of agricultural intensification in the resource utilization of Barn Owls (Veselovský *et al.* 2017, Horváth *et al*. 2018, Romanowski & Lesiński 2020, Jiménez-Nájar *et al*. 2021). Moreover, the temporal dynamics of food-niche and dietary trends were analysed with trophic niche metrics of Barn Owls (Marti 1988, 2010), while other studies performed the niche metric analysis with regard to the biological control of Hantavirus reservoir (Muñoz-Pedreros *et al.* 2010, 2016).

The trophic ecology studies of the Western Barn Owl demonstrated that the food-niche breadth of this owl species depends on habitat structure (de la Peña *et al*. 2003, Milchev 2015, 2022, Horváth *et al*. 2018), and it is influenced by small mammal community composition, the population fluctuation and density of prey species, particularly the availability of agricultural pest rodents (Kross *et al*. 2016), such as microtine vole species (Marti 1988, Taylor 1994, Petrovici *et al*. 2013, Purger 2014, Hindmarch & Elliott 2015). In European grasslands and different agricultural landscapes, the Common Vole *(Microtus arvalis)* is the main prey of the Western Barn Owl, and it is characterized by multiannual fluctuations with 3–5 year-long population cycles in agricultural fields (Tkadlec & Stenseth 2001, Cornulier *et al*. 2013, Jacob *et al*. 2014, 2020). The past availability of rodents significantly determines the food habits and trophic niche pattern of Barn Owls (Bernard *et al*. 2010, Szűcs *et al*. 2010, Milchev 2015, Veselovský *et al*. 2017, Horváth *et al*. 2018). Several studies have shown the relationship between the productivity and breeding success of the Western Barn Owl and the availability and population fluctuation of the Common Vole (Klok & de Roos 2007, Bernard *et al*. 2010, Pavluvčík *et al.* 2015). Earlier study of Horváth *et al*. (2020) demonstrated that the clutch size of the Western Barn Owl was determined ultimately by the availability and consumption rate of the Common Vole as main prey and this study confirmed the alternative prey role in case of the murid rodent prey categories (*Apodemus* spp., Muridae). Furthermore, numerous studies reported negative correlation between the vole (*Microtus* spp.) frequency and food-niche breadth of the Western Barn Owl (Marti 2010, Hindmarch & Elliott 2015, Milchev 2015, 2016, Horváth *et al*. 2018). These studies pointed out that the availability and abundance fluctuation of the microtine vole species, as the main prey for Barn Owls, significantly determined the food resource utilization, and thus, the resource niche parameters and trophic niche pattern of owls.

The present study aims to examine the food resource niche parameters with a trait-based framework of two local Western Barn Owl *(Tyto alba)* populations, taking into account the resemblance between resources (1), to analyse the niche pattern in two different demographic phases, namely the crash and outbreak of the Common Vole as main prey in both owl populations (2) and to evaluated the degree of resource specialization of the Western Barn Owl at the nesting pair and local population level (3).

Material and Methods

Study area and sample collection

In this study, we investigated two local populations of Western Barn Owl in Danube-Drava National Park (DDNP) (494.78 km^2) and Fertő-Hanság National Park (FHNP) (335.87 km^2). The Danube-Drava National Park is located in the southern Transdanubian region (32° 30′

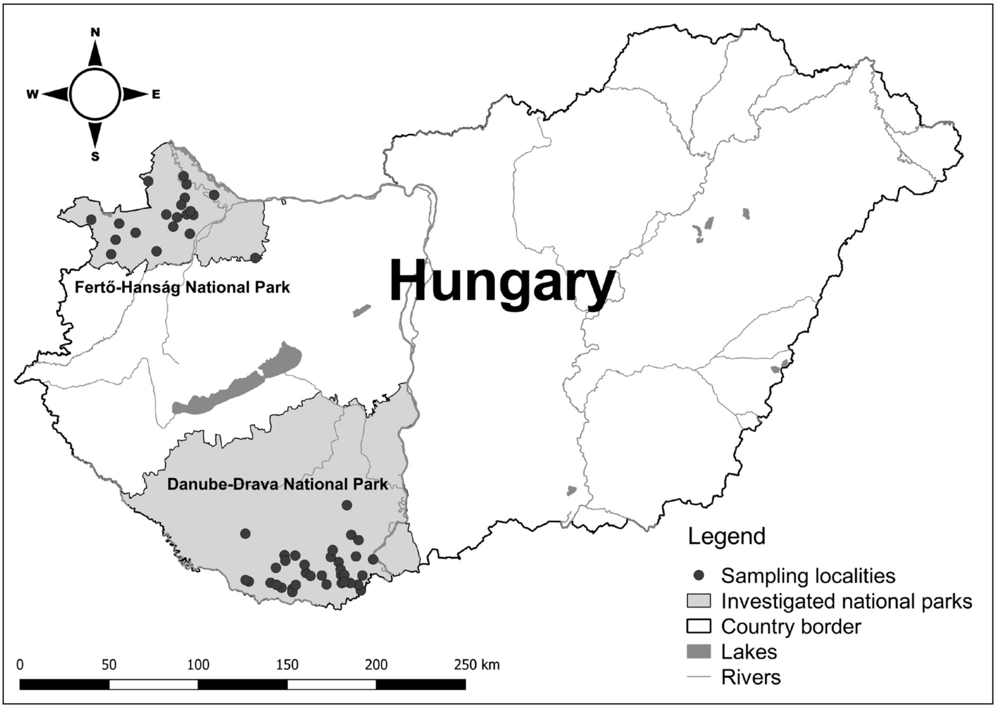

Figure 1. Study area located in the Duna-Drava National Park (DDNP) and Fertő-Hanság National Park (FHNP), Hungary, showing the location of sampled breeding pairs/sites in the two local populations of the Western Barn Owl

1. ábra A Duna-Dráva (DDNP) és a Fertő-Hanság Nemzeti Park (FHNP) területén található vizsgálati terület, feltüntetve a mintavételezett költőpárok/települések elhelyezkedését a gyöngybagoly két lokális populációjában

N, 35° 30′ E), which is part of the Danube-Drava-Sava Euroregion. The meteorological conditions of this area are influenced by the Mediterranean and sub-Mediterranean climates. The pellet samples were collected in two mesoregions: the Drava floodplain and the Mecsek and Tolna-Baranya hill country *(Figure 1)*.

The area of the Drava floodplain includes the erstwhile flood basin of the Drava, and the climate is moderately warm and humid. The average annual temperature is 10.4–10.6 °C, the number of sunny hours is 2,000–2,080, and the annual amount of precipitation is 630–720 mm.

The Mecsek and Tolna-Baranya hill country is located north of the previous mesoregion. The average annual temperature is between 9 °C and 12 °C, the number of sunny hours is 1,400–1,450, and the yearly mean precipitation is 680–720 mm. The Mediterranean climatic impact and the large number of village creates suitable environmental conditions for the survival and stability of Western Barn Owl stock; thus the largest local population of this species in Hungary can be found here (Bank *et al*. 2019).

FHNP is located in the western Transdanubian region (47° 45′ N, 16° 45′ E), covering the northern part of the West Pannonia Euroregion. The sampling sites are situated in four different mesoregion, most of the sampling sites are situated in the Győr basin and in Sopron-Vasi plains, but a few samples also came from the feet of the Alps and Bakony region. A moderately dry and cool climate is typical in the lowland areas of the national park. The average number of hours of sunshine is 1,700–1,900, the annual amount of precipitation is 650–750 mm, and the average annual temperature is 9–10 °C. This region is characterized by a strong westerly-north-westerly air movement. The mountainous mesoregions (feet of the Alps, Bakony region) are cooler and wetter than their surroundings. The density of the Western Barn Owl population is relatively low in this area.

The owl pellet sample collection and diet analyses were carried out within the framework of Hungarian Biodiversity Monitoring System (HBMS) (Horváth *et al*. 2019). Due to lower local density of Barn Owls, in the case of the FHNP, the pellet samples collected from fewer breeding pairs. Considering on the DDNP population, 20–20 breeding pairs were randomly selected for the evaluation, a total of 123 pellet samples and 4,046 owl pellets were processed during the analysis *(Table 1)*.

In total, 2,619 and 1,427 pellets of DDNP and FHNP Western Barn Owl population were analysed, respectively. Pellets were processed by the dry technique, the individual pellets were broken down by hand and prey items were identified to the lowest possible taxonomical level. Small mammals were identified based on skeletal parameters (features of skull, mandible and teeth; März 1972, Yalden 1977, Yalden & Morris 1990). In case of small mammal prey items, three different *Apodemus* species, the Wood Mouse *(Apodemus sylvaticus)*, the Yellow-necked Wood Mouse *(A. flavicollis)* and the Pygmy Field Mouse *(A. uralensis)* were categorized commonly as *Apodemus* spp. When the Striped Field Mouse *(A. agrarius)* was not separable from the Sylvaemus group (*Apodemus* spp.), the individuals were determined as 'unidentifed *Apodemus*'. The sibling species of the genus *Mus* were determined according to Macholán (1996) and Kryštufek & Macholán (1998). Birds were identified by their skulls, bills, feet, pelvises and feathers (Kessler 2015), and frogs (Anura) by their skulls and bones of the postcranial skeleton (Schaefer 1932). Prey items were identified to genus (small mammals, birds), to order (frogs), and to class (birds) level if major skeletal elements were missing.

The number of prey was estimated as the minimum number of individuals (MNI), which was determined by counting the same anatomical parts of bones in the case of small

Table 1. Distribution of the nesting and sample data in case of the two Western Barn Owl populations in the two different demographic phases of the Common Vole

1. táblázat A fészkelő- és köpetminta adatok megoszlása a két gyöngybagoly populáció esetében a mezei pocok két különböző demográfiai fázisában

Local population (NP) / demographic phase of *M. arvalis*	**Nesting data**		**Sample data**	
	locality	**# of nesting pairs**	**# of pellet samples**	**# of pellets**
DDNP – crash (2015–2016)	20	20	43	1726
DDNP – outbreak (2019–2020)	20	20	43	893
FHNP – crash (2015–2016)	12	14	16	540
FHNP – outbreak (2019–2020)	16	17	21	887

mammals (McDowell & Medlin 2009, Torre *et al*. 2015, Tulis *et al*. 2015, Horváth *et al*. 2022) and skulls, mandibles and long bones for birds, as well as skulls, remnants of ilium or frontoparietal bones for frogs.

Data analysis

Data were expressed as percent relative frequency of occurrence (%MNI) calculated for the total number of prey found in all pellets in case of the two local Western Barn Owl populations, and in two different demographic phase (crash vs. outbreak) of the Common Vole. First, to compare the relative abundance of main and alternative prey between the two owl populations in a given demographic phase and between the two time periods (phases) in a given local population, Chi-square (χ^2) heterogeneity test was applied by using the statistical software R with the command 'prop.test'.

As a next step, to evaluate the similarity of small mammal resource composition in the two Western Barn Owl populations and different demographic phases of the Common Vole, permutational analysis of variance (PERMANOVA) with Bray-Curtis similarity index was performed with the adonis2 function in package 'vegan' (v2.6.2, Oksanen *et al*. 2022), and 9,999 permutations were run to test for statistically measurable overall differences in case of both groupings. Pairwise comparisons between the populations and sampled periods were carried out with the FDR p-value adjustment method (Benjamini & Hochberg 1995). The dissimilarities based on the Bray-Curtis similarity index were presented on a scatter plot generated by principle coordinate analysis (PCoA). The 'betadisper' and 'permutes' functions in package 'vegan' were used to test whether there were any differences in dispersion between the samples.

Second, to describe and estimate the resource niche metrics, a trait-based framework was used which takes into account the resemblance between resources, and its key element is the consideration of the geometric relationships between resources (De Cáceres *et al*. 2011). As a first step in estimating niche metrics, four relevant body parameters (body weight (g), body, tail and mandible length (cm)) were used to create the distance matrix of resource (D) *(Table 3)* in order to determine and assess the resemblance between small mammals as food resources, according to literature data (De Bruijn 1979, Görner-Hackethal 1988, von Knorre 1973, Kraft 1982, Wijnandts 1984, Märcz 1987, Prete *et al.* 2012, Veselovsky *et al.* 2012). Due to units of measurement, these body characteristics were standardized to remove differences and the transformed variables were used to calculate the Euclidean distance between pairs of small mammal prey categories (d_{jk}). For further analysis, the distance values were normalized to the maximum to limit the distance values between 0 and 1, where 0 indicates that the two resources are absolutely equivalent, 1 denotes that the two resources are completely different (De Cáceres *et al*. 2011). Then, a hierarchical cluster analysis for graphic display with 'heatmap.2' function of the 'gplots' package (Warnes *et al*. 2022) and the 'colorRampPalette' function of the 'RColorBrewer' package (Neuwirth 2022) was performed to evaluate the arrangement of small mammal prey as food resource elements based on the distance matrix of resources. This analysis showed that the rat taxa (two *Rattus* species and *Rattus* spp.) which are considered the largest prey, form a separated group on the cluster heat map. The other small mammal taxa formed a larger cluster, within which the European Water Vole *(Arvicola amphibius)* and the European Mole *(Talpa europaea)* are separated by a larger distance value, which present also larger prey. The large body mass rodent (LBMR) species, such as European Water Vole, Brown Rat *(Rattus norvegicus)* and Black Rat *(R. rattus)* may be a possible alternative prey group for the Western Barn Owl to compensate for the lack and/or lower availability of the main prey species such as the Common Vole (Horváth *et al*. 2020). The other three groups form a cluster, within which shrews with low body parameter values are separated with a larger distance value, as well as the Eurasian Harvest Mouse *(Micromys minutus)*. The vole species and mice separated by the smallest distance value form a separate group primarily based on tail and mandible length *(Figure 2)*.

Third, to estimate the niche breadth difference between the two local populations of Western Barn Owl, and in case of each different demographic phases of Common Vole, Rao's quadratic entropy (De Cáceres *et al*. 2011) as adopted niche breadth metrics was used in the 'indicspecies' package with 'nichevar' function (De Cáceres 2013, 2014):

$$B_{pop} = \left(\frac{1}{2}\right) \sum_{j=1}^{r} \sum_{k=1}^{r} f_j f_k d_{jk}^2$$

where f is the relative abundance of the given prey item in the total resources (r) in the diet of Barn Owls, and d_{jk} is the distance between each pair of the small mammal resource.

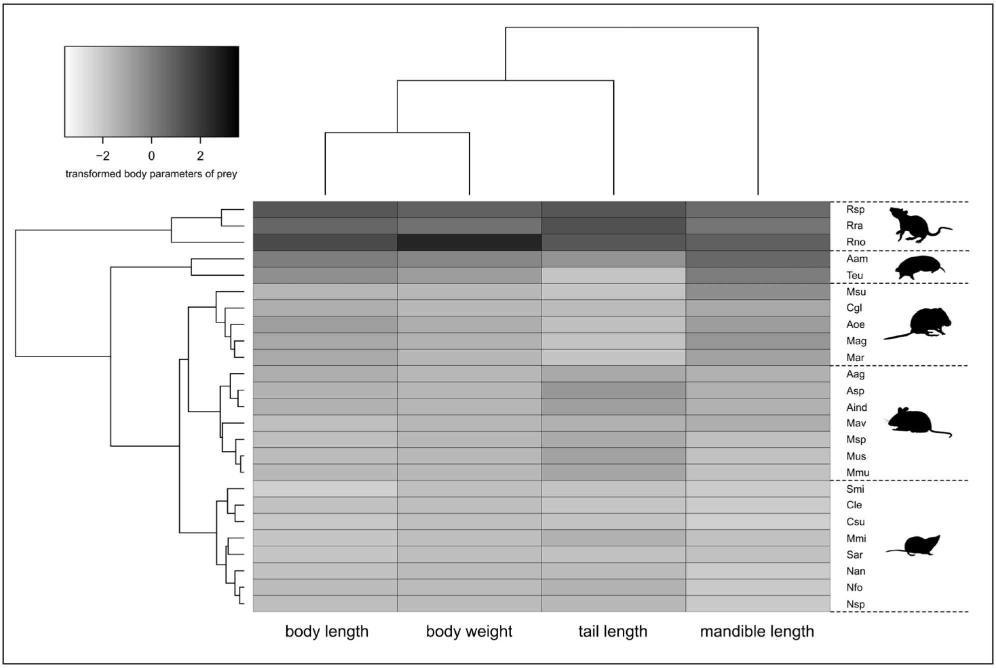

Figure 2. Cluster heat map of the small mammal taxa based on their body parameters
2. ábra A kisemlős taxonok klaszter hőtérképe a testparamétereik alapján

The minimum niche breadth is 0, which is resulted when all resources used are equal or when a single resource is used. In this equation, f_j value is the species relative preference, however, resource availability data are not available in this study, thus the relative species preference is equal to the relative resource use, that is $f_j = p_j$ for all resources (De Cáceres *et al*. 2011). Rao's quadratic entropy (Rao 1982) is a general diversity measure (De Cáceres *et al*. 2011), it was proposed and applied in several studies to evaluate both taxonomic (Pavoina *et al*. 2005, Ricotta & Szeidl 2009) and functional diversity (Botta-Dukát 2005, Laliberté & Legendre 2010, Ricotta & Moretti 2011, Botta-Dukát & Czúcz 2016, Balestrieri *et al*. 2019). In addition, niche overlap between the two local owl populations and in different time periods was calculated with modified and generalized Pianka's symmetrical niche overlap index to take into account the resemblance between resources (De Cáceres *et al*. 2011):

$$O_{pop} = \frac{\sum_{j=1}^{r}\sum_{k=1}^{r} f_{1j} f_{2k}(1 - d_{jk}^2)}{\sqrt{\sum_{j=1}^{r}\sum_{k=1}^{r} f_{1j} f_{1k}(1 - d_{jk}^2)\sum_{j=1}^{r}\sum_{k=1}^{r} f_{2j} f_{2k}(1 - d_{jk}^2)}}$$

This index of overlap is bounded between 0 (no overlap) to 1 (complete overlap). The confidence interval calculation for niche metrics was also performed in 'indicspecies' package with bootstrap estimation. To evaluate the statistical difference of the niche metrics (niche breadth and overlap) between the population/time periods, Wilcoxon's rank test was used from the 'indicspecies' package.

Next, a Principal Coordinates Analysis (PCoA) of matrix D with the 'pcoa' function in 'ape' package was performed to graphical display the resource space ('biplot' function, 'stats' package) which demonstrated the niche centre of the two Western Barn Owl populations and in the given time periods of these populations with the 95% confidence intervals in each resource dimension. Further, the arrows that represent effect vectors of small mammal traits were added, indicating the correlation between resource axes (PCoA) and small mammals' body characteristics (De Cáceres *et al*. 2011).

Finally, the resource niche analysis was performed at the breeding pair level to measure and evaluate the degree of Barn Owls' individual specialization. Due to absent of the sampling replicates at the individual level, the confidence interval bootstrap estimation of different niche parameters was not possible. However, the statistical analysis between individual niche metrics was performed with Wilcoxon's rank test. The basic of the individual specialisation analyses is the ratio between the within individual component (average niche width) and the total niche width of the population (WIC/TNW), which was suggested and defined by the study of Bolnick *et al*. (2002). This method was applied in numerous foraging niche variation analysis of birds (e.g. Rooney & Montgomery 2013, Catry *et al*. 2014, Maldonado *et al*. 2017). Similarly to this, the following proposed specialization measure was used, which takes into account the resemblance between resources (De Cáceres *et al*. 2020, Sol *et al*. 2021):

$$S_{pop} = \frac{\sum_{i=n}^{n} B_i/n}{B_{pop}}$$

where B_i is the niche breadth of each individual, and B_{pop} is the niche breadth of the population. In order to assess the statistical difference between the specialization of two population and time periods, the degree of specialization of each individual was calculated ($S_i = B_i/B_{pop}$) and Wilcoxon's rank test was also implemented for this analysis (De Cáceres *et al.* 2020).

All statistical analyses were conducted in R v4.2.3 (R Core Team 2023). Statistical tests were considered significant at the level $P \leq 0.05$ in all analyses (Sokal & Rohlf 1995).

Results

A total of 7,550 prey specimens were determined from the collected pellets in the two geographical region and investigated periods, of which 7,497 individuals were small mammals. Based on this, other prey accounted for less than 1% of the food composition, so only data of small mammals as main food resource were taken into account during the statistical analysis and evaluation. Within the order Eulipotyphla, we identified 1 species of Talpidae and 6 species of Soricidae. Furthermore, within the order of rodents, 6 species of Cricetidae, 6 species of Muridae, and 1 species of Gliridae were found in the diet of Barn Owls *(Table 2)*.

Based on the abundance data for the Danube-Drava National Park, the Common Vole proved to be the most common prey species in both periods, however, compared to its population crash (37.74%) this main prey was detected with higher proportion (62.80%) during the outbreak period (prop.test: $\chi^2 = 250.050$, $P < 0.001$) in the food composition *(Table 2)*. At the same time, the relative proportion of the wood mice prey group was the second highest in both the crash (19.73%) and outbreak (16.06%) periods ($\chi^2 = 8.910$, $P = 0.003$) *(Table 2)*. The Striped Field Mouse had a percent relative frequency of nearly 8% during the crash, and more than 6% during the period of the outbreak, the consumption of this species showed homogeneous distribution in the diet of the Barn Owls ($\chi^2 = 1.116$, $P = 0.291$) *(Table 2)*. Among the shrews, during the crash phase the Bicolored White-toothed Shrew *(Crocidura leucodon)* appeared with the highest relative abundance value ($\chi^2 = 75.992$, $P < 0.001$), in the outbreak period the Lesser White-toothed Shrew's *(C. suaveolens)* abundance was around 5% (DDNP crash vs outbreak: $\chi^2 = 7.881$, $P = 0.005$), while the relative frequency of the bigger *Crocidura* species was below 1% *(Table 2)*.

Based on the relative abundance data of FHNP population, the Common Vole was the most frequent prey during the crash phase, and it was present with an abundance of nearly 50% in the food composition. However, during the outbreak, contrary to the expected result, it reached a lower percent relative frequency of occurrence (27.38%) ($\chi^2 = 143.490$, $P < 0.001$) *(Table 2)*. The wood mice (*Apodemus* spp.) appeared in the food composition with a relative abundance of around 9% during the crash phase and around 5% during the outbreak ($\chi^2 = 13.569$, $P < 0.001$) *(Table 2)*. Among the Soricidae species, the Common Shrew *(Sorex araneus)* was the most frequent prey in both demographic phases; during the crash, it was present in an abundance approaching 14% while in the outbreak it exceeded 34%, so this small mammal was the most frequent prey in this latter period ($\chi^2 = 163.550$, $P < 0.001$) *(Table 2)*.

Table 2. Diet composition of the Western Barn Owl in the two investigated populations (MNI: minimum number of individuals, %MNI: percentage frequency of occurrence)

2. táblázat A gyöngybagoly táplálék-összetétele a két vizsgált populációban (MNI: minimum ismert egyedszám, %MNI: minimum ismert egyedszám százalékos értéke)

National Park	**Danube-Drava NP**				**Fertő-Hanság NP**			
	crash		**outbreak**		**crash**		**outbreak**	
Taxa [abbrevation]	**MNI**	**%MNI**	**MNI**	**%MNI**	**MNI**	**%MNI**	**MNI**	**%MNI**
Eulipotyphla	496	18.85	131	8.22	348	28.83	1027	48.49
Talpidae	2	0.08	3	0.19	0	0.00	0	0.00
Talpa europaea [Teu]	2	0.08	3	0.19	0	0.00	0	0.00
Soricidae	494	18.78	128	8.03	348	28.83	1027	48.49
Sorex araneus [Sar]	32	1.22	7	0.44	167	13.84	726	34.28
Sorex minutus [Smi]	10	0.38	12	0.75	53	4.39	107	5.05
Neomys fodiens [Nfo]	29	1.10	1	0.06	1	0.08	66	3.12
Neomys anomalus [Nan]	40	1.52	7	0.44	1	0.08	57	2.69
Neomys spp. [Nsp]	8	0.30	1	0.06	0	0.00	10	0.47
Crocidura suaveolens [Csu]	199	7.56	85	5.33	52	4.31	46	2.17
Crocidura leucodon [Cle]	176	6.69	15	0.94	74	6.13	15	0.71
Rodentia	2111	80.24	1447	90.78	855	70.84	1082	51.09
Cricetidae	1070	40.67	1036	64.99	622	51.53	852	40.23
Clethrionomys glareolus [Cgl]	9	0.34	7	0.44	11	0.91	20	0.94
Microtus agrestis [Mag]	9	0.34	5	0.31	0	0.00	1	0.05
Microtus arvalis [Mar]	993	37.74	1001	62.80	579	47.97	580	27.38
Microtus subterraneus [Msu]	17	0.65	9	0.56	7	0.58	13	0.61
Alexandromys oeconomus [Aoe]	0	0.00	0	0.00	21	1.74	229	10.81
Arvicola amphibious [Aam]	42	1.60	14	0.88	4	0.33	9	0.42
Muridae	1028	39.07	409	25.66	233	19.30	230	10.86
Rattus norvegicus [Rno]	16	0.61	0	0.00	2	0.17	0	0.00
Rattus rattus [Rra]	2	0.08	0	0.00	0	0.00	0	0.00
Rattus spp. [Rsp]	27	1.03	14	0.88	1	0.08	7	0.33
Apodemus agrarius [Aag]	196	7.45	105	6.59	53	4.39	50	2.36
Apodemus spp. [Asp]	519	19.73	256	16.06	104	8.62	113	5.34
Apodemus indet. [Aind]	128	4.87	1	0.06	14	1.16	0	0.00
Micromys minutus [Mmi]	23	0.87	4	0.25	20	1.66	33	1.56
Mus spicilegus [Msp]	34	1.29	7	0.44	12	0.99	3	0.14
Mus musculus [Mmu]	41	1.56	7	0.44	15	1.24	9	0.42
Mus spp. [Msp]	42	1.60	15	0.94	12	0.99	15	0.71
Gliridae	13	0.49	2	0.13	0	0.00	0	0.00

National Park	**Danube-Drava NP**				**Fertő-Hanság NP**			
	crash		**outbreak**		**crash**		**outbreak**	
Taxa [abbrevation]	**MNI**	**%MNI**	**MNI**	**%MNI**	**MNI**	**%MNI**	**MNI**	**%MNI**
Muscardinus avellanarius [Mav]	13	0.49	2	0.13	0	0.00	0	0.00
Other prey	24	0.91	16	1.00	4	0.33	9	0.42
Mammals	1	0.04	0	0.00	0	0.00	0	0.00
Birds	14	0.53	16	1.00	4	0.33	9	0.42
Frogs	8	0.30	0	0.00	0	0.00	0.00	0.00
Insects	1	0.04	0	0.00	0	0.00	0	0.00
Total:	**2631**		**1594**		**1207**		**2118**	

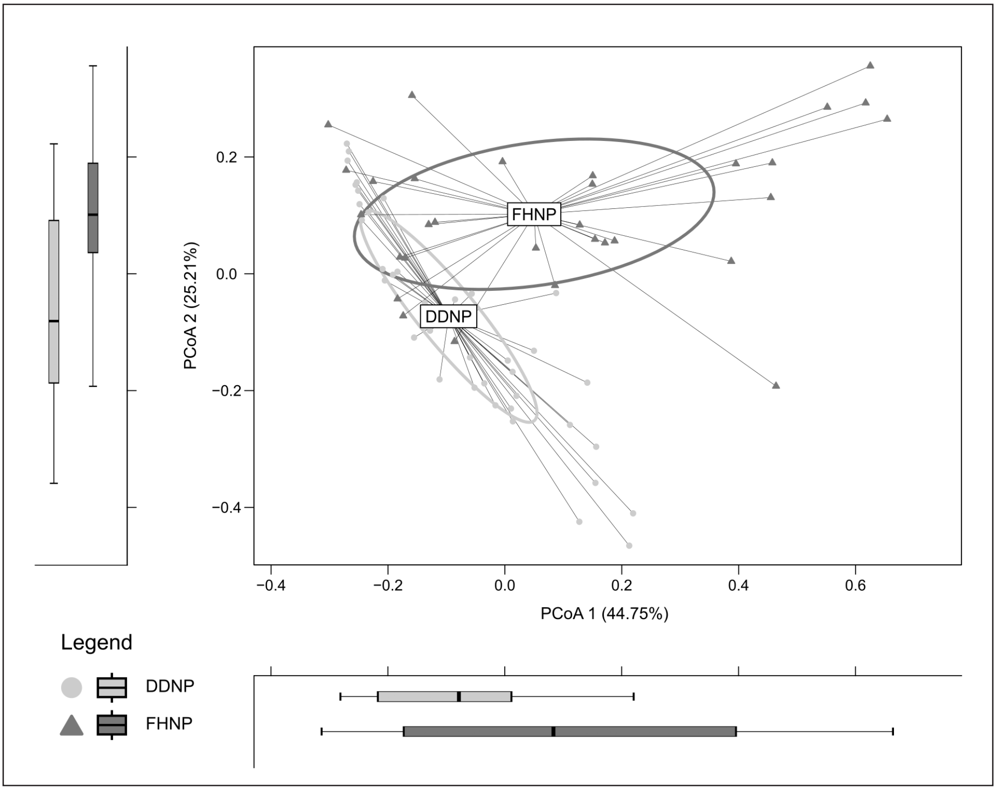

Figure 3. Principle Coordinate Analysis (PCoA) of distance (Bray-Curtis) matrix of small mammal consumption in case of the two examined local Barn Owl populations (ellipses represent a 95% confidence interval around the cluster centroid; box-and-whisker plots shown along each PCoA axis indicate the distribution of samples along the given axis)

3. ábra A kisemlős fogyasztás távolsági (Bray-Curtis) mátrixának főkoordináta-analízise (PCoA) a gyöngybagoly két vizsgált lokális populációja esetén (az ellipszisek 95%-os konfidencia intervallumot képviselnek a klaszter súlypontja körül; az egyes PCoA tengelyek mentén látható doboz diagramok a minták eloszlását jelzik az adott tengely mentén)

Based on summarised data of two examined Western Barn Owl populations, the PERMANOVA analysis confirmed that the small mammal resource utilization of owls was statistically dependent on populations ($F = 11.177$, $P < 0.001$), explaining 13.94% of variance in data. The comparison using PERMANOVA between the two populations yielded a significant result ($FDR\text{-}P < 0.001$). Based on the visualization of the PERMANOVA result, the Principal Coordinate Analysis detected significantly different resource dispersion between the populations ($F = 7.915$, $P = 0.005$). The cumulative variance explained by the first two axes was 69.96%. The PCoA scatter plot indicated that the Barn Owls' consumption of small mammal resources was distinct at the population level *(Figure 3)*, which was confirmed by Tukey's Honest Significant Difference test ($DDNP_{pop}$ vs $FHNP_{pop}$: $P = 0.006$).

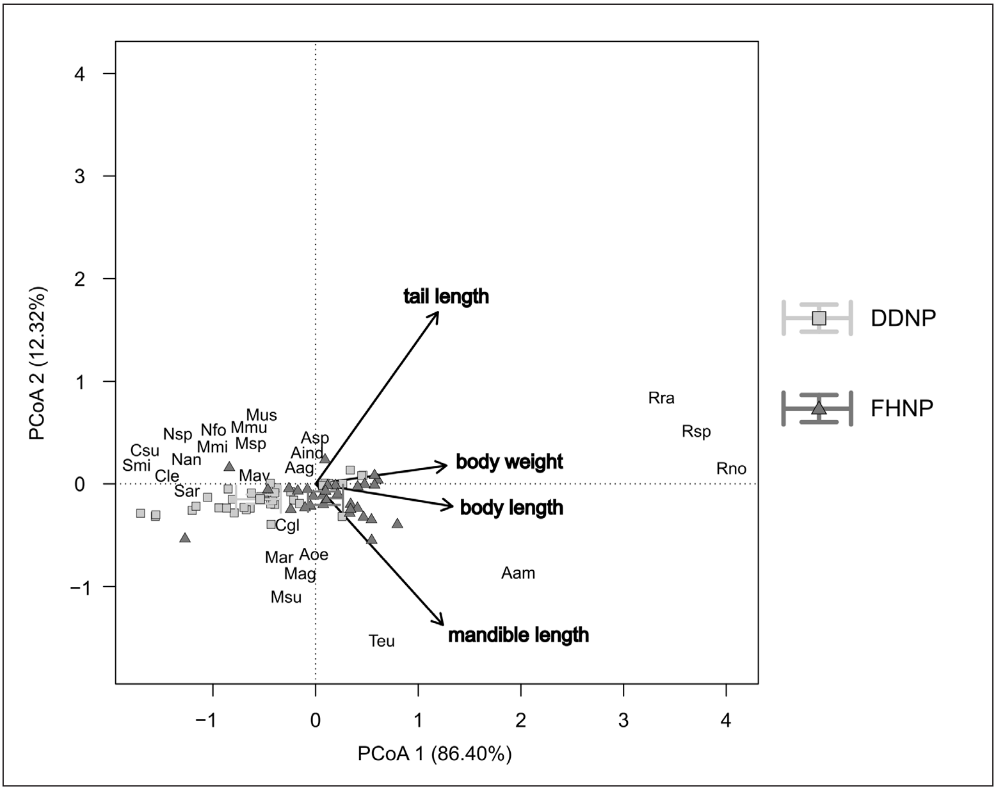

Figure 4. Food resource space displayed by Principal Coordinates Analysis (PCoA) of small mammal trait matrix (D) where the arrows indicating the correlation between resource axes and small mammal body parameters (the niche centres of the two Western Barn Owl populations displayed by square and triangle symbol with the 95% confidence intervals along the two PCoA resource axis)

4. ábra A kisemlős tulajdonságmátrix (D) főkoordináta-analízise (PCoA) által megjelenített táplálékforrás tér, ahol a nyilak a forrástengelyek és a kisemlősök test paraméterei közötti összefüggést jelzik (a két gyöngybagoly populáció demográfiai fázisok szerint elkülönült niche centrumait négy különböző szimbólummal és a két PCoA forrástengely menti 95%-os konfidencia intervallumokkal jelenítettük meg)

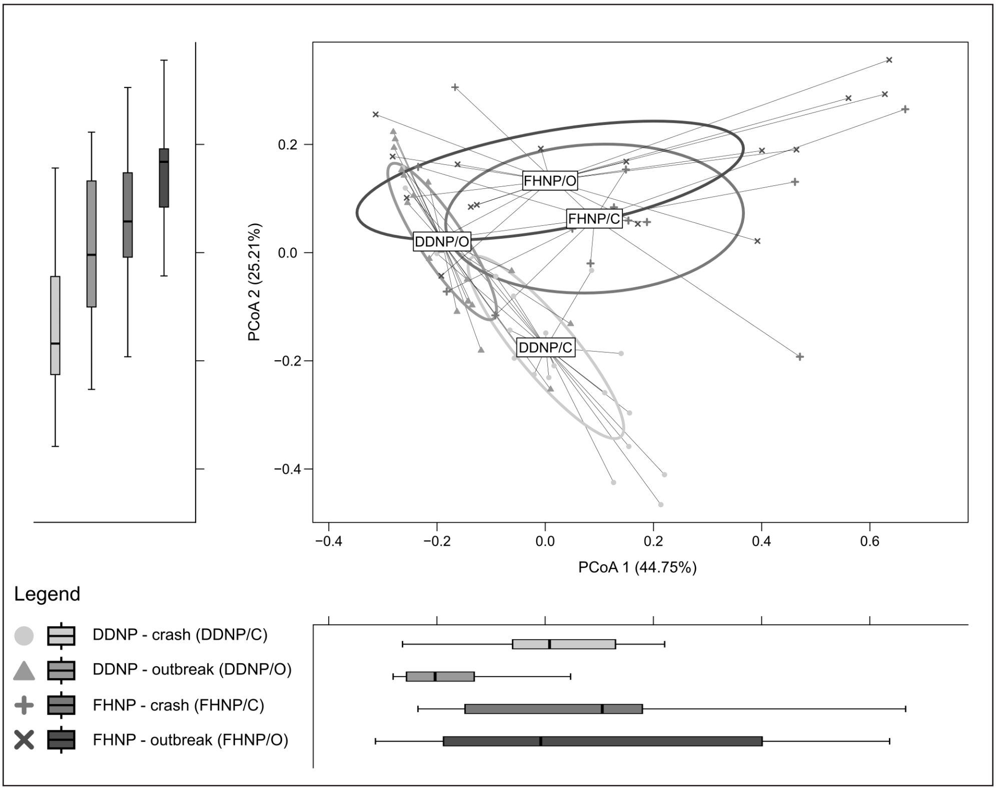

Figure 5. Principle Coordinate Analysis (PCoA) of distance (Bray-Curtis) matrix of small mammal consumption in case in the two Barn Owl populations/two demographic phases of the Common Vole (ellipses represent a 95% confidence interval around the cluster centroid; box-and-whisker plots shown along each PCoA axis indicate the distribution of samples along the given axis)

5. ábra A kisemlős tulajdonságmátrix (D) főkoordináta-analízise (PCoA) által megjelenített táplálékforrás tér, ahol a nyilak a forrástengelyek és a kisemlősök test paraméterei közötti összefüggést jelzik (az ellipszisek 95%-os konfidencia intervallumot képviselnek a klaszter súlypontja körül; az egyes PCoA tengelyek mentén látható doboz diagramok a minták eloszlását jelzik az adott tengely mentén)

According to results of the niche breadth estimation at the level of the two investigated Western Barn Owl populations, which analysis taking into account the resemblance between resources, the niche breadth of DDNP population ($B_{pop} = 0.164$, 0.145–0.180, 95% CI) was significantly smaller than FHNP population ($B_{pop} = 0.103$, 0.085 – 0.121, 95% CI) ($W = 980$, $P < 0.001$). Regarding the niche overlap between the two owl populations, the estimated niche overlap was very high ($O_{DDNP\ vs\ FHNP} = 0.974$, 0.947 – 0.988, 95% CI). Based on results of niche overlap among breeding pairs, the niche overlap at the individual level ($\bar{O}_{DDNP}= 0.936$, $\bar{O}_{FHNP}= 0.966$) was significantly different between the two populations ($W = 193$, $P < 0.001$). Regarding the visualization of resource space with niche centres of the two examined Barn Owl populations, the PCoA biplot demonstrated that the two niche centres significantly separated in the resource space, the confidence intervals of resource centres

Table 3. Mean value of the body parameters (traits) of small mammal prey (x̄) based on the literature data taken into account

3. táblázat A kisemlős zsákmányok átlagos testparaméter értékei (x̄) a figyelembevett irodalmi adatok alapján

Small mammal prey	**weight (g)**	**body length (cm)**	**tail length (cm)**	**mandible length (cm)**
T. europaea	83.50	13.75	3.25	2.17
S. araneus	9.93	6.88	4.25	0.96
S. minutus	4.45	5.15	3.70	0.74
N. fodiens	14.45	8.41	6.20	0.80
N. anomalus	13.25	7.62	5.10	0.75
Neomys spp.	14.52	8.06	5.65	0.78
C. suaveolens	5.06	6.52	3.57	0.65
C. leucodon	9.36	7.55	3.43	0.75
C. glareolus	23.98	10.01	5.23	1.38
M. agrestis	31.78	10.97	3.63	1.66
M. arvalis	26.13	10.58	3.62	1.49
M. subterraneus	19.22	9.00	3.18	1.84
A. oeconomus	45.50	11.90	4.48	1.56
A. amphibius	135.56	16.17	10.27	2.49
R. norvegicus	358.00	23.33	19.50	2.68
R. rattus	186.88	19.67	20.93	2.28
Rattus spp.	227.08	21.50	20.22	2.48
A. agrarius	22.33	10.30	7.82	1.27
Apodemus spp.	26.61	9.64	9.87	1.29
Apodemus indet.	25.88	9.90	8.96	1.28
M. minutus	6.91	6.73	6.82	0.97
M. spicilegus	21.50	8.03	7.32	1.02
M. musculus	20.60	8.63	8.12	0.94
Mus spp.	19.90	8.50	8.50	0.98
M. avellanarius	23.71	7.64	6.72	1.30

Table 4. The estimated value of the niche breadth and its 95% confidence interval at the level of Western Barn Owl population/demographic phases and results of the statistical analysis between the sampling pairs

4. táblázat A niche szélesség és 95%-os konfidencia intervallumának becsült értéke a két gyöngybagoly populáció/demográfiai fázisok szintjén és a mintapárok közötti statisztikai elemzés eredményei

Local population (NP) / phase of *M. arvalis* cycle	**Niche breadth values (Rao's quadratic entropy)**		**Statistical test between niche breadth**	
	Niche breadth (B_{pop})	**95% CI**	**Sample pairs / phase**	**Wilcoxon test (B_{pop})**
DDNP – crash	0.186	0.167 – 0.134	DDNP/C vs DDNP/O	W = 312, *P* < 0.01
DDNP – outbreak	0.134	0.107 – 0.142	DDNP/C vs FHNP/C	W = 238, *P* < 0.001
FHNP – crash	0.119	0.090 – 0.121	DDNP/O vs FHNP/O	W = 253, *P* < 0.05
FHNP – outbreak	0.089	0.069 – 0.168	FHNP/C vs FHNP/O	W = 149, *P* = 0.246

Table 5. The estimated value of the niche overlap and its 95% confidence interval at the level of Western Barn Owl population/demographic phases and results of the statistical analysis between the sampling pairs

5. táblázat A niche átfedés és 95%-os konfidencia intervallumának becsült értéke a két gyöngybagoly populáció/demográfiai fázisok szintjén és a mintavételi párok közötti statisztikai elemzés eredményei

Sample pairs / phase of *M. arvalis* cycle	**Niche overlap values**		**Wilcoxon test ($\bar{O}_{12}$) between niche overlap**
	Niche overlap ($\bar{O}_{12}$)	**95% CI**	
DDNP/C vs DDNP/O	0.978	0.935 – 0.996	W = 57, *P* < 0.001
DDNP/C vs FHNP/C	0.960	0.907 – 0.990	W = 60, *P* < 0.01
DDNP/O vs FHNP/O	0.982	0.961 – 0.995	W = 95, *P* < 0.05
FHNP/C vs FHNP/O	0.997	0.987 – 0.999	W = 41, *P* < 0.01

does not overlap for the two resource dimensions. The cumulative variance explained by the first two axes was 98.72% *(Figure 4)*. This results confirmed the significantly different niche breadth of the two Barn Owl populations. Despite the average value of individual niche breadth being larger than the estimated niche breadth at the population level in the case of both Barn Owl populations, the difference of these two niche breadth value was larger in the case of FHNP ($S_{pop} = 2.786$) than DDNP ($S_{pop} = 1.750$) population. Therefore, the calculated value of specialization of these Barn Owl populations was significantly higher in the FHNP than the DDNP population (W = 217, P < 0.001).

Based on small mammal consumption data of the two Barn Owl populations in two demographic phase of the Common Vole, the PERMANOVA analysis showed that the distribution of the small mammal resource utilization was statistically determined by the typically different consumption of populations in the given demographic phases (F = 6.939, P < 0.001), explaining 23.70% of variance in data. The comparison using PERMANOVA between the four sampling groups was significant in case of five sampling pairs (FDR-P = 0.0003 – 0.0007), except between FHNP/C and FHNP/O (FDR-P = 0.314). The Principal Coordinate Analysis which display the PERMANOVA result, detected significantly different resource dispersion between the populations/demographic phases (F = 4.619, P = 0.007). The cumulative variance explained by the first two axes was 69.96%. Although the PCoA scatter plot indicated that the Barn Owls' consumption of small mammal resources was distinct between crash and outbreak phase in DDNP population (with minimal overlap of ellipses which represent 95% CI around the centroid of the given sampling points of breeding pairs) *(Figure 5)*, which was not confirmed by Tukey's Honest Significant Difference test

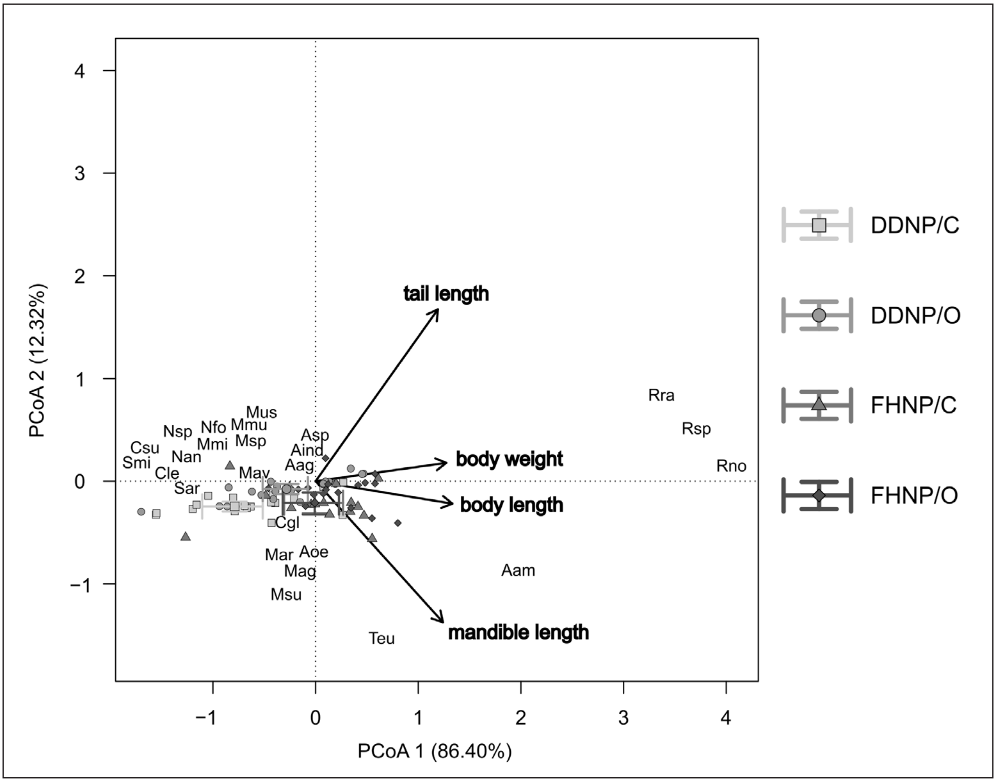

Figure 6. Food resource space displayed by Principal Coordinates Analysis (PCoA) of small mammal trait matrix (D) where the arrows indicating the correlation between resource axes and small mammal body parameters (the niche centres of the two Western Barn Owl populations separated according to demographic phases, displayed by four different symbols with the 95% confidence intervals along the two PCoA resource axis)

6. ábra A kisemlős tulajdonságmátrix (D) főkoordináta-analízise (PCoA) által megjelenített táplálékforrás tér, ahol a nyilak a forrástengelyek és a kisemlősök test paraméterei közötti összefüggést jelzik (a két gyöngybagoly populáció demográfiai fázisok szerint elkülönült niche centrumait négy különböző szimbólummal és a két PCoA forrástengely menti 95%-os konfidencia intervallumokkal jelenítettük meg)

(DDNP/C vs DDNP/O: P = 0.334). Based of larger overlap of confidence ellipses, the statistical test confirmed similar results between crash and outbreak phase in case of FHNP population (FHNP/C vs FHNP/O: P = 0.979) *(Figure 5)*.

Considering the niche breadth estimation of the two owl populations in different demographic phases of the Common Vole, the niche breadth of the owl population living in the DDNP was significantly higher during the crash period. In contrast, the estimated niche breadth of the population living in FHNP did not differ significantly between the two demographic phases *(Table 3)*. In both the crash and outbreak periods, the niche breadth of the Barn Owl population breeding in the DDNP was significantly higher compared to the population living in the region of FHNP *(Table 3)*.

Regarding the niche overlap, the highest niche overlap value was calculated for the population living in FHNP between the two demographic periods, while the lowest overlap was observed between the two investigated populations during the crash period *(Table 4)*. In the case of the investigated populations, there were significant differences between the average niche overlap of the breeding pairs in the comparison of the two periods, while comparing the populations in the two different demographic phases of the Common Vole resulted in a significant difference between the niche overlaps *(Table 4)*.

According to the visualization of resource space with niche centres of the two examined populations in the different demographic phases of the Common Vole, the PCoA biplot demonstrated that DDNP/C niche centres significantly separated from the two FHNP sampling groups, but were not significantly different from DDNP/O due to CI overlap. No significant difference between the niche centres was found in the case of FHNP populations, either *(Figure 6)*. The first two axes explained 98.72% of the cumulative variance.

Finally, in the case of population specialization in the two different demographic phases of the Common Vole, the population living in the FHNP during the crash period was the least specialized (S_{pop} = 1.356), while in the other three cases, we calculated a similar degree of specialization (DDNP/C: S_{pop} = 0.867, DDNP/P: S_{pop} = 0.889, FHNP/O: S_{pop} = 0.882), and these populations were more specialized. Nonetheless, based on the Wilcoxon test, there were no significant differences between the nesting populations in the investigated national parks and between the two periods (DDNP/C vs DDNP/O: W = 164, P = 0.341; DDNP/C vs FHNP/C: W = 135, P = 0.877; DDNP/O vs FHNP/O: W = 171, P = 0.988; FHNP/C vs FHNP/O: W = 112, P = 0.799).

Discussion

In this paper, we investigated the food resource niche parameters of two Western Barn Owl populations in two different demographic phases of the Common Vole. Research on the Barn Owl's diet has described that a significant part of the food composition of this owl species is made up of nocturnal, terrestrial small mammal species (e.g. Bosé & Guidali 2001, Trejo & Lambertucci 2007, Purger 2010, Milchev 2015, Torre *et al.* 2015, Horváth *et al.* 2018, 2020, Szép *et al*. 2021), which is supported by our results since, based on the remains found in the pellets, 99% of the prey in the periods we examined were different small mammals. In the case of the Danube-Drava National Park, the Common Vole was the most common prey in both periods, which corresponds to the results of research conducted in the temperate region of Europe (Frey *et al.* 2011, Veselovsky *et al.* 2017, Horváth *et al.* 2022, 2023), while wood mice (*Apodemus* spp.) proved to be an alternative prey. Several studies have described the higher consumption of different Murid species (*Apodemus* and *Mus* mice) during periods of low availability of the Common Vole in the European and Mediterranean regions (Pezzo & Morimando 1995, Bontzorolos *et al.* 2005, Rodrígez & Peris 2007, Horváth *et al*. 2020). Based on the evaluation of British Barn Owls' food change, the study of Love *et al*. (2000) reported that *Apodemus* mice were an important alternative prey, particularly in summer and autumn, when the relative percent frequency of the given *Microtus* vole species (in this case the Field Vole *(M. agrestis)*) was the lowest.

In the samples from Fertő-Hanság National Park, the Common Vole had the highest relative abundance in the crash period, while the Common Shrew was the most common prey during the outbreak. This was similar with our earlier results (Szűcs *et al*. 2014), thus the result of the previous and current analysis clearly illustrates that shrews, especially the Common Shrew, can be present as significant alternative prey in the Barn Owl's diet in this north-western region. The primary alternative prey character of the Common Shrew was highlighted by more studies in the aspect of the seasonal and multiannual change of the Barn Owls' prey consumption (Taylor 1994, Love *et al*. 2000, Bernard *et al*. 2010, Kitowski 2013). A similarly higher relative frequency of the Common Shrew was shown by the study of Benedek *et al.* (2007). The increased relative frequency of shrews such as the Common Shrew in the food composition of owls was evaluated as being the result of a functional response with prey switching to the decline of the Field Vole population.

Based on the above, Barn Owls can compensate for the lack of Common Voles as their main prey with different alternative prey taxa depending on geographical distribution, landscape structure, and land use, as well as climatic conditions (Love *et al.* 2000, Janžekovič & Klenovšek 2020, Romano *et al.* 2020).

The niche breadth of the Barn Owl's food composition depends on the amount and availability of prey species, so the niche breadth of this species may differ in disparate areas and periods (Marti *et al.* 1988, Pezzo & Morimondo 1995, Love *et al.* 2000, Milana *et al.* 2016). Our results are in accordance with this result, because the niche breadth within Barn Owl populations differed significantly between the populations and also between the two demographic phases.

Several studies described a very high niche overlap between Barn Owl populations in a comparison of nesting localities (Marti 1988, Bosè & Guidali 2001), seasons (Pezzo & Morimando 1995), and subsequent years at a given area (Marti 1988, 2010). In the case of our result, the high niche overlap values at the population level indicated that there is no significant difference in terms of small mammal fauna between the two geographical regions. However, the relative abundance of the prey species may differ significantly locally in the given periods depending on climatic and environmental features, which affects the niche parameters of breeding pairs. In a previously conducted niche analysis in relation to the two investigated regions, Szűcs *et al.* (2014) described that the availability of prey was determined by different geographical conditions and landscape patterns and it has a specific role in the different feeding niche patterns of owls, which is also supported by our results, as we showed a significant difference between the average niche overlap of the breeding pairs in the comparison of the two populations and the two periods.

Individual specialization is one of the many factors that contribute to the variability of niche breadth within a population (Rooney & Montgomery 2013, Sol *et al.* 2021), and it also has important ecological, evolutionary, and conservation implications. Specialization and the resulting niche variability support frequency-dependent interactions that influence population stability, the degree of intraspecific competition, fitness, and the rapid diversification and speciation ability of the population (Bolnick *et al.* 2002). According to our results, the degree of specialization differed between the populations but was not distinct within the populations or between demographic phases. The results of specialization analysis at the population level confirmed the results of significant niche breadth difference between the two populations. In light of the results, the applied trait-based framework of resource niche pattern analysis demonstrated that the differences of niche breadth were explored in more detail by this method between local Barn Owl populations of different geographical regions.

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What is the size of the Western Barn Owl *(Tyto alba)* hunting range in a mosaic landscape?

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Abstract Western Barn Owls hunt primarily small mammals in open areas, but they also hunt in urban, forest and wetland habitats. The landscape structure of their hunting range, therefore, affects the composition of their prey, knowledge of which can be a good starting point for estimating the size of their hunting range. Our goal was to estimate whether owls catch most of their prey within a circle with radius of 1, 2, 3, 4 or even 5 kilometres. In this study, we used five pellet samples of different size, collected between 2015 and 2019 from a settlement near the Drava River (Péterhida, Hungary). Our results showed that the annual distribution, diversity, and evenness of small mammal species detected from the samples was similar regardless of the sample size. The distribution of small mammal functional groups preferring urban, open, forest and wetland habitats was also similar. For this reason, the pellet samples were merged. Our results suggest that Western Barn Owls catch a significant part of their prey within a circle of 2-kilometre radius around its breeding or roosting site in the landscape, which consists of patches of habitat with a mosaic distribution. In a hunting range of this size, the proportion of small mammal functional groups preferring different habitats obtained from the pellets overlapped with the proportion of their preferred habitats.

Keywords: pellets, small mammals, habitat preference, landscape structure

Összefoglalás A gyöngybaglyok elsősorban nyílt élőhelyeken vadásznak, de urbán, erdős és vizes élőhelyeket preferáló kisemlősöket is elejtenek. A vadászterületük tájszerkezete tehát hatással van a zsákmányuk összetételére, aminek ismerete jó kiindulási pont lehet a vadászterületük nagyságának becslésére. Célunk az volt, hogy megbecsüljük, vajon a baglyok 1, 2, 3, 4 vagy esetleg 5 kilométeres sugarú körön belül ejtik-e el a zsákmányuk nagy részét. Ebben a vizsgálatban öt különböző méretű köpetmintát használtunk, amelyeket 2015 és 2019 között gyűjtöttünk egy Dráva menti településről (Péterhida, Magyarország). A mintákból kimutatott zsákmány évenkénti megoszlása, diverzitása és egyenletessége hasonló volt a minta nagyságától függetlenül. A zsákmányösszetétel a nyílt, urbán, erdős és vizes élőhelyeket preferáló kisemlősök funkcionális csoportjainak tekintetében is hasonló eloszlást mutatott. Az említett hasonlóságok miatt a köpetmintákat összevontuk. Az eredményeink arra utalnak, hogy a gyöngybaglyok zsákmányuk jelentős részét a költő- vagy pihenőhelyük körül egy 2 kilométeres sugarú körön belül ejtik el, amely mozaikos eloszlású élőhelyfoltokból áll. Ekkora nagyságú vadászterületen a köpetekből kimutatott különböző élőhelyeket preferáló kisemlős funkcionális csoportok aránya átfedésben volt a preferált élőhelyeik részesedésével.

Kulcsszavak: köpetek, kisemlősök, élőhely preferencia, tájszerkezet

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Introduction

The Western Barn Owl *(Tyto alba)* is a selective opportunistic predator that primarily preys on small mammals (Tores *et al.* 2005, Moysi *et al.* 2018). As a result, the small mammal community of the hunting range can be assessed more efficiently and precisely by analysing its pellets, compared to the trapping method (Torre *et al.* 2004, Heisler *et al.* 2016). Western Barn Owls breed in urban environments but mostly catch their prey in open habitats (Taylor 1994), consequently, insectivores and grassland rodents are oversampled in their pellets, and tree-dwelling and woodland rodents are underrepresented (Torre *et al.* 2004). The extent and arrangement of the habitats in the hunting range of the owls affects the probability that individuals of small mammal species will be caught (Horváth *et al.* 2023). However, the prey is not always dominated by small mammal species that prefer open habitats, as some species may permanently or periodically use other habitats. For example, among the small mammals that prefer forests, individuals of wood mouse *(Apodemus)* species live on the forest edge (Schlinkert *et al.* 2016), in agricultural areas (e.g. Tew *et al.* 2000, Todd *et al.* 2000, Tattersall *et al.* 2001, Heroldová *et al.* 2008), but are also present in urban habitats (Łopucki *et al.* 2013). The Harvest Mouse *(Micromys minutus)* associated with wetlands occurs in forests (Juskaitis & Remeisis 2007), agricultural areas (Bence *et al.* 2003), but also in various habitat patches in settlements (Dickman 1986). These examples show that few small mammal species can be considered habitat specialists, so the size of the hunting range can only be estimated based on the relative abundance of small mammal species detected in the pellets of Western Barn Owls.

In several studies, the hunting range of this owls species was considered to be the area of circles with different radii (between 1 and 5.6 km) starting from their breeding or resting site (e.g. Martinez & Zuberogoitita 2004, Meek *et al.* 2009, Milchev 2015, Torre *et al.* 2015), but the area of circle with 2 km radius seemed the most likely (e.g. Lovari *et al.* 1976, Horváth *et al.* 2005, Meek *et al.* 2009). Within hunting ranges of this size, significant relationships were found between the proportion of habitats and the relative abundance of small mammal species detected in Western Barn Owl pellets (Szép *et al.* 2017, 2018, 2019, 2021). However, by tracking the movements of owls, it was found that they hunt much further away than 2 kilometres (e.g. Taylor 1994, Guerra *et al.* 2014, Hindmarch *et al.* 2017, Cain *et al.* 2023), but it is still not known where they catch most of their prey. Upon a large pellet sample, it was shown that the hunting range of owls in the landscape dominated by open agricultural areas corresponds to a circle with a radius of 3 km (Purger & Szép 2022). Unfortunately, it was not tested how the result of the estimation would have developed if the assumed hunting range were further increased.

In this work, we sought answers to the following questions: 1) Can smaller pellet samples be merged to obtain a representative sample? 2) How large is the hunting range of Western Barn Owl (radius of 1, 2, 3, 4, or 5 km) supposed in a landscape where the arrangement of habitats is mosaic?

Materials and Methods

In the southern part of Hungary, the settlement of Péterhida is located on the Drava Plain, where Western Barn Owls regularly breed in nesting boxes placed in the attic of an abandoned cattle barn (Purger 2019, Sipter 2021). Between 2015 and 2019, a total of 1,018 pellets were collected from the nesting box and the attic, and the faunistic results, except for the year 2019, have already been published (Purger 2016, 2019). Most of the prey of Western Barn Owls were shrews and rodents, and were classified into four (urban, open, forest or wetland) functional groups based on their habitat preferences (Szép *et al.* 2018, Purger & Szép 2022). To estimate the size of the hunting range of owls, we used relative abundance of each functional groups.

The 2019 map of the CORINE Land Cover Project was used to characterize the landscape structure of the hunting range. Circles with 1, 2, 3, 4 and 5 km radius were marked around the nesting place located in Péterhida. We estimated the distribution of the habitat types in QGIS v2.12 (QGIS 2013). These various landscape structures were classified into 4 habitat types: urban, open, forest and wetland. According to the map of the national scale CORINE Land Cover Change 2012–2018, the land use change was estimated between 2015 and 2018. During this period the landscape changed only slightly: in a radius of 5 km circle 20 hectares of broad-leaved forest was replaced by transitional woodland-shrub. Based on Google maps, no significant intervention in the landscape took place in 2019 either.

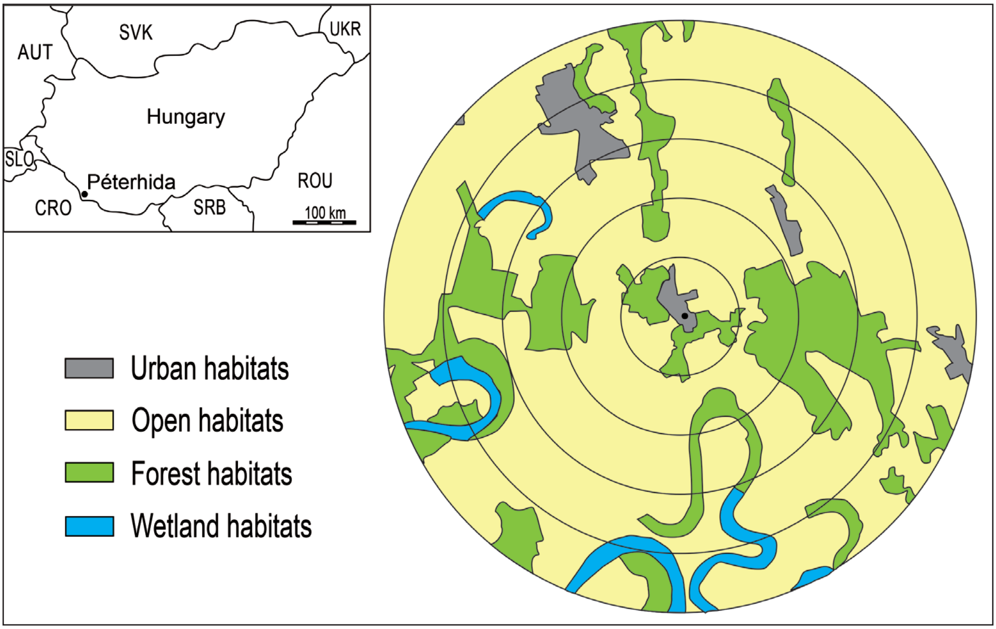

Figure 1. Distribution of four habitat types (urban, open, forest and wetland) in 1, 2, 3, 4 and 5 km radius circles (presumed hunting area) around the nesting place of the Western Barn Owl in Péterhida

1. ábra A gyöngybagoly péterhidai költőhelye körül kijelölt 1, 2, 3, 4 és 5 km sugarú körökben (feltételezett vadászterület) a négy élőhely típus (urbán, nyílt, erdei és vizes) eloszlása

The comparison of the relative abundances of small mammal functional groups detected in the five samples, and the proportion of the habitats within the corresponding hunting ranges were carried out by a homogeneity test (Zar 2010). The diversity (H) and evenness (J) of the small mammal prey of Western Barn Owls was calculated using the Past program (Hammer *et al.* 2001).

Results and Discussion

In the pellets collected in Péterhida in the abandoned cattle stable between 2015 and 2019, we identified 2,346 individuals of 19 small mammal species (considering only the shrew and rodent species). The number of species varied between 15 and 18 in the samples, which differed in size and were collected in different years *(Table 1)*. The number of pellets collected in different years varied between 71 and 430 *(Table 1),* but the diversity (H) and evenness (J) of the preyed small mammal species were similar *(Table 2)*.

The prey composition of Western Barn Owls can be considered similar in the years of our study as significant differences could only be detected in three cases concerning the groups of small mammals that prefer certain habitats *(Figure 2)*. During the five years of our study, the importance and relative abundance of small mammal species preferring urban and open habitats in the diet of Western Barn Owls was similar *(Figure 2)*. However, the relative abundance of small mammals preferring forest habitats was significantly higher in 2019 (G=4.30, P<0.05) than in 2016 *(Figure 2)*. The change was caused by that Western

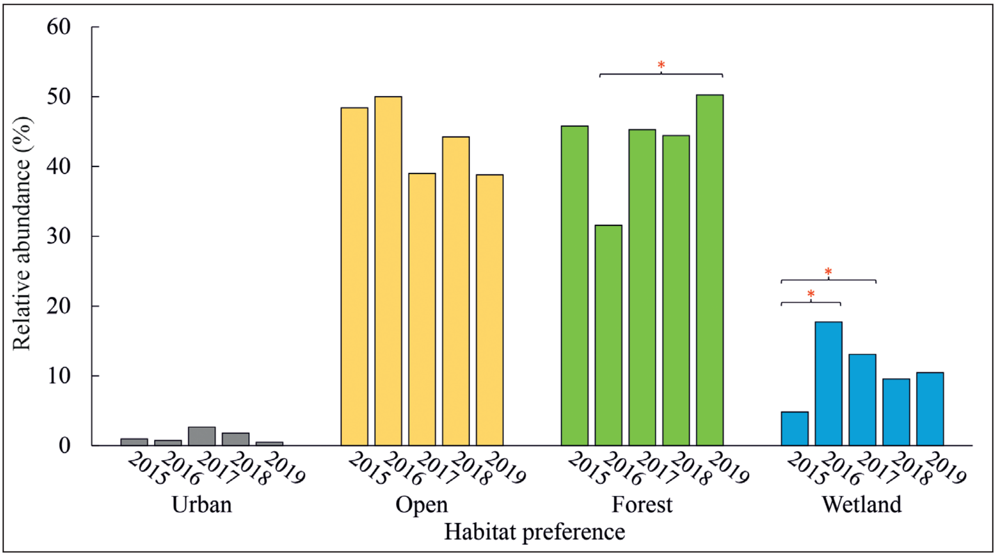

Figure 2. Changes in the relative abundance of functional groups based on the habitat preference of small mammals recovered from Western Barn Owl pellets between 2015 and 2019. (* P<0.05)

2. ábra A gyöngybagoly köpetekből előkerült kisemlősök élőhely preferenciája alapján kialakított funkcionális csoportok relatív gyakoriságának változása 2015 és 2019 között. (* P<0.05)

Table 1. Habitat preference (HP: U – urban, O – open, F – forest, W – wetland), relative abundance, diversity (H) and evenness (J) of small mammals (considering only shrew and rodent species) detected from Western Barn Owl pellets collected between 2015 and 2019.

1. táblázat A 2015 és 2019 között gyűjtött gyöngybagoly köpetekből kimutatott kisemlősök (csak a cickány és a rágcsáló fajokat figyelembe véve) élőhelypreferenciája (HP: U – urbán, O – nyílt, F – erdei, W – vizes), relatív gyakorisága, diverzitása és egyenletessége

Mammal species	HP	2015	2016	2017	2018	2019
Crocidura leucodon	O	18.71	20.33	7.26	3.09	2.99
Crocidura suaveolens	O	13.55	15.07	7.26	10.26	9.45
Sorex araneus	F	17.10	9.81	18.40	20.32	22.89
Sorex minutus	F	11.29	4.78	4.60	3.78	11.44
Neomys anomalus	W	2.26	11.24	7.26	1.10	0.50
Neomys fodiens	W	-	0.48	-	0.10	0.50
Muscardinus avellanarius	F	0.32	-	-	0.10	0.50
Microtus lavernedii	W	0.97	3.35	3.87	7.37	5.47
Microtus arvalis	O	15.47	14.60	24.47	30.87	25.86
Microtus subterraneus	F	2.26	1.44	1.21	5.18	1.99
Arvicola amphibius	W	-	0.24	1.94	0.70	0.50
Myodes glareolus	F	2.90	3.11	2.91	5.18	3.48
Apodemus agrarius	F	9.03	8.14	7.26	4.98	2.98
Apodemus flavicollis	F	2.26	2.39	8.72	3.59	6.47
Apodemus sylvaticus	F	0.65	1.91	2.18	1.29	0.50
Micromys minutus	W	1.61	2.39	-	0.30	3.48
Mus musculus	U	0.97	0.72	2.42	1.49	-
Mus spicilegus	O	0.65	-	-	-	0.50
Rattus norvegicus	U	-	-	0.24	0.30	0.50
Number of species		16	16	15	18	18
Number of preys		310	418	413	1004	201
Number of pellets		100	185	232	430	71
Diversity (H)		2.24	2.33	2.32	2.17	2.20
Evenness (J)		0.59	0.64	0.68	0.49	0.50

Barn Owls preyed on more Common Shrews *(Sorex araneus)* in 2019 (G=5.38, P<0.05) than in 2016 *(Table 1)*. Compared to 2015, the relative abundance of species preferring wetlands significantly increased in the prey in 2016 (G=11.27, P<0.01) and 2017 (G=3.93, P<0.05) *(Figure 2)*. Despite that most of the species associated with wetlands showed an increasing tendency in the prey *(Table 1)*, only the Mediterranean Water Shrew *(Neomys anomalus)* was preyed by owls in 2016 in a significantly greater number (G=6.52, P<0.05) than in 2015 *(Table 1)*.

Several factors may have influenced the observed differences, for example, the number of pellets collected yearly, which in several cases was much less than what can be expected in an optimal case (at least 300 pellets) (Purger & Szép 2022). The other fact is that Western

Table 2. Comparison of the diversity (H) and evenness (J) of small mammals detected from Western Barn Owl pellets collected in different years. N.S. – non-significant

2. táblázat A különböző években begyűjtött gyöngybagoly köpetekből kimutatott kisemlősök diverzitásának (H) és egyenletességének (J) összehasonlítása. N.S. – nem-szignifikáns

		2015	**2016**	**2017**	**2018**
2016	**H**	G = 0.001 N.S.			
	J	G = 0.002 N.S.			
2017	**H**	G = 0.001 N.S.	G = 0.000 N.S.		
	J	G = 0.006 N.S.	G = 0.001 N.S.		
2018	**H**	G = 0.001 N.S.	G = 0.005 N.S.	G = 0.004 N.S.	
	J	G = 0.014 N.S.	G = 0.028 N.S.	G = 0.040 N.S.	
2019	**H**	G = 0.000 N.S.	G = 0.003 N.S.	G = 0.003 N.S.	G = 0.000 N.S.
	J	G = 0.006 N.S.	G = 0.017 N.S.	G = 0.026 N.S.	G = 0.001 N.S.

Barn Owls can show prey preference during hunting (Yom-Tov & Wool 1997, Taylor 2009). However, we can also consider the weather, which can have a significant effect on the density and availability of small mammal species (Meek *et al.* 2012, Charter *et al.* 2017). In the period of our study, the differences can be explained primarily by meteorological conditions. In 2014 and 2015, large waterlogging areas formed as a result of the increased rainfall can also be seen on Google maps, but it is not represented on the CORINE maps we used. The waterlogging

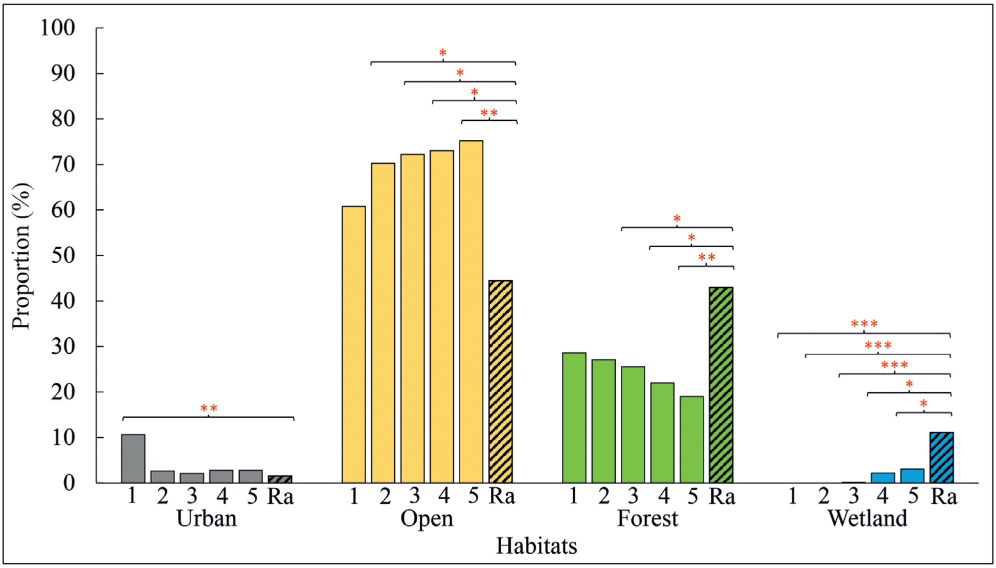

Figure 3. Comparison of the ratio of habitats and the relative abundance (Ra, striped bars) of small mammals that prefer them, in circles with a radius of 1–5 km (* P<0.05, ** P<0.01, *** P<0.001)

3. ábra 1–5 km-es sugarú körökben az egyes élőhelyek arányának összevetése az azokat preferáló kisemlősök funkcionális csoportjainak relatív gyakoriságával (Ra, csíkos oszlopok) (* P<0.05, ** P<0.01, *** P<0.001) must have contributed to the fact that by 2016, species preferring wetlands were present with a higher density of individuals in the hunting ranges of the owls. As a result, in 2016 and even in 2017, the owls could more easily access and prey on individuals of species that prefer wetlands. In addition, the waterlogging also extended to the forests of the floodplains and bog forests covering the riversides of the Drava, so the density of individuals of species that prefer forest habitats may have decreased as a result, which can be confirmed by the fact that owls preyed fewer individuals of forest species in 2016 *(Figure 2)*. Weather changes can also be tracked through the small mammal prey of Wester Barn Owls (Meek *et al.* 2012, Charter *et al.* 2017). Despite the differences shown, to achieve a representative pellet number, it is advisable to combine or merge pellet samples from different years.

Moving away from the nesting and resting places of Wester Barn Owls, i.e., increasing the hunting ranges, the proportion of particular habitats changed *(Figure 3)*. Therefore, we examined the relationship between the relative abundance (Ra) of small mammals preferring different habitats and the proportion of habitats within the areas of circles with a radius of 1, 2, 3, 4, and 5 km *(Figure 3)*.

The proportion of urban habitats around the nest site, within a radius of 1 km was the highest *(Figure 3)*, nevertheless, the relative abundance of species associated with urban habitats in the prey of owls was significantly lower *(Table 3)*. This is expected since Western Barn Owls hunt primarily in open areas, therefore, the proportion of species preferring open habitats in the prey was similar as the distribution of open habitats within a radius of 1 km,

Table 3. Differences between the functional groups of small mammals detected from the whole sample of pellets of the Western Barn Owl, based on their habitat preference and the proportion of their preferred habitats within radii of 1, 2, 3, 4 and 5 km, using G test of homogeneity

3. táblázat Az egyes élőhelyek aránya és az azokat preferáló fajok relatív gyakoriságai közti különbségek a homogenitás G teszt alapján a gyöngybagoly feltételezett vadászterületén 1, 2, 3, 4 és 5 km-es sugarú körökben

Radius of circle	Habitat	Proportion of habitat (%)	Relative abundance (%)	G	P
1km	Urban	10.60	1.53	7.61	<0.01
1km	Wetland	0.00	11.08	15.36	<0.001
2km	Open	70.25	44.42	5.87	<0.05
2km	Wetland	0.00	11.08	15.36	<0.001
3km	Open	72.20	44.42	6.68	<0.05
3km	Forest	25.54	42.97	4.48	<0.05
3km	Wetland	0.14	11.08	14.02	<0.001
4km	Open	73.05	44.42	7.05	<0.05
4km	Forest	21.96	42.97	6.92	<0.05
4km	Wetland	2.20	11.08	6.48	<0.05
5km	Open	75.20	44.42	8.01	<0.01
5km	Forest	19.01	42.97	9.51	<0.01
5km	Wetland	3.03	11.08	4.88	<0.05

but significant differences were observed in circles with a larger radius *(Figure 3, Table 3)*. This result, however, suggests that owls do not have to move further than 1 km to catch their main food. Likely, the open agricultural habitats were rich in food sources, since Western Barn Owls living in such habitats exploited smaller ranges than individuals whose nests were established in habitats with lower prey availability (Séchaud *et al.* 2022).

The proportion of forest species was similar to the proportion of forests within circles with a radius of 1 and 2 km *(Figure 3, Table 3)*. In the circles with a larger radius, the proportion of species preferring forest habitats was significantly higher in the pellets compared to the proportion of these habitats *(Figure 3, Table 3)*. In every year, except in the sample from 2016, the proportion of forest-preferring species was almost 50% of the total prey, which suggests that many forest species, such as the Wood Mouse *(Apodemus sylvaticus)* or the Striped Field Mouse *(Apodemus agrarius)* are also often preyed on outside the forest (e.g. Gliwicz & Kryštufek 1999, Tattersall *et al.* 2001). Wood mouse species are often caught by Western Barn Owls in smaller woody bushy habitats not shown on maps, such as around tree lines and hedges (Taylor 1994).

The relative abundance of species preferring wetlands was higher, in all cases, than the proportion of wetlands determined based on the maps *(Figure 3, Table 3)*. The smallest difference was observed in the radius of 2 km *(Figure 3, Table 3)*. The maps we used do not depict small watercourses and seasonal inland waters, so these habitats are usually underrepresented, which is why the established differences appear (Szép *et al.* 2019). The results of our present study indicate that Western Barn Owls caught their prey within a circle with a radius of 2 km since the habitat preference of the small mammal species detected in the prey in this case best reflected the distribution of different habitats. This result confirmed that this area size is acceptable to characterize the hunting range of Western Barn Owls (e.g. Lovari *et al.* 1976, Horváth *et al.* 2005, Meek *et al.* 2009, Szép *et al.* 2017). It is worthy to note that if the assumed hunting range is a typical agricultural landscape, the owls caught most of their prey within a 3 km circle (Purger & Szép 2022). The question, therefore, arises as to how accurate our estimation is, but it is perhaps possible to decide this if small mammal trapping is carried out in parallel with the pellet analyses, and only habitat specialist species from the pellets are included in the analyses. Unfortunately, this will require even larger samples, as the intensification of agriculture has negative effects on the density of rare and habitat specialist species (de la Peña *et al.* 2003).

Conclusion

It is worthy to note that the pellet samples can be merged to achieve a representative sample size if the ratio of each habitat type does not change significantly around the nesting site of the Western Barn Owls during the study period. Based on the assumption that most of the shrews and rodent species common in the prey of Wester Barn Owls show a certain level of habitat preference, the prey of owls can indicate the share of habitats found in the hunting range. The relative abundance of small mammal functional groups that prefer urban, open, forest, or wetland habitats in the prey in a hunting range of a certain size may overlap with the proportion of the distribution of the habitats found there. Therefore, it is possible to estimate how large hunting range the Western Barn Owls can use to catch their prey. The result of the estimation can help reconstruct the proportion of each type of habitat within the presumed hunting range based on archive data of pellet analysis. It is conceivable that, despite the robustness of the method, it can be further refined, e.g., so that only the proportion of habitat specialist small mammal species are taken into account during the estimations.

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Breeding and conservation status of the Western Barn Owl *(Tyto alba)* in Zala County, Hungary. An overview of 39 years of data

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Abstract In this study, we analysed the occurrence, nesting, and ringing data spanning 39 years for the Western Barn Owl *(Tyto alba)* population in Zala County. Data on Barn Owl surveys originate from 166 out of the total of 258 settlements in the county. During the examined period, nesting was recorded in 74 settlements, while an additional 28 locations have confirmed Western Barn Owl presence (pellets, owl sightings). Furthermore, surveys were conducted at least once in an additional 64 locations without any sign of the species. Based on Barn Owl presence and nesting data, preferred locations for the species can be identified at the local and landscape level. Nesting may be occasional in some places, while a few traditional nesting sites, which show nearly continuous occupation over decades, can be considered stable. The results from Zala County are in line with other research, highlighting the continued importance of church buildings for the species' nesting. Maintaining these buildings is essential for the conservation of a stable population. Given the decreasing number of accessible churches, there is a need for providing alternative nesting sites. In addition to building closures, the future doubling of the length of motorways in the county will pose another significant threat to the regional population.

Keywords: Common Kestrel, conservation biology, pole-mounted box, roadkill, traditional nest sites

Összefoglalás A gyöngybagoly *(Tyto alba)* Zala vármegyei populációjának 39 évet felölelő előfordulási, költési és gyűrűzési adatait elemeztük. A megye 258 településéből 166-ról származik valamilyen gyöngybagoly felmérési adat. A vizsgált közel négy évtizedből 74 településről ismert a faj költése, 28 további helységből van bizonyított gyöngybagoly jelenlét (köpet, észlelt bagoly), és további 64 helyen történt legalább egyszer felmérés a fajra utaló jelenlét nélkül. A gyöngybagoly jelenléti és költési adatok alapján kistáji léptékben és konkrét költőhelyeket illetően is megállapíthatók preferált helyek a faj egyedei számára. Egyes költőládákban a költés esetleges, míg van néhány stabilnak tekinthető tradicionális költőhely, amely évtizedeken keresztül szinte folyamatosan foglalt. A zalai eredmények – más hazai kutatásokkal összhangban – alátámasztják, hogy a gyöngybagoly költése szempontjából továbbra is kiemelt szerepük van az egyházi épületeknek, ezek fenntartása elengedhetetlen a stabil állomány megőrzéséhez. A baglyok számára elérhető templomok csökkenő száma miatt szükség van alternatív költőhelyek biztosítására is. Az épületlezárások mellett a megyei populáció másik jelentős veszélyeztető tényezője a gyorsforgalmi utak hosszának megduplázódása a következő években.

Kulcsszavak: oszlopláda, természetvédelem, tradicionális költőhelyek, úthálózat fejlesztés, vörös vércse

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Introduction

The Western Barn Owl *(Tyto alba)* (for simplicity referred to as Barn Owl in the text), has both a large geographical range and population size in Europe. Hence, in the most recent Red List Assessment of the International Union for Conservation of Nature (IUCN), the Barn Owl does not approach the thresholds for vulnerable (BirdLife International 2021). The previous assessment published in 2015 treated this species as a stable and Least Concern species (BirdLife International 2015). In most recent 2020 assessments, however, its population trend is regarded decreasing in Europe. This important alteration in the European population trend appears to be excessively careful, especially knowing the many early publications that reported local or regional population declines. In the major part of Europe, between 1970 and 1990 a decrease of 20% was reported (Osieck & Shawyer 1997), and the species became extinct in Malta. Bruce (1999) stated that its populations have been declining for about 50 years in Europe and North America. It must be noted that the trend analysis of the Barn Owl holds several uncertainties that makes the judgement of the population predictions unreliable (Barn Owl Trust 2012), but Barn Owl conservationists see a flashing emergency red light based on their field experiences. Conservationists cite changes to the global agricultural landscape (Colvin 1985), loss of nest sites and increases in vehicle traffic from expanding road networks (Massemin 1998, Mátics 2000, 2004, Fajardo 2001) as the most important factors in their decline.

A recent comprehensive overview of the Hungarian bird fauna underpins this concern. Conventionally, the population size of the Barn Owl in Hungary had been regarded between 800 and 1,000 breeding pairs (Hadarics & Zalai 2008). In contrast, based on the most recent evaluation models, this number falls only between 340–860 pairs (Klein 2021). The population fluctuation might be naturally extreme, since this bird species is very sensitive to harsh winter conditions (Altwegg *et al.* 2006). Interestingly, the average annual temperature in Hungary rose 1.15 °C between 1907 and 2017, outpacing the global average temperature change (+0.9 °C). In spite of mildening winters in Hungary, a poorer population resilience can be seen. Average winter temperature increased by 0.8–1.2 °C, and according to the climate change models, the number of frosty days will show a definite reduction by 14–15 days in winter by 2040 (International Energy Agency 2020). The slowly recovering Barn Owl populations in the series of several consecutive mild winters raises questions regarding unidentified or underrated endangering factors, that represses population resilience.

In this review, we summarise all the available data deriving from Zala County, an area that belongs to the Transdanubian hills. This geographical region in Hungary holds a robust Barn Owl population that can be acknowledged not only to the ideal landscape structure (Klein *et al.* 2022), but to the long-term intensive conservation efforts as well (Bank *et al.* 2019). The many negative processes both at nesting site and landscape levels indicate the importance of overviewing biotic data from time to time. This helps conservationists to identify endangering factors at an early phase. This is especially relevant for the declining Barn Owl, knowing the extensive traffic infrastructure development plans for the future. It has been widely discussed through the example of other nocturnal, seemingly common owls, such as the Scops Owl *(Otus scops)*, that its significant population decline over the past 25 years in Slovenia can be acknowledged to the adverse landscape transformation that reaches even the last strongholds of this sensitive iconic species (Klein *et al.* 2020).

Materials and Methods

Study area

Zala County is located in the western part of Hungary *(Figure 1)*, adjacent to the border of Croatia and Slovenia. Zala is the second most densely forested county in Hungary (KSH 2021), that is not favourable for the Barn Owl (Bruce 1999, Marti *et al.* 2020), but the grasslands and extensively cultivated areas along the rivers and canals provide suitable habitats. The distribution of land use in the county is: 33% arable land, 31.6% forest, 26% non-agricultural, 7% grassland, 0.5% vegetable garden, 0.5% orchard, 0.5% vineyard, <0.5% reedbed and <0.5% fishpond (KSH 2022). The area of the county is 3,784 km^2 and there are 258 settlements with an average human population density of 71/km^2. Nationally, it falls into the category of moderately populated counties.

Figure 1. Location of Zala County in Hungary
1. ábra Zala vármegye elhelyezkedése Magyarországon

Data acquisition

During the research, we utilized three different sources of data related to Barn Owls. We analysed the ringing data from the Ringing Centre of BirdLife Hungary spanning the years from 1985 to 2022, historical records from the Zala County Group of BirdLife Hungary, and research data from the Barn Owl Foundation (BOF) collected between 1997 and 2023. The ringing data primarily provided information about the location of ringing and the age of the birds. In cases where the database indicated a nestling or a young bird, we considered it as evidence of breeding at that location in the respective year. The surveys conducted by the Zala County Group of BirdLife Hungary provided information regarding the presence and breeding of the Barn Owl for the period between 1984 and 1989. The data of the BOF indicate the presence of Barn Owls and their breeding are derived from building surveys and the inspection of interior and pole-mounted boxes. For each surveyed building, the type of the building, its suitability for nesting, presence of owl-related signs, breeding information, and if breeding occurred, the number of eggs and nestlings were recorded. Suitable buildings were re-inspected year by year, whereas buildings that became inaccessible for the owls due to human interventions, were left out from further surveys. Thus, for some breeding sites decade long datasets are available. Data from the three databases were combined to determine the long-term breeding characteristics and conservation status of the Barn Owl in the area. Due to different sampling protocols, for the first two databases (ringing and historical), we only utilized data indicating breeding or presence. In the case of the BOF's dataset, we incorporated additional variables as well (e.g. the presence of telecommunication devices, other notable endangering factors, presence of other species, etc.).

We summarized evidence of breeding or presence of the species. If a breeding or a young bird hatched in the particular nest box was observed, the given location (settlement) was considered as a nest site. In case only pellets, feathers or adult birds were found at a particular site, only the presence of the species was proven for that locality. If there had been a survey in a given locality but breeding or presence of the bird was not known, we assumed that the species was not present in that settlement. We have compiled the total number of breedings for each settlement over the course of 39 years. In cases where a settlement had breedings in two locations within a single year, we counted it as two instances. However, since second broods were not systematically surveyed, they were not included in the analyses. To determine the Barn Owl breeding population of the county, we annually summarized the number of breeding and roost sites (fresh pellets, adult birds). As the BOF commenced a systematic survey of the county's Barn Owl population in 2009, we conducted the assessment starting from that year.

As a conservation measure, a significant number of pole boxes as alternative breeding sites were installed in Zala County from 2008 onwards with a design based on Klein and László (2015). A total of 37 pole boxes were installed, out of which 25 were erected during the winter of 2022–2023. We also summarised the usage and frequency of breeding for these pole boxes by Barn Owls and Common Kestrel *(Falco tinnunculus)* and examined the speed of occupancy of the pole boxes and those placed inside the buildings.

We extracted data from the Hungarian Central Statistical Office (referred to as KSH in the references) to gain information about the road development in Zala County.

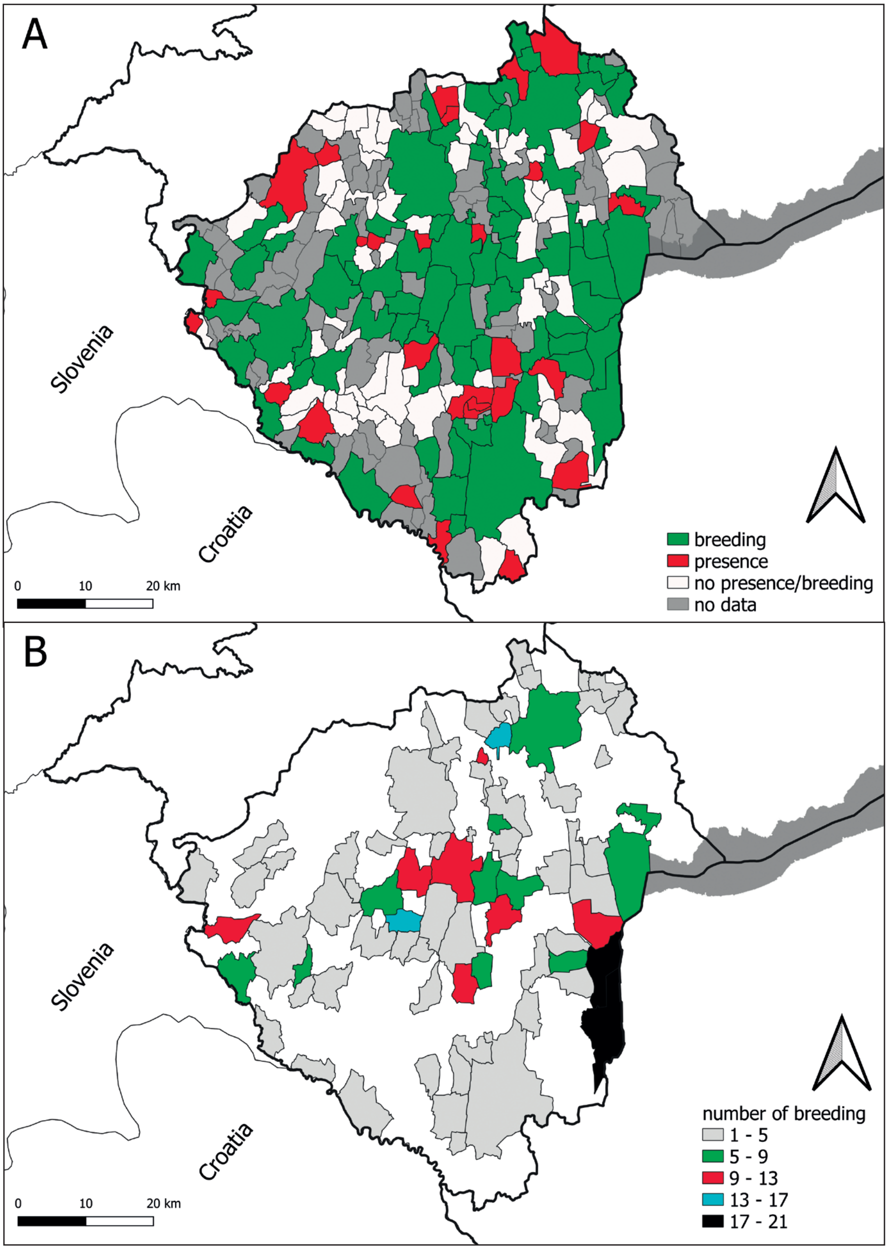

Figure 2. *A*: Distribution map of the Barn Owl in Zala County between 1984 and 2023 (absence/presence/breeding), *B*: Barn Owl breeding frequency per settlement between 1984 and 2023 in Zala County. Second broods were not included, while multiple nesting sites within the same breeding season were considered

2. ábra *A:* A gyöngybagoly hiányának/jelenlétének/költésének előfordulása Zala megyében 1984 és 2023 között, *B*: Az ismert gyöngybagoly költések gyakorisága településenként 1984 és 2023 között Zala megyében. A másodköltések nem kerültek beszámításra, míg az egy településen, de több helyen is jelenlévő költés igen

Results

Data related to Barn Owl surveys were available from 166 villages out of the total of 258 settlements in Zala County. There were 64 locations, where, despite the surveys, no signs of owls were found. In 28 settlements, the presence of the birds was detected, but breeding was not proved. Furthermore, there were 74 settlements where the birds' breeding is confirmed. Zalakomár and Balatonmagyaród are the settlements with the highest breeding frequency. Both settlements had breeding occurrences for 21 out of the examined 39 years *(Figure 2)*.

The number of surveyed buildings varied significantly each year, ranging from 50 to 128 *(Figure 3)*. Between 2009 and 2023, the number of documented Barn Owl breedings in the county ranged from 7 to 27. The years with the least breedings were 2013 and 2014, while in 2023 the highest number of Barn Owl nestings was observed.

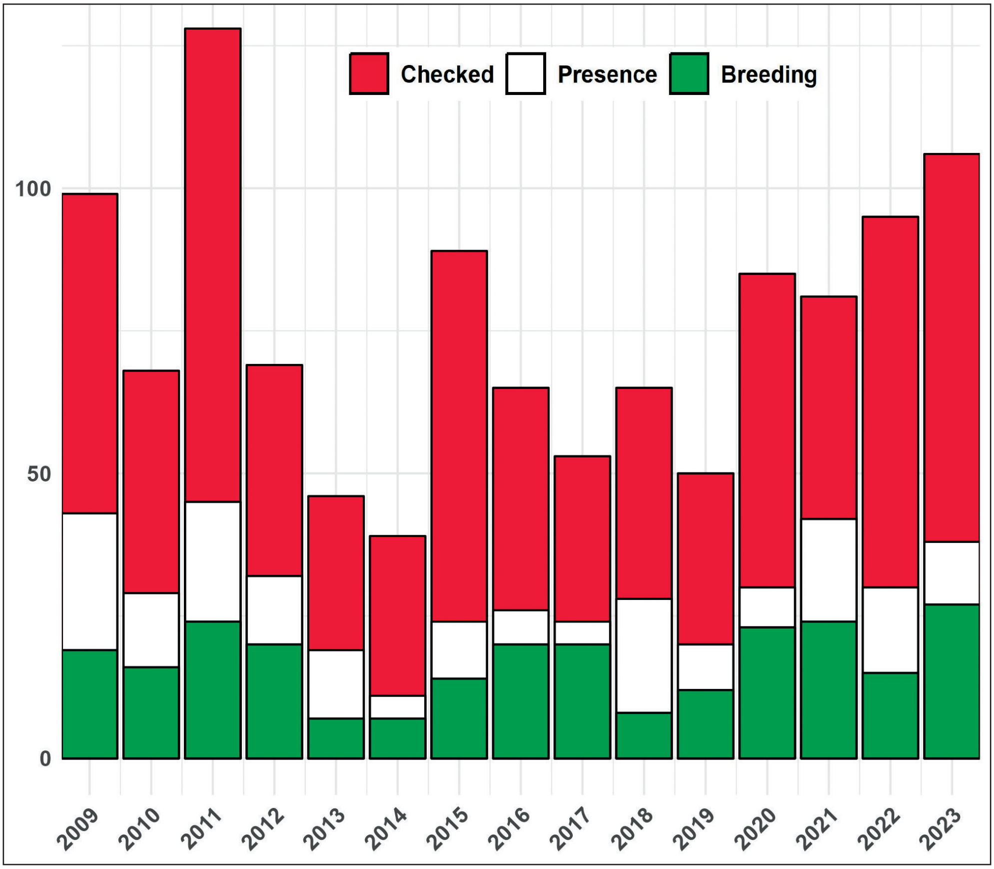

Figure 3. Number of buildings surveyed (red), roost sites (white) and breedings (green) between 2009 and 2023 in Zala County

3. ábra A gyöngybagoly felmérés során átvizsgált épületek (piros), a költés nélküli gyöngybagoly jelenlét (fehér) és a biztos költések (zöld) száma 2009 és 2023 között Zala vármegyében

Ringing

A total of 1,275 birds have been ringed in the past 38 years. The first Barn Owl ringing in the county took place in 1985. Prior to that, there are only records of dead recoveries: in 1956, a Barn Owl ringed in Croatia (Prelog, Međimurje), while in 1963, one from Germany (Niederfrohna) was found. A total of 22 ringers participated in the Barn Owl ringing activities, and ringing took place in 71 different settlements in the county *(Table 1)*.

Conservation status, pole boxes and road development

We identified 16 churches that had been surveyed previously and were accessible to owls, but by 2023 had been closed. Summing up the nesting outcomes of the pole-mounted boxes, we have determined that Barn Owl nesting has occurred in 14% of the erected boxes (a total of 11 nesting in five pole boxes); 36% of the pole boxes were occupied by the Common Kestrel at least once *(Figure 4)*.

In Zala County, the length of dual carriageways is continuously increasing. According to published governmental development plans, the construction of new sections of dual

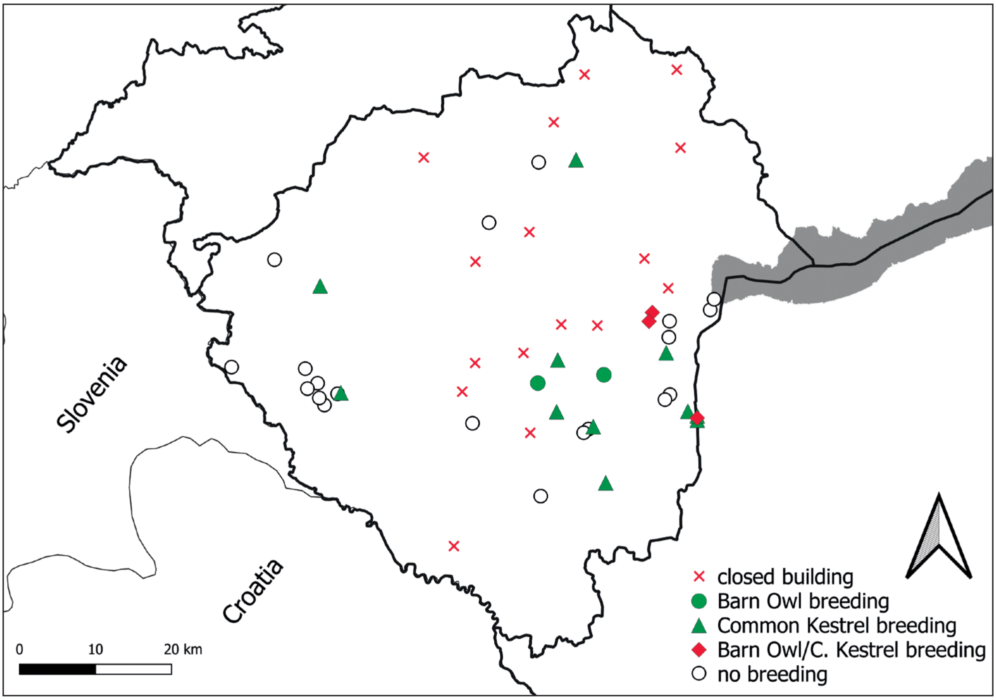

Figure 4. Lost nest sites in church buildings and the breedings of Barn Owls and Common Kestrels in pole-mounted boxes in Zala County

4. ábra Az ismert lezárt egyházi épületek, valamint gyöngybagoly oszlopládák helyzete a költési sikerükkel Zala megyében

Table 1. The number of Barn Owls ringed in Zala County by year and age group (P = pullus, F = age not determined, but not pullus, 1y = fledglings and birds within their first calendar year, 1+ = adults older than one year, 2y or 2+ = birds certainly in their second year or beyond second calendar year)

1. táblázat A Zala megyében gyűrűzött gyöngybaglyok száma évenként és korcsoportonként (P = fióka, F = fejlett, ismeretlen korú, 1y = első naptári éves fiatal madár, 1+ = adult, de bizonyosan idősebb egy évnél, 2y és 2+ = adult a második életévben vagy annál idősebb)

year	P	F	1y	1+	2y or 2+	Total
1985	3			2		5
1988		1				1
1989	15		1	2		18
1990	3		17			20
1991			3	1		4
1992			9			9
1993	30		8	1		39
1994	5	3		1		9
1995	14	1	8	5		28
1996	6		10	1		17
1997	17					17
1998	29	2	6			37
1999	26	1	2	1		30
2000	12					12
2001	14					14
2002	7					7
2003			1	1		2
2004	2					2
2005	1					1
2006	16			1		17
2007	28					28
2008	49					49
2009	60		1	5		66
2010	28			2		30
2011	87		20	1		108
2012	76		3	6		85
2013	16		1	5	1	23
2014	24			2		26
2015	60		1			61
2016	104			2		106
2017	94			5		99
2018	34	1		1		36
2019	50		12	1	2	65
2020	83	1		3		87
2021	65			3		68
2022	47			2		49
sum	**1105**	**10**	**103**	**54**	**3**	**1275**

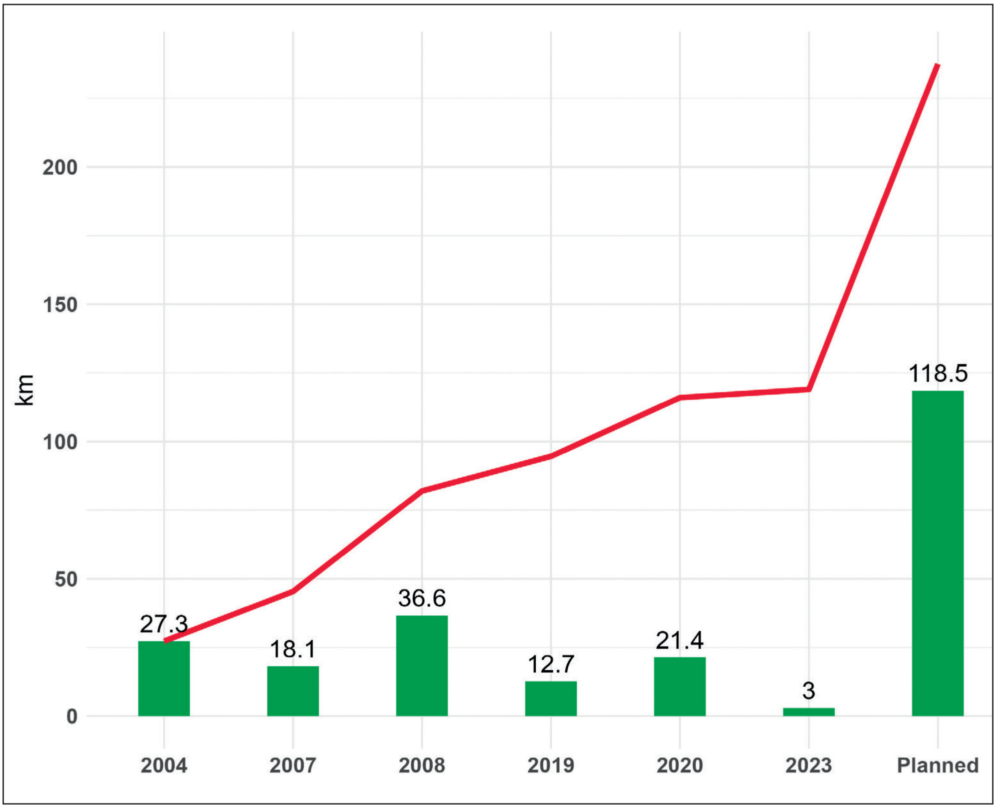

Figure 5. Development of the network of dual carriageways in Zala County. The columns represent the length of major roads built in a given year, while the line shows the cumulative length of the dual carriageways

5. ábra Zala vármegye gyorsforgalmi úthálózat fejlesztése. Az oszlopok az adott évben megépült úthosszt, a vonaldiagram az összeadódó teljes gyorsforgalmi úthálózat hosszát jelöli

Table 2. First owl signs and breedings in church-towers and in pole-mounted boxes (years after box installation). Pole-mounted box occupancy comprises data of Common Kestrel as well

2. táblázat A költőláda kihelyezést követő első gyöngybagoly nyom és költés épületben, és első költés oszlopládában években megadva. Az oszlopládák esetében a vörös vércse költése is beszámításra került

	First sign detected (building)	**First nesting detected (building)**	**First nesting detected (pole box)**
mean	4.2	4.6	5.5
max.	10.9	11.8	6.8
min.	0.6	0.3	0.3
SD	3.9	3.4	2.6
n	8	17	9

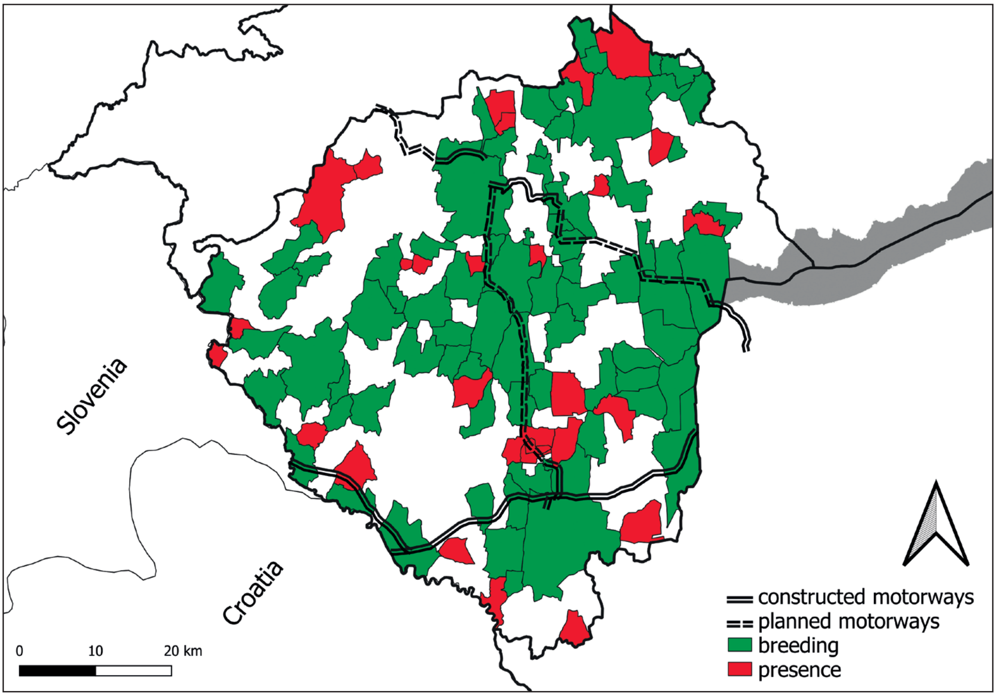

Figure 6. The current (double line) and planned (double dashed line) dual carriageway network in Zala County in relation to known Barn Owl nesting/roosting sites

6. ábra Zala vármegye jelenlegi (dupla vonal) és tervezett (szaggatott dupla vonal) gyorsforgalmi úthálózata az ismert gyöngybagoly előfordulások és költések függvényében

carriageways will double the already existing network by 2030 *(Figure 5)*. The comparison of the planned new motorway routes (nearly 120 km) with the currently known Barn Owl nesting and roost sites shows a notable overlap *(Figure 6)*.

Occupation dynamics of new nesting sites

The nest box occupation dynamics calculated from the data in the BOF conservation database shows practically no difference between nest boxes in buildings and pole boxes *(Table 2)*.

Discussion

In Zala County the highest registered number of breeding was 27 (2023), while the lowest was 7 (second clutches not included). Bank *et al.* (2019) studied the Barn Owl population in Baranya County between 1995 and 2018. The lowest recorded yearly number of breeding pairs was 7, and the highest 94, with box occupancy ranging from 9.7% to 73.4%. Despite Baranya County having an area 17% larger than Zala, the significantly higher breeding rate could be attributed to small-village structure characteristic to Baranya County, along with a more favourable landscape and a well-established network of conservation activist. Also, due to its geographical location Baranya County has a milder Sub-Mediterranean climate (Bank 1990, Bank *et al.* 2019) important for the winter survival of the Barn Owls.

The most stable Barn Owl populations in Zala were found along river valleys and water courses (Kis-Balaton, Kerka-vidék, Principális canal). Two settlements around Kis-Balaton (Balatonmagyaród and Zalakomár) have exceptionally high number of breedings. Since 2009 there has been only 3 years without breeding in Balatonmagyaród. This nest box had been installed in the 1980s in the attic of a large community building, as the local church tower is closed.

The dual carriageway network in Zala County has shown continuous growth over the past two decades, with plans for construction to match the length of the already built roads. Since roadkill is a severe threat to Barn Owl populations (Massemin & Zorn 1998, Mátics 2000, 2004, Bozó & Csathó 2017, Borza *et al.* 2021, Monoki *et al.* 2022, Tamás & Kőhalmi 2022), this will increasingly become a significant problem for the local population. As Zala County has significant forest coverage and hilly areas, the newly planned major roads will primarily circumvent these areas by running through lowland regions and alongside canals and rivers, where the Barn Owl population density is the highest. The planned routes will, in fact, consistently intersect with settlements where the species' regular nesting is well documented. It is very probable that this infrastructure development will have a significant negative impact on the local population.

The Barn Owl is a strictly protected species in Hungary, yet, during building renovations the bird's interests are often overlooked. In Zala County, 16 buildings that were previously surveyed and found to be accessible to Barn Owls, have now been completely closed off. This includes 8 churches where Barn Owl nesting was confirmed earlier. If we also consider the non-surveyed churches, this ratio could potentially be much higher. Our results are consistent with a study from Poland showing that in Mazovia 59% of the buildings visited in the period 1989–1992 were occupied by Barn Owls and 79% of them were accessible to owls, whereas by 2000 this had decreased to 31% and 52% respectively (Golawski *et al.* 2003).

Three significant reasons can be identified behind the loss of nest sites in the churches: i) the installation of telecommunication devices within the towers (mobile phone aerials, signal amplifiers, internet antennas), ii) carelessly executed building renovations, and iii) dismissive attitude of the building managers. The installation of telecommunication device poses a particularly challenging concern due to the necessity of ongoing maintenance, resulting in more frequent disturbance, often coinciding with the breeding season. Furthermore, the large equipment very often completely occupies exactly those spaces in the church towers, where the nest boxes could be installed.

Pole-mounted boxes are commonly used in the conservation of Barn Owls (Leech *et al.* 2009, Barn Owl Trust 2012), especially in regions where biological pest control plays an important role in the agricultural practices (Richard 2012). The initial findings of our experimental pole box scheme highlight that properly installed pole boxes in well selected habitats may serve as alternative breeding sites. This alternative nest site provision can mainly gain importance in locations where owl-friendly conditions within traditional buildings cannot be maintained anymore. However, based on our past experiences, it can take years for the pole boxes to be discovered by Barn Owls and for the first breeding to appear. We experienced the first occurrence of multiple nesting when there were simultaneous breedings of Barn Owls in the church tower and in a pole box located at the outskirts of the same settlement. The two nesting sites were 1,030 metres apart. Both nesting attempts proved to be successful (six and five fledglings left the boxes of the church tower and the pole box, respectively). To determine the extent to which these pole boxes can substitute traditional nesting sites in Hungary, further long-term studies are needed.

Common Kestrels are also beneficiaries of the Barn Owl nest site schemes in Zala County. In many cases, the pole-mounted box was already occupied by Common Kestrels shortly after the installation, and the nestlings also reached the fledging age. Very little data was known about Common Kestrel nesting in Zala County before our pole box scheme. Despite 36–39% of the Common Kestrel population in Hungary breeds in artificial nest boxes (Kotymán & Solt 2022), only three breeding instances were documented in Zala County during the period between 2010 and 2020.

The figures demonstrate that nest box occupation time varies strongly. In extreme cases conservationists have to wait longer than 10 years before the nest box is being used by Barn Owls. Our experiences reinforce the observations, that nest site fidelity is strong (Barn Owl Trust 2012). Traditional nest sites are re-occupied quicker after reopening, and newly created nest sites can remain unvisited by owls for a very long time. Even carefully designed attractive nest sites stay empty and the reasons behind this are hardly known. Factors like height from ground level (Wendt & Johnson 2017), exposition to wind, orientation (Charter *et al.* 2010), land use and landscape structure (Bond *et al.* 2005, Wendt & Johnson 2017), prey availability and the general quality of the hunting area, direct disturbance by human activities certainly must be taken into consideration. However, beyond these features, there might be further aspects that make certain nest sites appealing to owls.

The practical conservation consequence of the described phenomena is the strict protection of the traditional nest sites. Field data do not support the concept yet, that newly created nest sites efficiently and rapidly enough substitute the damaged historical ones.

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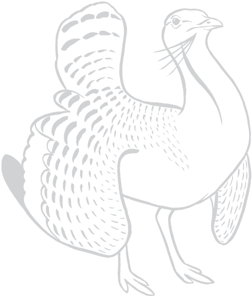

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Investigation of roadkilled Western Barn Owls *(Tyto alba)* in Csanádi-hát region (SE Hungary)

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Abstract The Western Barn Owl *(Tyto alba)* is a common breeder in Hungary. It is a resident bird of open areas, staying near nesting sites in winter. Its population is strongly influenced by food availability, weather conditions and several anthropogenic activities. One of the most important factors of these in recent decades has been road mortality. In this work, we processed data of roadkilled individuals and field observation records in the Csanádi-hát region in south-eastern Hungary from the period 1995–2022. In Battonya, we have been recording roadkill individuals since 1995, while observations of Barn Owl individuals from Kevermes have been available since 2005. The species is a regular, but scarce breeder in the area, so both the number of roadkilled individuals and the number of field observations were relatively low. Nevertheless, we had the opportunity to examine how the number of individuals of the species that were killed in the traffic varied over time and within years. According to our data, more birds collided during the winter, and also between July and November. This can be explained mostly by the seasonal lack of food and the fledging time of inexperienced juveniles. The temporal distribution of field observations were different from the dynamics of the roadkills, as the species was mainly observed during the breeding season. The exact population size of the area can be difficultly estimated, as it breeds mainly in attics of stable, granary and church buildings. The breeding population of Kevermes was estimated at 3–4 pairs and did not change significantly in the studied period. Over the same 28-year period, using the same methods to the two other most common nesting owl species of the region, we found that the within-year roadkill dynamics of the Little Owl *(Athene noctua)* and the Northern Long-eared Owl *(Asio otus)* differed from that of the Western Barn Owls, which may be due to the different feeding habits of the species. We can conclude that the number of roadkilled birds was proportional to the local population of the species.

Keywords: roadkills, road mortality, animal-vehicle collisions, road ecology, agricultural landscape, Great Hungarian Plain, farmland bird, Strigiformes

Összefoglalás A gyöngybagoly *(Tyto alba)* Magyarországon elterjedt fészkelőfajnak számít. A nyílt területek madara, állandó faj, télen is a fészkelőhelyek közelében tartózkodik. Állományára az aktuális táplálékkínálat és az időjárás mellett különféle antropogén tényezők is jelentős hatással vannak. A faj esetében a közúti gázolások okozta elhullás az utóbbi évtizedekben az egyik legjelentősebb mortalitási faktornak számít. Munkánk során a Délkelet-Magyarországon elhelyezkedő kistáj, a Csanádi-hát területén gyűjtött elütési és terepi megfigyelési adatokat dolgoztuk fel. Az elütési adatok gyűjtésének központi települése Battonya, míg az állományfelméréseké Kevermes volt. Battonyán 1995 óta jegyezzük fel az elütött gyöngybaglyokat, míg Kevermesről 2005 óta állnak rendelkezésre megfigyelések. A battonyai adatsor mellett a Csanádi-hát más településeiről származó elütési adatokat is felhasználtunk. A faj a térségben rendszeres, de csak kisszámú fészkelő, ezért mind az elütött példányok, mind a terepi megfigyelések száma viszonylag alacsony. Mindazonáltal lehetőségünk volt megvizsgálni, hogy hosszú távon és éven belül hogyan változott a faj elütött egyedeinek száma. Az elütések szempontjából az éven belül bimodális eloszlást találtunk. Az egyik csúcs télen volt, míg a másik elhúzódott július és november között. Előbbi a téli táplálékhiányra, utóbbi elsősorban a tapasztalatlan fiatal példányok önállósodását követő időszakra vezethető vissza. A terepi megfigyelési adatok időbeli eloszlása eltért az elütések dinamikájától, mivel a fajt elsősorban a nászidőszakban észleltük. Pontos állományának becslése nehéz a térségben, mivel elsősorban mezőgazdasági telepeken és padlásokon költ, ahol a fészkelő madarakat gyakran nehéz megtalálni. Kevermesi állományát ezzel együtt 3–4 párra becsültük, és az nem változott jelentősen a vizsgált időszakban. Azonos 28 éves időszakban, megegyező módszereket alkalmazva megállapítható, hogy a térségben a másik két legnagyobb számban fészkelő bagolyfaj, a kuvik *(Athene noctua)* és az erdei fülesbagoly *(Asio otus)* éven belüli elütési dinamikája jelentősen eltér a gyöngybagolyétól, ami elsősorban a fajok eltérő táplálkozási szokásaira vezethető vissza. A két különböző módszer eredményei alapján arra következtethetünk, hogy az elütött madarak száma arányos volt az adott faj helyi populációméretével.

Kulcsszavak: közúti elütések, állatgázolások, útökológia, agrártáj, Alföld, bagolyalakúak

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Introduction

The Western Barn Owl – *Tyto alba* (Scopoli, 1769) – is a polytypic species with 10 subspecies (Gill *et al.* 2023). Previously 30+ subspecies of Barn Owl were defined, which were lately divided into three groups, with the Western Barn Owl restricted to Africa and Europe (Uva *et al.* 2018, Marti *et al.* 2020). The species avoids colder regions such as high mountains, but is also absent from eastern Europe and Scandinavia (Almasi & Roulin 2020). Its density is the highest in southern and central Europe, decreasing eastwards as temperatures fall and the number of snowy days increase (Almasi & Roulin 2020). It feeds primarily on mice (*Apodemus* spp.) and voles (*Microtus* spp.) (Love *et al.* 2000, Bontzorlos *et al.* 2005, Kitowski 2013), which show significant fluctuations in their populations (Ylönen 1994). These fluctuations impact the Western Barn Owls, as the species does not leave their breeding area for the winter (Marti *et al.* 2020). In years when the density of rodents is high, and the winter is milder, up to 45% of pairs may breed twice, and occasionally even three times in Hungary (Bank *et al.* 2019, Haraszthy 2019). In food-poor years, both breeding occasions and egg production decrease, or pairs even may not breed at all (Haraszthy 2019).

Occasionally, major population collapses occur in certain periods (Altwegg *et al.* 2006, Chausson *et al.* 2014). Its European populations decreased before the 1990s and have been stable since, although local declines have been observed in several populations (Almasi & Roulin 2020).

In Hungary, two subspecies can be found, one is the *T. a. guttata*, which is a widespread breeder, and the other is the *T. a. alba*, which is only occasionally found (Bozó & Csathó 2022). The species occurs mainly in areas near grasslands, agricultural fields bordered by treelines, tree groups and open cultivated areas on which streams or rivers flow through, avoiding closed forests (Hadarics & Zalai 2008, Haraszthy 2019, Klein 2021). Its biggest populations occur in the Southern Transdanubia, the Marcal Basin, the Lake Fertő, the Hanság, the Bácska Plain, the North Kiskunság, the Borsod Plain, the Upper Tisza Plain, the Bodrogköz, the Szatmár–Bereg Plain, the Hortobágy and the Békés Plain (Klein 2021).

A significant portion of the population breeds in anthropogenic environments, especially in the attics of churches and agricultural buildings (Fenyősi *et al.* 1998, Haraszthy 2019), but may also use dovecotes and water towers.

Breeding is prolonged, taking place between March and October, but after mild winters breeding pairs may be present as early as February (Haraszthy 2019).

In addition to natural fluctuations in the food, the species' population is also affected by various anthropogenic factors. Road collisions are considered a particularly significant threat (Baudvin 1986, Percival 1990, Taylor 1994, Mátics 2000, Borza *et al.* 2021, Monoki *et al.* 2022, Tamás & Kőhalmi 2022). According to Borza *et al.* (2021), published data place the Western Barn Owl among the 10 most frequently recorded roadkilled bird species in Hungary. For this reason, bird–vehicle collisions mean a serious conservation problem for the species, which is extremely difficult to solve (Monoki *et al.* 2022).

In our work, we estimated the long-term changes in the total and annual number of roadkilled individuals in the area of the Csanádi-hát region (Békés County, SE Hungary).

The Western Barn Owl is a regular nesting species in the area with a small population (Bozó 2017), and roadkilled individuals are also regularly found (Csathó & Csathó 2009). Field observation data are available from one of the settlements in the area, which provide an opportunity to understand the within-season roadkill dynamics of the species and also provide a basis for population estimation. We also collected data of roadkilled individuals of the most common breeding owl species in the region, the Little Owl *(Athene noctua)* and Northern Long-eared Owl *(Asio otus)*, so we could compare our results with those obtained for the other two species.

Material and Methods

Between 1995 and 2022 we carried out roadkill surveys in the entire administrative area of Battonya town (14,577 hectares). The surveys were carried out by bicycle in most cases once a month during the whole year. There are four busy roads in the outer area of Battonya: Kovácsházi road (length: 8.4 km), Dombegyházi road (4.3 km), Tornyai road (5.0 km) and Mezőhegyesi road (3.4 km) (Csathó & Csathó 2009). All of the Western Barn Owls found roadkilled were recorded. Estimated date of the collision and the location along the road was recorded for each found individual. In most cases photos were also taken of the roadkilled Western Barn Owls.

We presented a graph on the between- and within-year distribution of the data. To create the database and the figures we used Microsoft Excel 2016.

Data from Battonya were compared with data from roadkilled individuals found in other areas of the Csanádi-hát region. In these areas, data collection was non-standard, with only occasional visits.

Field observations were carried out in Kevermes between 2005 and 2022 and the occurrence of the species was recorded. In total, observations were made on 2,465 different days during the study period. We considered data as one observation of the species per day. From these data, we estimated the local population of the species and the within year distribution of observations. This was then used for comparison with the date of the roadkills.

In the case of Little Owl and Northern Long-eared Owl, we used the same methods to collect the roadkilled individuals, with the same collection period (1995–2022), the location of the survey was also the administrative area of Battonya (without any data from other settlements of the Csanádi-hát).

Results

In Battonya, we found a total of 21 roadkilled individuals of Western Barn Owl during the 28 years of the data collection. In other settlements of Csanádi-hát region, we found additional 15 roadkilled birds *(Figure 1–2)*.

In Kevermes, 22 individuals were observed, one of which was found dead *(Figure 3)*. Based on our observations, there were at least 3–4 breeding pairs in the settlement during the studied period. The exact nesting sites were not known, but in one case, a nest of the

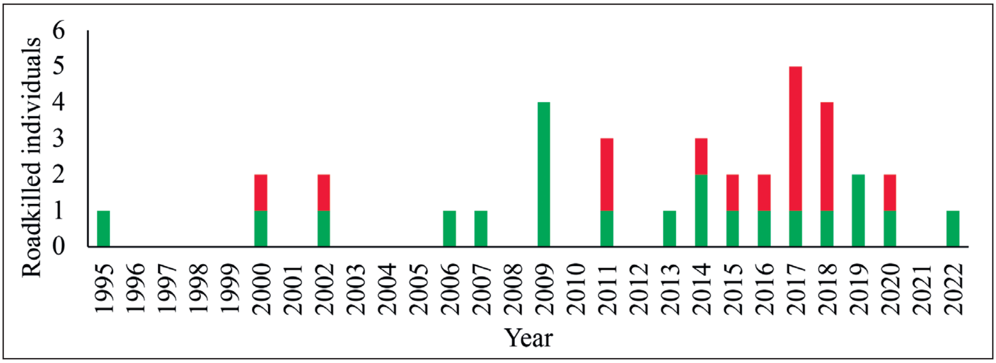

Figure 1. Annual distribution of roadkilled Western Barn Owls found in Battonya (green columns) and the other settlements of the Csanádi-hát (red columns) between 1995 and 2022

1. ábra A Battonyán (zöld oszlopok) és a Csanádi-hát egyéb településein (piros oszlopok) 1995 és 2022 között elütve talált gyöngybaglyok száma éves bontásban

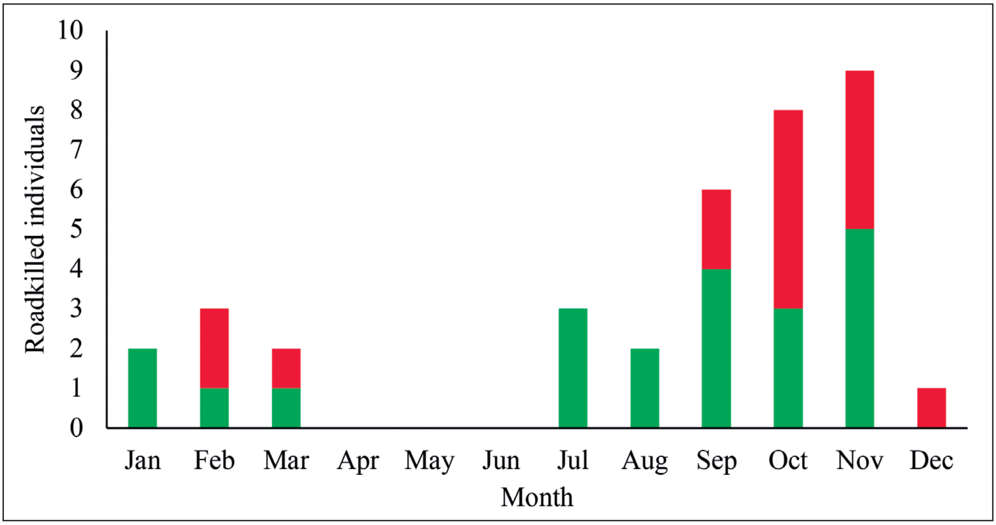

Figure 2. Monthly distribution of roadkilled Western Barn Owls found in Battonya (green columns) and the other settlements of the Csanádi-hát (red columns) between 1995 and 2022

2. ábra A Battonyán (zöld oszlopok) és a Csanádi-hát egyéb településein (piros oszlopok) 1995 és 2022 között elütve talált gyöngybaglyok száma havi bontásban

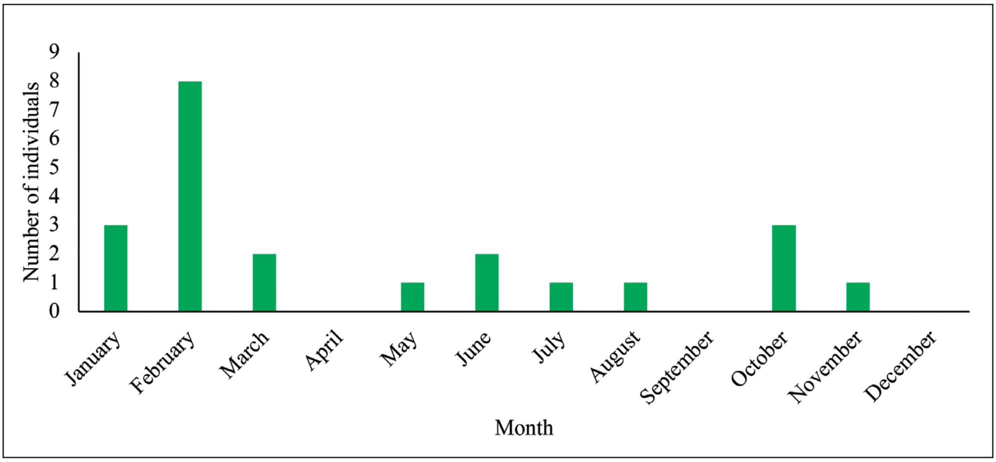

Figure 3. The within-year distribution of the Western Barn Owl observation from Kevermes between 2005 and 2022

3. ábra A kevermesi gyöngybagoly-megfigyelések éven belüli eloszlása a 2005–2022 közötti időszakban

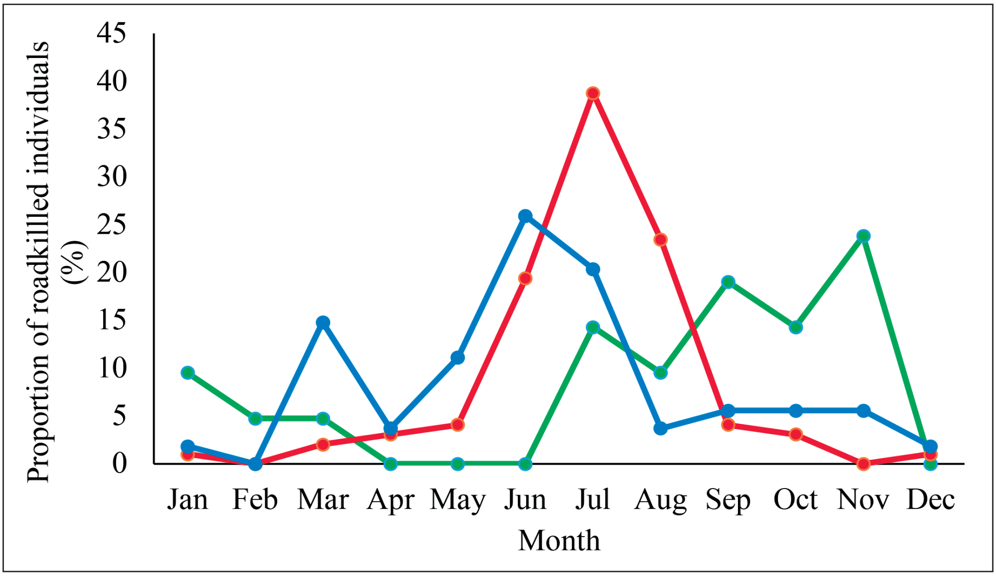

Figure 4. Proportion of roadkilled Western Barn Owls (green), Little Owls (red) and Northern Long-eared Owls (blue) found in Battonya by months between 1995 and 2022

4. ábra A Battonyán 1995 és 2022 között elütve talált gyöngybaglyok (zöld színnel), kuvikok (piros színnel) és erdei fülesbaglyok (kék színnel) éven belüli százalékos eloszlása

species was found in a bale pit of a farm in the countryside. Breeding was also observed in the centre of the settlement and in the surroundings of a former mill. No sightings have been made in recent years in the vicinity of the outlying granaries.

We found a total of 98 roadkilled Little Owls and 54 Northern Long-eared Owls in Battonya in the same 28-year period *(Figure 4)*.

Discussion

In the case of the Western Barn Owl, road collisions are a significant mortality factor. The road mortality of juveniles is much higher than that of adults, ranging from about 50–70% (Baudvin 1986, Percival 1990, Taylor 1994, Mátics 2000, de Jong *et al.* 2018). This may be due to the inexperience of the birds. In Mátics's (2000) study, only juveniles were affected by electrocution, drowning or mortality due to human hunting (birds could not find suitable shelter).

The following results support the conservation relevance of bird–vehicle collisions: in France, 73.2% of juveniles and 26.8% of adults (Baudvin 1986), in Great Britain 49% of juveniles and 48% of adults (Percival 1990), in Scotland 56.5% of juveniles and 22.7% of adults (Taylor 1994) died from being hit by a car. Nonetheless, it is important to mention that fatalities are over-represented because it is much easier to find individuals that became victims of traffic on roads, than those that have died naturally or from other causes, as Mátics (2000) pointed out. In contrast, a few years later, he found that the most important threat to the species in Hungary was road collision, with a mortality rate of 20.6% for juveniles and 13.5% for adults (Mátics 2004). These rates were much lower than those observed in western Europe at the time, most likely due to the relatively underdeveloped road network in Hungary. It should be noted that during the same interval, the rate of deliberate shootings dropped to almost zero. Similar results were obtained in Great Britain, where in the second half of the 20th century, road killings were increasingly responsible for the mortality of owls (Newton *et al.* 1997). In Jász-Nagykun-Szolnok County, Monoki *et al*. (2022) found a total of 424 roadkilled Western Barn Owls between 2005 and 2021.

Tamás and Kőhalmi (2022) found that the Western Barn Owl was the second most frequently roadkilled owl species after the Northern Long-eared Owl in their 7-year study in North Bácska region. In our survey, roadkilled Western Barn Owls were found regularly, but not in every year and this owl species was found in the highest numbers after the Little Owl and the Northern Long-eared Owl. This is in correlation with the population of these species in the area (Bozó 2017). The Western Barn Owl was never common in the area due to lack of suitable habitat, and its most important nesting sites here may be agricultural buildings. However, several of these have been renovated in recent years, which may explain why no roadkilled individuals have been found in Kevermes in the past few years.

The frequency of roadkills has increased compared to the 1990s, and the increase in traffic has certainly contributed significantly to this. There was no population increase during this period, so this seems the most likely explanation. However, the peak in 2009 can most likely be explained by high breeding success in that year, possibly due to colder and snowy weather. We were not able to investigate probable differences between age groups. According to Taylor (1994), the roadkilled birds were in poor condition and the roadkills typically occurred in winter. This is contradicted by a study in the Netherlands by de Jong *et al.* (2018), in which they found that hit Western Barn Owls were typically in good condition. The condition of the individuals in our survey was not assessed (partly because the condition of the individuals no longer allowed it), but the higher number of winter roadkills might be explained by the lack of food and weakening due to adverse weather conditions. In contrast, inexperience may be the primary cause of roadkills in summer, when there was no significant lack of food. The inexperience of birds as main reason for roadkills most likely supported by the fact that the two most common owl species in the region, the Little Owl and the Northern Long-eared Owl, show only a single peak after the young have fledged, while in winter the number of roadkills is very low (Bozó & Csathó 2017, Bozó *et al.* 2020). In these two species, weather plays a much less important role in mortality than in the case of the Western Barn Owl, which is less adapted to cold temperature and thick snow cover.

For the seasonal pattern of mortality, Mátics (2000) obtained a bimodal distribution. One peak was in October, which was due to the high mortality of newly fledged individuals. The other peak was in January–February, in the coldest period. This, together with the fact that the seasonal mortality pattern of adult birds did not differ from that of young birds, suggests that weather is the most important factor influencing the pattern. Birds become weaker and thus die more easily from natural or also from anthropogenic causes. However, a few years later, Mátics (2004) concluded that, compared to the 1980s, the seasonal dynamics of the mortality in the 1990s had widened from a peak between August and February to a period between June and March, i.e. by three months. These results are in line with our results and supporting the idea that the dynamics of roadkills widened within a year. Monoki *et al.* (2022) found the highest number of roadkilled Western Barn Owls between November and March, especially between January and March in Jász-Nagykun-Szolnok County.

The within-year distribution of field observation data partly matches the pattern of the roadkills. Most observations occur in January and February, but there is a small peak in October. In contrast to the specimens found hit by a vehicle, the species was very rarely sighted in the second half of summer and early autumn, whereas it could have been more frequently seen in the first half of summer. The pattern of field observations is mainly related to the breeding biology of the species. Sightings occur mainly during the mating season when birds are actively calling. This is mainly in February, while in early summer the birds are likely to be more active due to second broods. The minor peak in October may be due to dispersal movements of juveniles.

The species is not considered common in the study area, and this is supported by both roadkill and field observation data. However, it is important to note that unlike in other parts of the country, the most important breeding sites are not church steeples but agricultural buildings and lofts even though in the late 1990s it also bred in the church tower of Kevermes (Pabar 2000) and in the recent in Battonya. Therefore, the exact population size remains unknown, but we can agree on that it is much rarer than the Little Owl and the Northern Long-eared Owl.

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Diet of Pharaoh Eagle-Owl, *Bubo ascalaphus*, from Ara’r region, northern Saudi Arabia

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Abstract The diet of the Pharaoh Eagle-Owl, *Bubo ascalaphus,* was investigated based on 338 pellets collected from caves and underground caves in Ara’r region, northern Saudi Arabia. Small mammals constituted the highest number of consumed prey (75.75%), followed by arthropods (20%), birds (2.9%) and reptiles (1.26%). The Libyan Jird, *Meriones libycus*, was the most consumed rodent (26.46%) followed by Sundevall’s Jird, *Meriones crassus* (20.47%), while the least were Cheesman Gerbil, *Gerbillus cheesmani*, and Wagner’s Gerbil, *Gerbillus dasyurus*. At least three species of scorpions, *Androctonus crassicauda*, *Compsbuthus* sp. and *Scorpio* sp., and two species of reptiles *(Ptyodactylus hasselquistii* and *Trapellus agnetae)* were recovered. Study of owl pellet contents proved to be a valuable tool to study species composition in unexplored regions. Also, our findings substantiate the fact that the Pharaoh Eagle-Owl is an opportunistic species that adapts to available preys in its habitat.

Keywords: underground caves, biodiversity, vertebrates, feeding behaviour, Saudi Arabia

Összefoglalás Az egyiptomi uhu *(Bubo ascalaphus)* táplálék-összetételét az Észak-Szaúd-Arábiában fekvő Ara’ar régióban barlangokból és föld alatti üregeiből gyűjtött 350 köpet alapján vizsgáltuk. Az elfogyasztott zsákmány legnagyobb arányát a kisemlősök adták (75,75%), ezt követték az ízeltlábúak (20%), a madarak (2,9%) és a hüllők (1,26%). A legnagyobb arányban fogyasztott rágcsáló a sivatagi versenyegér *(Meriones libycus)* volt (26,46%), ezt követte a nagy versenyegér *(Meriones crassus)* (20,47%), míg a legkisebb arányban a Cheesman-futóegér *(Gerbillus cheesmani)* és a Wagner-futóegér *(Gerbillus. dasyurus)* került elő. A köpetekből továbbá három skorpiófajt (*Androctonus crassicauda*, *Compsbuthus* sp. és *Scorpio* sp.), valamint két hüllőfajt *(Ptyodactylus hasselquistii, Trapellus agnetae)* azonosítottunk. A köpetvizsgálat az eddig feltáratlan régiókban értékes eszköznek bizonyult a fajösszetétel tanulmányozásában. Eredményeink alátámasztják, hogy az egyiptomi uhu képes alkalmazkodni az élőhelyén nagyobb számban előforduló prédához.

Kulcsszavak: földalatti üregek, biodiverzitás, gerincesek, táplálkozási viselkedés, Szaúd-Arábia

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Introduction

Seven species of owls in two families are considered as resident in Saudi Arabia; Family Tytonidae: *Tyto alba* (Scopoli, 1769) and Family Strigidae: *Otus brucei* (Hume, 1873), *Otus pamelae* Bates, 1937, *Bubo ascalaphus* Savigny, 1809, *Bubo africanus* (Temminck, 1821), *Strix hadorami* Kirwan, Schweizer and Copete, 2015 and *Athene noctua* (Scopoli, 1769). Both *B. ascalaphus* and *A. noctua* are the most common species, with a wide range of distribution across the Arabian Peninsula (Jennings 2010, Boland & Al Suhaibany 2020). Another two species are considered as winter visitors, *Asio flammeus* (Pontoppidan, 1763) and *Otus scops* (Linnaeus, 1758) (Boland & Al Suhaibany 2020).

Little is known on the diet of owls inhabiting Saudi Arabia. Bauer (1988) reported on seven rodent species found in owl pellets, possibly of the Common Barn-owl, *Tyto alba,* in Summan Plateau, northeastern Saudi Arabia. Evans and Bates (1993) found at least two species of rodents, and two arachnids recovered from the Pharaoh Eagle-Owl, *Bubo ascalaphus,* pellets from Harrat al Harrah reserve. Jennings (2010) reported on prey items consumed by *B. ascalaphus* in Arabia, including rodents, hare, bats, birds and insects. Based on 112 pellets for *B. ascalaphus*, Abi-Said *et al.* (2020) found that rodents constituted the highest percentage of consumed prey items (91%), followed by scorpions (5.91%), other insects (2.96%) and birds (2.46%) from Wadi As Sulai, near Riyadh.

The diet of the Pharaoh Eagle-Owl was studied in Algeria (Biche *et al*. 2001, Benamor *et al*. 2021), Egypt (Goodman 1990, Sándor & Moldován 2010), Jordan (Amr *et al.* 1997, Rifai *et al.* 2000, Shehab & Ciach 2008, Obuch 2018), Qatar (Mohedano *et al.* 2014), and the United Arab Emirates (Cunningham & Aspinall 2001). These studies demonstrated that the Pharaoh Eagle-Owl is an opportunistic feeder preying on a wide range of animals including rodents, birds, reptiles and arthropods.

In this study, we report on the diet of the Pharaoh Eagle-Owl from Ara'r area, northeast of Saudi Arabia based on 338 pellets collected from 25 underground caves. This is the first work in the Middle East to study owl pellets from a large number of caves in an area that have never been studied. Also, our aim is to have an insight on the biodiversity of this little-known area.

Material and Methods

A total of 338 regurgitated pellets from at least six Pharaoh Eagle-Owls roost sites located at the entrance of 25 underground limestone caves or sinkholes in Ara'r region in northern Saudi Arabia were collected during July – December 2022 *(Table 1, Figure 1, 2)*. These underground caves vary in diameter and length, ranging from 15 × 12 m wide entrance for the largest cave, to 2–3 m wide entrance for small ones *(Figure 2)*. The owls were seen near the caves or sitting on the ledges surrounding the caves *(Figure 1)*. The caves are located in flat rocky areas surrounded by gravel and sand. The studied area is barren desert with no farmlands or human settlements.

The length and width of the collected 159 intact pellets were measured by a digital calliper. Each pellet was soaked in warm water and teased using a pair of forceps and a

Table 1. List of caves from which pellets were collected in Ara'r region
1. táblázat A bagolyköpetek gyűjtési pontjainak listája az Ara'r régióban

No.	**Cave name**	**No. of pellets collected**	**Coordinates of localities**	
			N	**E**
1	Luga Al Dahal	20	41.44351	29.41716
2	Sanar Al Ra'an 1	42	41.44358	29.41697
3	Sanar Al Ra'an 2	30	41.44358	29.41697
4	Al Boom	20	42.1773	29.45498
5	Al Boom Sanar Al Ra'an	64	41.47038	29.41297
6	Thraia' Al Ra'an	6	41.24977	23.57355
7	Al Habaka south	4	42.18391	29.45453
8	Al Fohood	8	42.27269	29.47229
9	Al Akrab	10	42.18535	29.46127
10	Al Habaka west 1	1	42.13951	29.50143
11	Al Habaka west 2	6	42.12763	29.52148
12	Um Al Hammam	2	41.2844	29.52281
13	Sanar Al Ra'an 3	29	41.44372	29.41702
14	Sanar Al Ra'an 4	44	41.42288	29.4156
15	Na'jan	5	42.0472	29.35767
16	Sanar Al Ra'an 5	14	41.48966	29.4102
17	Al Habaka west 3	2	42.12628	29.5018
18	Jal Al Thour	3	42.08812	30.01453
19	Al Markouz	2	44.230543	30.00126
20	Al Habaka north 2	4	42.21049	29.49322
21	Al Habaka north 1	5	42.16095	29.57066
22	Al Habaka north 3	3	42.16581	29.57621
23	Mehthem Al Raka'a	2	42.34089	29.42472
24	Al Habaka north 4	1	42.17764	29.56311
25	Jal Al Mazwa	23	42.64605	29.785189

needle to separate prey remains for identification. Recovered items from each pellet were placed in a Petri dish. For each species, lower and upper jaws were cleaned and preserved. Prey remains were identified using distinctive morphological characteristics of body and/or skull parts (e.g. mouthparts, mandibles, dentaries) described based on previous collections from the region (Amr 2012) as well as Iyad Nader small mammals collection kept at the National Center for Wildlife (NCW). Arthropod remains were identified to the family level.

Diet composition was expressed by the Minimum Number of Individuals (MNI) and percentage (number of individuals divided by the total number of prey individuals). The total number of prey individuals in a pellet was determined using the total number of mandibles and/or skulls found. In addition, average prey biomass (body weight in grams)

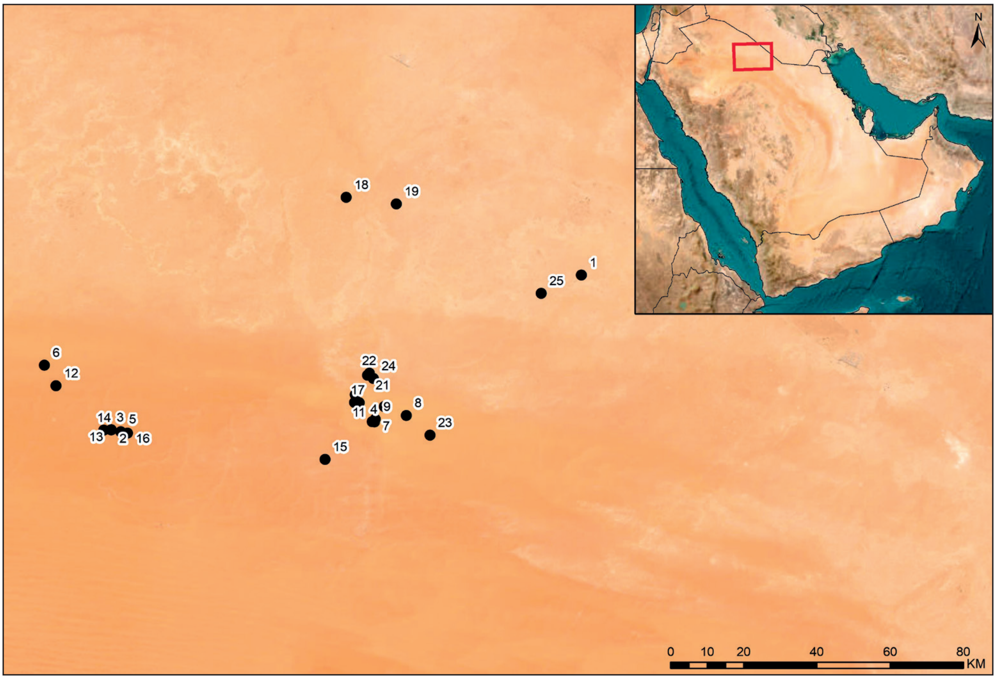

Figure 1. Map of Saudi Arabia showing locations of the investigated underground caves (NCW)
1. ábra Szaúd-Arábia térképe a vizsgált földalatti üregek helyével (NCW)

Figure 2. Underground caves in Ara'r region
2. ábra Földalatti üregek az Ara'r régióban

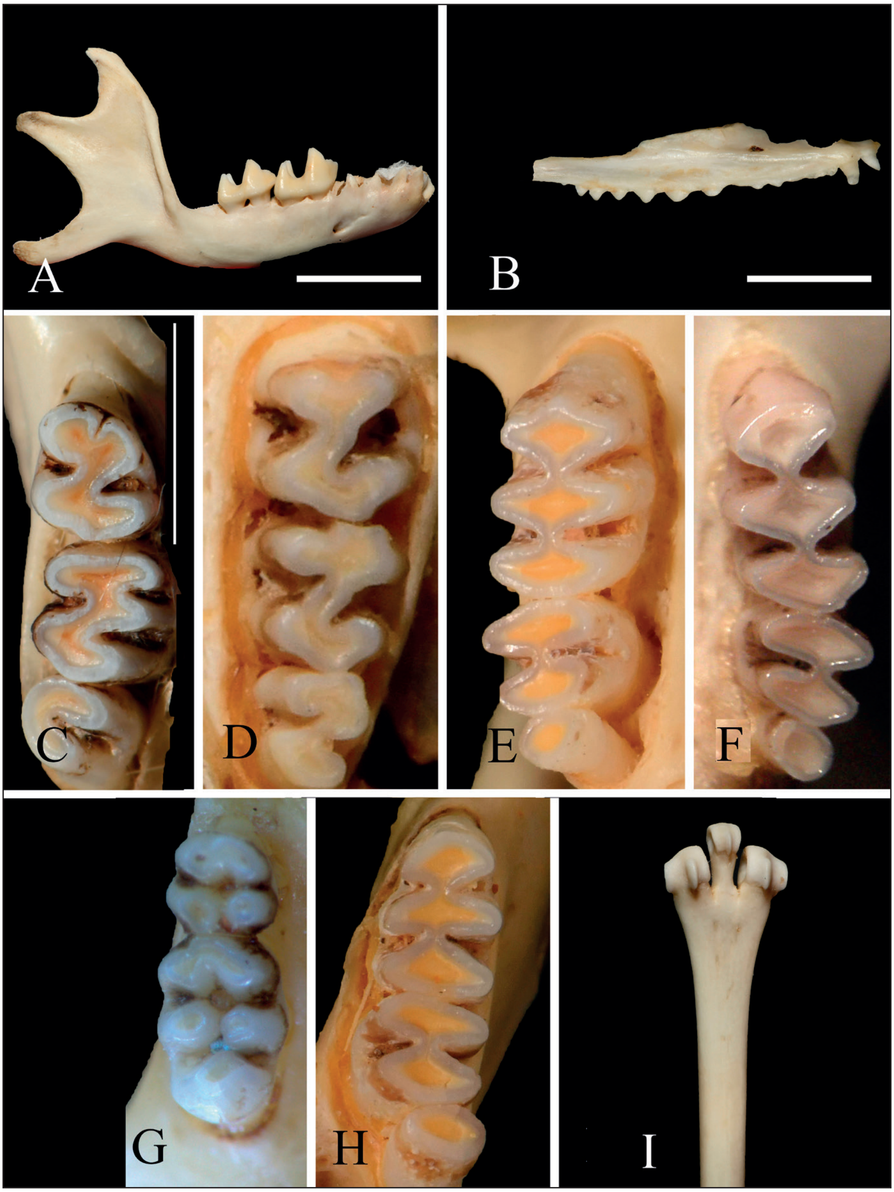

Figure 3. Bone remains recovered from the Pharaoh Eagle-Owl pellets. A. mandible of *Paraechinus aethiopicus* (Scale bar 1 cm). B. *maxilla* of *Trapellus agnetae*. C. *maxilla* of *Scarturus euphratica* (Scale bar 5 mm). D. *maxilla* of *Jaculus loftusi.* E. upper maxillary teeth of *Meriones libycus.* F. *maxilla* of *Meriones crassus.* G. *maxilla* of *Gerbillus nanus.* H. *maxilla* of *Gerbillus dasyurus.* I. *metatarsus* of *Jaculus loftusi*

3. ábra Az egyiptomi uhu köpeteiből meghatározott csontmaradványok. A. *Paraechinus aethiopicus mandibula* (a fehér csík 1 cm-t jelöl). B. *Trapellus agnetae maxilla*. C. *Scarturus euphratica* állcsonti fogak (a fehér csík 5 mm-t jelöl). D. *Jaculus loftusi* állcsonti fogak. E. *Meriones libycus* állcsonti fogak. F. *Meriones crassus* állcsonti fogak. G. *Gerbillus nanus* állcsonti fogak. H. *Gerbillus dasyurus* állcsonti fogak. I. *Jaculus loftusi metatarsus* was estimated using previous collections and reports (e.g. Harrison & Bates 1991, Amr 2012). Spearman's rank correlation test (Microsoft Excel for Mac, version 16.66.1) between the prey body weight and its percentage in the rodent data was used to assess for weight-dependent predation.

Results

Pellets were cylindrical in shape with an average length of 52.74±11.64 mm (mean±SD) and 28.52±4.79 mm in width. *Figure 3* shows the morphology of bone remains for the recovered vertebrates from owl pellets. Both *Scarturus euphratica* and *Jaculus loftusi* have a very distinctive *metatarsus (Figure 3I)*.

A total of 635 individuals were recovered from all studied pellets, representing nine mammals, birds, at least two species of reptiles and arthropods *(Table 2)*. Small mammals constituted the highest number of consumed prey (n=481, 75.75%), followed by arthropods (n=127, 20%), birds (n=19, 2.9%) and reptiles (n=8, 1.26%). The Libyan Jird, *Meriones libycus*, was the most consumed rodent (26.46%) followed by Sundevall's Jird, *Meriones crassus* (20.47%), while the least were the Baluchistan Gerbil, *Gerbillus nanus*, and Wagner's Gerbil, *Gerbillus dasyures.* The percentage of prey item in the pellets correlated

Table 2. Food composition of the Pharaoh Eagle-Owl, *Bubo ascalaphus,* from Ara'r region in terms of number of prey items and percentages

2. táblázat Az egyiptomi uhu *(Bubo ascalaphus)* Ara'r régióban gyűjtött köpeteiben azonosított zsákmányelemek száma és biomassza értéke, illetve ezek százalékos megoszlása

Species	No. of individuals (MNI)	%	Individual weight in grams	Biomass in grams	Biomass %
Jaculus loftusi	62	9.76	57	3,534	10.54
Scarturus euphratica	24	3.78	52	1,248	3.73
Gerbillus sp.	41	6.46	25	1,025	3.05
Gerbillus nanus	6	0.94	26	156	0.46
Gerbillus dasyurus	4	0.63	25	100	0.29
Meriones crassus	130	20.47	80	10,400	31.02
Meriones libycus	168	26.46	70	11,760	35.08
Paraechinus aethiopicus	12	1.89	280	3,360	10.03
Unidentified rodent	34	5.35	30	1,020	3.04
Birds	19	2.99	25	475	1.44
Reptiles	8	1.26	15	120	0.35
Scorpions	42	6.61	5	210	0.63
Solifugae	20	3.15	2	40	0.12
Tenebrionidae	55	8.66	1	55	0.16
Scarabaeidae	10	1.57	2	20	0.06
	635	**100**		**33,523**	**100**

Table 3. Number and composition of prey items per pellet consumed by the Pharaoh Eagle-Owl, *Bubo ascalaphus*

3. táblázat Az egyiptomi uhu *(Bubo ascalaphus)* által köpetenként elfogyasztott zsákmányállatok száma és összetétele

No. of prey items	Frequency	Prey items recovered from pellets
1	46	1 *M. crassus*
	44	1 *M. lybicus*
	19	1 *J. loftusi*
	4	1 *S. euphratica*
	5	1 *P. aethiopicus*
	5	1 *Gerbillus* sp.
	17	1 Unidentified rodent
	4	1 Bird
	2	1 Lizard
	3	1 Tenebrionid
	1	1 Scorpion
	1	1 Solifugid
2	20	2 *M. crassus*
	16	2 *M. lybicus*
	5	2 *J. loftusi*
	1	2 *S. euphratica*
	3	1 *M. crassus*, 1 *Gerbillus* sp.
	1	1 *M. crassus*, 1 *S. euphratica*
	8	1 *M. crassus*, 1 *J. loftusi*
	7	1 *M. crassus*, 1 scorpion
	3	1 *M. crassus*, 1 solifugid
	5	1 *M. crassus*, 1 tenebrionid
	1	1 *M. crassus*, 1 bird
	5	1 *M. lybicus*, 1 *J. loftusi*
	3	1 *M. lybicus*, 1 *G. dasyurus*
	2	1 *M. lybicus*, 1 *G. nanus*
	1	1 *M. lybicus*, 1 *S. euphratica*
	4	1 *M. lybicus*, 1 *P. aethiopicus*
	2	1 *M. lybicus*, 1 bird
	2	1 *M. lybicus*,1 lizard
	3	1 *M. lybicus*, 1 scorpion
	6	1 *M. lybicus*, 1 tenebrionid
	1	1 *Gerbillus* sp., l bird
	1	1 *Gerbillus* sp., 1 scorpion
	2	1 *J. loftusi*, 1 *S. euphratica*
	1	1 *J. loftusi*, 1 *P. aethiopicus*
	1	1 *J. loftusi*,1 *Gerbillus* sp.
	2	1 *J. loftusi*, 1 tenebrionid
	1	1 *J. loftusi*, 1 solifugid
	1	1 *S. euphratica*, 1 Unidentified rodent
	2	1 *S. euphratica*, 1 bird
	1	1 *G. nanus*, 1 Unidentified rodent
	1	1 *P. aethiopicus*, 1 scorpion
	5	1 Unidentified rodent, 1 tenebrionid
	3	1 Unidentified rodent, 1 scorpion

No. of prey items	Frequency	Prey items recovered from pellets
3	1	3 *Gerbillus* sp.
	1	3 *M. lybicus*
	2	2 *M. crassus*, 1 *J. loftusi*
	1	2 *M. crassus*, 1 *Gerbillus* sp.
	1	2 *M. crassus*, 1 *M. lybicus*
	1	2 *M. crassus*, 1 *G. dasyurus*
	1	2 *M. crassus*, 1 scorpion
	1	2 *M. crassus*, 1 solifugid
	1	2 *M. crassus*, 1 tenebrionid
	1	2 *M. lybicus*, 1 *J. loftusi*
	1	2 *M. lybicus*, 1 *S. euphratica*
	1	2 *M. lybicus*, 1 *G. nanus* 1
	1	2 *M. lybicus*, 1 tenebrionid
	1	2 *M. lybicus*, 1 bird
	1	2 *M. lybicus*, 1 scorpion
	1	2 *M. lybicus*, 1 *Gerbillus* sp.
	1	2 *G. nanus* 1, *M. lybicus*
	1	2 *Gerbillus* sp., 1 *M. crassus*
	1	2 *J. loftusi*, 1 bird
	1	1 *M. lybicus*, 1 *J. loftusi*, 1 tenebrionid
	1	1 *M. lybicus*, 1 *J. loftusi*, l bird
	1	1 *M. lybicus*, 1 lizard, 1 tenebrionid
	2	1 *Gerbillus* sp., 2 scorpions
	1	1 *M. crassus*, 1 *J. loftusi*, 1 tenebrionid
	1	1 *M. crassus*, 1 *J. loftusi*, 1 solifugid
	2	1 *M. crassus*, 1 scorpion, 1 tenebrionid
	1	1 *M. lybicus*, 1 *S. euphratica*, 1 lizard
	1	1 *M. lybicus*, 1 *M. crassus*, 1 tenebrionid
	1	1 *M. lybicus*, 2 scorpions (1)
	1	1 *M. lybicus*, 1 *J. loftusi*, 1 bird
	1	1 *M. lybicus*, 1 tenebrionid, 1 scorpion
	1	1 *G. nanus*, 1 tenebrionid, 1 scorpion
	1	1 *M. lybicus*, 1 *Gerbillus* sp., 1 tenebrionid
	2	1 *J. loftusi*, 1 *G. dasyurus*, 1 solifugid
	1	1 *J. loftusi*, 1 *M. crassus*, 1 tenebrionid
	1	1 *J. loftusi*, 1 *Gerbillus* sp., 1 solifugid
	1	1 *J. loftusi*, 1 tenebrionid, 1 scorpion
	1	1 *S. euphratica*, 1 tenebrionid, 1 scorpion
	2	1 *Gerbillus* sp., 1 tenebrionid, 1 scorpion
	1	1 Unidentified rodent, 2 scorpions
	2	1 Unidentified rodent, 1 tenebrionid, 1 scorpion

No. of prey items	Frequency	Prey items recovered from pellets
4	1	4 *Gerbillus* sp.
	1	3 *J. loftusi*, 1 *S. euphratica*
	1	2 *M. lybicus*, 1 *J. loftusi* 1, *P. aethiopicus*
	1	2 *M. lybicus*, 1 tenebrionid, 1 Unidentified roden
	1	2 *M. crassus*, 2 *Gerbillus* sp.
	1	2 *M. lybicus*, 1 *Gerbillus* sp., 1 scorpion
	1	2 *M. lybicus*, 1 tenebrionid, 1 scorpion
5	1	3 *M. lybicus*, 2 solifugid
	1	2 *M. lybicus*, 2 *Gerbillus* sp., 1 *J. loftusi*
	1	2 *M. lybicus*, l bird, 2 tenebrionid
	1	2 *M. lybicus*, l bird, 1 solifugid, 1 undetermined rodent
	1	2 *G. dasyurus*, 1 *M. lybicus*, 1 *J. loftusi*, 1 solifugid
	1	2 *M. lybicus*, 1 *P. aethiopicus*, 1 lizard, 1 tenebrionid
	1	1 *M. crassus*, 3 scorpions, 1 tenebrionid
6	1	3 *M. lybicus*, 1 solifugid, 1 tenebrionid, 1 undetermined rodent
7	1	2 *M. crassus*, 1 lizard, 1 tenebrionid, 3 solifugid
	1	3 *M. crassus*, 1 *S. euphratica*, 1 *P. aethiopicus*, 1 tenebrionid, 1 scorpion
8	1	3 *M. crassus*, 2 *Gerbillus* sp., 1 *P. aethiopicus*, 1 bird, 1 tenebrionid
9	1	4 *M. crassus*, 2 *Gerbillus* sp., 1 *P. aethiopicus*, 1 *J. loftusi*, 1 tenebrionid
10	1	3 *M. lybicus*, 2 tenebrionid, 2 scorpions, 1 bird, 1 *J. loftusi*, 1 *S. euphratica*

significantly with its average body weight (Spearman's rank correlation rs=0.72, P<0.05), suggesting significant selection by the Pharaohs Eagle-Owls for larger prey.

Number of individuals per pellet ranged from 1 to 10 (1.9±54.46). Most pellets contained one prey item (n=150), while pellets with 10 items were the least (n=1). *Table 3* shows the frequency of each category of prey items per pellet.

The average biomass of prey per pellet was 59.4 g, ranging between 10–270 g.

Scorpions represented at least three species, *Androctonus crassicauda*, *Compsbuthus* sp. and *Scorpio* sp. The first is characterized by its heavy tail granulation, the second by its thin metasomal segments, while the third can be recognized by its lobster-like pedipalps. At least two species of reptiles were found, *Ptyodactylus hasselquistii* and *Trapellus agnetae*. Only two species of tenebrionids and scarabids were identified to the species level, *Prionotheca coronata* and *Scarabaeus sacer,* respectively.

Discussion

Owl pellets are excellent indicators for the abundance of rodent species in their feeding grounds. This helps to understand species richness and abundance especially for desert rodents (Heisler *et al.* 2016). The proportions of the small mammal's species in owl pellets demonstrate the abundance for these species in their habitat (Andrade *et al.* 2016).

In the study site, both *M. crassus* and *M. libycus* were the most abundant, followed by species of the genus *Gerbillus*. This study shows clearly that the Arabian Jerboa, *J. loftusi* is more common than the Euphrates Jerboa, *S. euphratica*. Abi-Said *et al.* (2020) found that both *M. crassus* and *M. libycus* were the prey items most consumed by *B. ascalaphus* in Eastern Saudi Arabia. Similar findings were reported by Bauer (1988) on the feeding behavior possibly of the Barn Owl, *Tyto alba,* in the Summan Plateau. He also indicated that the Euphrates Jerboa was more common in owl pellets than the Arabian Jerboa.

The Libyan Jird, *M. libycus,* and Sundevall's Jird, *M. crassus,* were the prey items most consumed by *B. ascalaphus*. Both are common species that exist together across the deserts of the Arabian Peninsula and the surrounding arid region of Jordan and Iraq (Harrison & Bates 1991, Amr 2012). Moreover, *S. euphratica* is considered rare in Saudi Arabia with distribution limited to the northeastern part of the country, compared to the more common *J. loftusi* (Harrison & Bates 1991). The Pharaohs Eagle-Owl is the largest owl in the area, and the results suggest that it has nocturnal, opportunistic feeding habits, it prefers larger, more profitable rodent prey items (*M. crassus* and *M. libycus*), but smaller (*Gerbillus* sp.) are also hunted. Rifai *et al.* (2000) and Obuch (2018) recorded similar prey items in the diet of *B. ascalaphus* in the Eastern Desert of Jordan including *M. crassus, M. libycus* and *J. loftusi*. Four mammals (*M. crassus*, *J. loftusi, Gerbillus* sp., *Lepus capensis*), one bird *(Merops persicus)*, 1 reptile, and scorpions were recovered from *B. ascalaphus* in Qatar (Mohedano *et al.* 2014). This indicates that this owl is dependent on relatively large-sized murids as *M. crassus* and *M. libycus* as main food items, to meet its bioenergetic demand. In contrast, the feeding behavior of this owl in wetlands in the close proximity of urban areas showed a distinctive pattern. It fed mainly on the Lesser White-toothed Shrew, *Crocidura suaveolens*, and the House Mouse, *Mus musculus* in the Azraq wetland in Jordan (Amr *et al.* 1997). In the urban Hurghada area in Egypt, 78.05% of its diet consisted of commensal rodents: *Rattus norvegicus* and *M. musculus* (Sándor & Moldován 2010). Rodents (i.e. *M. libycus, Meriones shawi,* and *M. musculus*) were the most consumed prey items in Algeria (Biche *et al.* 2001, Benamor *et al.* 2021). Smaller and diurnal owls, such as Little Owl, *Athene noctua*, fed mainly on reptiles (35.5%) in the Eastern Desert of Jordan (Al-Melhim *et al.* 1997).

Obuch (2014) listed 56 mammal and more than 100 species of birds, in addition to amphibians, reptiles, fishes and invertebrates as part of the Eurasian Eagle-Owl, *Bubo bubo* diet across different habitats in Iran. This suggests that this species is highly opportunistic and feeds on a variety of prey items as they occur in its habitat.

Further studies on the diet composition of other owl species in Saudi Arabia should be conducted to better understand their feeding behavior. Underground caves in the desert of eastern Arabia represent valuable refuge sites for the terrestrial wildlife that may be used for nesting and/or shelter in the open desert habitats, these sites should be mapped and monitored to better understand their importance as subterranean habitats (Culver & Pipan 2019).

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Food habits of Rufous-legged Owl in a protected area of south-central Chile affected by mixed wildfire

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Abstract The diet of Rufous-legged Owl, *Strix rufipes,* a small raptor present in an Andean protected area, is described here. During the fall of 2017, 44 pellets were collected in the study area, being subsequently analyzed. The occurrence of small mammal prey items in pellets was compared with capture frequencies with live-trapping through Sherman traps. Regarding occurrence frequencies in the diet, arthropods were the most frequent (49.34%), followed by mammals (39.31%), birds (7.86%) and reptiles (3.37%). However, in terms of biomass, mammals had the highest biomass contribution. The observed frequency of consumed preys showed a random pattern, according to the captures of small mammals obtained with Sherman traps. The role of wildfire in the composition of prey in the observed trophic spectrum of these forest owls is also discussed.

Keywords: biomass, disturbances, selectivity, trophic behavior, rodents

Összefoglalás A tanulmányban az Andok egyik védett területén élő kistermetű ragadozó madár, a vöröslábú bagoly *(Strix rufipes)* táplálékbázisát ismertetjük. 2017 őszén 44 köpetet gyűjtöttek a vizsgált területen. Az ezekben talált kisemlős zsákmányállatok előfordulását összehasonlítottuk a Sherman-csapdák általi élőcsapdás fogási gyakorisággal. A táplálék előfordulási gyakoriságát tekintve az ízeltlábúak voltak a leggyakoribbak (49,34%), őket követték az emlősök (39,31%), a madarak (7,86%) és a hüllők (3,37%). A biomassza vonatkozásában az emlősöknek volt a legnagyobb szerepe. Az elfogyasztott zsákmányállatok gyakorisága a Sherman-csapdákkal befogott kisemlősöknek megfelelően véletlenszerű mintázatot mutatott. Az erdőtüzek szerepe a zsákmány összetételében ezen erdei baglyok megfigyelt trofikus spektrumában szintén megvitatásra került.

Kulcsszavak: biomassza, zavarás, szelektivitás, táplálkozási viselkedés, rágcsálók

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Introduction

The Rufous-legged Owl (*Strix rufipes* King, 1828) is a nocturnal forest raptor of the Strigidae family, with a distribution in Chile that ranges between the Mediterranean climate zone and the Patagonian Tierra del Fuego, from 32° S to 53° S (Pavez 2004). This raptor is a habitat specialist inhabiting mainly mature native forests and secondary forest formations (Ibarra *et al.* 2012). This species consumes predominantly small mammals and birds, with variations according to the local distribution of their prey (Martínez 1993, Figueroa *et al.* 2006, Alvarado *et al.* 2007), which are associated mainly with native forests (Murúa 1996, Rozzi *et al.* 1996). However, the progressive change in land use in southern Chile is noteworthy, mainly due to production activities (Echeverría *et al.* 2008), which can compromise its occurrence on a local scale, a fact that has been reported for raptors from other latitudes (Rodríguez-Estrella *et al.* 1998).

Wildfires are the main type of disturbance worldwide (Whelan 1995), which are characterized by their high combustion of plant biomass (Bond & Keeley 2005). These disturbances have the potential to reconfigure the structure of ecosystems, and also affect the persistence of many animal taxa (Whelan 1995, DellaSalla & Hanson 2015). In southern-central Chile, there is a knowledge gap regarding responses of predators in environments disturbed by fire, which is becoming increasingly important due to the high frequency of fires that occur in Chilean territories (Úbeda & Sarricolea 2016). In this sense, reports showed that fire affects the structure of rodent and arthropod assemblages (Zúñiga *et al.* 2021, Zúñiga *et al*. 2022), affecting prey availability at the local scale. The objective of this study is to document the diet of Rufous-legged Owl in a protected area in Southern-central Chile affected by a wildfire.

Methods

The China Muerta National Reserve (38°42’00”S – 71° 26’00”W) is a governmental protected area in southern-central Chile. This reserve encompasses 11168 ha, and the vegetation is composed by araucaria *(Araucaria araucana)* trees in association with *Nothofagus* forests (CONAF 2014). In 2015, this reserve suffered a fire that affected 3700 ha and different degrees of severity (CONAF 2015).

During March-May 2017 (fall in the southern hemisphere), trails of this protected area were travelled in search of pellets. Pellets recognition was based on morphological criteria (Muñoz-Pedreros & Rau 2019), and this identification was reinforced through auditory records of the species in the collection site (Egli 2006). Subsequently, pellets were collected in paper bags and stored for further processing. In laboratory, pellets were manually shredded to obtain undigested prey remains, which were visualized using an electronic magnifying glass. These were identified through keys associated with hair, feathers and skulls (Chehébar & Martin 1989, Pearson 1995), as well as reference collections. The analysis of the diet was carried out based on the percentage frequency of occurrence of different prey in relation to the total number observed prey (Rau 2009). Dietary diversity was calculated through the

Levins index (β; Levins 1968). This index fluctuates between 0 and n, where n is the number of prey categories obtained. The standard deviation of this index was calculated through the jackknife procedure (Jaksić & Medel 1987).

To determine the effect of prey biomass on the dietary spectrum of these owls, the geometric mean of the respective weights of different prey was calculated (Jaksić & Braker 1983). Simultaneously, the method of trophic isoclines was used (Kruuk & DeKock 1980), establishing a relationship between the biomass consumed and the occurrence frequency of prey, and thus their importance in the trophic spectrum (Rau 2000). Biomass of the registered prey were obtained from Muñoz-Pedreros and Gil (2009) for rodents, and Norambuena and Riquelme (2014) for birds.

To determine the trophic selectivity of *S. rufipes* in relation to the availability of prey in the environment, we used small mammal capture frequency values obtained as part of a previous study in the same study area (Zúñiga *et al.* 2021). In this way, the expected proportions of consumption of rodents were obtained through their capture rate in Sherman traps. Comparisons with the proportion of prey consumed by *S. rufipes* were made with a goodness-of-fit tests, and Bonferroni confidence intervals (Byers *et al.* 1984, Sokal & Rohlf 1995). These analyses were performed with HABUSE 4.0 program (Zúñiga *et al.* 2020).

Results

A total of 44 pellets were analyzed, in which a total of 99 prey items were identified, distributed in five trophic categories *(Table 1)*. Of these, arthropods showed the highest frequency, with a representation close to 50%. Next, cricetid rodents were the second most consumed group, with four species. Birds were group found with intermediate frequency, while reptiles were the least frequent. When comparing the frequencies of the consumption of rodents with respect to those obtained by trapping, it was found that *S. rufipes* consumed native rodents with a frequency different from that expected at random (χ^2=11.65, P<0.001). However, it was subsequently demostrated that all the consumption frequencies of all the species were within the Bonferroni confidence intervals *(Table 2)*, which denies any type of selectivity.

Table 1. Frequency and percentage of prey consumption by *Strix rufipes* in the study area

1. táblázat A vöröslábú bagoly *(Strix rufipes)* elfogyasztott zsákmányainak gyakoriságai és százalékos arányuk a vizsgálati területen

Prey item	Frequency (Percentage)
MAMMALS	
Rodentia	
Cricetidae	
Abrothrix longipilis	10 (11.23)
Abtothrix olivaceus	12 (13.48)
Irenomys tarsalis	4 (4.49)
Olygoryzomys longicaudatus	9 (10.11)
BIRDS	
Unidentified birds	7 (7.86)
REPTILES	
Liolaemus sp.	3 (3.37)
ARTHROPODS	
Unidentified insects	44 (49.34)

Table 2. Comparison of prey frequencies of *S. rufipes* in relation to observation by Sherman traps
2. táblázat A Sherman-csapdák által fogott zsákmányfajok és a vöröslábú bagoly által elfogyasztott zsákmány gyakoriságának összehasonlító táblázata

Species	Consumption frequency (observed/expected)	Bonferroni's confidence intervals
Abrothrix longipilis	(0.285/0.530)	(0.079–0.421)
Abrothrix olivaceus	(0.342/0.269)	(0.119–0.481)
Irenomys tarsalis	(0.114/0.040)	(0.060–0.390)
Olygoryzomys longicaudatus	(0.252/0.158)	(0.060–0.390)

The observed dietary diversity was β=3.39±5.78. In relation to biomass, a geometric mean of 5.59 grams was calculated. In the representation of the trophic isoclines, it was obtained that the three most abundant rodents and birds were found in the intermediate segments (between isoclines of 5% and 20%) *(Figure 1)*, while *Irenomys tarsalis* and arthropods were located in the lower isocline, between 1% and 5%. The remaining prey had a minimum representation, under the 1% isocline.

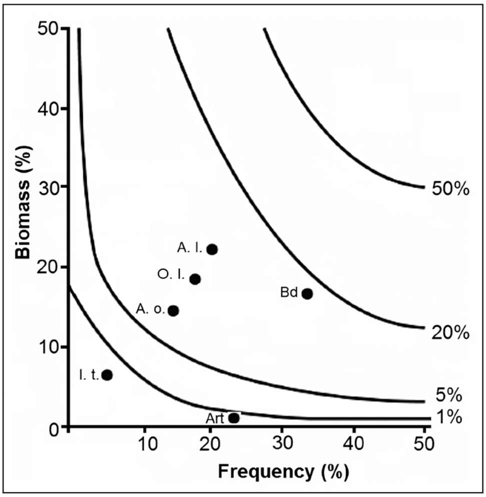

Figure 1. Trophic isoclines for Rufous-legged Owl in the study area. A. l.: *Abrothrix longipilis*; A. o.: *Abrothrix olivaceus*; I. t.: *Irenomys tarsalis*; O. l.: *Oligoryzomys longicaudatus*; Art: Arthropods; Bd.: Birds

1. ábra A vöröslábú bagoly táplálkozási izoklin vonalai a vizsgálati területen. A. l.: *Abrothrix longipilis*; A. o.: *Abrothrix olivaceus*; I. t.: *Irenomys tarsalis*; O. l.: *Oligoryzomys longicaudatus*; Art: Rovarok; Bd.: Madarak

Discussion

The observed dietary spectrum is partially in line with that reported in south-central Chile (Martínez 1993, Figueroa *et al.* 2006), where arthropods represent the majority of the trophic spectrum in terms of frequency, but rodents occupy the largest proportion in terms of biomass. The high value of the standard deviation in the dietary diversity index arises due to the proportion of arthropods consumed, which should be viewed with caution due to its low contribution in biomass. The low taxonomic resolution in this group is of special importance, due to the spatial differentiation that various species occupy (Peña 1987). This fact, added to the effect of fire on the composition of arthropods observed (Zúñiga *et al.* 2022), makes the observed picture to be viewed with caution. It is important to highlight that the low diversity of rodents would be a consequence of the burned condition of the study area, which restricted the possibility of detecting more species (Zúñiga *et al.* 2021). In the same sense, the absence of capture selectivity towards some rodent would be explained by their low abundances, although that season of sampling (fall) was in the period of highest abundance, according to their reproductive patterns (González & Murúa 1983). This fact suggests that this raptor would be in a suboptimal condition in terms of food availability, according to their energetic requirements (Graber 1962), forcing *S. rufipes* to migrate to patches with greater availability of small mammal prey species, which has been reported for species in other latitudes (Körpimaki & Hongell 1986). This situation is confirmed by the fact that this raptor was not sighted the following year of monitoring (Zúñiga, personal observation), as well as a decline in prey populations was reported (Zúñiga *et al.* 2021). However, this hypothesis has to be tested in the study area.

As conclusion, it was observed that the diet of *S. rufipes* was comprised mainly of arthropods, while vertebrates, and specifically rodents, had the highest representation in terms of biomass. It is especially important to monitor the diet of this raptor in the study area in the long term in order to assess how it evolves in a context of recovery from the fire, and therefore, if there is a correlation with the availability of prey.

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Scavenging by young tortoises (*Testudo* sp.) could induce their predation by the Eurasian Eagle-Owl *(Bubo bubo)*

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Abstract Eating owl pellets by non-predator vertebrates is a rare and difficult-to-prove food chain relationship. In this paper, I reported the first record of a Spur-thighed Tortoise *(Testudo graeca)* eating a Eurasian Eagle-Owl *(Bubo bubo)* pellet with remains of a right Wood Pigeon *(Columba palumbus)* wing. Scavenging of food remains around owl nests by young tortoises may possibly explain the few cases of tortoise-eating Eurasian Eagle-Owls.

Keywords: diet, owl pellet, facultative scavenging, *Testudo graeca*

Összefoglalás A nem ragadozó gerincesek bagolyköpet fogyasztása egy ritka és nehezen bizonyítható kapcsolat a táplálékhálózatokban. Jelen munkában elsőként számolok be a mór teknős *(Testudo graeca)* bagolyköpet fogyasztásának egy esetéről, amikor a teknős uhu *(Bubo bubo)* köpetben található, örvös galamb *(Columba palumbus)* jobb szárnyának maradványát ette. A bagolyfészkek körüli táplálékmaradványok fiatal teknősök általi fogyasztása lehetséges magyarázatot nyújt az uhu teknős predációjának néhány ismert esetére.

Kulcsszavak: étrend, bagolyköpet, fakultatív dögevés, *Testudo graeca*

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The Eurasian Eagle-Owl *(Bubo bubo)* is usually a nocturnal ambush hunter in a wide variety of habitats preferring more open landscapes (Penteriani & Delgado 2019, Scherzinger & Mebs 2020). This largest owl predates opportunistically primarily mammals and birds with a preferred mass between 200 and 1,900 g (Glutz von Blotzheim & Bauer 1994). As a generalist, the Eurasian Eagle-Owl also includes many other vertebrates and larger invertebrates in its varied diet especially when the main local prey is scarce (Glutz von Blotzheim & Bauer 1994, Penteriani & Delgado 2019).

Tortoises (*Testudo* sp.) are one of its rarest prey in a sympatric distribution with this predator around the Mediterranean and in Asia Minor. Young tortoises with a not yet well ossified shell are accessible to the Eurasian Eagle-Owl *(Table 1)* (Tzankov & Milchev 2014). The robust shell of adult tortoises is reliable protection from this predator. The only adult tortoise in the diet of this owl (Bayle & Prior 2006) was most likely to be carrion (review Allen *et al*. 2019). The very low number of young tortoises in the hunting territory of the Eurasian Eagle-Owl could be an explanation for their rarity in the diet of this opportunistic predator: Spur-thighed (Common) Tortoise *(Testudo graeca)* is listed as vulnerable and

Table 1. Tortoises (*Testudo* sp.) in Eurasian Eagle-Owl *(Bubo bubo)* diets
1. táblázat Teknősök (*Testudo* sp.) az uhu *(Bubo bubo)* táplálékában

Tortoise number	Total prey number	% by prey number	Country	Reference
two young *Testudo* sp.	630	0.3	northeastern Greece	Papageorgiou *et al*. (1993)
one *Testudo* sp.	3,004	0.03	eastern Turkey	Obuch (1994)
an adult *Testudo* sp.	86	1.2	Lebanon	Bayle & Prior (2006)
an about 6–7 years old *Testudo graeca*	62,314	0.002	southeastern Bulgaria	Tzankov & Milchev (2014) Milchev & Georgiev (2019)
two young *Testudo graeca*	9,461	0.02	Israel	Hadad *et al*. (2022)

Hermann's Tortoise *(Testudo hermanni)* as near threatened, respectively (IUCN 2023). However, tortoises were not found, for example, in the Bulgarian owl's diet, even with their higher numbers in the 20th century (Tzankov & Milchev 2014), when tortoises were the main prey of the Golden Eagle *(Aquila chrysaetos)*, another opportunistic raptor in the area (Milchev 2022). The Eurasian Eagle-Owl appears to ignore young tortoises as potential prey, and some emergency situation underlies the rare cases of tortoise preying.

A young Spur-thighed Tortoise, 7–8 years old, was found with a piece of a Eurasian Eagle-Owl pellet in its' mouth of the rocky slope near the owl's nest in southeastern Bulgaria

Figure 1. A young Spur-thighed Tortoise *(Testudo graeca)* with a piece of a Eurasian Eagle-Owl *(Bubo bubo)* pellet in the mouth in SE Bulgaria
1. ábra Fiatal mór teknős *(Testudo graeca)*, szájában uhu *(Bubo bubo)* köpetének maradványával Dél-Bulgáriában

on 03.05.2023 *(Figure 1)*. The unswallowed piece included part of a right Wood Pigeon *(Columba palumbus)* wing: a distal ulna and radius and a proximal carpometacarpus. The tortoise could not break and swallow this hard and large group of bones. Nor could the tortoise gnaw through the strong tendons that connected the bones to the already swallowed part of the pellet. Separating the bones from the tendons to free the tortoise from its predicament did not induce vomiting.

Tortoises are mainly vegetarians, but animal food has been found in their diet: some invertebrates and carcasses of various vertebrates (Bertolero *et al*. 2011, Stojanov *et al*. 2011, Türkozan *et al*. 2023). Hermann's Tortoise ate pellets of Western Barn Owl *(Tyto alba)* and Yellow-legged Gull *(Larus michahellis)* (Bertolero 2015). Feeding on Eurasian Eagle-Owl pellet is new to the Spur-thighed Tortoise diet. But this case also shows a possibility to explaining the rare cases of fatality for young tortoises from conflict with this owl. Not only pellets, but also carcasses of prey are found around the Eurasian Eagle-Owl's nest during the breeding season (Glutz von Blotzheim & Bauer 1994, Penteriani & Delgado 2019). When the carcasses of prey are available for the tortoises to scavenge, this can provoke the attack of the owl guarding them. The only other prey of similar origin in Bulgarian Eurasian Eagle-Owl diets is probably the scolopendra (Arthropoda: *Scolopendra* sp.). Live scolopendras were found under prey items of this owl (author's observations), and 16 specimens (0.03%, n=62314 prey items) were reported in Eurasian Eagle-Owl pellets in SE Bulgaria (Milchev & Georgiev 2019).

The Eurasian Eagle-Owl and both tortoise species are endangered animals in the national red list (Golemanski 2015), and predation by this owl does not threaten the survival of the tortoise population. However, this study adds to the knowledge of facultative scavenging of non-predator species (Sebastián-González *et al*. 2023) and difficult-to-trace food chain relationships between threatened vertebrates.

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