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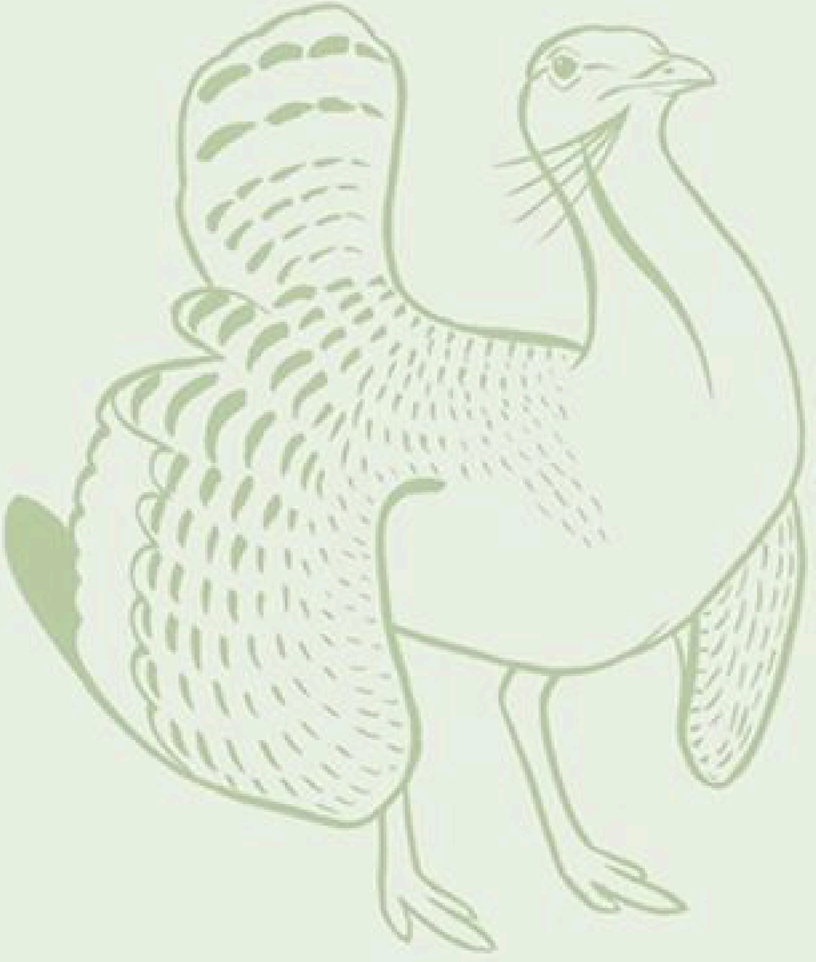

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Influence of seasonal change and anthropogenic activities on the avifauna composition in a seasonal wetland of India

Rupam Debnath[1] & Sandip Pal[2*]

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Abstract Seasonal wetlands harbour a mosaic of habitats that support a variety of niches for bird species. When seasonal change and anthropogenic activities are coupled with the landscape, the species richness and species composition are presumably influenced by such factors. This study aimed to evaluate avifauna diversity, to investigate feeding guilds, and to determine the impact of seasonality and tourism pressure as anthropogenic disturbance on the avian community of a wetland. Comprehensive surveys were conducted to gather all necessary data, followed by the application of analytical methods to assess the hypotheses formulated in the current research. A total of 61 bird species belonging to 14 orders have been recorded during this year-round study, where Passeriformes was the most dominant order with 27 bird species. The species richness was highest in winter, and five feeding guilds were identified. This study revealed a significant role of seasonality, and tourism pressure on avian species richness of Bortir Bil. The outcomes of the present study could serve as an important baseline to adopt sustainable and bird-friendly management plan for this seasonal wetland.

Keywords: anthropogenic activity, birds, Bortir Bil, seasonal wetland, tourism pressure

Összefoglalás Az évszakos mocsarak mozaikjai különböző élettereket kínálnak a madárfajok számára. Amikor az évszakos változások és az emberi tevékenységek összekapcsolódnak a táj sajátosságaival, a fajgazdagság és a fajösszetétel feltételezhetően ilyen tényezők által befolyásoltak. A tanulmány célja a madárvilág sokféleségének értékelése, a táplálkozási guildek vizsgálata, valamint a szezonalitás és a turizmus, mint kiemelkedő emberi tevékenység hatásának meghatározása a mocsárterület madárállományára. Összesen 61 madárfajt, amelyek 14 rendbe tartoznak, rögzítettek a vizsgálati időszak során, ahol az énekesmadarak rendje volt a legmeghatározóbb, 27 fajjal. A madárvilág fajgazdagsága télen volt a legmagasabb, és öt táplálkozási guildet azonosítottak. Ez a tanulmány a szezonalitás és a turizmus, mint antropogén tevékenység jelentős szerepét mutatta ki a Bortir Bil madaraira. A közölt eredmények fontos kiindulópontként szolgálhatnak fenntartható és madárbarát kezelési tervek kidolgozásához ezen évszakos mocsárvidék számára.

Kulcsszavak: antropogén tevékenység, madarak, Bortir Bil, szezonális vizes élőhelyek, turisztikai nyomás

[1] *Department of Zoology, West Bengal State University, Barasat, West Bengal, India*
[2] *Department of Zoology, Barrackpore Rastraguru Surendranath College, Barrackpore, West Bengal, India*
** corresponding author, e-mail: sandipzoologybrsc@gmail.com*

Introduction

Wetlands serve as a transitional zone between terrestrial and aquatic ecosystems, offering a rich source of biodiversity. They hold diverse utility for various life forms, but for birds, wetlands primarily serve as crucial habitats for breeding, nesting, and feeding purposes (Parchizadeh & Williams 2018). Avian fauna is an important component of different ecosystems and provides varied functional roles including predation, scavenging, pest control, seed dispersal, and nutrient deposition (Şekercioğlu *et al.* 2012). In India, about 60.45% of the terrestrial area is under agricultural cultivation (Yashmita-Ulman & Singh 2021). The agricultural landscape provides resources and habitats for many bird species (Sundar & Subramanya 2010) but hosts lower bird species richness than other habitats (Şekercioğlu *et al.* 2019). These landscapes are a mosaic of different land use and land cover features such as cultivated land, wetland, fallow land, grassland, scattered trees, orchards, or small forest patches (Katuwal *et al.* 2022). Birds often choose to live in a heterogeneous environment, and hence, the heterogeneity, created by landscape features, affects the bird community composition (Redlich *et al.* 2018). Along with other factors, seasonal changes and anthropogenic pressure in an agricultural field can also modify the avian community structure (Şekercioğlu *et al.* 2019).

The low-lying agricultural landscapes which get inundated every year during monsoon can be considered seasonal wetland habitats. These wetlands are beneficial for birds by providing enormous numbers of insects, crustaceans, shrimps, and molluscs as food (Ng'weno 1992, Mukhopadhyay & Mazumdar 2019). Bortir Bil is a seasonal wetland and a popular seasonal tourist spot in the state of West Bengal in India. Fishing is a major local activity along with boating. The tourists mostly visit the area during the monsoon and post-monsoon seasons when the agricultural lands get flooded with rainwater. These activities not only create anthropogenic disturbance to the bird populations but also pollute their habitats. Many birds of wetlands are threatened and declining faster than in other habitats (IUCN 2023a). A decline in avian diversity can cause a dramatic change in the integrity of species interactions and ecosystem functions as birds occupy higher trophic levels in the food chain. Hence, the identification of potential threats or factors that influence the avian community is the primary concern of conservation at present in order to maintain biodiversity.

Earlier studies conducted on wetlands have indicated that avian species richness tends to be higher in the wetlands of semi-urban areas and agricultural lands compared to wetlands of highly urbanized areas (Panda *et al.* 2021). Wetlands experiencing anthropogenic disturbances and agricultural practices exhibit reduced species diversity compared to more natural and less-altered areas (Datta 2011). Despite the rapid urbanization observed worldwide, which has had alarming consequences for various components of biodiversity, seasonal wetlands have received much less attention compared to natural wetlands (Mukhopadhyay & Mazumdar 2019). It is only in the past few decades that bird communities in human-dominated landscapes have garnered attention (Marzluff *et al.* 2001). This increased interest is primarily driven by growing concerns about the detrimental influence of anthropogenic effects on biodiversity and environmental processes (McKinney *et al.* 2011). However, there have been limited studies conducted on avian diversity in seasonal wetlands in India, the avian diversity of many such areas remains undocumented to date. The first ever scientific documentation on the avifauna of Bortir Bil was made by the authors of this study (Debnath & Pal 2022). An in-depth study of avifauna diversity and the factors affecting it in a seasonal wetland has not been done yet in India. Hence, the present study aimed to assess the diversity and richness of the avifauna in Bortir Bil, to explore the feeding guilds, and to assess whether seasonality, tourism pressure (as an anthropogenic disturbance) had any significant role on the avian community of this wetland.

Material and Methods

Study area

The present study was conducted in the Bortir Bil (22°47′ N and 88°26′ E) of Beraberia village in North 24 Parganas district, West Bengal, India *(Figure 1)*. This landscape consists of marshy lowlands with cultivated fields and most of the lands get flooded during the monsoon (Debnath & Pal 2022). The tropical climate of the study area consists of four seasons: summer (March to May), monsoon (June to August), post-monsoon (September to November), and winter (December to February). Weather varies from sunny to cloudy, and cloudy to rainy during summer and monsoon.

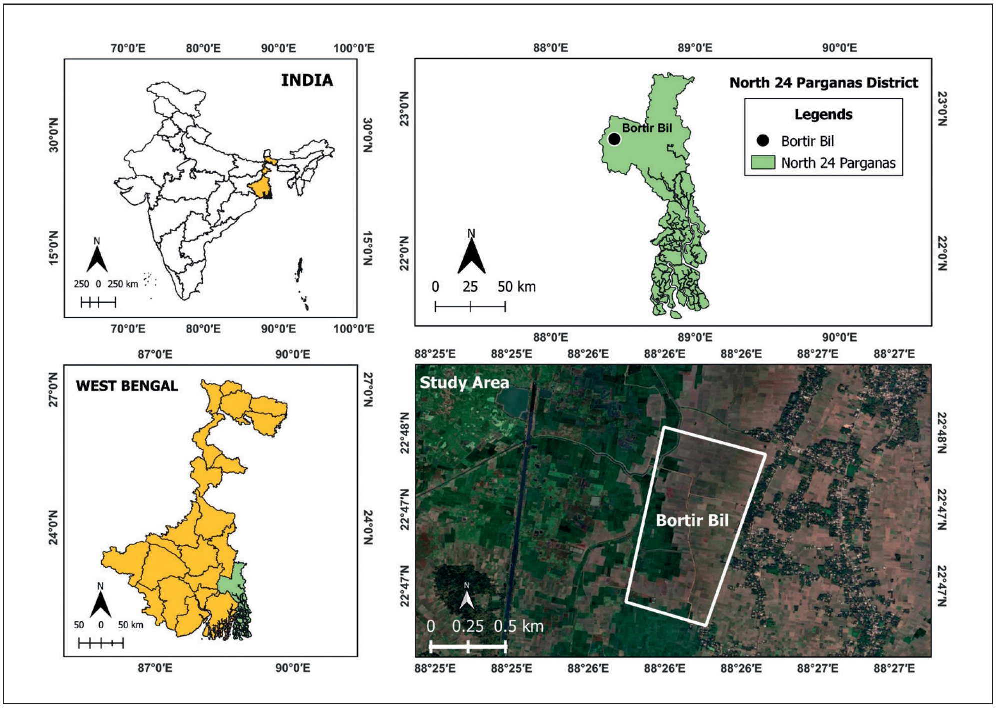

Figure 1. Map of the study area Bortir Bil, West Bengal, India
1. ábra A kutatási terület térképe: Bortir Bil, Nyugat-Bengál, India

Bird and tourist survey

Surveys were conducted from April 2021 to March 2022 for a year in the agricultural landscapes of the study area. The surveys were carried out at weekly intervals to document both birds and tourists. Field visits were carried out on foot only on the days with suitable weather conditions i.e. in the absence of rain, storm, or strong wind. The point-transect method was used to record the bird species (Sutherland 2006). A total of 10 points were marked on the study area at every 200 m distance to avoid the overlapping of bird countings. Bird species were recorded within a 100 m radius of each of these points in a 360° arc for 20 minutes. To ensure that the same birds would not be counted again, birds were counted at their point of the first detection. In addition, opportunistic observations of birds in the study area were also taken in order to prepare a comprehensive checklist of the avifauna of the study area (Mukhopadhyay & Mazumdar 2017). Birds were counted and recorded either with the unaided eye or using binoculars (Olympus 10×50 S), and photographs were taken, whenever possible, with a digital camera (Nikon COOLPIX P900) for documentation of the avifauna. In some cases, call notes of birds were also used to identify a particular bird along with locating and recording a photograph. The common names of the birds and their respective conservation status and global population trends (GPT: I- increasing, D- declining, S- stable, U- unknown) were assigned from Birds of the World (2024) and the IUCN Red List of species (IUCN 2023b), respectively. The standard method of Khan and Naher (2009) was applied to assign the local status to each recorded bird species based on the percentage of frequency of records: very common (VC) – recorded on 80–100% of field visits, common (C) – recorded on 50–79% of field visits, fairly common (FC) – recorded on 20–49% of field visits and rare (R) – recorded on less than 20% of the field visits. The recorded bird species were categorized into five feeding guilds based on the direct observations of their feeding habits such as – carnivore (CAR): species that feed on vertebrates; frugivore (FRU): species that feed on fruits; granivore (GRA): species that feed on grains or seeds; insectivore (INS): species that feed on insects; omnivore (OMN): species that feed both plant and animal parts (Sundar & Subramanya 2010). The number of tourists was counted following the same method as the bird survey technique mentioned earlier.

Data analysis

Season-wise species richness data were considered to test whether there was any seasonal pattern of the avian assemblage in the study site. The relative diversity (RD_i) of the recorded bird families was calculated by using the formula from La Torre-Cuadros *et al.* (2007). Species similarity between any two seasons was calculated by the Jaccard similarity index based on the species present-absent binary community matrix. Shannon-Wiener's diversity index (H′) was used to assess the species diversity of the avian community. Shannon-Wiener's diversity index of avifauna and Jaccard similarity index were estimated using the PAST statistical package (Hammer *et al.* 2001) software.

Shapiro-Wilk test and subsequent histogram revealed that the species richness of avifauna was normally distributed ($W = 0.987$, $df = 48$, $P > 0.05$). We performed the analysis of variance (ANOVA) using species richness as the dependent variable and seasons as a categorical explanatory variable to find out whether the distribution of species richness across different seasons was statistically different or not. Subsequently, post hoc Tukey's tests were executed where significant differences were noticed. Shapiro-Wilk test and subsequent histogram revealed that the species richness of residents, summer visitors, and winter visitors was non-normally distributed. Hence, we performed the Kruskal-Wallis test in the case of resident, summer, and winter visitors to test whether the seasonal variation had a significant role in their distribution or not. Subsequently, multiple pairwise comparisons using Dunn's procedure were executed where significant differences were noticed. As the avian species richness was normally distributed, the linear regression was performed to test whether the number of tourists had any significant role in shaping the species richness, using species richness as a dependent variable and the number of tourists as an independent variable. Statistical tests were computed using SPSS Version 24.0 (IBM Corp., Armont, New York) and graphical works were executed using Origin Version 8.0 (OriginLab Corp., Northampton, MA, USA).

Results

Avian diversity and feeding guilds

A total of 9,494 observations of 61 bird species belonging to 14 orders and 31 families were recorded during the study period *(Table 1)*. The study area supported 7.01% of the avian species found in West Bengal. Passeriformes was the dominant order with 27 species (44.26%) and Ardeidae was the most diverse bird family in the study area (7 species, $RD_i = 11.48$) *(Table 2)*. According to the dispersal status of the 61 recorded species, 45 were residents (73.77%), 15 species were winter visitors (24.59%) and only one species was summer visitor (1.64%). Analysis of local status revealed that ten species (16.39%) were very common, seven species (11.48%) were common, 17 species (27.87%) were fairly common and 27 species (44.26%) were rare. Assigning global population trends to the recorded bird species of the study area revealed that 15 species (24.59%) were declining, 10 species (16.39%) were increasing, 21 species (34.43%) were stable, and 15 species (24.59%) were of unknown status. Among the 61 species, two species: Lesser Adjutant *(Leptoptilos*

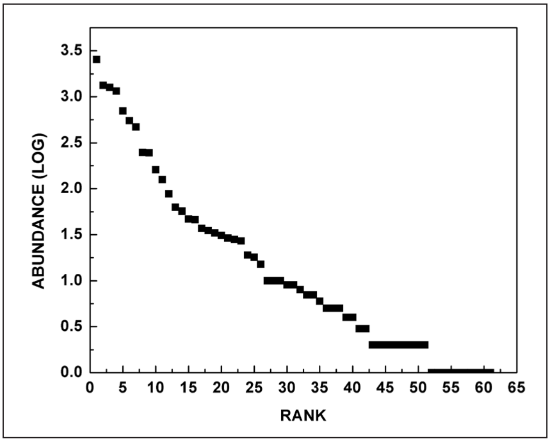

Figure 2. Rank abundance curve of the avifauna in the study area

2. ábra Rang-abundancia görbe a kutatási terület madárfaunája alapján

Table 1. Present status of avian species recorded in the agricultural landscape of Bortir Bil, West Bengal, India [IUCN: International Union for Conservation of Nature and Natural Resources; GPT: Global Population Trend; SM: Summer, M: Monsoon, PM: Post-Monsoon, W: Winter; RE: Residential, SV: Summer Visitor, WV: Winter Visitor; Y: Present or recorded, LC: Least Concern, VU: Vulnerable, NT: Near Threatened; R: Rare, FC: Fairly Common, C: Common, VC: Very Common; I: Increasing, S: Stable, D: Decreasing, U: Unknown; CAR: Carnivore, INS: Insectivore, FRU: Frugivore, GRA: Granivore, OMN: Omnivore]

1. táblázat A Bortir Bil-i mezőgazdasági tájban (Nyugat-Bengál, India) feljegyzett madárfauna jelenlegi helyzete [IUCN: Természetvédelmi Világszövetség; GPT globális állomány trend; SM: nyári; M: monszun; PM: monszun utáni; W: téli; RE: állandó; SV: nyári vendég; WV: téli vendég; Y: jelenlét bizonyított; LC: nem fenyegetett, VU: sebezhető, NT: mérsékelten fenyegetett; R: ritka, FC: közepesen gyakori, C: gyakori, VC: közönséges; I: növekvő, S: stabil, D: csökkenő, U: ismeretlen; CAR: ragadozó, INS: rovarevő, FRU: gyümölcsevő, GRA: magevő, OMN: mindenevő]

Sl.	Family	Common Name	Scientific Name	Seasonal Occurrence				Dispersal Status	IUCN Status	Local Status	GPT	Feeding Guild
				SM	M	PM	W					
Order – Podicipediformes												
1	Podicipedidae	Little Grebe	*Tachybaptus ruficollis*	–	–	Y	–	RE	LC	R	D	CAR
Order – Columbiformes												
2	Columbidae	Eurasian Collared-Dove	*Streptopelia decaocto*	Y	–	–	–	RE	LC	R	I	GRA
3	Columbidae	Spotted Dove	*Spilopelia chinensis*	Y	Y	Y	Y	RE	LC	C	I	GRA
Order – Cuculiformes												
4	Cuculidae	Asian Koel	*Eudynamys scolopaceus*	Y	–	–	Y	RE	LC	R	S	OMN
5	Cuculidae	Greater Coucal	*Centropus sinensis*	Y	–	Y	Y	RE	LC	FC	S	CAR
6	Cuculidae	Pied Cuckoo	*Clamator jacobinus*	–	Y	–	–	SV	LC	R	S	INS
7	Cuculidae	Plaintive Cuckoo	*Cacomantis merulinus*	–	–	–	Y	RE	LC	R	S	INS
Order – Caprimulgiformes												
8	Apodidae	Asian Palm Swift	*Cypsiurus balasiensis*	Y	Y	Y	Y	RE	LC	VC	S	INS
Order – Charadriiformes												
9	Charadriidae	Little Ringed Plover	*Charadrius dubius*	–	–	Y	Y	RE	LC	FC	S	INS
10	Charadriidae	Pacific Golden Plover	*Pluvialis fulva*	Y	–	–	–	WV	LC	R	D	INS
11	Charadriidae	Red-wattled Lapwing	*Vanellus indicus*	–	Y		–	RE	VU	R	U	INS
12	Jacanidae	Pheasant-tailed Jacana	*Hydrophasianus chirurgus*	–		Y	–	RE	LC	R	D	INS

Sl.	Family	Common Name	Scientific Name	Seasonal Occurrence				Dispersal Status	IUCN Status	Local Status	GPT	Feeding Guild
				SM	M	PM	W					
13	Laridae	Whiskered Tern	*Chlidonias hybrida*	–	Y	–	–	WV	LC	R	S	CAR
14	Scolopacidae	Wood Sandpiper	*Tringa glareola*	–	Y	Y	Y	WV	LC	FC	S	INS
Order – Ciconiiformes												
15	Ciconiidae	Asian Openbill	*Anastomus oscitans*	Y	Y	Y	Y	RE	LC	VC	U	CAR
16	Ciconiidae	Lesser Adjutant	*Leptoptilos javanicus*	–	Y	–	–	WV	VU	R	D	CAR
17	Ciconiidae	Painted Stork	*Mycteria leucocephala*	–	Y	–	–	WV	NT	R	D	CAR
Order – Suliformes												
18	Phalacrocoracidae	Little Cormorant	*Microcarbo niger*	Y	Y	Y	Y	RE	LC	VC	U	CAR
Order – Pelecaniformes												
19	Ardeidae	Eastern Cattle Egret	*Bubulcus coromandus*	Y	Y	Y	Y	RE	LC	VC	I	CAR
20	Ardeidae	Great Egret	*Ardea alba*	–	Y	Y	–	RE	LC	R	U	CAR
21	Ardeidae	Gray Heron	*Ardea cinerea*	–	Y	–	–	RE	LC	R	U	CAR
22	Ardeidae	Indian Pond-Heron	*Ardeola grayii*	Y	Y	Y	Y	RE	LC	VC	U	CAR
23	Ardeidae	Medium Egret	*Ardea intermedia*	–	Y	Y	Y	RE	LC	FC	D	CAR
24	Ardeidae	Little Egret	*Egretta garzetta*	Y	Y	Y	Y	RE	LC	FC	I	CAR
25	Ardeidae	Purple Heron	*Ardea purpurea*	–	Y	–	–	RE	LC	R	D	CAR
Order – Accipitriformes												
26	Accipitridae	Black Kite	*Milvus migrans*	–	–	Y	Y	RE	LC	R	S	CAR
Order – Bucerotiformes												
27	Upupidae	Eurasian Hoopoe	*Upupa epops*	Y	–	–	Y	RE	LC	FC	D	INS
Order – Coraciiformes												
28	Meropidae	Asian Green Bee-eater	*Merops orientalis*	Y	Y	Y	Y	RE	LC	FC	I	INS
29	Alcedinidae	Common Kingfisher	*Alcedo atthis*	Y	–	–	Y	RE	LC	FC	U	CAR
30	Alcedinidae	Pied Kingfisher	*Ceryle rudis*	–	Y	–	–	RE	LC	R	U	CAR

Sl.	Family	Common Name	Scientific Name	Seasonal Occurrence				Dispersal Status	IUCN Status	Local Status	GPT	Feeding Guild
				SM	M	PM	W					
31	Alcedinidae	Stork-billed Kingfisher	*Pelargopsis capensis*	–	–	Y	–	RE	LC	R	U	CAR
32	Alcedinidae	White-throated Kingfisher	*Halcyon smyrnensis*	Y	Y	Y	Y	RE	LC	C	U	CAR
Order – Piciformes												
33	Picidae	Eurasian Wryneck	*Jynx torquilla*	–	–	–	Y	WV	LC	R	D	INS
Order – Psittaciformes												
34	Psittacidae	Rose-ringed Parakeet	*Alexandrinus krameri*	Y	–	–	–	RE	LC	R	I	FRU
Order – Passeriformes												
35	Sturnidae	Indian Pied Starling	*Gracupica contra*	Y	Y	Y	Y	RE	LC	VC	I	OMN
36	Hirundinidae	Barn Swallow	*Hirundo rustica*	Y	Y	Y	Y	WV	LC	C	U	INS
37	Alaudidae	Bengal Bushlark	*Mirafra assamica*	Y	Y	–	–	RE	LC	FC	S	OMN
38	Dicruridae	Black Drongo	*Dicrurus macrocercus*	Y	Y	Y	Y	RE	LC	VC	U	INS
39	Oriolidae	Black-hooded Oriole	*Oriolus xanthornus*	Y	Y	–	–	RE	LC	FC	S	OMN
40	Muscicapidae	Bluethroat	*Luscinia svecica*	Y	–	–	–	WV	LC	R	S	INS
41	Laniidae	Brown Shrike	*Lanius cristatus*	Y	–	–	Y	WV	LC	FC	D	CAR
42	Sturnidae	Chestnut-tailed Starling	*Sturnia malabarica*	Y	–	–	Y	RE	LC	FC	U	OMN
43	Motacillidae	Citrine Wagtail	*Motacilla citreola*	Y	–	Y	Y	WV	LC	C	I	INS
44	Acrocephalidae	Clamorous Reed Warbler	*Acrocephalus stentoreus*	Y	–	Y	–	WV	LC	R	S	INS
45	Sturnidae	Common Myna	*Acridotheres tristis*	Y	Y	Y	Y	RE	LC	VC	I	OMN
46	Cisticolidae	Common Tailorbird	*Orthotomus sutorius*	Y	–	–	–	RE	LC	R	S	INS
47	Motacillidae	Eastern Yellow Wagtail	*Motacilla tschutschensis*	Y	Y	Y	Y	WV	LC	VC	D	INS
48	Corvidae	House Crow	*Corvus splendens*	Y	Y	Y	Y	RE	LC	VC	S	OMN
49	Oriolidae	Indian Golden Oriole	*Oriolus kundoo*	Y	–	–	–	RE	LC	R	U	OMN
50	Leiotrichidae	Jungle Babbler	*Argya striata*	Y	–	–	–	RE	LC	R	S	INS

Sl.	Family	Common Name	Scientific Name	Seasonal Occurrence				Dispersal Status	IUCN Status	Local Status	GPT	Feeding Guild
				SM	M	PM	W					
51	Sturnidae	Jungle Myna	*Acridotheres fuscus*	Y	Y	–	Y	RE	LC	FC	D	OMN
52	Corvidae	Large-billed Crow	*Corvus macrorhynchos*	Y	Y	–	Y	RE	LC	C	S	OMN
53	Laniidae	Long-tailed Shrike	*Lanius schach*	–	–	Y	Y	WV	LC	FC	U	CAR
54	Muscicapidae	Oriental Magpie-Robin	*Copsychus saularis*	Y	–	–	–	RE	LC	R	S	INS
55	Alaudidae	Oriental Skylark	*Alauda gulgula*	Y	–	–	–	RE	LC	R	D	OMN
56	Cisticolidae	Plain Prinia	*Prinia inornate*	Y	Y	Y	Y	RE	LC	C	S	INS
57	Pycnonotidae	Red-vented Bulbul	*Pycnonotus cafer*	Y	Y	–	Y	RE	LC	C	I	OMN
58	Corvidae	Rufous Treepie	*Dendrocitta vagabunda*	Y	–	Y	Y	RE	LC	FC	D	OMN
59	Estrildidae	Scaly-breasted Munia	*Lonchura punctulate*	–	Y	Y	–	RE	LC	FC	S	GRA
60	Acrocephalidae	Thick-billed Warbler	*Arundinax aedon*	–	–	–	Y	WV	LC	R	D	INS
61	Motacillidae	White Wagtail	*Motacilla alba*	–	–	Y	Y	WV	LC	FC	S	INS

Table 2. Relative diversity (RD_i) of different avian families recorded in the study area
2. táblázat A kutatási területen feljegyzett madárcsaládok relatív diverzitása (RDi)

Avian families	Number of species	RD_i (%)
Ardeidae	7	11.48
Alcedinidae, Cuculidae, Sturnidae	4	6.56
Charadriidae, Ciconiidae, Corvidae, Motacillidae	3	4.92
Acrocephalidae, Alaudidae, Cisticolidae, Columbidae, Laniidae, Muscicapidae, Oriolidae	2	3.28
Accipitridae, Apodidae, Dicruridae, Estrildidae, Hirundinidae, Jacanidae, Laridae, Leiotrichidae, Meropidae, Phalacrocoracidae, Picidae, Podicipedidae, Psittacidae, Pycnonotidae, Scolopacidae, Upupidae	1	1.64

javanicus), Red-wattled Lapwing *(Vanellus indicus)* were 'Vulnerable', one species: Painted Stork *(Mycteria leucocephala)* was 'Near Threatened' and the rest were 'Least Concern' according to IUCN Red List *(Table 1)*. The rank abundance curve *(Figure 2)* revealed that Indian Pied Starling *(Gracupica contra)* was the most abundant bird species in the study area followed by Common Myna *(Acridotheres tristis)*, Eastern Yellow Wagtail *(Motacilla tschutschensis)*, and others. The Shannon-Wiener's diversity index of the avifauna of the study area was 2.407. Season-wise Shannon-Wiener's diversity index was highest in winter ($H' = 2.461$), followed by post-monsoon ($H' = 2.307$), summer ($H' = 2.223$), and monsoon ($H' = 2.048$). Five feeding guilds were found in the study area. Among the 61 recorded bird species, insectivores were the most predominant (23 species, 37.70%), followed by carnivores (21 species, 34.43%), omnivores (13 species, 21.31%), granivores (3 species, 4.92%) and frugivores (1 species, 1.64%).

Seasonality on species richness

Among the months, the highest bird species richness (Mean±SD) had been recorded in January (18.75±0.47) *(Figure 3)*. Species richness was highest in winter (18.16±0.76) followed by summer (16.58±0.97), post-monsoon (13.75±0.65), and monsoon (13.08±0.72) *(Figure 4A)*. Jaccard similarity index indicated that species composition was seasonally similar. The highest similarity existed between the winter and post-monsoon (0.60), followed by winter and summer (0.56), whereas the lowest similarity existed between post-monsoon and summer (0.40). ANOVA revealed that the avian species richness was significantly different across the four seasons ($F_{3,44} = 10.942$, $P < 0.05$). A post hoc Tukey test showed that summer and monsoon, summer and post-monsoon, winter and monsoon, and winter and post-monsoon differed significantly at $P < 0.05$ *(Figure 4)*. The species richness of summer visitors (Kruskal-Wallis test: $K = 6.130$, $df = 3$, $P > 0.05$), showed non-significant variation across the seasons, remaining similar throughout the study period. However, a significant seasonal difference was noticed in the case of residents (Kruskal-Wallis test: $K = 15.502$, $df = 3$, $P < 0.05$) and winter visitors (Kruskal-Wallis test: $K = 20.108$, $df = 3$, $P < 0.05$) *(Figure 4)*. Multiple pairwise post hoc comparisons using Dunn's procedure revealed that the species richness of residents was highest in summer and differed significantly between summer and monsoon, summer and post-monsoon, winter and monsoon, winter and post-monsoon ($P < 0.05$)

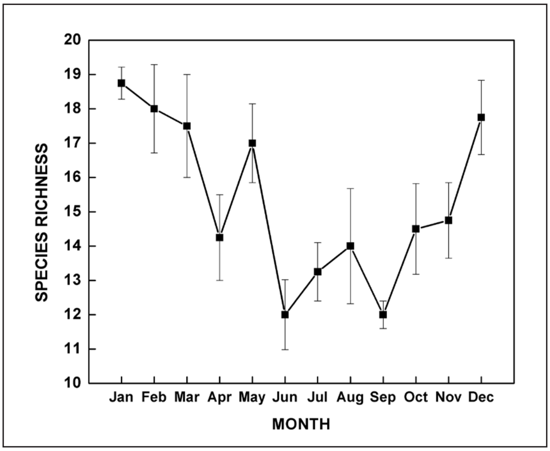

Figure 3. Monthly bird species richness in the study area. Bars denote the standard error of the mean

3. ábra Madár fajgazdagság havi értékei a vizsgálati területen. A hibasávok az átlag standard hibáját jelölik

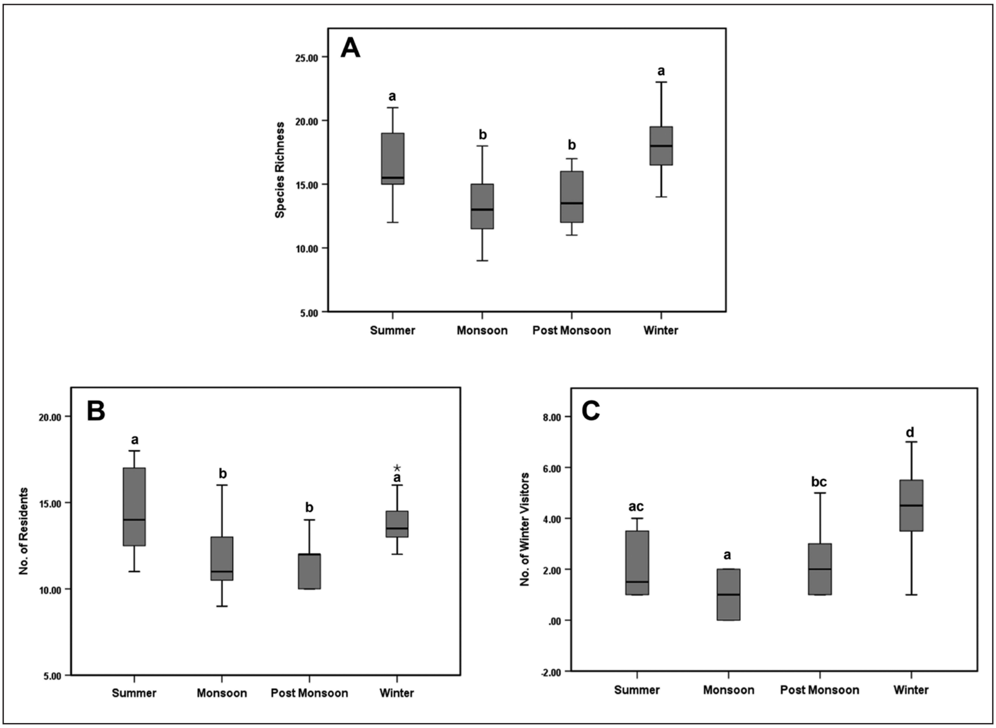

Figure 4. Study of seasonality on species richness. A. Box-plot showing season-wise species richness of avifauna in Bortir Bil; B. Box-plot showing resident (RE) species richness across different seasons; C. Box-plot showing winter visitor (WV) species richness across different seasons. Box-plots with different letters indicate a significant difference in species richness between a pair of seasons as per multiple pairwise comparisons. Bars denote the standard error of the mean.

4. ábra A szezonalitás hatása a fajgazdagságra. A. Évszakonkénti fajgazdagság a Borti Bil-i madárfauna alapján. B. Az állandó fajok (RE) fajgazdagsága a különböző évszakokban. C. A téli vendég fajok (WV) fajgazdagsága a különböző évszakokban. A dobozdiagramokon a különböző betűvel jelölt csoportok szignifikáns különbséget jelölnek a páronkénti összehasonlítás alapján. A hibasávok az átlag standard hibáját jelölik

(Figure 4B). In case of winter visitors, species richness was highest in winter and differed significantly ($P < 0.05$) from all other seasons *(Figure 4C)*.

Tourism pressure on species richness

The maximum number of tourists visited the site during monsoon followed by post-monsoon, summer, and winter. The number of tourists explained 36% of the variance in species richness ($R^2 = 0.36$, $F_{1,46} = 25.824$, $P < 0.05$). The number of tourists played a significant role in shaping avian species richness ($B = -0.013$, $t = -5.082$, $P < 0.05$) *(Figure 5)*.

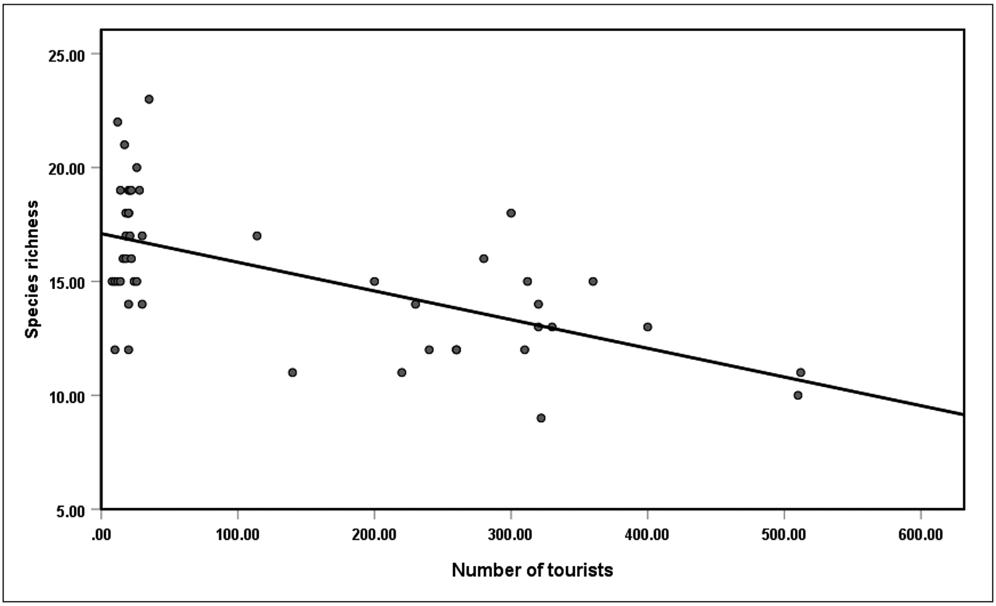

Figure 5. Linear regression plot depicting the effect of tourism pressure on species richness. Regression equation, Species richness = 17.09 – (0.013 × Number of tourists)

5. ábra A turizmus által jelentett terhelés és a fajgazdagság kapcsolatát bemutató lineáris regresszió grafikonja. A regressziós egyenlet. Fajgazdagság = 17.09 – (0.013 × Turisták száma)

Discussion

This year-round study of Bortir Bil found that avian diversity is influenced by seasonal change and anthropogenic activities, also revealing the current conservation status of the avifauna. The bird species richness of Bortir Bil is comparable to many wetlands across India. For instance, Datta (2011) documented 80 and 42 bird species from two wetlands of Jalpaiguri, West Bengal; Kumar and Gupta (2009) found 54 bird species in Kurukshetra, Haryana; Pattnaik *et al.* (2022) documented 77 species at Kirtipur wetland, Odisha; Pawar and Wanjari (2013) reported 34 species at Muchi lake wetland, Maharashtra; Panda *et al.* (2021) documented 68 species at Chilika wetland; Shahbaz *et al.* (2023) documented 73 and 67 species from two wetlands of Patna, respectively. In India, Passeriformes is considered the most dominant order (Praveen *et al.* 2016) which is also consistent with our findings.

The species richness of the avifauna was lowest during the monsoon as compared to the other three seasons. This may be due to some birds like storks, and egrets dispersing in search of nesting sites with the advent of monsoon (Urfi 1996). This trend has been observed by Mukhopadhyay and Mazumdar (2019) during their study in the suburban area of the lower Gangetic plains. However, during the monsoon, these low-level agricultural fields get flooded by rainwater and hence act as a seasonal wetland. This provides sufficient food supply to the resident birds, as well as attracts migratory birds in winter. Many of the bird species like Eastern Cattle Egret *(Bubulcus coromandus)*, Asian Openbill *(Anastomus oscitans)*, Whiskered Tern *(Chlidonias hybrida)*, and kingfishers were found during the monsoon, and post-monsoon because of the availability of abundant food. Common water hyacinth was the most abundant and invasive floating macrophyte species found at Bortir Bil during the monsoon and post-monsoon. Many wetlands support large breeding populations of the Pheasant-tailed Jacana *(Hydrophasianus chirurgus)* which thrive on floating vegetation (Mukhopadhyay & Mazumdar 2019). In this context, Pheasant-tailed Jacanas were also found during the monsoon on the floating vegetation of water hyacinths at Bortir Bil. During monsoon, ground birds like Common Myna, and Indian Pied Starling were also found on the floating vegetation and the floating jute logs, which provide food resources like insects, and gastropods for the birds. In Bortir Bil, aquatic insects act as one of the major food resources for the birds during the monsoon and post-monsoon. Additionally, crustaceans, molluscs, fishes were also available during this time. With decreasing water levels in winter and summer, this seasonal wetland was much favoured by carnivorous bird species like Asian Openbill, Eastern Cattle Egret, Great Egret *(Ardea alba)*, Indian Pond Heron *(Ardeola grayii)*, and many more. In the study area, the major feeding guild was insectivores followed by carnivores and omnivores, while granivores and frugivores were less common. More than 75% (46 species) of the avian species documented during this study were resident. The wetlands attract and serve as a wintering ground for migratory birds (migratory ducks) every year. Our study reported that the species richness of winter visitors (14 species, 22.95%) exhibited significant variations between different seasons in Bortir Bil. This is due to their appearance only during the winter season. Mukhopadhyay and Mazumdar (2017) also reported in their study that significant seasonal differences were noticed for winter visitors.

The studied seasonal wetland is a frequented tourist spot during monsoon, post-monsoon, and winter seasons along with associated disturbances such as the use of loudspeakers, music systems, and horns of vehicles. A primary threat to waterbirds of Bortir Bil includes hunting, which poses a direct challenge to their conservation efforts, along with the potential for planning and causing physical harm to eggs and chicks. Additionally, solid waste originating from tourists and nearby villages had been indiscriminately disposed of within the wetland, resulting in contamination of the waters of Bortir Bil. Ferrarini *et al.* (2021) reported that tourism pressure not only disturbs the avian community, especially birds during their breeding season but also destroys their nesting habitat, nests, and eggs, and sometimes increases the mortality of the chicks (Bukaciński *et al.* 2020). The wetlands of South Asia are facing extensive anthropogenic pressure, which can greatly influence the structure of the bird community (BirdLife International 2023). Changes in vegetation composition due to adverse effects of anthropogenic disturbances, climate change, and natural calamities can affect the quality and quantity of habitats for birds in terms of resources and shelter, which can further affect their diversity, abundance and distribution (Chen *et al.* 2011, Şekercioğlu *et al.* 2012). IUCN Red List of Endangered Birds has already recognized 1,445 threatened species globally, 94 species of which are from India (IUCN 2023a). Although Passeriformes is the dominant order of most of the avifauna studies of India, this order has the highest number of threatened species worldwide. These findings emphasize the immediate importance of the study of different environmental factors that control the community structure of avian fauna across different potential seasonal wetlands of India. As more footfalls of tourists are expected at Bortir Bil in the upcoming years, more research in this direction is required to evaluate the effect of anthropogenic disturbances and other biotic, abiotic factors on the avian community structure.

Conclusion

Anthropogenic threats pose significant challenges to seasonal wetlands. Therefore, it is crucial to maintain the ecological stability and resource availability of these wetland habitats to preserve the overall diversity of bird species in the area. This research provides a valuable foundation for assessing the impact of seasonality and tourism on avifauna, allowing future surveys to compare species richness in Bortir Bil. It is recommended to establish regular and long-term monitoring of avifauna, focusing on abundance, feeding and breeding ecology, and resource utilization patterns. Such monitoring efforts will contribute to the development of a sustainable and bird-friendly management plan for this study area. Involving local communities in monitoring efforts can help garner public support for habitat protection and the conservation of avifauna in this seasonal wetland.

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The impacts of land use change on partridge's population in the Marghazar valley of Swat District, Pakistan

Atta Ullah[1]*, Khurshaid Khan[1], Nehafta Bibi[2] & Shakeel Ahmad[3]

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Abstract In landscape ecology, it has become increasingly essential to understand the consequences of past, current, and future human land use patterns for biodiversity and ecosystem function. The most significant factor affecting biodiversity loss is land-use and land-cover change (LULCC). We examine here the impact of long-term changes in LULCC from 2000–2020 on the biodiversity of Marghazar valley in Swat District. Information was also gathered on the perceptions of the surrounding communities based on the flow of ecosystem services (ES), historical changes, and the causes of those changes. Satellite imagery data were used to map LULCC, identify possible causes, and assess the impact of LULCC on the population of partridges. In the last 20 years, forest area has reduced by 23 km^2 (33%) and the seasonal water body has declined by 1.015 km^2 (2.15%). There was a 38.5 km^2 decrease in agricultural land. In contrast, the built-up area increased by 384%, resulting in a total growth of 26.3 km^2 and an expansion of 41.1 km^2 grassland. Deforestation, agricultural expansions, urbanization, economic considerations and changes in land tenure policy were identified to be the main drivers of LULCC. The primary impact of LULCC on partridges in the studied area are land degradation, population declines, habitat disruption, displacement of partridges by livestock and increasing human-wildlife conflicts. Despite ongoing human pressure, the Marghazar valley still provides extensive habitat for wildlife. Interventions may be needed to maintain biodiversity and ensure long-term ecological services in the area.

Keywords: land use land cover change, communities' perception, ecosystem services, urbanization, partridges, Pakistan

Összefoglalás A tájökológiában egyre fontosabbá vált a múltbeli, jelenlegi és jövőbeli emberi földhasználati minták biológiai sokféleségre és az ökoszisztéma működésére gyakorolt hatásainak megértése. A biológiai sokféleség csökkenését befolyásoló legjelentősebb tényező a földhasználat és a felszínborítottság változása (LULCC). Itt megvizsgáltuk a LULCC 2000–2020 közötti hosszú távú változásainak (LULCC) hatását a Marghazar-völgy biológiai sokféleségére (Swat District). Információkat gyűjtöttünk a környező közösségek észleléséről is az ökoszisztéma-szolgáltatások áramlása (ES), a történelmi változások és e változások okai alapján. A műholdas képadatokat a LULCC feltérképezésére, a lehetséges okok azonosítására és a (LULCC) fogolypopulációra gyakorolt hatásának felmérésére használtuk. Az elmúlt 20 évben (2000–2020) az erdőterület 23 km^2-rel (-33%), a szezonális víztest pedig 1,015 km^2-rel (2,15%) csökkent. A mezőgazdasági földterületek 38,5 km^2-rel csökkentek. Ezzel szemben az elmúlt 30 évben a beépített terület 384%-kal nőtt, ami összesen 26,3 km^2 növekedést és 41,1 km^2 gyepterület bővülését eredményezte. A LULCC fő mozgatórugói az erdőirtás, a mezőgazdasági terjeszkedés, az urbanizáció, a gazdasági megfontolások és a földbirtoklási politika változásai voltak. A LULCC elsődleges hatása a vizsgált terület fogoly állományára a talajromlás, a népességcsökkenés, az élőhelyek megzavarása, a foglyok állatállomány általi elmozdulása és az ember-vadon élő állatok konfliktusainak fokozódása. A folyamatos emberi nyomás ellenére a Swat régióban található Marghazar-völgy továbbra is kiterjedt élőhelyet biztosít a vadon élő állatok számára. Beavatkozásokra lehet szükség a biológiai sokféleség fenntartása és a terület hosszú távú ökológiai szolgáltatásainak biztosítása érdekében.

Kulcsszavak: földhasználat, felszínborítottság változása, a közösségek felfogása, ökoszisztéma-szolgáltatások, urbanizáció, fogoly, Pakisztán

[1] *Department of Zoology, Abdul Wali Khan University Mardan, Pakistan*
[2] *Government Girls Degree College Mansehra, 21300, Mansehra, Pakistan*
[3] *Carnivore Conservation Lab Quaid-i-Azam University, Islamabad, Pakistan*
** corresponding author, e-mail: attakhan_154@yahoo.com*

Introduction

Changes in biodiversity occur at all scales as a result of ongoing human alteration of the earth surface (Newbold *et al.* 2015). Around 32% of all known vertebrate species are experiencing decline in population or range contractions globally, with recorded species extinction rates many times greater than natural rates (Ceballos *et al.* 2017). Recent global meta-analyses have shown that some biodiversity metrics, such as species richness, have not decreased at smaller scales, such as biodiversity sampling scale (Vellend *et al.* 2017). However, these findings have been questioned, specifically whether the data is geographically and temporally biased (Gonzalez *et al.* 2016) or whether locations with and without land change were different (Cardinale *et al.* 2018). Land-use and land-cover change (LULCC) have been highlighted as a major driver of terrestrial biodiversity loss (Díaz *et al.* 2019). This raises a question of whether changes in land use can account for changes in local biodiversity measurements throughout time and space. Local biodiversity is also influenced by current LULCC around the world. Local biodiversity has been found to be consistently decreasing in areas with more intensively exploited land (Murphy & Romanuk 2014), in comparison to undisturbed primary vegetation, with 13.6% fewer species and 10.7% fewer individuals recorded (Newbold *et al.* 2015). The effects on biodiversity increases with the frequency of land use, ranging from no impact to a loss of more than 95% of mean species abundance (Taylor *et al.* 2014). For example, when more than 20% of a landscape is cleared, wildlife begins to disappear, and when less than 30% of the native vegetation remains, the loss of species accelerates rapidly (McAlpine *et al.* 2002). While the loss of habitat is the primary negative impact of clearing on biota, fragmentation and change of the remaining habitat has a significant negative secondary effect (Haddad *et al.* 2015). At landscape scale, which is defined as the extent to which spatiotemporal dynamics influence ecological processes (Pickett & Cadenasso 1995), regional biodiversity is affected by resource variability, such as food or nesting material, as well as ecological processes, such as migration or parasitism (Ullah *et al.* 2022). Until now, comparative studies have been attributed to a lack of data on local biodiversity change and landscape-wide LULCC (De Palma *et al.* 2018). As satellite imagery becomes more widely available, it is now possible to examine LULCC over a wider range of spatial and temporal scales (Pasquarella *et al.* 2016). Long-term satellite programs, such as NASA's Landsat, offer one of the most reliable sources of time series for monitoring land surface changes (Hermosilla *et al.* 2018).

The impact of local biodiversity change as measured by recurrent breeding bird surveys (BBS) has been extensively studied (Pardieck *et al.* 2018). Changes in bird diversity are often non-linear and reliant on the specific biodiversity measure used (Barnagaud *et al.*

2017). Bird diversity has changed differently across ecoregions and for birds with specific functional features (Jarzyna & Jetz 2017), like migratory or grassland-dependent species, which have dropped significantly in developed countries (Stanton *et al.* 2018).

Rittenhouse *et al.* (2010) reported that the composition of bird assemblages was altered in areas with more 'disturbed forests', as measured by remotely sensed time series. To our knowledge, no previous study has attempted into whether variations in LULCC throughout the landscape connect with and explain variations in local bird diversity. The goal of the study was to assess the changing land use patterns in Marghazar of Swat District from 2000 to 2020, as well as the likely reasons of these changes and their consequences on the wild partridge population. The study postulated that changes in land use patterns had resulted in a significant decline in partridge populations in the study region, and that land use changes in Marghazar might be caused by an increase in human population and associated activities.

Material and Methods

An overview of the study area

Marghazar, a mountainous region of Pakistan with numerous valleys, scrub and coniferous forests on the upper slopes, and alpine pastures on the ridges. It is located between 34–40 and 34–50 degrees North and 72–20 and 72–30 degrees East *(Figure 1)*. The annual rainfall ranges between 1,000 to 1,500 mm, providing enough water for infiltration and for a variety of plants. The valley rises gradually from 1,000 meters above sea level at Kokrai village to 3,000 meters at the summit of Mount Elem. The valley covers a total area of 367.7 km^2. The former King of Swat chose it for the Summer Palace, which is now known as Marghazar White's place, because of its natural beauty, and the valley attracts local and national tourists all year, especially in the summer. Marghazar is named after a combination of the words "Margha" and "Zar," as evidenced by its name. Margha is a local word that means "pertaining to birds," and Zar is a Persian word that means "garden" or "a spot where birds and flowers are nurtured." Despite the fact that the name was given some 50 years ago, it represents the fact that this valley was once a welcoming habitat for a variety of birds and plant species. Agricultural forming, livestock rearing, timbers and fuel wood are the primary sources of income for the majority of the population. On the basis of land-use and land-cover change (LULCC), three representative villages were chosen: Oghaz, Mount Elem and Jambil. The dominant tree species of the study area include *Pinus wallichiana, Pinus roxburghii Sarg. Cedrus deodara, Melia azedarachta, Ficus racemose, and Quercus baloot,* Shrubs include *Dodonea viscosa, Berberis lyceum, Desmodium elegans, Datura stramonium, Zizyphus oxyphylla,* and *Rubus fruticosus.* Herbs include *Poa annua, Heliotropium strigosum, Origanum vulgare, Solanum xanthocarpum* and *Hypricum perforatum*.

Among the area's main wildlife species are Brown Bear *(Ursus arctos isabellinus)*, Side-striped Jackal *(Lupulella adusta)*, Gray Wolf *(Canis lupus)*, European Rabbit *(Oryctolagus cuniculus),* Resus Macaque *(Macaca mulatta)*, Red Fox *(Vulpes vulpes)*, Indian Crested

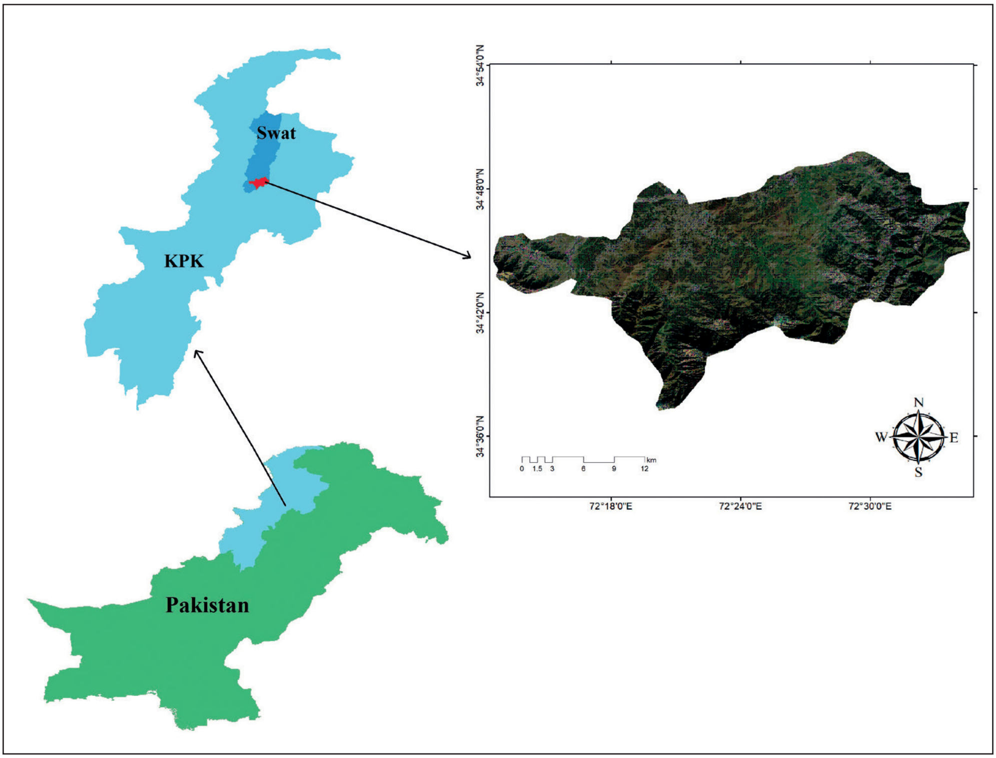

Figure 1. Map of Marghazar in Swat District, Pakistan
1. ábra Marghazar térképe, Swat körzet, Pakisztán

Porcupine *(Hystrix indica)*, Himalayan Goral *(Naemorhedus goral),* Chukar *(Alectoris chukar)*, Black Partridge *(Melanoperdix niger),* Grey Partridge *(Perdix perdix)*, Kalij Pheasant *(Lophura leucomelanos),* Koklass Pheasant *(Pucrasia macrolopha)*. A large population of small mammals, reptiles, and amphibians live in the ecosystem.

Study area selection

The study area was chosen based on the following characteristics. (1) The region has the highest coverage of temperate coniferous forest, which is threatened by deforestation. (2) Due to the present cease-fire in the district of Swat as a result of the present terrorism situation in the area, the fauna of the study area are rich.

Time periods selection

The data starts with the baseline of August 2000 when the infrastructure of Marghazar valley was less developed, when there were only local residents at the time and the outside peoples not coming that much. The next data point selected was 2010 with approximately one decade gap when there were Taliban militancy. They had complete hold of the whole valley and did a fast range of deforestation which affected the ecosystem of the area. The last data point is 2020, which is the latest available data. When the population is its peak and peoples from the outside valley came to reside here which has affected grossly the ecosystem of the valley as well. Several important institutional changes occurred during this period, and several development projects, were initiated in the region. The majority of these initiatives focused on economic growth, agriculture, and road infrastructure, all of which are often cited as a key drivers of land use change.

Tools and a participatory approach

To understand the people's perceptions on past biodiversity and the drivers of land use/cover dynamics for Marghazar region, we used a few participatory rural appraisal (PRA) methods such as focus groups, resource mapping, and transect walks, as well as a structured qualitative household survey using a semi-structured questionnaire of open-ended and closed questions. We divided the study area into three sites. We selected 40% of the 419 households in three sample sites for a household survey (N=170). *Table 1* shows a summary of the sample area for the household survey. The survey was performed in the local language at home in the morning and evening. Regardless of gender, the head of the household was interviewed (above 40 years). The survey questioned about people's attitudes toward land use changes and their impact on wild partridges, human population census numbers and ecosystem dependence, partridge population census details, and livestock population trends. Land use change data was collected using ARCGIS and EDRAS tools to acquire, view, and analyze satellite images. Identification of partridge species, present land use patterns, and land degradation were all done by direct observations. This included a 40-kilometer long line transect walk that ran diagonally through the study area. This was performed with the help of local game scouts. All species found at a distance of 1 km on either side of the line transect walk were identified and individual species counted. This happened during the month of September 2020. Using a digital camera, data was captured through photographs. It was useful in classifying land uses in the area as evidence of actual practice. Field visits were used to make ground validation in order to enhance change detection. This involved randomly selecting sites from the most recent land use base map and visiting each site to examine and verify if the land use type on the ground matched what was depicted on the map.

Table 1. Description of sampling areas for household survey
1. táblázat A háztartások felméréséhez használt mintavételi területek leírása

Study area	**MARGHAZAR**			**Total**
Village name	Oghaz	Mount Elem	Jambil	–
Location	34.7420° N, 72.4552° E	34.6182° N, 72.3327° E	34.7222° N, 72.4450° E	
Total house hold	121	84	214	419
Sample size	49	34	87	170

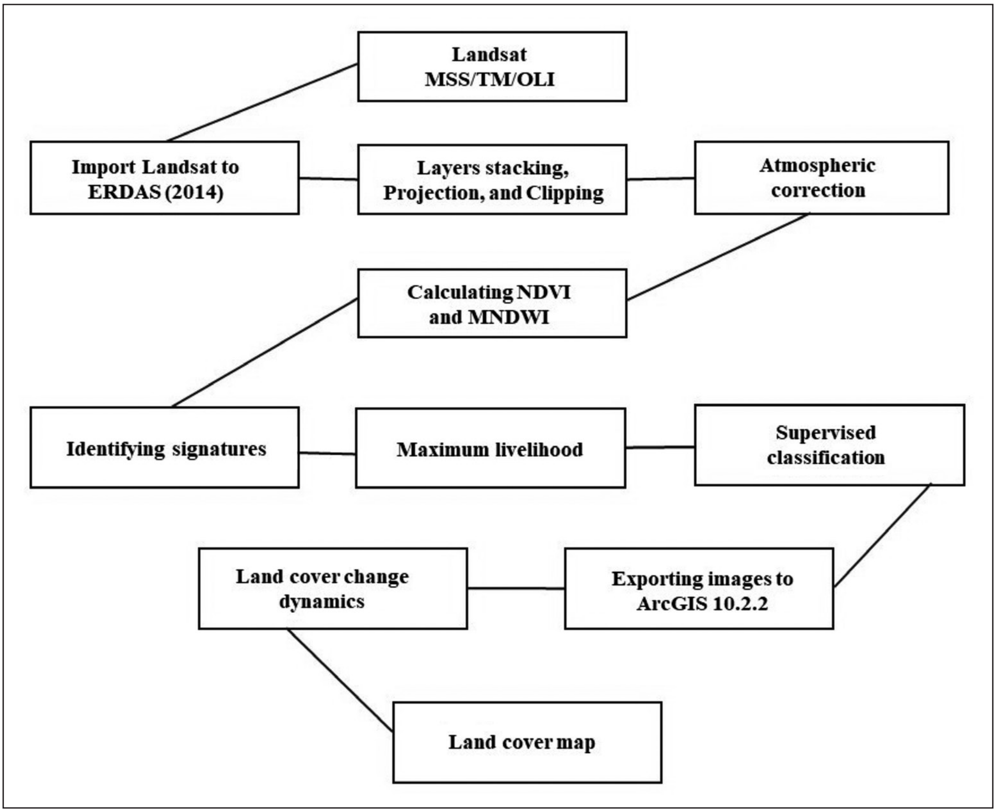

Figure 2. Paradigm of the overall methodology of LULCC
2. ábra A LULCC általános módszertanának paradigmája

Land use land cover change analysis

August was selected for obtaining satellite data for the study area due to least amount of cloud this month. The entire archive was observed and examined carefully to observe the images taken throughout in August month. Remotely sensed data for land cover assessment were obtained for three years 2000, 2010 and 2020. The data were obtained from Landsat Look Viewer comprises of Landsat MMS with spatial resolution of 60 m, having four bands and Landsat TM having spatial resolution of 30 m consist of 8 band. Spatial resolution of Landsat OLI is 30 m. The digital elevation model (DEM) was obtained from the Shuttle Radar Topography Mission (SRTM) from United State Geological Survey (USGS). *Figure 2* describes the overall processes that are included in the study.

Statistical analyses

All experimental results were examined by statistical package for social sciences IBM (SPSS) version 20 software database. Observations were considered statistically significant at ($p<0.05$).

Table 2. Change matrix of land cover (km^2) in 2000 to 2020
2. táblázat A felszínborítottság (km^2) változása 2000 és 2020 között

Total area of Marghazar region (367.7) km^2			
Land cover type	2000	2010	2020
Barren area	102.99	95.68	103.80
Forest cover	68.23	54.19	45.26
Snow land	0.124	14.51	0
Agriculture	65.235	81.47	26.68
Water bodies	7.920	5.732	1.015
Buildup area	7.173	22.95	33.50
Grass land	115.97	93.21	157.16

Results

In 2000, Marghazar ecosystem had a total area of 367.7 km^2 *(Table 2)* out of which barren land had occupied 102.99 km^2, forest 68.23 km^2, snow cover 0.124 km^2, agricultural land 65.235 km^2, water bodies 7.920 km^2, buildup area 7.173 km^2 and grassland 115.97 km^2. By 2020 barren land had occupied 103.80 km^2, forest 45.26 km^2, snow cover 0 km^2, agricultural land 26.68 km^2, water bodies 1.015 km^2, buildup area 33.50 km^2 and grassland 157.16 km^2, respectively. The land use change maps *(Figure 3a,b,c)* show two strong trends: increasing fragmentation from 2000 to 2020 and change in land cover types especially decrease in forest cover (-33%), agriculture (-58.7%), snow (-100%), water bodies (-90.6%) and increase in built up area (384%), grass land (35.5%) and barren land (1.07%) *(Table 3)*.

Local communities' perspectives on the status of ES and LULCC

Figure 4 illustrates how communities have seen changes in ES flow during the last decade. Around 82% of the respondents believe that the forest ecosystem has decreased in the last 20 years. Fuel wood exploitation, illicit logging, charcoal production, shifting cultivation, agricultural area expansion, and population growth all contributed to the deteriorated forest ecosystem. In addition, the communities claim that there is almost no forest remained in the

Table 3. Summary of land cover statistics for 2000, 2010 and 2020
3. táblázat A 2000., 2010. és 2020. évi felszínborítottsági statisztikák összefoglalása

Land cover type	**2000**	**2010**	**2020**	**P1 (2000–2010)**	**P2 (2010–2020)**	**Total% change**
Barren area	28	26	28.3	-7.1	8.8	1.07
Forest cover	18.5	14.7	12.3	-20.5	-16.3	-33
Snow land	0.03	0.3	0	900	-100	-100
Agriculture	17.7	22.1	7.3	24.8	-66.9	-58.7
Water bodies	2.15	1.5	0.2	-30.2	-86.6	-90.6
Buildup area	1.9	6.2	9.2	226.3	48.3	384
Grass land	31.5	25.3	42.7	-19.6	68.7	35.5

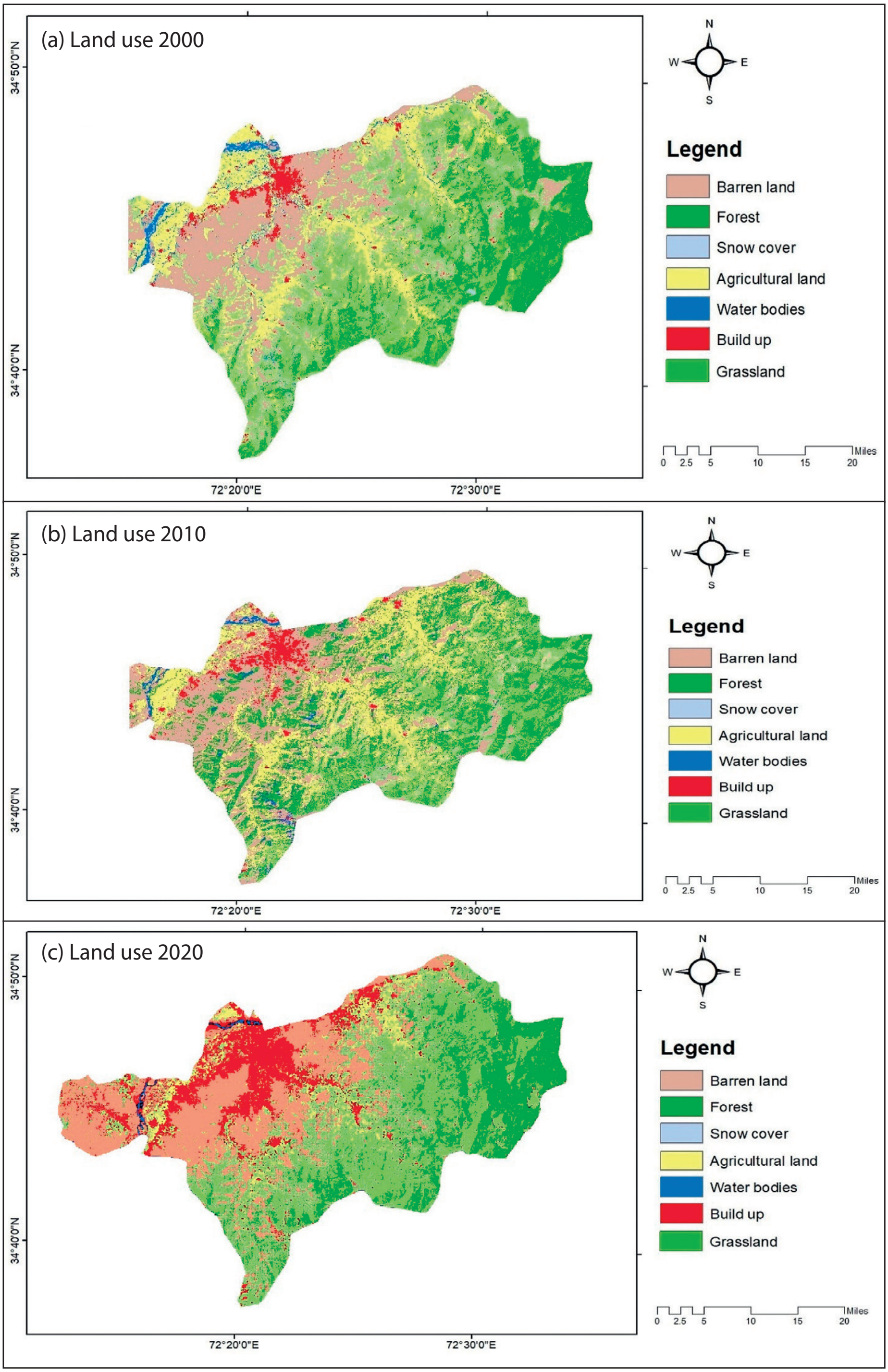

Figure 3. Land use and land cover maps of Marghazar valley (2000–2020)
3. ábra A Marghazar-völgy földhasználati és felszínborítottsági térképei (2000–2020)

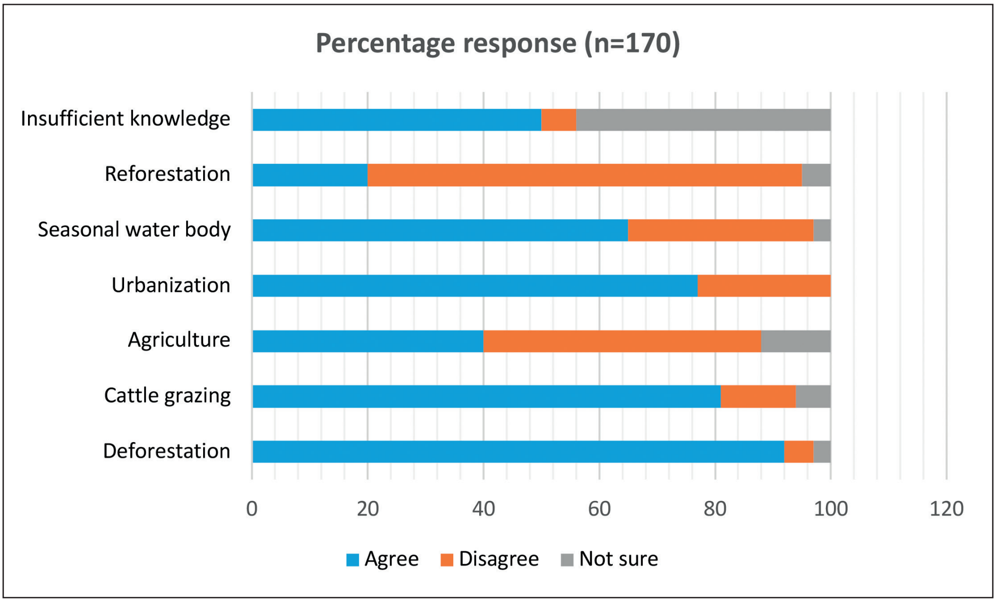

Figure 4. Local people's perspectives on the factors affecting land use/cover dynamics
4. ábra A helyi lakosság nézőpontja a földhasználat/felszínborítottsági dinamikáját befolyásoló tényezőkről

village area. Around 40% of the respondents said there had been an increase in the amount of land used for agriculture; while 48% of the respondents are disagree for such changes. Communities have stated that excessive use of chemical fertilizers has affected soil fertility and water quality. Approximately 77% of respondents indicated that the area used for urbanization has increased. Other factors for change include cattle grazing 81%, and a lack of concern about environmental problems, which accounts for 10% of the changes. Prior to the 1970s, the majority of the people in the study area said there were significant numbers of wild sheep, bears, jackals, wolves, rabbits, monkeys, and foxes in the area. These animals are now extremely rare in the area; the decline in species abundance appears to have started in the early 1980s, when livestock keepers arrived. Such changes in the study area have resulted in a significant decrease in biodiversity. Deforestation, urbanization, and increased soil erosion leading to sedimentation, erratic rainfall, and the drying out of rain water storage ponds are all major concerns. Around 20% of those surveyed said that reforestation had helped to mitigate some of the negative effects. During the dry season, a large number of respondents (65%) perceived a substantial decrease in seasonal water bodies.

Population change

According to the 2010 census, Marghazar region of Swat District has an annual human population growth rate of 17%. In 2020, this translates to 4,927 people and a population density of 24 people/km^2. The entire human population in the area is expected to reach 6,245 person by 2030. Because of the increasing population growth in the area, there is a greater

Table 4. Local communities depend on ecosystem services (ES) for their livelihoods
4. táblázat A helyi közösségek megélhetése az ökoszisztéma szolgáltatásoktól (ES) függ

Ecosystem	Oghaz	Mount Elem	Jambil
Goods and services provisioning	Timber	Timber	Fuel wood
	Fuel wood	Fuel wood	Vegetables
	Fruits	Drinking water	Fruits
	Vegetables	Water for irrigation	Ornamental plants
	Cereals	Wild edible fruits	Water for irrigation
	Drinking water	Vegetables	Drinking water
	Water for bathing	Grazing	Grazing
	Grazing		
	Medicinal plants		

demand for land for farming, habitation, and infrastructure development, which has resulted in the destruction of large areas of wetland, forestland, woodland, mountain, and grassland that serve as partridge's habitats.

Use of ES as a source of livelihood

Communities in the three study areas, namely Oghaz, Mount Elem and Jambil, showed varying levels of dependence depending on ecosystem proximity. It was found that all of the dependent communities seem to make the best use of the ecosystems available to them. Our qualitative data revealed that local residents depend on a variety of ES from the study area to support their livelihoods *(Table 4)*. Nearly all of the respondents in Oghaz village cited that they consume vegetables (60%) and wild edible fruits/vegetables (50%) from the forest ecosystem. Around 100% of respondents use water for drinking, 90% for bathing, and 100% of the villagers collects wood for fuel and 2% use medicinal plants. Despite deforestation and destruction of forest areas, forests continue to provide the village with fuel wood. About 80% of the respondents in Mount Elem consumed fuel wood from forests. Deforestation in the valley is dominant. Similarly, the local agro-ecosystem looms vegetable production (50%) as well as wild and edible fruits (30%). Water is used by about 60% of respondents for drinking and 30% for irrigation.

In Jambil village, only 15% of those surveyed said they used forest fuel wood. The agro-ecosystem in the region appears to be very productive. Around 70% of the households cultivate vegetables, 10% ornamental plants, and 50% cultivate fruits. Fresh water is mostly used for drinking (90%) and for irrigation purposes (10%).

Effects of Land Use Change on partridge population in Marghazar

According to 91% of respondents, LULCC in the study area had a significant effect on partridges population (χ^2 =123.70, DF=1, P<0.0001). The main effects are a significant

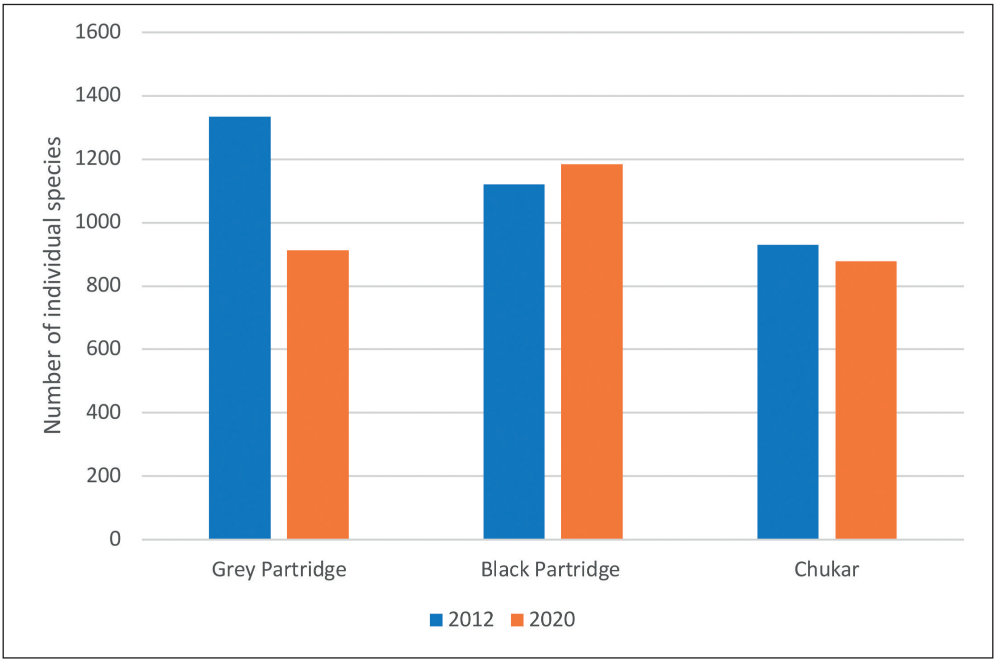

Figure 5. Partridge's population estimates for 2012 and 2020 in the study area
5. ábra A foglyok 2012-re és 2020-ra vonatkozó populációs becslései a vizsgált területen

decrease in the number of partridges and other wildlife habitats, a significant increase in human and wildlife conflicts (χ^2 =165.38, DF=1, P<0.0001), habitat degradation, displacement of partridges, land degradation and appearance of invasive plant species.

Trends in decrease of partridge population in Marghazar

Bird counts conducted in the study area by different agencies on three species of wild partridges have shown a decline in their numbers. According to the 2012 bird counts, the most numerous partridge was the Grey Partridge, which had a population total of approximately 1,334 individuals, followed by Black Partridge (1120) and Chukar (930). In 2020, Black Partridge was the most numerous with a population estimate of 1,185 individual followed by Grey Partridge (912) and Chukar (878) *(Figure 5)*. A comparison of 2012 and 2020 count for the same species in the same region showed a decrease in numbers for Grey Partridge and Chukar and an increase for Black Partridge.

Discussion

The LULCC has been highlighted as one of the most significant change agents on the planet (Chettri & Sharma 2016). As a result of this LULCC, the flow of ES is disrupted (Janssen & Anderies 2007). Widespread deforestation and unplanned LULCC threatens natural ecosystems (Sidle *et al.* 2007), reduces multi functionality (Kandziora *et al.* 2014), and restricts the habitat of globally threatened species (Kandziora *et al.* 2014). In recent years, the Swat District has shown a considerable LULCC (Ullah *et al.* 2021), which our study has confirmed. Many previous studies have reported similar significant changes (Qasim *et al.* 2011). As a result, it represents a constant change in the size of the land. Changes in ES availability, however, bring challenges to communities who depend on it for their livelihood (Chaudhary *et al.* 2016). Despite the huge reduction in forested area, communities in Oghaz village still rely on forests for fuel wood. Landscapes are always changing due to natural and anthropogenic factors, hence these affects are dynamic (Turner & Gardner 2015). Previous studies have reported that LULCC across a landscape can have a long-term impact on local biodiversity due to 'biotic lag' effects (Ewers *et al.* 2013). However, most research (Ullah *et al.* 2021) focused on smaller geographical regions and changes in forest cover, rather than focusing on the main effects of landscape-wide LULCC on local biodiversity across spatiotemporal ranges. Increased agricultural production affects 40% of land area, posing a serious threat to biodiversity (Foley *et al.* 2011). According to a Chinese study, increased food production and arable land have a negative impact on biodiversity (Hou *et al*. 2015). Intensive agricultural techniques and herbicide use are having an increasingly negative impact on the natural capacities of lands to sustain biodiversity and ecosystem function. The decrease in land used for wildlife habitats indicates that wildlife conservation is not an important source of livelihood for the local inhabit of the area. As a result, convincing the local population to maintain wildlife habitats because of its long-term benefits is impossible. Local residents benefit directly from the study area through timber, fuel wood, grazing, and horticulture crops. As a result, it is not surprising that they have recently cleared their land for human settlements, irrigation and infrastructure development, all at the expense of conservation efforts. Livestock overcrowding has led to overgrazing in the study area, especially in areas appropriate for feeding and breeding. The effects of overgrazing, as seen during the visit, include landslides, soil erosion and the emergence of invasive plant species. Overgrazing can disrupt the structure and composition of the vegetation, which can affect biodiversity and predator-prey interactions (Blaum *et al.* 2007).

Land use/cover changes affect the development of biodiversity in the study area, and so the transition of forest and woodland into pasture and arable land exposes wild animals to illegal hunting, eventually leading to an increase in human-wildlife conflicts. Our findings have major implications for conservation and management in developing countries' more human-dominated forest landscapes (Newbold *et al.* 2020, Sol *et al.* 2020). In the recent decade, changing land use patterns in Marghazar have led to the loss of key habitats and decline in partridge's population. The land that used to be good for partridge habitat is now personal land. The regions that have been transformed into human settlements are no longer accessible to partridges. Urbanization has been particularly noticeable in places where partridge favorability has declined, suggesting that it may have had a significant negative impact on partridges population. This is supported by a study conducted on Arizona native birds (Green & Baker 2003). Replacement of natural forests with monocultures of tree species has been a major source of biodiversity loss in various parts of the world (Ullah *et al.* 2021). Our studies clearly indicate that recent landscape changes in this region have altered the distribution of favorable habitats for partridges. It is noteworthy, for example that the proportion of areas that are suitable for natural vegetation in 2012, has dropped in areas where the species' habitat has degraded. In contrast, partridge favorability increased as the area under these vegetation types increased, especially in scrubland. Newbold *et al.* (2020) and Sol *et al*. (2020) also found similar findings in global reviews of field studies. The biodiversity of the study area and other portions of the valley will continue to decline as a result of this changes. Despite the fact that anthropogenic deterioration is producing significant habitat fragmentation in the valley, the majority of biodiversity, including flora and fauna goes unquantified. Linking land use/cover and biodiversity loss is crucial for determining how much we have lost and how much we will lose if the current trend continues. Political producers and regulators should adopt an approach to providing "buffer zones" around key biodiversity sites, while promoting community and cultural activities to enhance the biodiversity of the region and improve local livelihoods (Munishi *et al.* 2011).

Conclusions

There is clear evidence that Marghazar valley land use/cover has changed drastically over time. The majority of the region was transformed into agricultural, urbanization, and grazing area as a result of anthropogenic activities. The biodiversity of the area is being degraded by the local community. The majority of the population is impoverished, illiterate, and unconcerned about biodiversity conservation. Conservation efforts for wildlife habitats and communities will aid in the maintenance of a variety of ecosystem services that will benefit human well-being.

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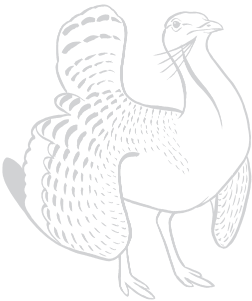

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MaxEnt modelling for predicting habitat suitability and future range of Black-breasted Parrotbill (*Paradoxornis flavirostris* Gould, 1836) in Northeast India

Chiranjib Bora* & Prasanta Kumar Saikia

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Bora, C. & Saikia, P. K. 2024. MaxEnt modelling for predicting habitat suitability and future range of Black-breasted Parrotbill (*Paradoxornis flavirostris* Gould, 1836) in Northeast India. – Ornis Hungarica 32(2): 31–44. DOI: 10.2478/orhu-2024-0003

Abstract Habitat suitability models are powerful tools in predicting species distributions and assessing the potential impacts of environmental changes. In this article, a habitat suitability model was developed for *Paradoxornis flavirostris*, a threatened (Vulnerable) bird species found in the northeastern part of India, using remote sensing data and machine learning techniques. The occurrence records for *P. flavirostris* were considered from primary as well as multiple secondary sources like GBIF & eBird, and bioclimatic variables such as temperature, precipitation, and humidity were collected from www.worldclim.org. Then, MaxEnt algorithm was used to model the habitat suitability of *P. flavirostris* based on the collected data. Additionally, the model was also run to project the future range of *P. flavirostris* under different climate change scenarios. The model also predicts potentially suitable habitats for *P. flavirostris* outside of its current range, suggesting areas where the species may expand or contract its distribution in the future. This research provides valuable insights into the habitat suitability and potential range dynamics of *P. flavirostris*, and can inform conservation planning and management efforts for this threatened bird species.

Keywords: Habitat Suitability Model, MaxEnt, vulnerable, climate change, *Paradoxornis flavirostris*

Összefoglalás Az élőhely-alkalmassági modellek hatékony eszközök a fajok elterjedésének prediktálására és a környezeti változások potenciális hatásainak becslésére. A jelen cikkben egy veszélyeztetett (Sérülékeny – IUCN), India északkeleti részén élő madárfaj, a dzsungel-papagájcsőrű cinege *Paradoxornis flavirostris* élőhely-alkalmassági modelljét készítettük el távérzékelési adatok és géptanulásos technikák alkalmazásával. A vizsgált faj előfordulási adatait elsődleges és számos másodlagos forrásból gyűjtöttük, mint amilyen a GBIF vagy az eBird, míg a bioklimatikus változókat (hőmérséklet, csapadék és páratartalom) a worldclim.org adatbázisból töltöttük le. Ezt követően a MaxEnt algoritmust alkalmaztuk a *P. flavirostris* élőhely-alkalmassági modelljének elkészítéséhez. A modellt arra is alkalmaztuk, hogy a faj különböző klímaváltozási szcenáriók szerinti jövőbeli elterjedési területeit jósoljuk. A modell alkalmas élőhelyeket jelez a *P. flavirostris* számára a jelenlegi elterjedési területén kívül, illetve olyan területeket is jelez, amelyekre a faj jövőbeli elterjedése kiterjedhet vagy szűkülhet. A kutatás értékes szempontokat fogalmaz meg a vizsgált faj élőhely-alkalmassági és potenciális elterjedési területbeli dinamikája szempontjából, valamint e veszélyeztett faj megmentését célzó fajmegőrzési és élőhelykezelési programokhoz.

Kulcsszavak: élőhely-alkalmassági modell, MaxEnt, veszélyeztett, klímaváltozás, *Paradoxornis flavirostris*

Department of Zoology, Gauhati University, Guwahati-781014, Assam, India
** corresponding author, e-mail: chiranjibbora9@gmail.com*

Introduction

Black-breasted Parrotbill (*Paradoxornis flavirostris* Gould 1836) is a globally threatened passerine that has been listed as a Vulnerable species in the IUCN Red List. This species is endemic to the Indian subcontinent, appearing in the plains and foothills of Arunachal Pradesh and Assam of northeastern India (BirdLife International 2001). Individuals are known for their distinct black breast and yellow bill, and are a popular subject for ornithologists and bird enthusiasts *(Figure 1A)*. This species is one of the few that specializes in lowland reed swamps and tall grassland habitats *(Figure 1B)*. Formerly the species was recorded commonly, from the upper Assam region (India), particularly observed from many localities, like Dhansirimukh (near Kaziranga) in the west, to Dibrugarh in the east, and in the basin of the Subansiri river near North Lakhimpur, from where series of specimens were collected (Stevens 1914). Subsequently, it seems that the species was unreported for a significant portion of the 1900s, and by the 1990s, it was included among the rarest birds of India. Except for one oral report from Jaldapara Wildlife Sanctuary in 1984 (which was the last time the species was documented at this location), the species was virtually unknown from 1911, until it was re-discovered at Dibru-Saikhowa National Park (Choudhury 1995, Allen 2002, Choudhury 2006, Krishnan 2021) and Kaziranga National Park (Barua & Sharma 1999) in the 1990s. It was also discovered at D'Ering Memorial Wildlife Sanctuary, Arunachal Pradesh around the same time (Singh 1995). Additionally, it has since been discovered in Manas National Park, Assam (Choudhury 2011), considerably to the west of recently known areas, and Keibul Lamjao National Park, Manipur (Rahmani 2016, Rahmani *et al.* 2018), from where it was previously unknown, grasslands in the Siang (A. Choudhury, personal observation, Krishnam 2021) and Dibang river valleys (Rahmani *et al.* 2018). However, there are no recent records from West Bengal, Cachar, the Subansiri basin in Assam, or Bangladesh. The remaining populations appear severely fragmented and isolated from each other and are likely declining. Formerly, the species may have occurred wherever

Figure 1. **A.** Black-breasted Parrotbill. **B.** Habitat of Black-breasted Parrotbill (Photo: © Chiranjib Bora)

1. ábra **A.** dzsungel-papagájcsőrű cinege. **B.** A dzsungel-papagájcsőrű cinege élőhelye (Fotó: Chiranjib Bora) there was suitable grassland in its range, suggesting that the extensive loss of grassland has isolated populations from each other (Collar *et al.* 2001). The primary threat to the Black-breasted Parrotbill (BBP) is habitat loss due to the drainage and conversion of floodplain grasslands (Rahmani 2016, Krishnan 2021).

Climate change is an important determinant of the range of many species (Pearson & Dawson 2003), also birds are highly sensitive to it, with a strong ability to move. They are often considered as pioneering indicator species of climate change on animals (Stephens *et al.* 2016). Changes in the climate are correlated with the temporal organization of bird species, including migration and breeding (Brown *et al.* 1999). Several bird species are likely to be affected by climate change in the future (Sekercioglu *et al.* 2008). Therefore, assessing the suitable habitat as well as the impact of climate change on threatened and endemic bird species is crucial for its conservation efforts. Habitat Suitability Models (HSM) are powerful tools and are applied in many fields of ecology, yet their outputs are based on several assumptions. Specially, in studies on biological consequences of climate change, HSMs have been used extensively to estimate the current distributions and future range shifts of species (Araujo & New 2007, Thuiller *et al.* 2008, Li *et al.* 2010, Li & Wang 2012). Researchers have described a wide variety of Habitat Suitability Models (HSMs) based on the algorithms. (Li & Wang 2013, Jha 2021).

Objective of the study

This study aims to estimate the current as well as the future geographic range of the Black-breasted Parrotbill, also the influential bioclimatic variables for the northeastern region of India using Habitat Suitability Modelling.

Materials and Methods

Study extent

The HSM was performed for the northeastern region of India which is an entity of eight states (Assam, Arunachal Pradesh, Manipur, Nagaland, Meghalaya, Tripura, Mizoram, and Sikkim). However, seven states (excluding Sikkim) were considered for this study. Presently, BBP is restricted only in the 3 states of NE India (Assam, Arunachal Pradesh, and Manipur), to evaluate the future range of BBP, the other 4 states were also considered.

Species occurrence data and bioclimatic predictors

Occurrence records of BBP were considered from primary field surveys as well as secondary sources like available literature and the Global Biodiversity Information Facility (GBIF, https://www.gbif.org). Literature were searched using the Google Scholar search engine and for model purposes, 84 occurrence points were considered *(Figure 2)*. To assess the current as well as future distribution range of BBP 19 bioclimatic variables *(Table 1)* downloaded

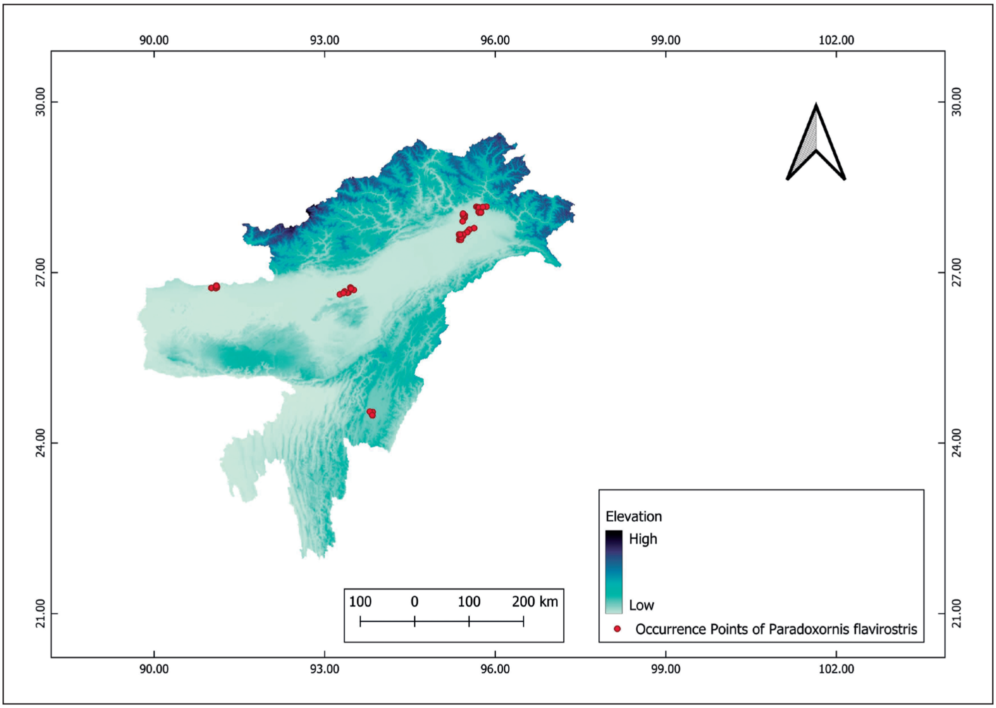


Figure 2. Map showing the study extent and the locations of the BBP
2. ábra A vizsgált terület és a vizsgált faj előfordulási adatainak térképe

at a spatial resolution of 30 arc sec (approx. 1 km resolution at the equator) from the Worldclim Climate database, version 2.1 (https://www.worldclim.org, Hijmans *et al.* 2005). These variables were calculated from minimum, maximum and average values of monthly, quarterly, and annual ambient temperature as well as precipitation values recorded from 1950–2000. As these bioclimatic variables are often correlated, this results in poor model performance and misleading interpretations (Dormann *et al.* 2013). Therefore, Pearson's correlation analysis was performed and the variables which had a correlation coefficient (r<0.7) were selected for modelling. A total of 7 bioclimatic variables viz., Bio1, Bio2, Bio3, Bio4, Bio5, Bio12, and Bio18 *(Table 1)* along with the elevation were retained for modelling the distribution of *Paradoxornis flavirostris* in Northeast India. For future climatic scenarios, bioclimatic variables from HadGEM3-GC31-LL of the Coupled Model Intercomparison Project Phase 6 (CMIP6) model for Shared Socio-economic Pathways (SSPs) 126 and 585 for the period "2041–2060" (2060s) and "2081–2100" (2100s) were considered to look into two different future scenarios with enough temporal intervals to allow for the observation of potential medium- and long-term trends and changes in species distributions.

Model algorithm

Maximum entropy (MaxEnt) is an efficient modelling algorithm for making predictions from presence-only data on species' distribution (Phillips *et al.* 2006, Tesfamariam *et al.* 2022).

Table 1. List of Bioclimatic variables (https://www.worldclim.org)
1. táblázat A bioklimatikus változók listája (https://www.worldclim.org)

Code	Environmental Variables	Unit
Bio1*	**Annual Mean Temperature**	°c
Bio2*	**Mean Diurnal Range (Mean of monthly (max temp – min temp))**	°c
Bio3*	**Isothermality (BIO2/BIO7) (×100)**	%
Bio4*	**Temperature Seasonality (standard deviation ×100**)	°c
Bio5*	**Max Temperature of Warmest Mont**h	°c
Bio6	Min Temperature of Coldest Month	°c
Bio7	Temperature Annual Range (BIO5-BIO6)	°c
Bio8	Mean Temperature of Wettest Quarter	°c
Bio9	Mean Temperature of Driest Quarter	°c
Bio10	Mean Temperature of Warmest Quarter	°c
Bio11	Mean Temperature of Coldest Quarter	°c
Bio12*	**Annual Precipitation**	mm
Bio13	Precipitation of Wettest Month	mm
Bio14	Precipitation of Driest Month	mm
Bio15	Precipitation Seasonality (Coefficient of Variation)	%
Bio16	Precipitation of Wettest Quarter	mm
Bio17	Precipitation of Driest Quarter	mm
Bio18*	**Precipitation of Warmest Quarter**	mm
Bio19	Precipitation of Coldest Quarter	mm

Used for Modelling Purposes

It establishes the relationship between the environmental conditions at the locations where the species occurs and the environmental conditions throughout the remainder of the study area. The main goal of MaxEnt is to find a probability distribution with the largest entropy, or most spread out while taking into account the limitations imposed by the data on species existence and related environmental factors throughout the area of study (Phillips *et al.* 2006, Elith *et al.* 2011, Tesfamariam *et al.* 2022). MaxEnt uses a deterministic sequential-update algorithm that iteratively picks and adjusts the weights of predictors, which is guaranteed to converge to the maximum entropy probability distribution (Phillips *et al.* 2004, 2006, Tesfamariam *et al.* 2022).

Model evaluation

The area under the ROC curve (AUC): The receiver operating characteristic (ROC) curve provides an alternative technique for the assessment of the accuracy of ordinal score models (Fielding & Bell 1997). The sensitivity and specificity of each confusion matrix are obtained by applying all feasible thresholds for score classification, and the resulting ROC curve is constructed by comparing the sensitivity to the corresponding proportion of false positives (equal to 1 – specificity). Using all thresholds avoids the arbitrary choice of a single threshold

(Manel *et al.* 2001, Liu *et al.* 2005), and considers the trade-off of sensitivity and specificity (Pearce & Ferrier 2000, Shabani *et al.* 2018).

Sensitivity and Specificity: Sensitivity is calculated as, *a/a+c* where *a* is the number of cells in which the species was detected but whose absence was predicted by the model, and *c* is the number of cells in which the existence of the species was properly predicted. Specificity is a measure of how many absences are accurately projected, which allows for the calculation of commission errors. Specificity is calculated as *d/b+d*, where *d* is the number of cells that the model correctly predicts to be absent and *b* is the number of cells in which the species was not found. It's crucial to remember that when comparing models, sensitivity and specificity are independent of one another, and prevalence, which is the percentage of sites where the species was found to be present (Shabani *et al.* 2018).

Data analysis

The habitat suitability model was performed in RStudio (ver. 2023.09.1+494 „Desert Sunflower") with the help of packages: raster (3.6-23), rgdal (1.6-7) and rjava (1.0-6). The output raster images were reclassified using ArcMap (Ver. 10.8) in four different classes such as: 'Not Suitable'<0.2, 'Moderately Suitable'<0.4, 'Highly Suitable'<0.6 and 'Excellent'>0.6. Then, it was converted to a polygon using the conversion tool in ArcMap and calculated the area of each class. The final maps were also prepared in ArcMap (10.8).

Results

Habitat suitability model

The HSM was performed with 84 BBP locations from the north-eastern region of India. The result shows that the average test AUC (area under curve) for the replicate runs is 0.935 *(Table 2)*. The AUC of the model indicates that above 93.5% of the area was well predicted. The current climatic scenario shows that Temperature Seasonality (Bio4) played a major role from the climatic perspective in the distribution of BBP, with a 17.27% contribution. Further, the future models show that with the global climate change, Temperature Seasonality (Bio4) and Max Temperature of Warmest Month (Bio5) will

Table 2. AUC, Sensitivity, and Specificity values for the model run
2. táblázat A modellfuttatások AUC, modellérzékenységi és specifitási értékei

Parameters	**Current Model**	**Future Models**			
		2041–2060		**2081–2100**	
		SSP_126	**SSP_585**	**SSP_126**	**SSP_585**
AUC	0.935	0.936	0.934	0.921	0.88
Sensitivity	0.94	0.94	0.94	0.92	0.88
Specificity	0.93	0.933	0.928	0.922	0.88

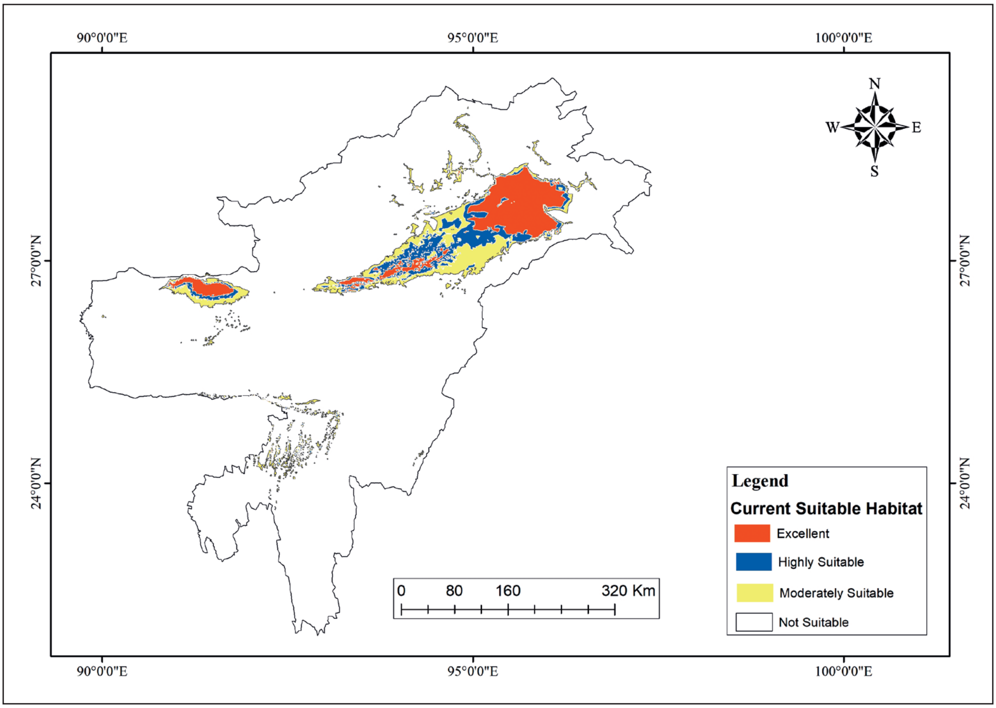


Figure 3. Map showing current potential range of Black-breasted Parrotbill in the study extent
3. ábra A dzsungel-papagájcsőrű cinege vizsgált területen belüli potenciális elterjedési területét ábrázoló térkép

play major roles in the distribution of BBP by the 2060s and 2100s climate scenarios, respectively. However, the geophysical variable i.e. altitude also played a major role in three climatic scenarios for the BBP habitat.

Current suitable habitat of Black-breasted Parrotbill in study extent

The current suitable habitat of BBP is mainly concentrated in the selected areas of Study Extent. Out of the total area of 253,393.02 km^2 in the study extent, 10,848.08 km^2, 7,743.48 km^2, 10,216.89 km^2, and 224,568.62 km^2 were predicted to be 'Excellent', 'Highly suitable', 'Moderately suitable' and 'not suitable' for BBP respectively *(Figure 3)*. The results also showed the potential suitable habitat within the protected areas of Northeast India, where BBP is recorded. Dibru-Saikhowa National Park and D'Erring Wildlife Sanctuary of Arunachal Pradesh fall under the 'excellent' suitable area for the BBP. Also, Kaziranga National Park and Manas National Park showed a substantial percentage of 'Excellent' and 'Highly Suitable' areas but Keibul Lamjao National Park did not show suitable areas for the species *(Figure 4)*.

Future predictive suitable habitat of Black-breasted Parrotbill in study extent

The world's flora and fauna could be severely impacted by global climate change. The study models showed that as climate change accelerates, the total potential habitat of BBP in Northeastern India would decrease. The study models revealed that the overall potential

Table 3. Probable potential area for Black-breasted Parrotbill in current and future climate change scenarios

3. táblázat A dzsungel-papagájcsőrű cinege valószínűsíthető potenciális elterjedési területe a jelenlegi és jövőbeli klímaszcenáriók alapján

Class	**Current**		**2041-2060_SSP 126**		**2041-2060_SSP 585**		**2081-2100_SSP 126**		**2081-2100_SSP 585**	
	km²	**%**	**km²**	**%**	**km²**	**%**	**km²**	**%**	**km²**	**%**
Not Suitable	224568.62	88.63	226748.93	89.49	226593.63	89.57	226424.6	89.36	230507.9	90.97
Moderately Suitable	10216.892	4.03	10676.118	4.21	10871.85	4.29	11948.95	4.72	11398.87	4.5
Highly Suitable	7743.486	3.06	7469.248	2.95	7240.672	2.85	6989.38	2.76	4931.49	1.95
Excellent	10848.082	4.28	8472.024	3.34	8300.22	3.27	8004.792	3.16	6533.68	2.57

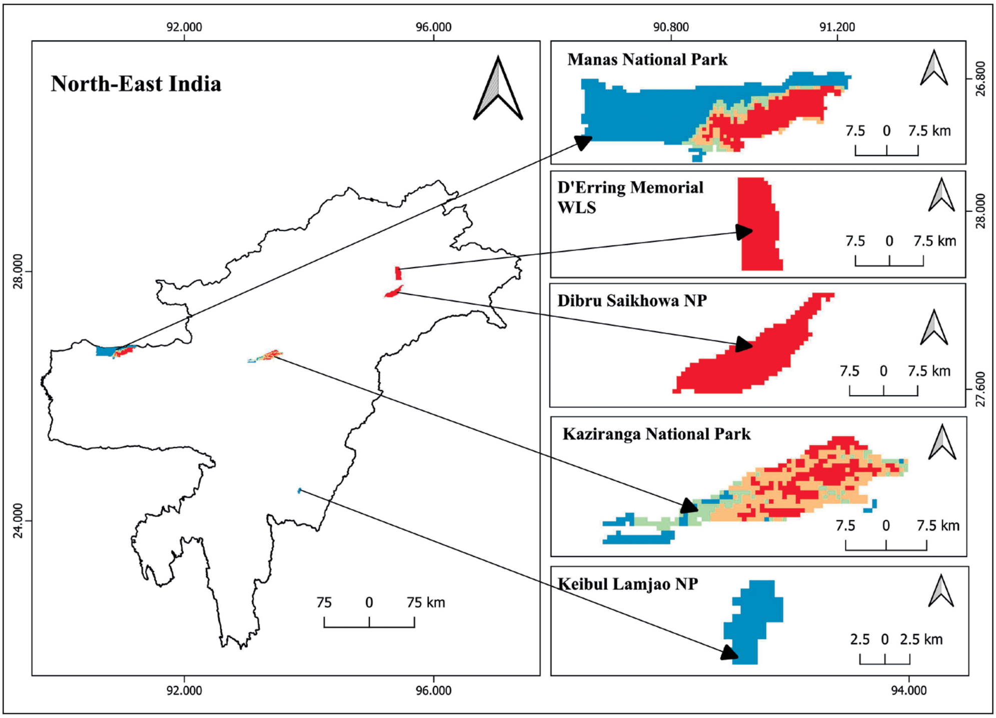
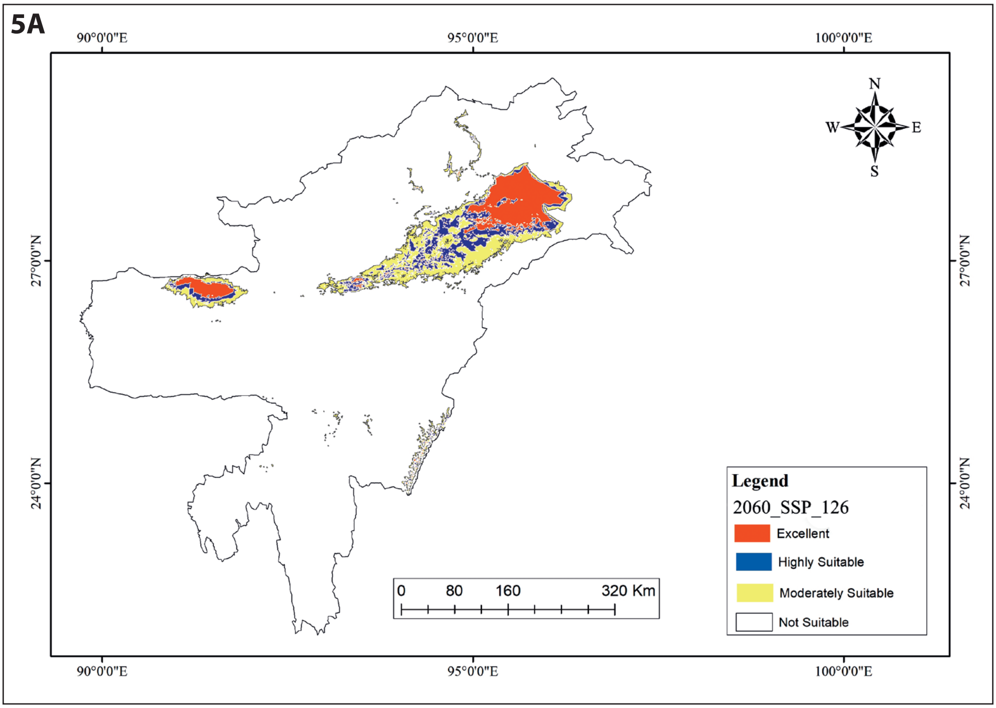


Figure 4. Map showing current potential range of Black-breasted Parrotbill in the Protected areas where the species is still present

4. ábra A dzsungel-papagájcsőrű cinege még jelenlévő állományait tartalmazó védett területeken belüli potenciális elterjedési területét ábrázoló térkép

5A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2060_SSP_126
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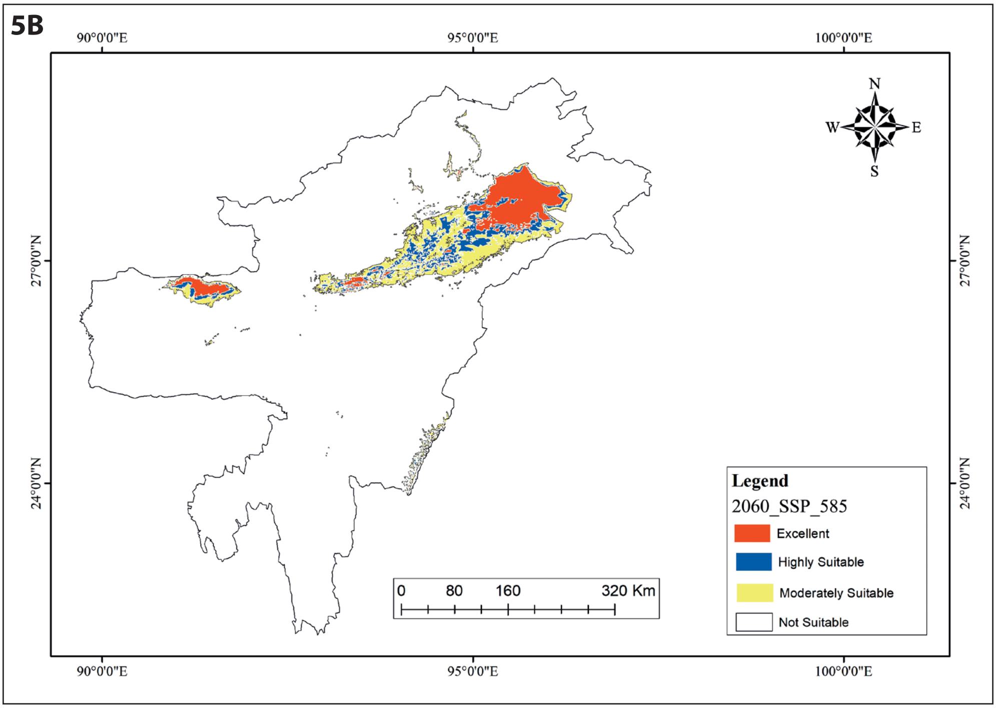
5B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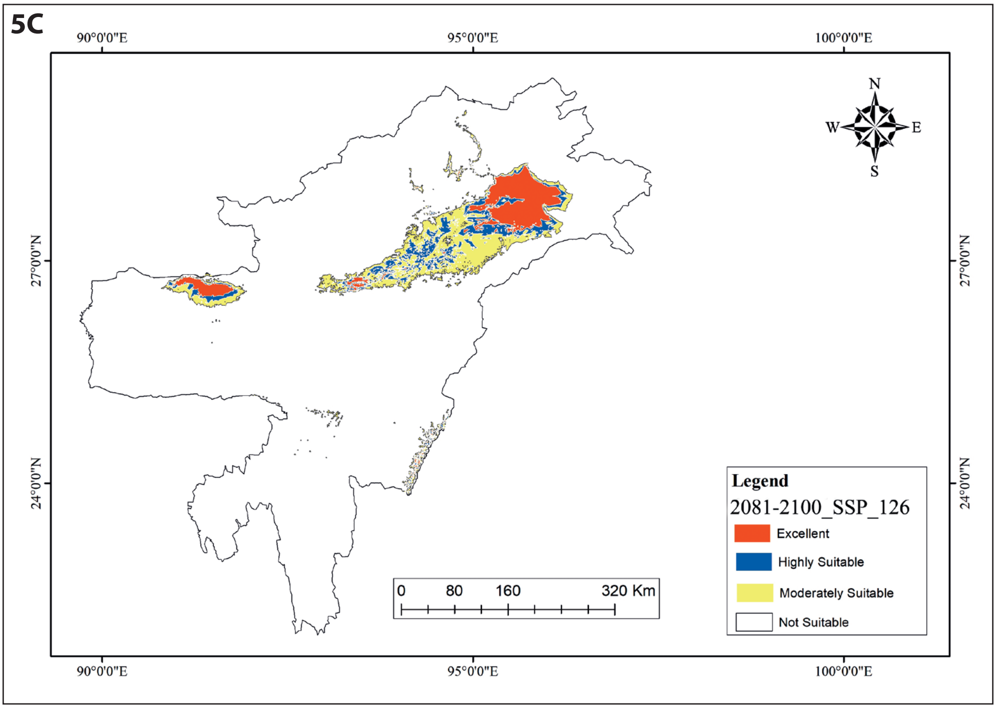
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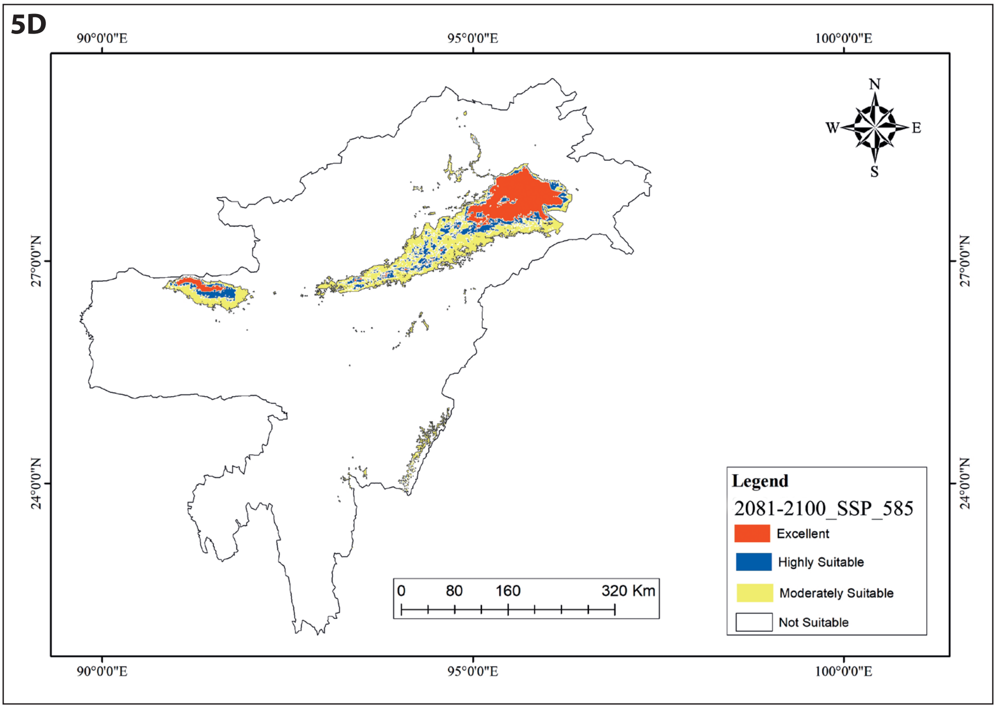
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Legend
2081-2100_SSP_585
Excellent
Highly Suitable
Moderately Suitable
Not Suitable

Figure 5. **A.** Map showing future (2041–2060_SSP126) potential range of Black-breasted Parrotbill in the study extent, **B.** Map showing future (2041–2060_SSP585) potential range of Black-breasted Parrotbill in the study extent, **C.** Map showing future (2081–2100_SSP126) potential range of Black-breasted Parrotbill in the study extent, **D.** Map showing future (2081–2100_SSP585) potential range of Black-breasted Parrotbill in the study extent.

5. ábra **A.** A dzsungel-papagájcsőrű cinege vizsgált területre eső, jövőbeli (2041–2060_SSP126) potenciális elterjedési területét ábrázoló térkép; **B.** A dzsungel-papagájcsőrű cinege vizsgált területre eső, jövőbeli (2041–2060_SSP585) potenciális elterjedési területét ábrázoló térkép; **C.** A dzsungel-papagájcsőrű cinege vizsgált területre eső, jövőbeli (2081–2100_SSP126) potenciális elterjedési területét ábrázoló térkép; **D.** A dzsungel-papagájcsőrű cinege vizsgált területre eső, jövőbeli (2081–2100_SSP585) potenciális elterjedési területét ábrázoló térkép

habitat of BBP in the region would shrink due to climate acceleration *(Table 3)*. Areas with high potential will be decreased at a higher rate *(Figure 5A–D)*. Only 6,533.68 km^2 of the excellent potential area will exist in 2081–2100 (SSP585) *(Table 3)*. Between 2041–2060 (SSP585) and 2081–2100 (SSP585), there will be a loss of 1,938.34 km^2 of the excellent potential habitat under the influence of climate change. Areas with the non-potential and moderate potential will increase, whereas areas with excellent and high potential will decrease.

Discussion

The small, declining, and fragmented populations of Black-breasted Parrotbill are severely affected by the various anthropogenic factors. Within the range of the species, vast tracts of grassland have been transformed into plantations and agriculture, or have been submerged and changed by dams and irrigation projects. Remaining areas of grassland, even within protected areas, are potentially threatened by overgrazing, harvesting for thatch and fodder, inappropriate fire management practices, and the construction of hydroelectric projects (particularly on the Subansiri, Dibang, and Siang rivers) (Collar 2001, Rahmani 2016, Krishnan 2021). In India, grasslands are generally poorly represented in protected areas, and they are neglected in conservation policy, which further compounds the conservation problems facing the fauna of these habitats (Krishnan 2021). Along with these factors changing climate will also affect the remaining populations of the BBP. The 'current' model showed most of the suitable areas in the eastern part of the study extent. Dibrisaikhowa National Park and D'Erring Wildlife Sanctuary are the two protected areas that hold most of the 'excellent' potential areas, even in future models these two Protected areas also hold a substantial portion of 'excellent' potential areas. So, the grasslands of this region require serious conservation attention.

The ecology and population sizes of species are largely affected by climate change, including by altering ranges (Miller-Rushing *et al.* 2010, Deka *et al.* 2022). The ranges of many bird species are already shifting towards higher altitudes, allowing species to survive in new locations (Root *et al.* 2003, Deka *et al*. 2022). However, changes in climatic conditions can cause range expansions in some species (Miller-Rushing *et al.* 2010, Deka *et al.* 2022). The study revealed the range shift of the species in the future climate scenarios. The easternmost population showed a range shift towards high altitude and the southernmost population showed a range shift towards the eastern direction. The distributions of several terrestrial organisms are currently shifting due to climate change (Chen *et al.* 2011, Deka *et al.* 2022). However, range shifting is determined by a combination of internal species traits and external change drivers. The most common range shifts reported in response to recent climate change are poleward and altitudinal (Lenoir *et al.* 2015, Deka *et al.* 2022). With this regard, BBP may shift its range towards 2060s.

The study forecasted the potential suitable areas for the Black-breasted Parrotbill in the northeastern region of India. The spatial resolution of 1 km helped to precisely predict the suitable habitats through modelling. Bioclimatic factors regarding temperature and precipitation are significant in defining the BBP's distribution. The results showed the potential distribution range for the species which draws a baseline for future research work on this species. Additionally, our result enables the locating of sensitive habitat zones for immediate conservation actions. Also, there is an urgent need for public awareness and capacity-building initiatives from non-governmental organizations (NGOs), other institutions, Government agencies, and forest dwellers to safeguard the Black-breasted Parrotbill population from further declining.

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Effects of body mass and taxonomic order on the masses of functionally classified groups of the jaw musculature in birds

D. Charles Deeming*, Shannon L. Harrison & Gregory P. Sutton

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Abstract There is increasing interest from evolutionary biologists in the evolution of avian bill shape, how the bill is used during feeding and, in particular, the bite forces the bill can deliver. Bite force exhibits isometry with the total mass of the jaw musculature, but there is variation in the functional categories of the jaw muscles in different avian taxa. Qualitative descriptions of the jaw musculature do not allow analysis of the relative contributions that adductor or retractor muscles play in generating a bite force. This study is a meta-analysis of published data for body mass and the mass of the jaw musculature in 66 bird species from 10 orders. The masses of the different muscles contributing to adduction and retraction in closing the jaw, and to depression and protraction in opening the jaw, were summed and allometric relationships explored before investigating the effects of taxonomic order on these relationships. The categories of muscles, and the masses of each category of jaw musculature varied among avian orders. Some species, such as the flightless ratites, had relatively small jaw muscle mass but parrots had an additional adductor muscle. Phylogenetically controlled relationships between body mass and the mass of each muscle category irrespective of taxonomic order were isometric. However, analysis of covariance revealed significant interactions between body mass and taxonomic order. Most orders had low values for body-mass-specific muscle masses in the jaw with the notable exceptions of the Passeriformes (songbirds) and Psittaciformes (parrots). The values of these orders were 3–4 times greater, although the relative amounts of muscles contributing to adduction and retraction were similar in Psittaciformes, but adduction was markedly higher in Passeriformes. The results of these analyses highlight the lack of species-specific data for most birds, which is adversely impacting our understanding of the anatomical features that are determining the functional properties of the bill during feeding.

Keywords: anatomy, jaw, adductor muscles, allometry, depressor muscles, protractor muscles, retractor muscles

Összefoglalás Az evolúcióbiológusok egyre nagyobb érdeklődést mutatnak a madárcsőr alakjának evolúciója, a csőr táplálkozás közbeni használata, és különösen a csőr által kifejtett harapási erő iránt. A harapás erőssége izometriát mutat ("pozitívan korrelál") az állkapocs teljes izomzatának tömegével, azonban eltérések vannak az állkapocs izmok funkcionális kategóriáit illetően az egyes madártaxonok között. Az állkapocs izmainak minőségbeli leírása nem teszi lehetővé a nyitó- és záróizmok elemzését a tekintetben, hogy mennyiben járulnak hozzá a harapás erejéhez. Jelen tanulmány egy metaanalízis a már publikált testtömeg és az állkapocs izomzat tömegének adataira vonatkozóan 10 rendből, 66 madárfaj esetében. Az állkapocs zárásához a közelítő és retractor, valamint az állkapocs nyitásához a lefelé húzó és protractor mozgásban résztvevő izmok tömegeit összegeztük és allometrikus összefüggéseket véltünk felfedezni mielőtt megvizsgáltuk volna a különböző csoportok ezen összefüggésekre gyakorolt hatásait. Az izomcsoportok és az izomcsoporthoz tartozó tömegek eltérnek a különböző madárcsoportok között. Egyes fajok, például a röpképtelen futómadarak relatív kicsi izomtömeggel rendelkeznek, ellenben a papagájok esetében egy további adduktor izom is megfigyelhető. A filogenetikailag kontrollált kapcsolatok a testtömegre és az egyes izomcsoportokra vonatkozóan rendtől függetlenül izometrikusak. Ennek ellenére a kovarianca elemzés szignifikáns kapcsolatot mutatott a rend és a testtömegadatok között. A legtöbb rend alacsony értékeket mutatott a testtömeg specifikus izomtömegre az állkapocsra vonatkozóan, ez alól kivételt csak a Passeriformes (verébalakúak) és a Psittaciformes (papagájalakúak) rendek képeztek. Ezeknek a rendeknek az esetében az értékek háromszor-négyszer nagyobbak, bár a relatív mennyisége a közelítés és visszahúzás során szerepet játszó izmoknak a Psittaciformes rendnél hasonló volt, de a közelítés tekintetében jelentősen nagyobb volt a Passeriformes rend esetében. Az elemzés eredményei rávilágítanak a fajspecifikus adatok hiányára a legtöbb madár esetében, amelyek hátrányosan befolyásolják azoknak az anatómiai jellemzőknek a megértését, amelyek meghatározzák a csőr funkcionális jellemzőit a táplálkozást illetően.

Kulcsszavak: anatómia, állkapocs, adduktor izmok, allometria, záróizmok, protraktor izmok, retractor izmok

Department of Life Sciences, School of Life and Environmental Sciences, University of Lincoln, Joseph Banks Laboratories, Lincoln, LN6 7DL, UK
**corresponding author, e-mail: cdeeming@lincoln.ac.uk*

Introduction

Variation in bill morphology is a key aspect of feeding behaviour in birds with bill types being generally associated with the acquisition and manipulation of a particular food type. For example, competition among wading shorebirds (Charadriiformes) is often circumvented by different bill lengths and shapes that are specialised for feeding on different prey items (Ritchison 2023). Food acquisition and manipulation requires the bill to apply sufficient source to secure the food item and then to process it prior to swallowing; for example, for granivorous finches (Fringillidae, Passeriformes) typically de-husk seeds before swallowing the kernels (van der Meij & Bout 2006). Therefore, bite force is of increasing interest from evolutionary biologists because it helps to determine food selection and acquisition in birds and is important to their feeding behaviour and broader ecology (Herrel *et al.* 2005, van der Meij & Bout 2004, 2006, 2008, Sustaita & Hertel 2010, Corbin *et al.* 2015, Soons *et al.* 2015, Bright *et al.* 2016, 2019, Cooney *et al.* 2017, Navalón *et al.* 2019, Deeming *et al.* 2022).

A bite force is a consequence of the forces generated by the various jaw muscles being transmitted via the mechanical apparatus of the jaw (Bright *et al.* 2016). Deeming *et al.* (2022) reviewed patterns of bite force in birds and showed that, when controlling for phylogeny, there was a significant positive allometric relationship between total jaw muscle mass and bite force, despite considerable variation between taxa for any given body mass. Moreover, whilst bite force in birds varied with body mass, non-passerine species generated lower mass-specific bite forces compared with passerine species, which seemed to reflect smaller masses of jaw musculature, but this study was limited by the fact that it was based on a relatively small sample size of only 122 species from 14 different orders (Deeming *et al.* 2022).

The types of muscles observed in avian jaws can be categorised into four groups that are associated with closing or opening the bill (Burger 1978, Baumel *et al.* 2013, Bhattacharyya 2013). These are the adductors, which close the bill by raising the lower jaw, and the retractors, which close the bill by lowering the rostrum. Two other muscle categories are involved in opening the bill: the protractors elevate the upper jaw, and the depressors rotate the lower jaw around the quadrate bone. Many studies of the avian jaw musculature are descriptive (e.g. Burton 1974, Bhattacharyya 1994, Donatelli 2012, Quayle *et al.* 2014, Mahmoud *et al.* 2017). Different orders seem to vary in the categories of muscle present and in the levels of complexity of each muscle category (e.g. see Carril *et al.* 2015, Soons *et al.* 2015). For example, the adductor *musculus pseudotemporalis superficialis pars medialis* is present in some, but not all, New World Darwin's finches (Thraupidae; Passeriformes) and is one third of a subdivided *musculus pseudotemporalis* (Soons *et al.* 2015). By contrast, in the Old World Black-throated Finch (*Poephila cincta*, Estrildidae, Passeriformes) the *musculus pseudotemporalis* is subdivided into two (To *et al.* 2021). In *Phalacrocorax* cormorants (Phalacrocoracidae, Suliformes) the *musculus pseudotemporalis* is not subdivided (Burger 1978). Parrots (Psittaciformes) have an additional adductor, the *musculus ethmomandibularis*, which is rarely reported in other birds (Homberger 2003, 2017, Tokita 2003). Despite this variation, to date, there has been no analysis of the masses of the variety of jaw muscles in birds.

Bite force of birds can be measured directly (Carril *et al.* 2021), either determined from simulations using finite element analysis (Cost *et al.* 2020), or calculated from masses of the appropriate muscles (Sustaita 2008, Soons *et al.* 2015, Harrison 2023). Ultimately, the force of a bite is a function of the mass of jaw muscles that deliver the force to the jaw bones, yet birds seem to vary in the categories and amounts of jaw musculature (Sustaita 2008, Bhattacharyya 2013, Soons *et al.* 2015). For instance, the jaw can be closed by the action of both adductor and retractor muscles (Bhattacharyya 2013). The proportional difference in mass between these muscle groups may cause a relative difference in their bite force contribution (e.g. see Carril *et al.* 2015). Deeming *et al.* (2022) showed that the combined mass of the muscles used to close the jaw exhibited positive and negative allometric relationships with body mass for passerines and non-passerines, respectively. However, when the relationship between jaw muscle mass and bite force was modelled, there were no any notable differences between taxa; instead, there was an overall positive allometric relationship (Deeming *et al.* 2022). Deeming *et al.* (2022) suggested that perhaps the anatomical categories of the jaw musculature observed in birds might be involved in determining the magnitude of the bite force. Given the variation in bill morphology and size, and its association with food categories, the functional properties of the jaw musculature are increasingly of interest to evolutionary biologists (Bright *et al.* 2016, 2019, Navalón *et al.* 2019, Dickinson & Hartstone-Rose 2023).

This study is a meta-analysis of data collated from published reports to investigate the allometry of the relationships between body mass and the masses of each of the four jaw muscle categories. Although physiological cross-sectional area of muscle is an important determinant of force (Dickinson & Hartstone-Rose 2023), data for mass of muscles, which also strongly correlates with bite force (Deeming *et al.* 2022, Dickinson *et al.* 2022), were available for a wider range of taxa. The analysis tested the hypothesis that observations of taxonomic differences in jaw muscle morphology for birds translated into differences for their respective muscle masses. The analysis initially focussed on the allometry of each category of muscles irrespective of taxonomic order but progressed to investigate the prediction that taxonomy would be a significant factor in determining jaw muscle masses. The aim of the study was to determine whether avian jaw musculature is comparable among birds from different orders. Therefore, the masses of the adductor and retractor muscles were compared to test the prediction that there would be no difference in their relative roles in closing the jaw in different orders.

Methods

Data were collected from the peer-reviewed reports for the mass of the individual jaw muscles (mg) from one side of the jaw as described for a variety of bird species (Goodman & Fisher 1962, Burger 1978, Hull 1993, Gusseklo & Bout 2005, Sustaita 2008, pers. comm.

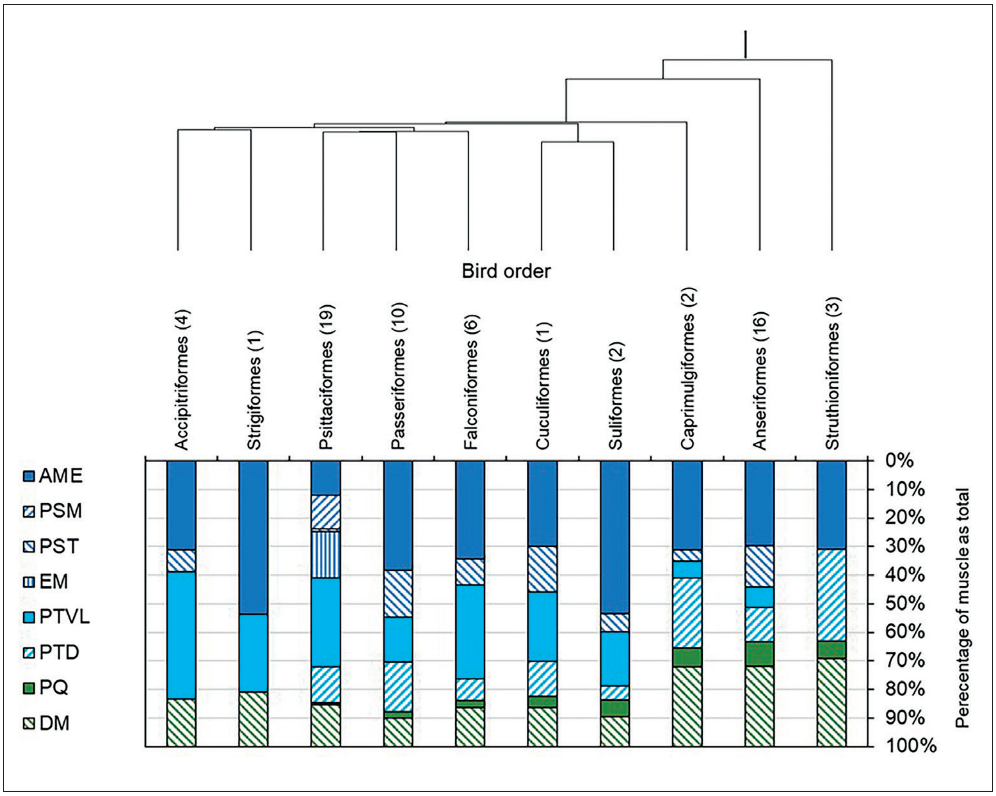

Figure 1. The percentage values of each muscle category associated with opening (green) or closing (blue) of the avian jaw expressed as a percentage of the total muscle mass. Adductors (dark blue): AME = *M. adductor mandibulae externus* complex; PSM = *M. pseudomasseter*; PST = *M. pseudotemporalis*; EM = *M. ethmomandibularis*; Retractors (light blue): PVTL = *M. pterygoideus ventralis*; PTD = *M. pterygoideus dorsalis*; Protractors (solid green): PQ = *M. protractor quadrati*. Depressors (hatched green): DM = *M. depressor mandibulae*. The degree of relatedness between the orders is shown by the phylogenetic tree was drawn up in birdtree.org using representatives of each order. The number of species represented in the order are shown in parentheses after the order name

1. ábra Az egyes izomkategóriákra vonatkozó értékek, amelyek az állkapocs nyitásában (zöld) és zárásában (kék) játszanak szerepet, százalékosan kifejezve a teljes állkapocs izomzat tömegéhez képest. Adduktorok (sötétkék): AME = *M. adductor mandibulae externus* complex; PSM = *M. pseudomasseter*; PST = *M. pseudotemporalis*; EM = *M. ethmomandibularis*; Retraktorok (világoskék): PVTL = *M. pterygoideus ventralis*; PTD = *M. pterygoideus dorsalis*; Protraktorok (középzöld): PQ = *M. protractor quadrati*. Depresszorok (sávozott zöld): DM = *M. depressor mandibulae*. Az egyes rendek közötti kapcsolat mértéke a birdtree.org által alkotott filogenetikai fán van feltüntetve. A rendhez tartozó fajok száma a rend mögött, zárójelben található

2021, Genbrugge *et al.* 2011, Carril *et al.* 2015, Soons *et al.* 2015, Demmel Ferreira *et al.* 2019, Pestoni *et al.* 2019, To *et al.* 2021, Harrison 2023). Mean body mass (g) for each species was derived from the original source or, if not measured, mean values reported by Dunning (2008) were used. In total, 66 species from 10 orders were represented in the dataset for jaw muscle masses (the number of species represented in each order is shown in *Figure 1*; see *Table 1* electronic supplementary materials). Not all muscle categories were present in all orders of birds; only 38 species sampled possessed protractor muscles.

Data were combined into the following four classifications of muscles according to their actions involved with opening or closing the jaw (Burger 1978, Bhattacharyya 2013). These were: (1) the adductors represented by the *m. adductor mandibulae externus* complex, *m. pseudotemporalis*, *m. pseudomasseter*, and, where present, *m. ethmomandibularis*; (2) The retractors represented by the *m. pterygoideus ventralis*, and *m. pterygoideus dorsalis*; (3) The protractors represented by the *m. protractor quadrati*; and (4) the depressors represented by the *m. depressor mandibulae*.

Where appropriate, data for mass were either $\log_{10}$-transformed (Fowler *et al.* 1995), or proportion data were logit-transformed (Warton & Hui 2011), prior to analysis. To account for non-independence of data points, a randomly generated phylogenetic tree of the 66 species in the dataset (see *Figure 1*, electronic supplementary materials) was produced based on a Hackett backbone using birdtree.org (Jetz *et al.* 2012). Using this tree, phylogenetically controlled general linear modelling (pglm) was performed in R (R Core Development Team 2021) using the packages *ape* (Paradis *et al.* 2004), *mvtnorm* (Genz & Bretz 2009) and *MASS* (Venables & Ripley 2002) as used by Deeming (2022). The models initially tested the effect of body mass on the mass of each muscle category. Further phylogenetically controlled analysis of covariance (run as a pglm) involved a reduced dataset in which orders were represented by more than two species and explored the effects of body mass as a covariate, and order as a categorical factor, on the mass of the four different muscle categories. Order

Table 1. Results of phylogenetically controlled analysis of covariance to test for the effect of order as a fixed factor and body mass as a covariate on the masses of the different categories of jaw muscles. Values are F-values with degrees of freedom in brackets and the p-value in parentheses. The coefficient of determination (R^2) and lambda (λ) value are included for each model

1. táblázat A kovariancia filogenetikailag ellenőrzött analízisének eredményei a rend, mint fix faktor és a testtömeg, mint kovariáns hatásának tesztelése a különböző állkapocs izom kategóriáinak tömegére. Az értékek F-értékek, zárójelben a szabadságfokokkal és a p-értékkel. A determinációs együttható (R^2) és a lambda (λ) értéke minden modellnél szerepel

Muscle category	LogBM	Order	Interaction	R^2	λ
Adductor	559.47 [1,48] (< 0.0001)	23.61 [7,48] (< 0.0001)	4.06 [7,48] (0.0014)	0.940	<0.0001
Retractor	453.34 [1,48] (< 0.0001)	25.38 [7,48] (< 0.0001)	4.80 [7,48] (0.0004)	0.933	<0.0001
Depressor	957.34 [1,47] (< 0.0001)	17.18 [7,47] (< 0.0001)	4.05 [7,47] (0.0015)	0.959	<0.0001
Protractor	654.34 [1,25] (< 0.0001)	14.10 [4,25] (< 0.0001)	3.10 [4,25] (0.0336)	0.967	<0.0001

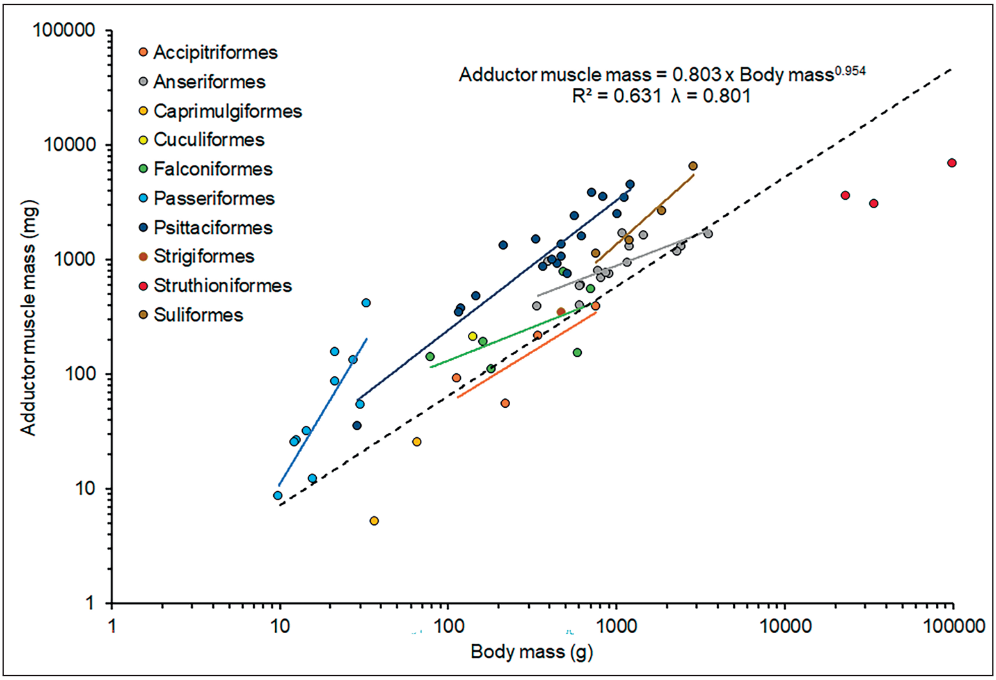

Figure 2. Relationship between body mass and the mass of the adductor muscles combined for a range of orders as indicated. Dashed line is the phylogenetically controlled relationship through all of the data points irrespective of order. Note the $\log_{10}$ scale on both axes. For slopes of coloured regression lines for each order (N > 3) see *Table 2.*

2. ábra A testtömeg és az adduktor izmok tömege közötti összefüggés az egyes rendekkel feltüntetve. A szaggatott vonal a filogenetikailag ellenőrzött kapcsolatot jelöli az összes adatponton, rendtől függetlenül. Az értékek mindkét tengelyen $\log_{10}$ skálán ábrázoltak. A színes regressziós egyenesek meredekségeihez tartozó értékek az egyes rendek esetében (N > 3) a 2. táblázatban találhatóak

was used as a factor here to explore differences between higher taxonomic groups but the analysis still had to be phylogenetically controlled because of the variation in body mass for the species represented in each of the orders, which could bias any relationship within an order. All models incorporated phylogeny as a random effect to deal with non-independence at the within-species level. Additional analysis explored the departure from isometry (slope = 1.0) by relationships between body mass and muscle masses within an order, where at least three species were represented. Comparison of slopes of all regression lines was performed using one-sample t-tests against an expected isometric slope of 1.0 (Bailey 1981). The phylogenetic signal (lambda, λ) was calculated by the analysis. A lambda value of 0 represented no evolutionary signal (no covariance in the residuals due to shared ancestry), and of 1 indicated that the observed covariance in residuals was expected under a Brownian motion model of trait evolution (Freckleton *et al.* 2002).

To compare patterns in the proportions of the adductor and retractor muscle masses, analysis of repeated samples from the same species involved phylogenetic mixed models (PMMs) using the MCMCglmm package (Hadfield 2010) as used by Deeming (2022).

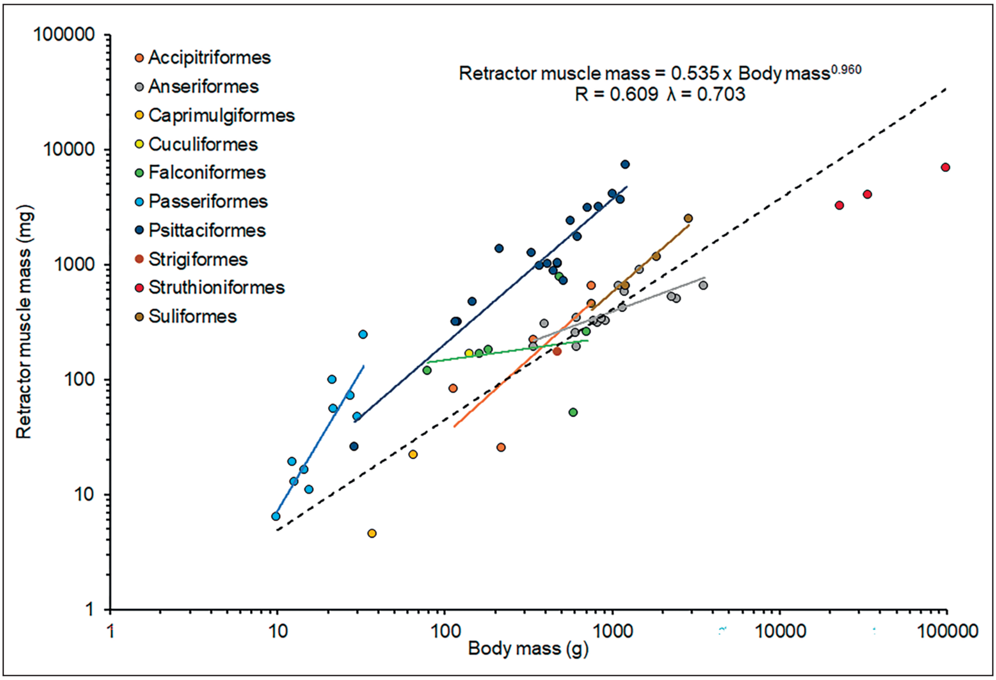

Figure 3. Relationship between body mass and the mass of the retractor muscles combined for a range of orders as indicated. Dashed line is the phylogenetically controlled relationship through all of the data points irrespective of order. Note the $\log_{10}$ scale on both axes. For slopes of coloured regression lines for each order (N > 3) see *Table 2*.

3. ábra A testtömeg és a retraktor izmok tömege közötti összefüggés az egyes rendekkel feltüntetve. A szaggatott vonal a filogenetikailag ellenőrzött kapcsolatot jelöli az összes adatponton, rendtől függetlenül. Az értékek mindkét tengelyen $\log_{10}$ skálán ábrázoltak. A színes regressziós egyenesek meredekségeihez tartozó értékek az egyes rendek esetében (N > 3) a 2. táblázatban találhatóak

This analysis included a phylogenetic covariance matrix, with species retained as a second random effect within the models (random = ~animal). The analysis ran 500,000 iterations for the MCMC models, with sampling taking place every 500 iterations after a burn-in of 10,000. Lambda (λ) was calculated by dividing the variance explained by the phylogeny by the sum of all variance components.

Results

Data on all muscle groups were not available in all orders; for instance, the *m. ethmomandibularis* and *m. pseudomasseter* were observed only in the Psittaciformes (parrots), and the *m. pseudotemporalis* was not reported in the one owl (Strigiformes) species in the dataset *(Figure 1)*. The *m. protractor quadrati* was not observed in the Accipitriformes (hawks and allies) or Strigiformes reported to date but formed almost 40% of the mass of muscles opening the jaw in Suliformes (cormorants; *Figure 1*). The proportions of the

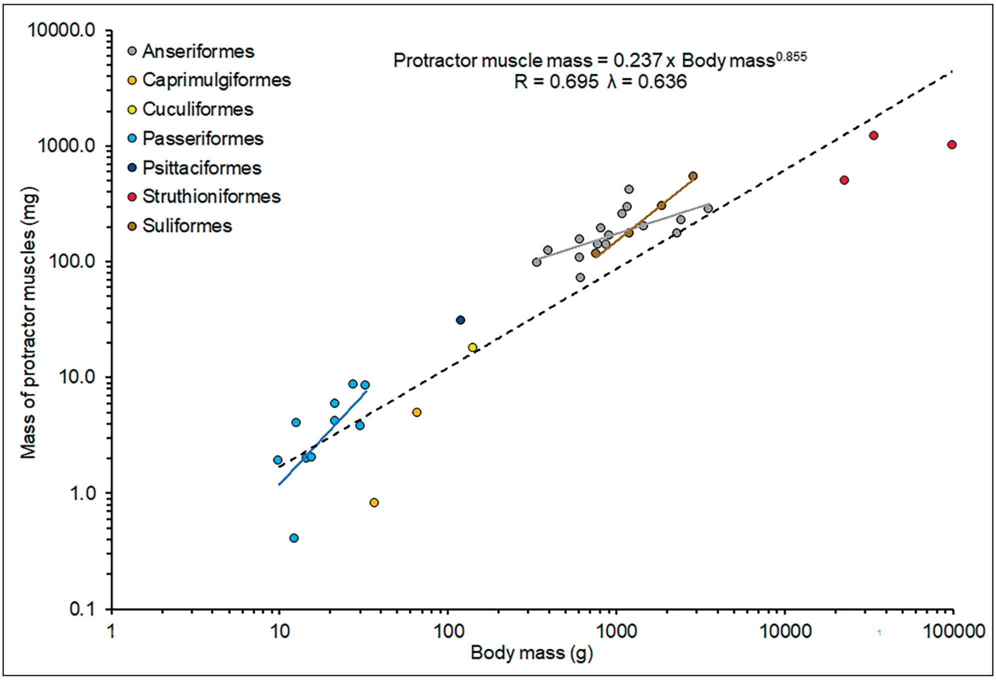

Figure 4. Relationship between body mass and the mass of the protractor muscles combined for a range of orders as indicated. Dashed line is the phylogenetically controlled relationship through all of the data points irrespective of order. Note the $\log_{10}$ scale on both axes. For slopes of coloured regression lines for each order (N > 3) see *Table 2*.

4. ábra A testtömeg és a protraktor izmok tömege közötti összefüggés az egyes rendekkel feltüntetve. A szaggatott vonal a filogenetikailag ellenőrzött kapcsolatot jelöli az összes adatponton, rendtől függetlenül. Az értékek mindkét tengelyen $\log_{10}$ skálán ábrázoltak. A színes regressziós egyenesek meredekségeihez tartozó értékek az egyes rendek esetében (N > 3) a 2. táblázatban találhatóak

individual muscle groups varied between orders and the proportions of the muscle ascribed to the four muscle categories also varied between orders *(Figure 1)*.

There were positive relationships between body mass and the masses of the combined adductor *(Figure 2)*, retractor *(Figure 3)*, protractor *(Figure 4)*, and depressor muscles *(Figure 5)*, for individual species. All of these relationships exhibited isometry when the slopes of the lines were compared against a slope of 1.0 (t_{65} = -0.496, p = 0.621; t_{65} = -0.405, p = 0.687; t_{36} = -1.517 p = 0.138; and t_{64} = -0.468, = 0.641, for the four muscle categories, respectively). The coefficient of determination values (R^2) ranged between 0.600 and 0.720 and the λ-values ranged between 0.63–0.80 for each of the relationships *(Figures 2–5)*.

A phylogenetically controlled analysis of covariance (pANCOVA) revealed a significant interaction between body mass and order that had a very low lambda value and a very high coefficient of determination *(Table 1)*. This pattern was repeated for the pANCOVA analysis for the other three muscle categories *(Figures 2–5, Table 1)*. Within individual orders of birds, the scaling relationship between body mass and jaw muscle mass was isometric in some cases, but not in others. In the Anseriformes (waterfowl), all muscle masses scaled with exponents

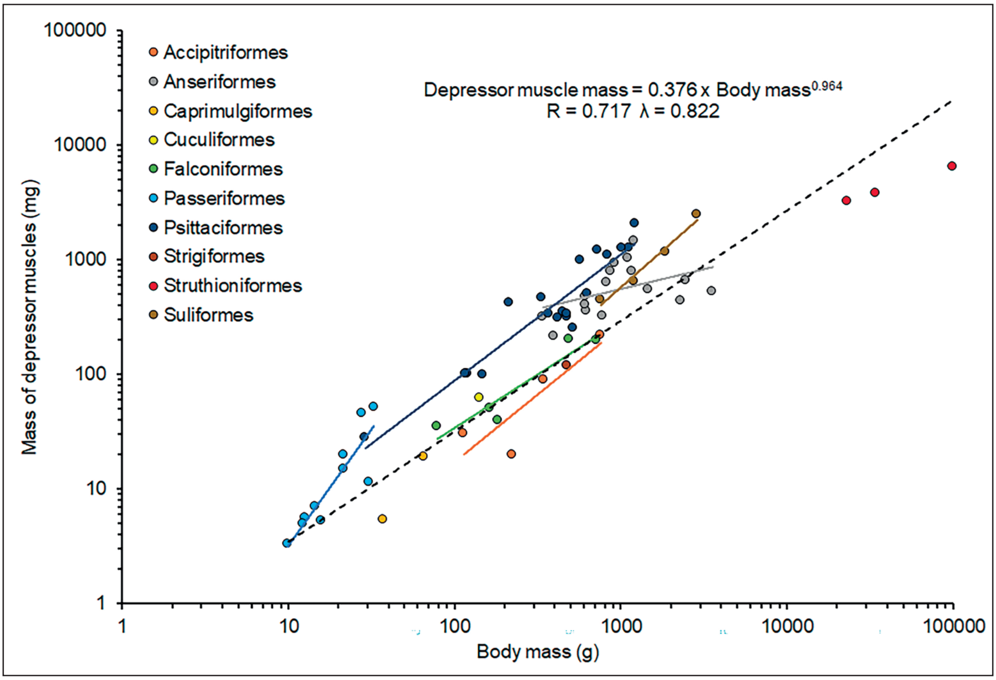

Figure 5. Relationship between body mass and the mass of the depressor muscles combined for a range of orders as indicated. Dashed line is the phylogenetically controlled relationship through all of the data points irrespective of order. Note the $\log_{10}$ scale on both axes. For slopes of coloured regression lines for each order (N > 3) see *Table 2*.

5. ábra A testtömeg és a depresszor izmok tömege közötti összefüggés az egyes rendekkel feltüntetve. A szaggatott vonal a filogenetikailag ellenőrzött kapcsolatot jelöli az összes adatponton, rendtől függetlenül. Az értékek mindkét tengelyen $\log_{10}$ skálán ábrázoltak. A színes regressziós egyenesek meredekségeihez tartozó értékek az egyes rendek esetében (N > 3) a 2. táblázatban találhatóak

significantly less than isometry would predict, with muscle groups having masses that scaled negatively allometrically *(Figures 2–5, Table 2)*. A similar negative allometric relationship was observed for retractors in the Struthioniformes (ratites; *Figures 2–5, Table 2*). These exponents reflected that neither waterfowl nor ratites are famous for their powerful bites. By contrast, the Passeriformes (perching birds), which were represented by strong biters, had significantly positively allometric relationships between the body mass and the masses of the adductors and retractors *(Figures 2–5, Table 2)*. Similarly, the retractors of Psittaciformes had an exponent that was significantly positively allometric *(Table 2)*. Other orders, such as the Accipitriformes (hawks/eagles), Suliformes, and Falconiformes (falcons) had exponents for adductors and retractors that were not significantly different from isometry *(Table 2)*.

When adductors and retractors were expressed as a proportion of the total muscle mass that close the jaw, the Struthioniformes, Caprimulgiformes (nightjars), Psittaciformes and Accipitriformes had similar proportions, but most orders had a greater proportion of adductor muscles, especially the Suliformes and Anseriformes *(Figure 6)*. After the single representatives of the Cuculiformes (cuckoos) and Strigiformes were removed from the

Table 2. Slopes (SE in parentheses) of phylogenetically controlled regression lines for log$_{10}$-transformed values for muscle mass versus body mass for the four muscle categories for orders of birds where N > 3. Values in square brackets are t-values, degree of freedom, and p-value for each slope as tested against an isometric slope of 1.0 using a one-sampled t-test (Bailey 1981). Values in bold exhibit significant departure from isometry. A dash (-) indicates that this muscle category was not recorded in the order

2. táblázat A filogenetikailag ellenőrzött regressziós egyenesek meredeksége (zárójelben SE) az izomtömeg és a testtömeg log$_{10}$-transzformált értékeihez képest a négy állkapocs izom kategória esetében az egyes madárrendeknél, ahol N > 3. A szögletes zárójelben szereplő értékek t-értékek, szabadságfokok és p-értékek minden meredekségre, 1,0 izometrikus meredekséggel szemben, egymintás t-próbával (Bailey 1981). A vastagon szedett értékek jelentős eltérést mutatnak az izometriától. A vízszintes vonal (-) azt jelzi, hogy ez az izomkategória nem volt elérhető az adott rendnél

	Adductors	**Retractors**	**Protractors**	**Depressors**
Accipitriformes	0.903 (0.441) [2.04, 3, 0.064]	1.313 (0.802) [1.63, 3, 0.103]	–	**1.177 (0.476)** **[2.47, 3, 0.040]**
Anseriformes	0.561 (0.127) [-3.46, 15, 0.004]	0.537 (0.116) [-3.99, 15, 0.001]	0.470 (0.140) [-3.77, 15, 0.002]	0.345 (0.186) [-3.51, 15, 0.003]
Falconiformes	0.839 (0.287) [-0.56, 5, 0.599]	0.612 (0.314) [-1.27, 5, 0.271]	–	0.932 (0.186) [-0.37, 4, 0.732]
Passeriformes	2.551 (0.273) [5.68, 9, <0.001]	2.438 (0.438) **[3.29, 9, 0.008]**	1.557 (0.541) [1.03, 9, 0.222]	**2.091 (0.278)** **[3.93, 9, 0.003]**
Psittaciformes	1.208 (0.110) [1.88, 18, 0.071]	**1.333 (0.117)** **[2.86, 18, 0.011]**	–	1.165 (0.100) [1.64, 18, 0.104]
Suliformes	1.313 (0.241) [1.30, 3, 0.151]	1.273 (0.149) [1.83, 3, 0.082]	1.163 (0.081) [2.02, 3, 0.066]	**1.308 (0.039)** **[7.99, 3, 0.001]**

dataset, phylogenetically controlled analysis showed that order had a significant effect on the logit-transformed proportions of the adductor muscles as part of the total muscle mass that close the jaw ($F_{7,56} = 6.26$, $p < 0.0001$).

When the mass of the adductor muscles was expressed relative to body mass, most of the orders had values of around 1 mg/g or less *(Figure 7)*. The two exceptions were the Passeriformes, which had almost 60% more adductor muscle than retractor muscle (3.8 versus 2.4 mg/g, respectively), and the Psittaciformes, in which the adductor and retractor muscles were of similar but comparatively higher relative masses (3.1 versus 3.2 mg/g, respectively). Phylogenetically controlled one-way ANOVA showed that there was a significant effect of order on log-transformed data for adductor muscle mass as a proportion of body mass ($F_{7,56} = 23.53$, $p < 0.0001$).

Discussion

The masses of the four functional categories of the jaw muscles of birds varied among avian orders. When order was not considered, the relationships between mass of the various muscle categories and body mass were isometric. When order was considered, it had a significant effect on the relationships between muscle masses and body mass with orders exhibiting

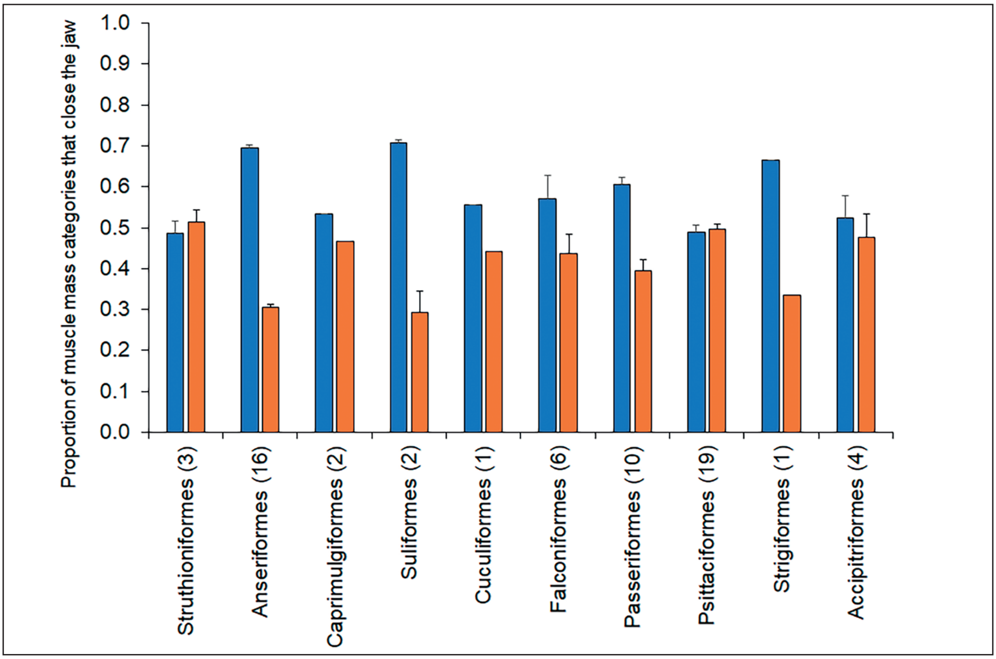

Figure 6. Mean (+SE) values for the mass of the combined adductor (blue bars) and retractor (orange bars) muscles for ten orders of birds expressed as a proportion of the total of the muscles used to close the jaw. Values in parentheses indicate the number of species represented in that order

6. ábra A testtömeg és az együttes adduktor (kék sávok) és retraktor (narancs sávok) izmok átlagértékei (+SE) a tíz madárrend esetében, az állkapocs zárásában szerepet játszó izmok összességének arányában kifejezve. A rendhez tartozó fajok száma a rend mögött, zárójelben található

significant positive or negative allometry relative to body mass. For this sample of data these relationships could be misleading because there was significant interaction between order and body mass for all four muscle categories. Most orders had low values for body mass-specific muscle mass for jaw closing with the notable exceptions of the Passeriformes and the Psittaciformes, which exhibited different patterns for the proportions of the adductor and retractor muscles.

Deeming *et al.* (2022) found that there was a significant difference between passerines and non-passerines in the allometry of jaw musculature (all muscles combined) and body mass. In the present study, for all four muscle categories, muscle mass was isometric with body mass, but the effect of order was very clear, which explains the result for all muscles combined. Deeming *et al.* (2022) had a small sample of species and this has been reduced further here because some studies report only combined values for jaw musculature rather than masses of the individual muscles. Phylogenetic relatedness influenced the isometric relationships between muscle mass and body mass, but as would be expected this effect was lost when order was included in the model. This suggests that there the high evolutionary signal reflects the higher taxonomic level rather than at the differences between individual species. This implies that when bill shape is conserved within an order (e.g. in waterfowl; Olsen 2017) this is also probably reflected in the underlying musculature.

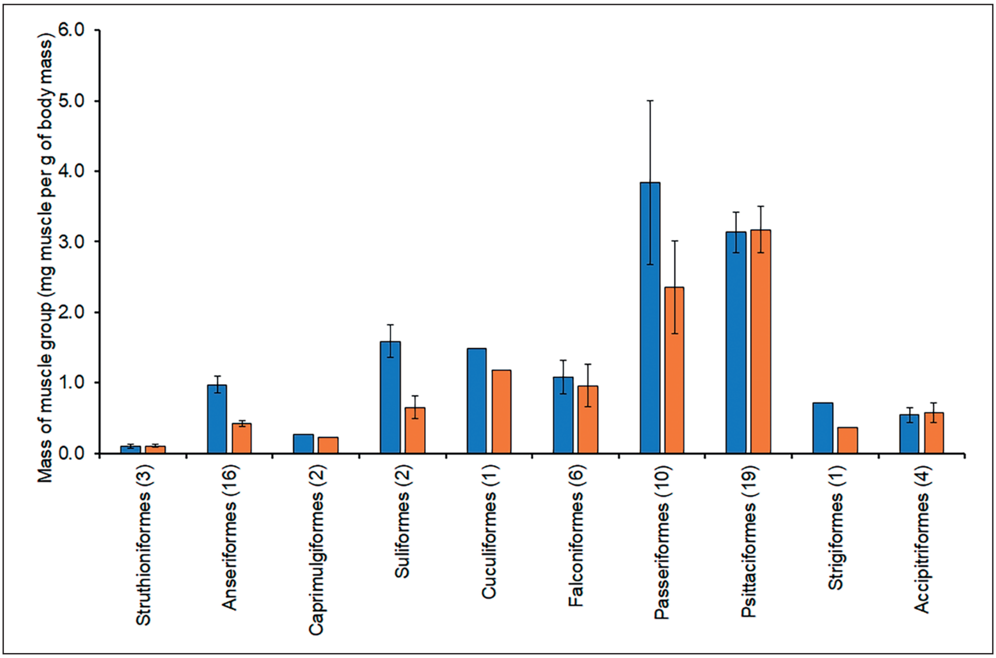

Figure 7. Mean (+SE) values for the mass of the combined adductor (blue bars) and retractor (orange bars) muscles for ten orders of birds expressed relative to the body mass of the birds (mg/g) Values in parentheses indicate the number of species represented in that order

7. ábra A testtömeg és az együttes adduktor (kék sávok) és retraktor (narancs sávok) izmok átlagértékei (+SE) a tíz madárrend esetében, a madarak testtömegéhez viszonyítva (mg/g). A rendhez tartozó fajok száma a rend mögött, zárójelben található

Although some muscle categories (e.g. the *m. adductor mandibulae externus* complex) were present in most species, there were muscle categories (e.g. the *m. pseudotemporalis*) that were absent from a few species. It was interesting that parrots have the *m. ethmomandibularis*, which seems to be a characteristic feature of parrot jaw musculature (Homberger 2003, 2017, Tokita 2003, Carril *et al.* 2015), which generates high bite forces (Cost *et al.* 2020, Pecsics *et al.* 2020, Dickinson *et al.* 2022, Harrison 2023). However, Sims (1955) also observed, but did not quantify, a *m. ethmomandibularis* in the hawfinch (*Coccothraustes coccothraustes*; Fringillidae, Passeriformes). van der Meij and Bout (2004) reported a high total jaw muscle mass for the hawfinch but did not report a bite force. The closely related Yellow-billed Grosbeak *(Eophona migratoria)* had a similar body mass and jaw muscle mass to the hawfinch and had a comparable bite force (van der Meij & Bout 2004). Given these similarities, it would be interesting to investigate whether grosbeaks also have a *m. ethmomandibularis* and the role that it plays in delivering a bite force.

The *m. pseudomasseter* seemed to be a characteristic of cockatoos (Cacatuidae) but it was not found in other parrots (Homberger 2003, 2017, Tokita 2003, Harrison 2023) or other avian taxa. It is unclear whether the development of additional muscles in parrots is a means by which their high bite forces can be generated (Cost *et al.* 2020, Dickinson *et al.* 2022, Harrison 2023), or whether this reflects how bite force can be applied by different parts of the bill as the jaw is closed. In parrots, the presence of relatively large adductor and retractor muscles suggests that the action of the jaw during feeding may require more of a balance between adduction and retraction than was observed in passerines in which, adductors were much larger. The passerines featured in the analysis reported here were mainly Darwin's finches (Thraupidae), which have very strong bite forces for their body mass (Soons *et al.* 2015). The presence of the *m. ethmomandibularis* in hawfinches (Sims 1950) suggests that some other finch species also rely more on adduction during feeding. It is unlikely that other passerine species that are less reliant on hard seeds would require larger adductor muscles, but further quantitative analysis of jaw masses in a wider range of passerine species is required to test these ideas.

It could be argued that the approach used here of treating all bellies of a muscle complex as one functional unit, is anatomically or physiologically inappropriate. However, the tendons of many jaw muscles do not originate and insert directly on bone but rather they have one end of their fibres attached to the 'tendinous' epimysium of another element of the muscle complex that may then attach to a bone. Therefore, any contraction of a part of a muscle complex will impact on the adjacent parts of the same complex and a contraction consequently has one action on the skeleton. Although muscle force was inversely related to muscle fibre length it is possible that greater forces can be delivered by having smaller bellies of jaw muscles (Deeming *et al.* 2022). However, the fine detail of how force is delivered as the jaws close is unclear from existing studies of avian jaw musculature.

Variation in the jaw musculature among birds is reflected in both skull morphology and bill shape, and all these morphological elements will influence the diet on which a bird will feed. Those passerines studied to date are characterised by their granivorous or other durophagous diets, which seem to necessitate strong bite forces delivered by robust bills (van der Meij & Bout 2004, 2006, 2008, Herrel *et al.* 2005, Soons *et al.* 2015). Other bird species that deal with food items that require less manipulation before ingestion, for instance herbivorous ratites, which feed primarily by grasping vegetation and pulling at it rather than shearing off leaves, have relatively less jaw musculature and so deliver a low bite force for their mass (Gusseklo & Bout 2005). This is also apparent in carnivorous birds of prey that often kill their prey using their talons and use the bill to tear off pieces of the carcass rather than applying a force to crush the food (Sustaita 2008, Sustaita & Hertel 2010) or, in the case of owls, swallow the prey whole (Shawyer 1994). Although falcons often rely on their bite to kill prey captured by their talons in flight, there was no obvious difference in the proportions of adductor and retractor muscles compared with the hawk species as observed in the study by Sustaita and Hertel (2010). Herbivory or carnivory may not, therefore, require a particularly strong bite force (Gusseklo & Bout 2005, Sustaita & Hertel 2010), but more research is needed on a wide range of species. It is clear, however, that mass of the jaw musculature is not a simple function of body size in birds.

The link between predominant feeding behaviour and jaw morphology is demonstrated in the Komodo Dragon *(Varanus komodoensis)*. This large lizard has a relatively weak bite force for its skull size, and the skull itself is not sufficiently strong to withstand an equivalent bite force that could be delivered by a Saltwater Crocodile *(Crocodylus porosus)* that has a similar skull size (Fry *et al.* 2009). The Komodo Dragon effectively has come to rely on a venomous bite to quell or kill prey rather than a direct killing bite and relies on strong neck muscles to tear muscle from a carcass (Fry *et al.* 2009). As interest in functional jaw morphology grows (Bright *et al.* 2016, 2019, Navalón *et al.* 2019, Dickinson & Hartstone-Rose 2022) then the interactions between muscle anatomy and size, skull, and bill morphology in the delivery of bite force will presumably of greater interest and stimulate research into a wider range of bird species that exhibit greater variety of feeding modalities.

Differing patterns of feeding behaviour and processing of food items by the bill and tongue in birds have not been fully explored in terms of the underlying musculature that delivers a bite force or serves to manipulate the food in the bill. This study shows that the jaw musculature varied between the limited sample of bird species from which data are available. Variation in bill morphology in relation to feeding is almost certainly reflected in the underlying musculature. More research of jaw musculature and architecture is needed in a wider range of feeding modalities to allow development of a better understanding of how bite forces are delivered in different bird species and how this might affect bite forces.

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Comparative study of annual and daily capture-recapture and biometrics of two treecreeper species (*Certhia* spp.) in the post-breeding season over 23 years in western Hungary

József Gyurácz[1*], Péter Bánhidi[2], József Góczán[2], Péter Illés[2], Sándor Kalmár[2], Péter Koszorús[2], Zoltán Lukács[2], Péter Molnár[1], Csaba Németh[2] & László Varga[2]

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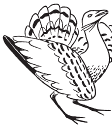

Gyurácz, J., Bánhidi, P., Góczán, J., Illés, P., Kalmár, S., Koszorús, P., Lukács, Z., Molnár, P., Németh, Cs. & Varga, L. 2024. Comparative study of annual and daily capture-recapture and biometrics of two treecreeper species (*Certhia* spp.) in the post-breeding season over 23 years in western Hungary. – Ornis Hungarica 32(1): 61–79. DOI: 10.2478/orhu-2024-0005

Abstract In this study, we detected and compared changes in the annual and daily captures of the Eurasian *(Certhia familiaris)* and Short-toed Treecreeper *(C. brachydactyla)* in the timing of their post-breeding movements, in the length of minimum stopover duration (MSD) in the area, and also in biometrics in western Hungary. The birds were captured and ringed, or recaptured from the end of July to the first weekend of November in all years from 2001 to 2023. The annual captures of both species indicated stable populations in this period, with milder February months having a positive effect on annual captures. There were similarities and differences in the movement strategies and habitat selection of the species. During the post-breeding season, the Eurasian Treecreeper was more strongly associated with the scrubland and forest edge than the Short-toed Treecreeper. There were two autumn capture waves in September and October for the Eurasian Treecreepers and just one in September for the Short-toed Treecreepers, which were primarily consisted of birds captured only once. There were no significant differences in wing length of the three capture intervals (July-August, September, October-November) in either species, which suggests that the dynamics of post-breeding movements cannot be explained on the bases of possible differences in the behavior of sexes, ages, or populations. The proportion of birds captured only once was about double of that of stopovers in both species each year. The average real length of stopover duration in the area for Eurasian Treecreepers was 94.25 days, and 84.31 days for Short-toed Treecreepers. The length of MSD in the area was not significantly associated with wing length and body mass in either species. Individuals of both species did not gain fat stores significantly during post-breeding season.

Keywords: post-breeding, migration, biometrics, Eurasian Treecreeper, Short-toed Treecreeper

Összefoglalás Jelen tanulmányban a hegyi fakusz *(Certhia familiaris)* és a rövidkarmú fakusz *(C. brachydactyla)* éves és napi fogásainak változásait, tartózkodási idejüket, szárnyhosszukat, testtömegüket és kondíciójukat hasonlítottuk össze. A madarakat 2001 és 2023 között, július végétől november első hétvégéig tartó időszakokban fogtuk be. Mindkét faj éves fogásai stabil populációkra utaltak, az enyhébb februári időjárást követő időszakokban több madarat fogtunk be. A két faj költés utáni diszperziós mozgása, vonulása és élőhelyválasztása között hasonlóságokat és különbségeket is kimutattunk. A költés utáni időszakban a hegyi fakuszt nagyobb arányban fogtuk be az erdős, cserjés élőhelyeken, mint a rövidkarmú fakuszt. A hegyi fakusz esetében két őszi fogási hullám volt szeptemberben és októberben, míg a rövidkarmú fakusz esetében csak egy szeptemberi, amelyben elsősorban az egyszer befogott madarak fordultak elő. A három fogási időszakban (július-augusztus, szeptember, október-november) befogott madarak szárnyhossza egyik faj esetében sem különbözött lényegesen, ami arra utal, hogy a költés utáni időszakban jellemző mozgások dinamikája nem magyarázható a nemek, a korcsoportok vagy a populációk különböző diszperziós vagy vonulási viselkedésével. A csak egyszer befogott madarak aránya mindkét faj esetében évente körülbelül kétszerese volt a visszafogott példányok arányának. A területen eltöltött valós idő átlagos hossza a hegyi fakusznál 94,25 nap, a rövidkarmú fakusznál 84,31 nap volt. A minimális tartózkodási idő egyik faj esetében sem függött a madarak szárnyhosszától és testtömegétől. Egyik faj egyedei sem növelték lényegesen zsírraktáraikat a költés utáni időszakban.

Kulcsszavak: költés utáni időszak, vonulás, biometria, hegyi fakusz, rövidkarmú fakusz

[1] *University of Eötvös Lorand, Savaria Campus, Department of Biology, 9700 Szombathely, Károlyi Gáspár tér 4. Hungary*
[2] *Local Group of BirdLife Hungary, 9700 Szombathely, Károlyi Gáspár tér 4. Hungary*
* *corresponding author, e-mail: gyuracz.jozsef@sek.elte.hu,*

Introduction

One consequence of the allopatric speciation during the last glacial period is the development of sibling treecreeper and other passerine species. In the postglacial period, the two treecreeper species maintained their independence, despite overlapping ranges (Moreau 1954). Both species are widespread in Europe, but the Eurasian Treecreeper *(Certhia familiaris)* is absent from the northernmost areas, the Mediterranean region and some parts of western Europe. The Short-toed Treecreeper *(C. brachydactyla)* also breeds in western Europe and the three large Mediterranean peninsulas (Berthold 1993, del Hoyo *et al*. 1992–2011). In central Europe, where their ranges overlap, the two species may occur in the same habitat and they may be in strong competition with each other (Clausel & Toft 1988, Moreno 1991, Gil 1997, Schepers & Török 1997).

Most Eurasian Treecreeper populations are largely resident in Europe. The small sample size of distant recoveries show only short-distance, less than 500 kilometres movements. A bird from central Europe (Germany) appeared during winter in southern Spain. Birds from Fennoscandia winter around the Baltic Sea, in western and central Europe, as well as European Russia. Their movements are more intensive in irruption years (Spina *et al*. 2022). The Short-toed Treecreeper population is sedentary in Europe. Some altitudinal movements were locally recorded; post-breeding dispersal is rather limited (Harrap 2008). The 85% of the distant recoveries were less than 300 kilometres away from the ringing site. They showed only local and short-distance movements in Spain, Germany, Italy, Netherlands, Denmark, France, and Switzerland. There were two “long-distance” movements in Europe: (1) bird ringed in Belgium was recoveried during winter in southern Portugal; (2) bird ringed in early spring in northern Spain was encountered during breeding season in western Africa (Mali) (Spina *et al*. 2022). Both species are partial migrants and strongly territorial and can be observed all year round in Hungary (Bauer & Kaiser 1991, del Hoyo *et al*. 2008, Gyurácz 2022a, 2022b). The Eurasian Treecreepers breeding in Hungary are resident, whereas the northern, probably mainly Slovakian migrants arrive during autumn, and may overwinter in Hungary. The Hungarian breeding population of the Short-toed Treecreeper is also resident, but there are some passing through in September-October. The origin of possible migrants is not known (Csörgő & Karcza 2000, Török 2009a, 2009b). Their breeding period is more extensively studied (Kuitunen 1985, 1986, Kuitunen & Aleknonis 1992, Suorsa *et al*. 2005, Jäntti *et al*. 2007, Haraszthy 2019), but little is known about their post-breeding occurrence, movement dynamics and habitat selection (Török 2009a, 2009b).

In the present study, 23 post-breeding seasons of capture data were processed. The aim of our study was to analyze annual and daily variation in the number of captures and duration of time spent in the area of the Eurasian and Short-toed Treecreepers at a study site in western Hungary and to identify changes in biometric parameters. We asked the following questions: (1) Do the annual and daily capture – recapture dynamics differ between species? (2) Is there a relationship between winter temperature, precipitation and the annual captures of bird species? (3) Do the minimum stopover duration (MSD) and real length of stopover duration in the area and habitat selection of birds differ between species? (4) Does the rate of change in body mass differ between species? (5) What biometrics determine the MSD and rate of change in body mass?

Material and Methods

Study area

The study was carried out at the Tömörd Bird Ringing Station in western Hungary (47°21'N, 16°40'E), located 15 km from Szombathely. The climate is continental with cold winters and warm summers. There are four natural habitat types in the 15 ha study area. (1) Bushes: bushes and herbs make up compact, dense vegetation, which is dissected by small grass patches; its characteristic plant is the blackthorn *(Prunus spinosa)*. (2) Forest: broadleaf trees and bushes form a compact, dense edge, making up an ecotone community with the Turkey oak *(Quercus cerris)* as the characteristic plant. There is plenty of felling and normal forestry management in the forest. (3) Grassland with shrubs: this unmanaged habitat type represents a transition between the wet habitats of the swamp and the steppe communities that used to cover the surrounding agricultural land; there are a few bushes in the grassland, with two small patches of dwarf elder *(Sambucus ebulus)*. (4) Marsh: a small (6 ha), permanent, and isolated wetland; the characteristic plant is the broadleaf cattail *(Typha latifolia) (Figure 1)*.

Data collection and analysis

The birds were captured and ringed, or recaptured during the post-breeding season between the end of July and the first weekend of November in all years from 2001 to 2023. This time period was the same every year (Gyurácz *et al.* 2017).

We used 28 numbered Ecotone mist-nets (12 m long and 2.5 m high, with 5 shelves and a mesh size of 16 mm) for trapping. The nets were distributed in the four habitat types *(Figure 1)*. Throughout the study period the number of nets and their location did not change. Birds were captured from dawn to dusk, except on rainy and stormy days. All birds were ringed according to Svensson (1992). First-year and older birds were examined together, because ageing is uncertain. Flattened maximum wing length was measured to the nearest

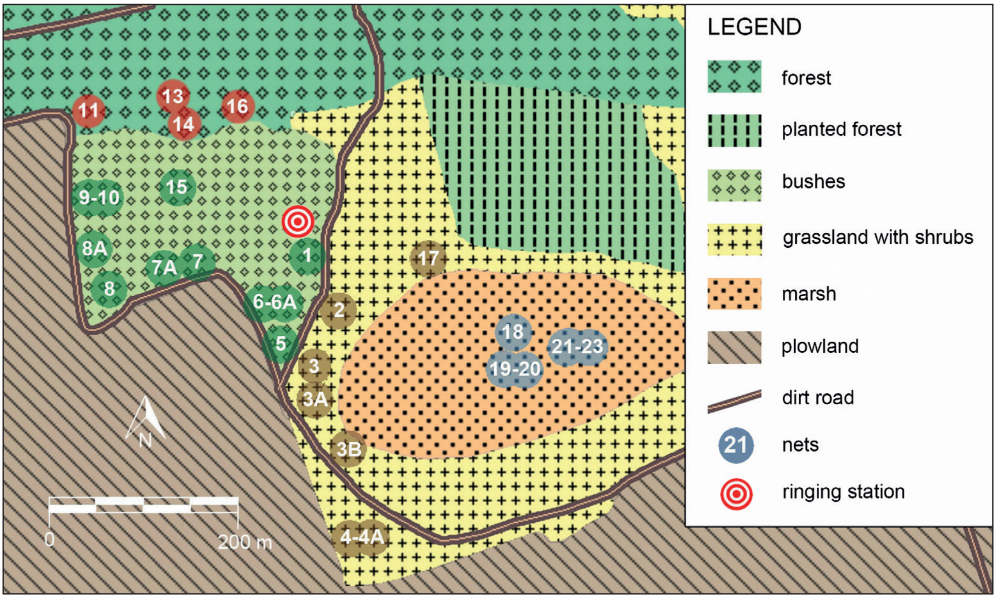

Figure 1. Habitat map of the study area with locations of mist-nets
1. ábra A vizsgálati terület élőhely-térképe a függönyhálók helyeivel

millimeter using a graded wing ruler, and birds were weighed to the nearest 0.1 g. Fat scores were estimated visually according to the SE European Bird Migration Network protocol, zero is the lowest value, eight is the highest (Busse & Meissner 2015).

The total annual capture of the first year (2001) was set as 100% and the population index of change in captures was calculated with the following formula (Greenwood *et al.* 1993):

$$I_x = \frac{N_x}{N_{x-1}} \times I_{x-1}$$

where I_x is the chain index of the specific year, I_{x-1} is the chain index of the previous year, N_x is the annual number of captures of species in the specific year, N_{x-1} is the annual number of captures of species in the previous year. Daily changes in the number of birds captured only once and individuals recaptured (birds captured at least twice in the same season) were analyzed separately. Generalized linear modelling (GLM) with identity link function was used to determine trends in the chain indices, timing of first captures and minimum stopover duration (MSD). The significance level was set at $P < 0.05$. GLM was also used to determine the effects of monthly mean temperatures, maximum and minimum daily mean temperatures and monthly precipitation totals during the winter months (December-March) preceding the breeding season and autumn migration on the annual captures. We used temperature and precipitation data from the Szombathely Meteorological Station, 15 km from the ringing station (NNDC 2023). GLM analyses were conducted using the Past program version 4.03 (Hammer *et al.* 2001). For some analyses, calendar dates were transformed to ordinal dates.

The length of MSD in the area of individuals recaptured was defined as the period from the date of first capture to the date of last recapture (Ellegren 1991). The real length of stopover duration (RSD) in the area was also calculated using the Cormack-Jolly-Seber model (Kaiser 1999, Schaub *et al*. 2001) in the capture-mark-recapture program MARK (Cooch & White 2017) as this is often longer than the length of MSD. In these studies, "lifespan" has been transformed to give an estimate of RSD using the formula RSD = −I / ln (I), as published in Brownie *et al.* (1985) where RSD is the mean estimated length of time spent in the area and I is the estimated daily survival probability between two capture days. These analyses were performed using MARK software, version 10.X (White & Burnham 1999).

Based on daily captures, three capture intervals were identified (July-August, September, October-November) for the comparison of the temporal changes in wing length, body mass and fat score of birds captured only once and birds recaptured. The body mass at the first arrival and last capture event were available for each recaptured individual. The difference between the two body mass values was used to assess the total body mass gain, expressed as a percentage of the initial body mass value (PBM). To determine the effects of the variables which influenced the length of MSD in the area and body mass change (PBM), we applied a multiple linear model (Yosef & Wineman 2010). Otherwise, non-parametric tests were used exclusively in the statistical analysis of biometrics (Kruskal-Wallis test, Wilcoxon's test, Spearman correlation). Based on the distribution of captured birds by habitat, the habitat diversity of the two species were compared using the Shannon formula and t test (Magurran 2004). All analyses were performed using R 3.6.0. (R Core Team 2015).

Results

Annual, daily captures, time spent and spatial distribution

We used the records of 267 Eurasian Treecreepers (173 birds captured only once, 94 birds recaptured) and 312 (202 birds captured only once, 110 birds recaptured) Short-toed Treecreepers captured and ringed from the end of July to early November within the study period of 2001–2023 *(Appendix 1)*.

There were no long-term trends in the chain index of annual captures, recaptures or recapture ratios between 2001 and 2023 in either species except for an increasing trend in Short-toed Treecreeper recaptures *(Figure 2, 3, 4)*. Annual captures and recaptures were positively correlated in both species (Eurasian Treecreeper: r_{Sp} = 0.67, P = 0.01, Short-toed Treecreeper: r_{Sp} = 0.75, P = 0.01), but the annual captures and recaptures of the two species were not correlated (capture: r_{Sp} = 0.06, P = 0.78, recapture: r_{Sp} = 0.17, P = 0.44). Among the environmental factors, the mean monthly temperature in February of the previous year was found to be correlated with annual capture of the Short-toed Treecreeper (GLM: slope = 0.22, SE = 0.07, G = 9.71, P = 0.01).

There was no significant trend in daily captures of Short-toed Treecreepers captured only once, but the daily captures of Eurasian Treecreepers captured only once showed a significant increasing trend and the daily captures of birds recaptured of both species a

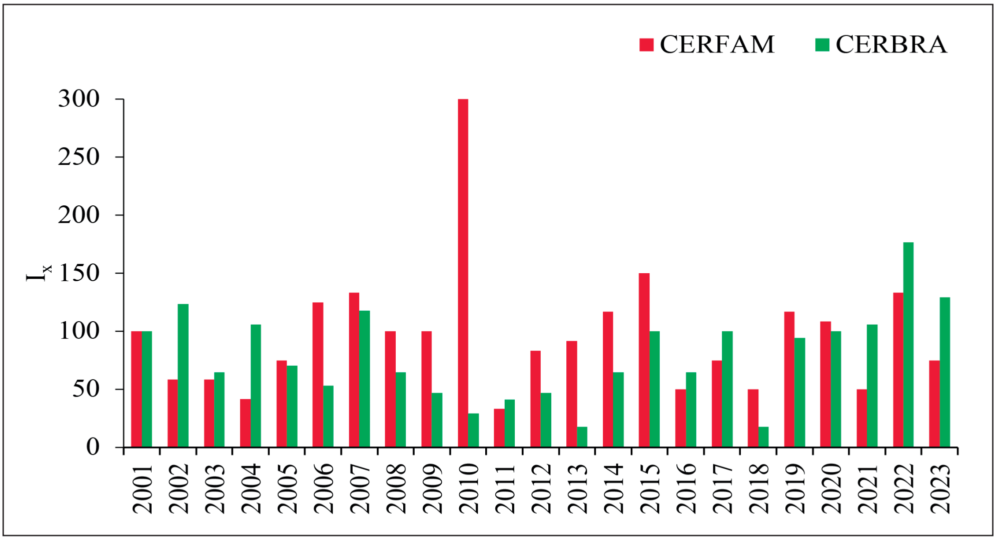

Figure 2. Capture indices at the study site calculated for 2001–2023. CERFAM: Eurasian Treecreeper GLM: slope = 0.12, SE = 1.77, G = 0.01, P = 0.94. CERBRA: Short-toed Treecreeper GLM: slope = 0.21, SE = 1.23, G = 0.97, P = 0.32

2. ábra A 2001 és 2023 közötti éves fogásokból számított fogási indexek Tömördön. CERFAM: hegyi fakusz GLM: meredekség = 0,12, SE = 1,77, G = 0,01, P = 0,94. CERBRA: rövidkarmú fakusz GLM: meredekség = 0,21, SE = 1,23, G = 0,97, P = 0,32

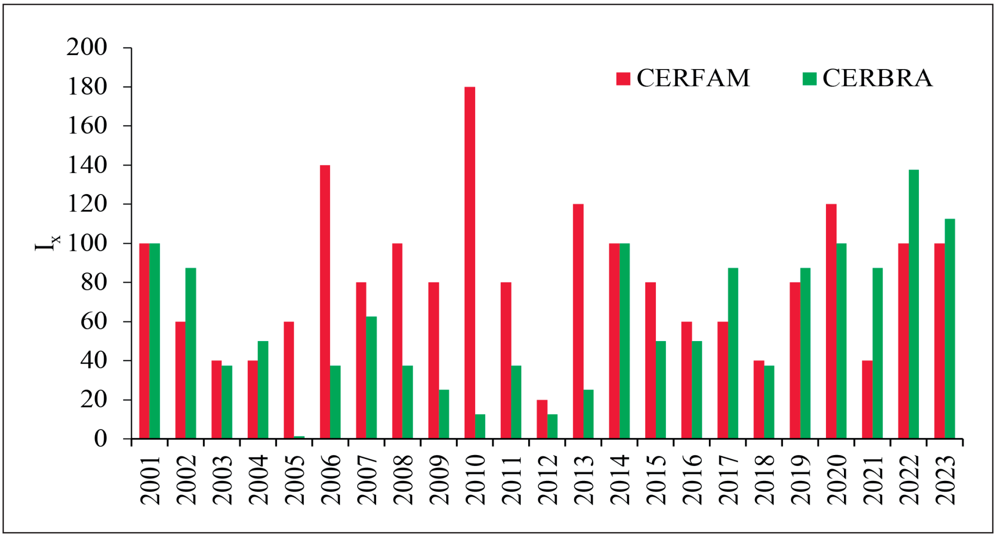

Figure 3. Recapture indices at the study site calculated for 2001–2023. CERFAM: Eurasian Treecreeper GLM: slope = 0.18, SE = 1.19, G = 0.03, P = 0.87. CERBRA: Short-toed Treecreeper GLM: slope = 0.25, SE = 1.05, G = 5.52, P = 0.02

3. ábra A 2001 és 2023 közötti éves visszafogásokból számított visszafogási indexek Tömördön. CERFAM: hegyi fakusz GLM: meredekség = 0,18, SE = 1.19, G = 0,03, P = 0,87. CERBRA: rövidkarmú fakusz GLM: meredekség = 0,25, SE = 1,05, G = 5,52, P = 0,02

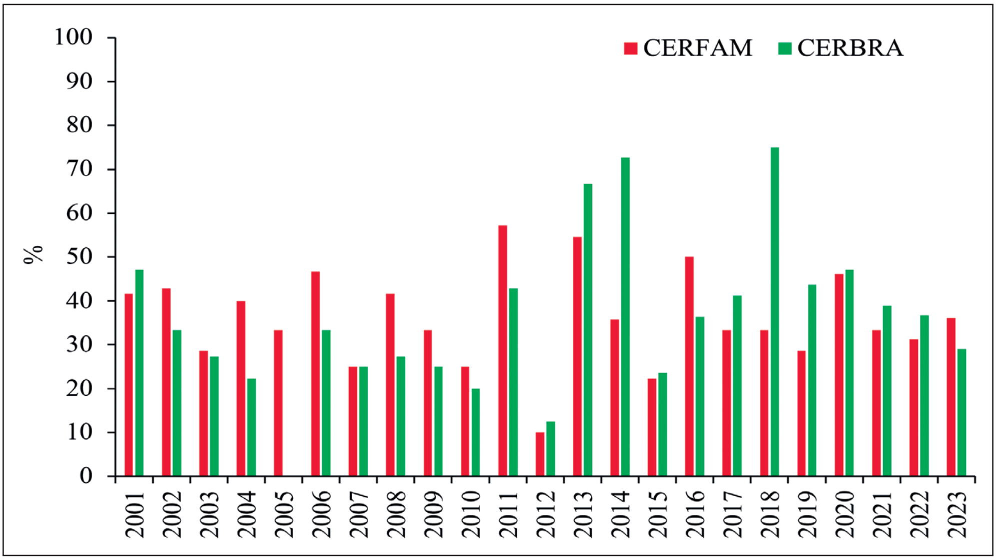

Figure 4. Recapture ratios at the study site calculated for 2001–2023. CERFAM: Eurasian Treecreeper GLM: slope = -0.15, SE = 0.35, G = 0.19, P = 0.66. CERBRA: Short-toed Treecreeper GLM: slope = 0.94, SE = 0.54, G = 3.02, P = 0.08

4. ábra A 2001 és 2023 közötti éves visszafogási arányok Tömördön. CERFAM: hegyi fakusz GLM: meredekség = -0,15, SE = 0,35, G = 0,19, P = 0,66. CERBRA: rövidkarmú fakusz GLM: meredekség = 0,94, SE = 0,54, G = 3,02, P = 0,08

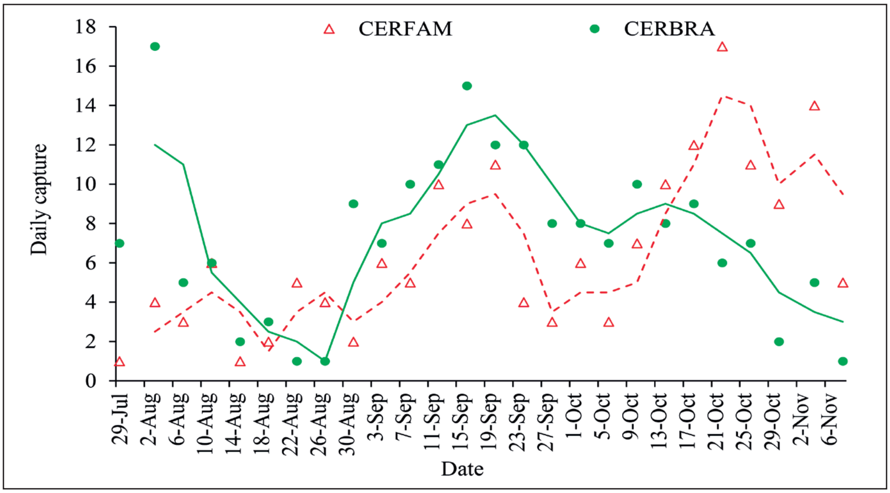

Figure 5. Total capture numbers of the birds captured only once (transients) per four days in the studied period. Lines – smoothed by 2-section moving mean. CERFAM: Eurasian Treecreeper GLM: slope = 0.09, SE = 0.02, G = 18.72, P = 0.01. CERBRA: Short-toed Treecreeper GLM: slope = -0.01, SE = 0.03, G = 0.19, P = 0.66

5. ábra Az egyes években négynaponként egyszer befogott madarak összegyedszáma a vizsgált időszakban Tömördön. Grafikonok – 2 négynapos időszakonkénti mozgóátlag. CERFAM: hegyi fakusz GLM: meredekség = 0,09, SE = 0,02, G = 18,72, P = 0,01. CERBRA: rövidkarmú fakusz GLM: meredekség = -0,01, SE = 0,03, G = 0,19, P = 0,66

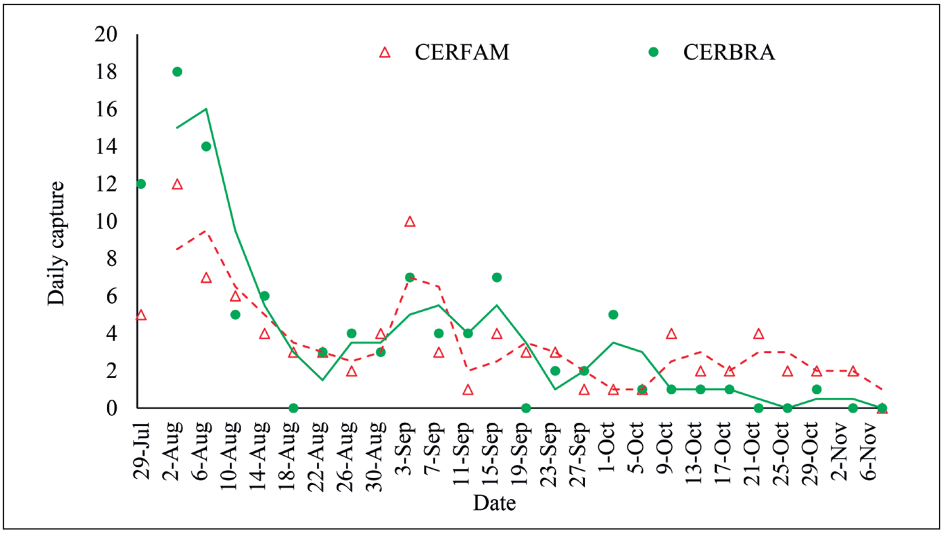

Figure 6. Total capture numbers of the birds recaptured per four days in the studied period. Lines – smoothed by 2-section moving mean, CERFAM: Eurasian Treecreeper GLM: slope = -0.05, SE = 0.01, G = 13.93, P = 0.01., CERBRA: Short-toed Treecreeper GLM: slope = -0.11, SE = 0.02, G = 26.77, P = 0.01

6. ábra Az egyes években négynaponként befogott és legalább egyszer visszafogott madarak összegyedszáma a vizsgált időszakban Tömördön. Grafikonok – 2 négynapos időszakonkénti mozgóátlag. CERFAM: hegyi fakusz GLM: meredekség = -0,05, SE = 0,01, 13,93, P = 0,01. CERBRA: rövidkarmú fakusz GLM: meredekség = -0,11, SE = 0,02, G = 26,77, P = 0,01

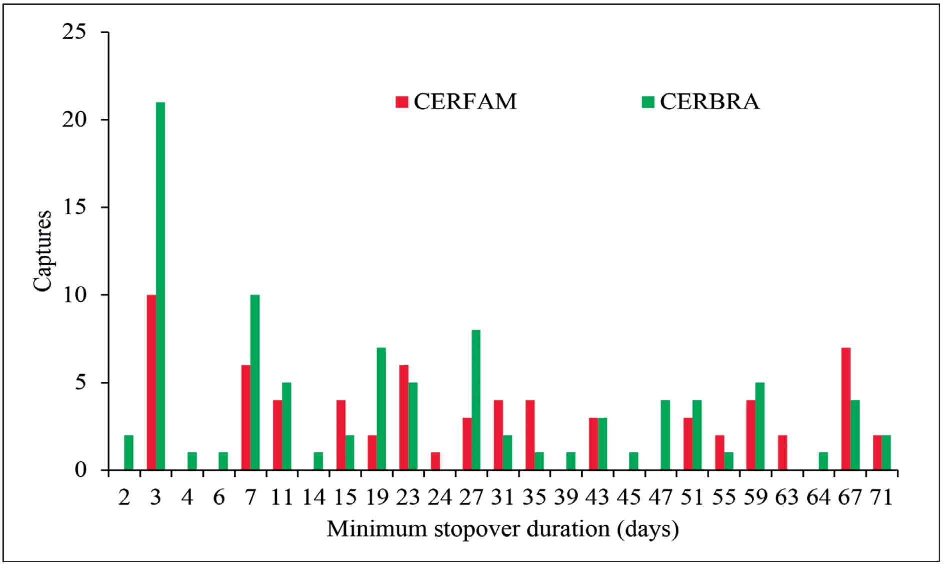

Figure 7. Length of MSD of birds recaptured at Tömörd, western Hungary, 2001–2023. CERFAM: Eurasian Treecreeper, CERBRA: Short-toed Treecreeper

7. ábra A visszafogott madarak minimum tartózkodási ideje Tömördön, 2001–2023. CERFAM: hegyi fakusz, CERBRA: rövidkarmú fakusz

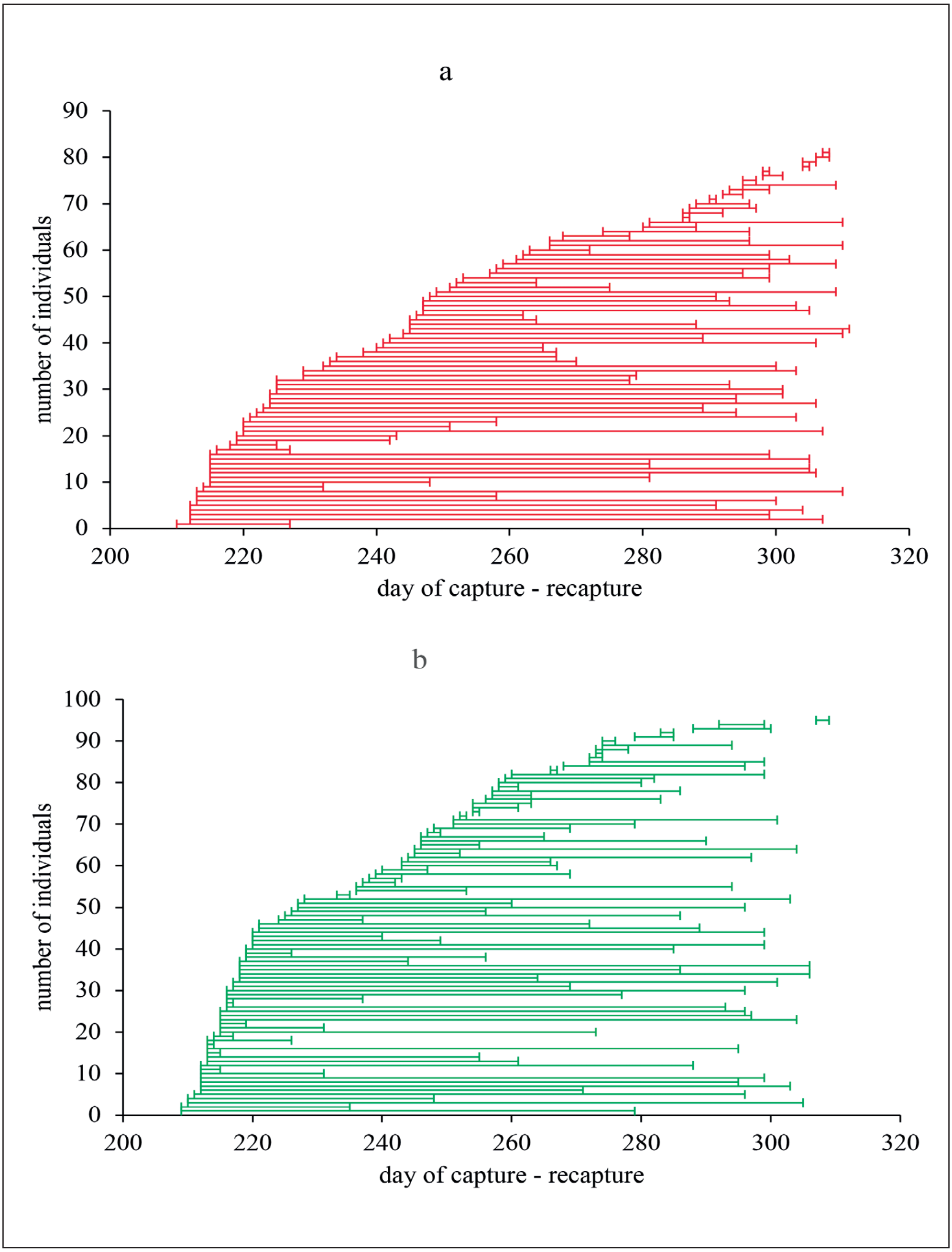

Figure 8. Individual capture-recapture histories of treecreepers at Tömörd, western Hungary. (a) Eurasian Treecreeper; (b) Short-toed Treecreeper. Horizontal lines: length of MSD in the area. Day 210 is 29 July.

8. ábra A visszafogott (a) hegyi és (b) rövidkarmú fakuszok első befogási idejének kumulatív eloszlása a vizsgált időszakban Tömördön. Vízszintes vonalak: minimum tartózkodási idők hossza a vizsgálati területen. A 210. nap július 29.

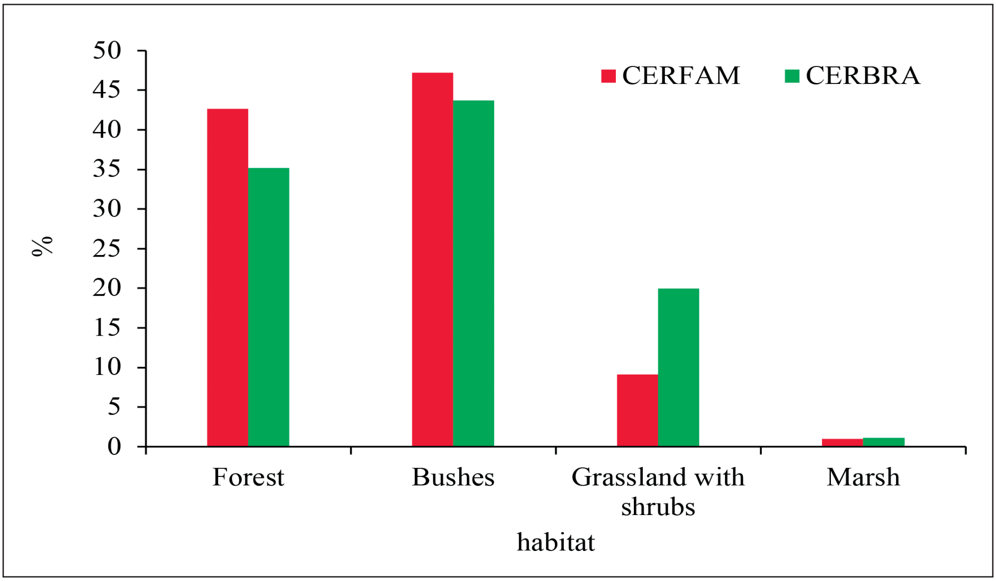

Figure 9. Capture rate in the four habitats at Tömörd, western Hungary. CERFAM: Eurasian Treecreeper, CERBRA: Short-toed Treecreeper

9. ábra A befogott madarak százalékos eloszlása a négy élőhely alapján Tömördön. CERFAM: hegyi fakusz. CERBRA: rövidkarmú fakusz

significant decreasing trend between the end of July and the early November *(Figure 5, 6)*. During 2001–2023, there was no significant shifts in the timing of first captures in either species (Eurasian Treecreeper GLM, slope = -0.01, SE = 0.51, G = 0.01, P = 0.98, Short-toed Treecreeper GLM, slope = -0.39, SE = 0.42, G = 0.88, P = 0.35).

The lengths of MSD of the two species were similar (r_{Sp} = 0.57, P = 0.01, *Figure 7, 8*). There was no long-term trend in the minimum length of MSD between 2001 and 2023 in either species (Eurasian Treecreeper GLM: slope = 0.32, SE = 0.43, G = 0.57, P = 0.45, Short-toed Treecreeper GLM: slope = 0.23, SE = 0.62, G = 0.14, P = 0.71). The Eurasian Treecreeper's average real length of time spent was 94.25 days (95% confidence interval: lcl 72.99, ucl 122.02), the Short-toed Treecreeper's was 84.31 days (95% confidence interval: lcl 65.84, ucl 108.03). The estimated daily survival probability between two capture days was 0.98, the capture probability of the birds was 0.03 for both species.

The distribution of the Short-toed Treecreeper by habitat (Shannon_H = 2.96) was significantly more diverse than that of the Eurasian Treecreeper (Shannon H = 2.84, t = -2.46, df = 1047, P = 0.01) *(Figure 9)*.

Biometrics

Eurasian Treecreepers which were recaptured had significantly lower median fat score at first capture than those which were not; Short-toed Treecreepers which were recaptured had significantly higher median body mass and fat score at first capture *(Table 1)*. The median body mass at last capture of recaptured Eurasian Treecreepers was slightly higher (8.6 g) than their median body mass at first capture (Wilcoxon's test for matched pairs = 1802.50, n = 89, P = 0.01). The Short-toed Treecreeper's did not change significantly (W = 2177.50, P = 0.60). The median fat scores at last capture of recaptured Eurasian Treecreepers (W = 512.50, P = 0.06) and Short-toed Treecreepers (W = 454.50, P = 0.06) were not significantly different from their median fat scores at first capture (median body mass and fat score at first capture and n for recaptured birds in *Table 1*). The median wing lengths of non-recaptured and recaptured treecreepers during the three capture intervals were not significantly different *(Tables 2, 3)*. The median body mass and fat score of non-recaptured and recaptured individuals were generally significantly lower in July-August than in September or October-November *(Tables 2, 3)*. The length of MSD was not significantly associated with wing length and body mass in either species (P > 0.05). The length of MSD of Short-toed Treecreepers with higher proportion of body mass change (multiple linear model, slope =

Table 1. Comparison of biometrics (median, n) of non-recaptured (NR) and recaptured (R) Eurasian and Short-toed Treecreepers at first capture in the studied period at the Tömörd Bird Ringing Station. W = Wilcoxon's rank sum with continuity correction

1. táblázat A Tömördön gyűrűzött és nem visszafogott (NR), illetve visszafogott (R) hegyi és rövidkarmú fakuszok első befogáskor mért biometriai adatainak (median, n) összehasonlítása. W = Wilcoxon-féle rangsorösszeg-teszt folytonossági korrekcióval

		Wing length (mm)	**Body mass (g)**	**Fat score**
Eurasian Treecreeper	NR	63.00, 159	8.70, 169	1.00, 156
	R	63.00, 71	8.50, 86	0.00, 80
		W = 5182, P = 0.32	W = 7547, P = 0.61	W = 7763, P = 0.01
Short-toed Treecreeper	NR	61.00, 172	8.40, 184	0.00, 164
	R	61.00, 86	8.60, 101	1.00, 91
		W = 7295, P = 0.86	W = 7549, P = 0.01	W = 6193, P = 0.02

Table 2. Comparison of bimometrics (median, n) of captured and non-recaptured Eurasian and Short-toed Treecreepers in the three capture intervals of the studied period at the Tömörd Bird Ringing Station. Kruskal-Wallis test

2. táblázat A vizsgált időszak három fogási periódusában Tömördön gyűrűzött és nem visszafogott hegyi és rövidkarmú fakuszok biometriai adatainak (median, n) összehasonlítása. Kruskal-Wallis teszt

		Wing length (mm)	**Body mass (g)**	**Fat score**
Eurasian Treecreeper	Jul-Aug	63.50, 26	8.60, 28	0.00, 26
	Sep	62.00, 42	8.70, 47	1.00, 38
	Oct-Nov	63.00, 91	8.70, 94	2.00, 92
	Kruskal-Wallis	$\chi^2 = 5.26$, P = 0.07	$\chi^2 = 0.35$, P = 0.83	$\chi^2 = 30.32$, P = 0.01
Short-toed Treecreeper	Jul-Aug	62.00, 47	8.10, 51	0.00, 46
	Sep	61.00, 71	8.50, 75	1.00, 71
	Oct-Nov	61.00, 54	8.30, 58	1.00, 47
	Kruskal-Wallis	$\chi^2 = 2.66$, P = 0.26	$\chi^2 = 12.37$, P = 0.01	$\chi^2 = 26.98$, P = 0.01

Table 3. Comparison of biometrics (median, n) of captured and recaptured Eurasian and Short-toed Treecreepers in the three capture intervals of the studied period at the Tömörd Bird Ringing Station. Kruskal-Wallis test

3. táblázat A vizsgált időszak három fogási periódusában Tömördön gyűrűzött és visszafogott hegyi és rövidkarmú fakuszok biometriai adatainak (median, n) összehasonlítása. Kruskal-Wallis teszt

		Wing length (mm)	**Body mass (g)**	**Fat score**
Eurasian Treecreeper	Jul-Aug	65.00, 32	8.45, 44	0.00, 39
	Sep	63.00, 21	8.80, 23	1.00, 23
	Oct-Nov	63.00, 18	8.40, 19	1.00, 18
	Kruskal-Wallis	$\chi^2 = 2.89$, $P = 0.23$	$\chi^2 = 8.87$, $P = 0.01$	$\chi^2 = 19.17$, $P = 0.01$
Short-toed Treecreeper	Jul-Aug	61.00, 54	8.50, 65	1.00, 57
	Sep	61.00, 24	8.75, 28	2.00, 26
	Oct-Nov	62.00, 8	8.40, 8	1.00, 8
	Kruskal-Wallis	$\chi^2 = 0.11$, $P = 0.94$	$\chi^2 = 10.55$, $P = 0.01$	$\chi^2 = 19.16$, $P = 0.01$

Table 4. Results of the multiple linear model test with proportion of body mass change (PBM) as dependent variable and body mass, wing length at first capture as independent variables of recaptured Eurasian and Short-toed Treecreepers

4. táblázat A visszafogott hegyi és rövidkarmú fakuszok testtömeg-változás aránya (PBM) és a madarak első befogáskor mért szárnyhossza és testtömege között feltételezett kapcsolat sokváltozós lineáris modellel ellenőrzött eredményei

Group	**Factors**	**slope**	**SE**	**t**	**P value**
Eurasian Treecreeper	Body mass	-0.06	0.01	-5.53	0.01
	Wing length	0.01	0.00	3.42	0.01
Short-toed Treecreeper	Body mass	-0.08	0.01	-7.32	0.01
	Wing length	0.02	0.00	5.01	0.01

-12.44, SE = 4.98, t = -2.49, P = 0.01) decreased. There was no such correlation in Eurasian Treecreepers ($P > 0.05$). Individuals with lower body masses and longer wing lengths upon arrival gained a significantly higher proportion of body mass (PBM) than heavier birds and birds with shorter wings in both species *(Table 4)*.

Discussion

Comparison of capture dynamics and habitat selection

Both species are relatively common breeders in the forests of western Hungary (Gyurácz & Kóta 2020). Although the annual capture dynamics of the species were different, the annual captures of both species indicated stable populations between 2001 and 2023, which are partly in line with national and European results (Gyurácz 2022a, 2022b, PECBMS 2023). Both species colonize new areas quickly, even small patches of habitats. The Eurasian Treecreeper's population declined moderately between 1980 and 2021 in Europe, but the population change was unknown in Hungary. The Finnish, Italian and Swiss population increased, while its populations declined in Greece, Ukraine, Scandinavia, the numbers of French and British birds were stable in recent decades (Knaus 2020b). The Short-toed Treecreeper's population increased moderately in Europe between 1982 and 2021, and the Hungarian breeding population was stable (annual average population change 1.3 ± 3.5%) between 1999 and 2018 (Gyurácz 2022a, 2022b, PECBMS 2023). The population trend was positive in Scandinavia, Netherlands, Poland, Spain, Italy and France in recent decades. The population was also stable in Germany, but short-term declines were reported from Poland, Austria, the Czech Republic, Ukraine, Albania and Turkey (Knaus 2020a).

The winter weather has affected the survival of the species in western Hungary, just as it has in other parts of Europe (Svensson 1981, Peach *et al*. 1995, Csörgő & Karcza 2000). In the northern and eastern parts of the Eurasian Treecreeper's range, there are irregular fluctuations in populations which may be linked to variations in the primary winter diet of the species, because they eat mainly seeds of pine and spruce as well as insects and spiders in winter (Cramp 1998, Harrap 2008). Usually, the small resident passerines show the largest population declines after hard winters because their potential prey animals become less available during cold and snow (Graber & Graber 1979, Gibbons *et al*. 1993). Our studies have demonstrated the positive effect of milder February on annual captures. In the Eurasian Treecreeper a significant relationship has been found between autumn numbers and mean April temperatures at two eastern Baltic sites (Sokolov *et al*. 2002). In case of high breeding success and high winter survival, and especially in years with early and warm spring, irruptive movements can occur. Irruptions of Eurasian Treecreepers usually occur in northern Europe when there is an early and warm spring. Significant correlation has been found between autumn captures of Coal Tits *(Periparus ater)*, also an irruptive migrant, and Eurasian Treecreepers in the eastern Baltics (Sokolov *et al*. 2002). In western Hungary, Coal Tits, like Eurasian Treecreepers, migrate in highly variable numbers in different years, with invasions in 2010 for both species (Takács *et al*. 2021). A highly significant relationship was found between autumn captures of juvenile Coal Tits and annual captures during the subsequent spring. This suggests that after an irruption, some juveniles survive the migration and winter and move back to the breeding area (Sokolov *et al*. 2002). This probably also occurs after an irruption of Eurasian Treecreepers.

During the migration season, both treecreeper species can occur in almost any habitat type (BirdLife Hungary 2023a, 2023b), but our studies showed that the Eurasian Treecreeper was more strongly associated with the scrubland and forest edge at the study site than the Short-toed Treecreeper. The Eurasian Treecreeper also showed a stronger preference for mature stands and large trees in the breeding season (Thibault 2023). Both species occurred in small numbers due to the lack of thick trunk trees in the marsh. Where the two species co-occur, contradictory results have been obtained when examining the species dominance relationship (Thielcke 1962, Clausel & Toft 1972).

Both species occurred at the study area during the post-breeding dispersal period, but the Short-toed Treecreeper was more common than the Eurasian Treecreeper. Both species breed in the forests around the study area (Gyurácz 2022a, 2022b), and individuals captured before the end of August are thought to be dispersing. There were two autumn capture peaks in September and October for the Eurasian Treecreepers and just one in September for the Short-toed Treecreepers. Similar to the treecreepers, the autumn migration dynamics of short-distance migratory tits in Hungary was also different. The annual capture peak of the Coal Tit was also in September, which was different from the October migration peak of Blue Tit *(Cyanistes caeruleus)* and Great Tit *(Parus major)*, but similar to that of Marsh Tit *(Poecile palustris)* (Lukács 2022).

One Eurasian Treecreeper ringed in Slovakia was recovered in Hungary and no Short-toed Treecreepers captured abroad have been found in Hungary since 1908. The furthest Eurasian Treecreeper recovery was 25 kilometres, the furthest Short-toed Treecreeper recovery was 17 kilometres (BirdLife Hungary 2023b), so we assume that the altitudinal migrant treecreepers captured in the September and October waves may have come from higher breeding areas, mainly from the Kőszeg Mountains, about 20 km from the study site: the regular migrants could fly a similar distance from here. In autumn, as the weather becomes less favourable in higher regions, more bird species are unable to access food and move to lower regions of Hungary, not only from the Hungarian mountains but also from the surrounding mountain regions (Csörgő *et al*. 2009). The Eurasian Treecreepers breeding in northern Europe migrate longer distances, but may also overwinter in western and southern Europe (Cramp 1998). The wing lengths of migratory birds captured in central Hungary also suggested that the birds originated from further north (Csörgő & Karcza 2000). It is more common to find resident Short-toed Treecreepers (Schepers 1997, Cramp 1998) but, as in Germany and central Hungary (Bauer & Kaiser 1991, Csörgő & Karcza 2000), our results also show that there were regular migrants of this species, although in lower numbers. The wing lengths of birds captured in the three capture intervals did not differ significantly, so it is assumed that the reason for the separation of the three capture intervals is not due to different post-breeding movement strategies of sex and age groups or populations (Cramp 1998). The higher body mass and fat stores of birds in September and October indicate both a higher proportion of migrants and the preparation of the winter population (Berthold 1993, Brodin 2000).

Comparison of movement ecology

Our results have shown both similarities and differences in the movement strategies of the species. The number of birds captured only once was about double that of birds recaptured in both species each year, which means that most of the birds continue to migrate after a short rest. The length of time spent and daily "survival" probabilities of the two species were similar, indicating that the habitats in the study area provide favorable feeding conditions for resident and stopover individuals of both species (Chernetsov 2012). Most of the birds of both species captured in August are present until November and probably overwinter in the study area. The equal, very low capture probabilities of the two species also suggest similar seasonal and diurnal activity. The length of time spent were not correlated to body size or condition of individuals at first capture in either of the treecreeper species.

Here, comparing the body mass and fat stores of recaptured and non-recaptured individuals of the two species, opposite results were found. One possible explanation for the difference is the different migration strategies of the two species. In Eurasian Treecreepers, which have a higher migratory activity, the non-recaptured individuals, with the higher fat score, were able to continue to migrate; in the mainly resident Short-toed Treecreeper, the recaptured individuals with higher body mass, and which consequently had a better competitive ability, remained in the study area. In other studies, as in the Eurasian Treecreeper in this study, individuals of pre-Saharan migrants caught only once showed a higher body mass than repeatedly recaptured birds during autumn and spring migrations (Petterson & Hasselquist 1985, Biebach *et al*. 1986, Kuenzi *et al*. 1991). However, the strategies of migrant individuals of the two species showed other differences and similarities. Individuals of both species did not gain fat stores significantly between their first and last recaptures, suggesting that they either stay on the site for longer periods, or migrate only short distances. The recaptured Short-toed Treecreepers that increased their body mass more stayed in the study area for shorter periods of time; this was not the case for the Eurasian Treecreepers, but this may be due to fewer recaptured Eurasian Treecreepers. Wing length was a significant determinant of proportion of body mass change (PBM) at Tömörd in both species. If the larger birds with longer wings are competitively dominant at stopover or overwintering sites, they probably forage more efficiently and accumulate more fat (Jarska *et al.* 2015).

Conclusions

A long-term capture-recapture study provided an opportunity to explore the autumn movements of the two sibling treecreeper species and the associated behavioral strategies. Both species occurred at the study area during the post-breeding dispersal period, but the Short-toed Treecreeper was more common than the Eurasian Treecreeper. Both species have both migrants and residents in their stable populations, but the dynamics of migrants are different. There were two autumn capture waves in September and October for the Eurasian Treecreepers and just one in September for the Short-toed Treecreepers. Wing length was a significant determinant of proportion of body mass change in both species. During the migration season, the Eurasian Treecreeper was more strongly associated with the scrubland and forest edge than the Short-toed Treecreeper.

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Appendix

Appendix 1. Annual captures, recaptures of the studied species at the Tömörd Bird Ringing Station, 2001–2023

1. függelék A vizsgált fajok éves fogása és visszafogása Tömördön, 2001–2023

	Eurasian Treecreeper			**Short-toed Treecreeper**		
	Capture	**Capture once**	**Recapture**	**Capture**	**Capture once**	**Recapture**
2001	12	7	5	17	9	8
2002	7	4	3	21	14	7
2003	7	5	2	11	8	3
2004	5	3	2	18	14	4
2005	9	6	3	12	12	0
2006	15	8	7	9	6	3
2007	16	12	4	20	15	5
2008	12	7	5	11	8	3
2009	12	8	4	8	6	2
2010	36	27	9	5	4	1
2011	4	0	4	7	4	3
2012	10	9	1	8	7	1
2013	11	5	6	3	1	2
2014	14	9	5	11	3	8
2015	18	14	4	17	13	4
2016	6	3	3	11	7	4
2017	9	6	3	17	10	7
2018	6	4	2	3	0	3
2019	14	10	4	16	9	7
2020	13	7	6	17	9	8
2021	6	4	2	18	11	7
2022	16	11	5	30	19	11
2023	9	4	5	22	13	9
Total	267	173	94	312	202	110

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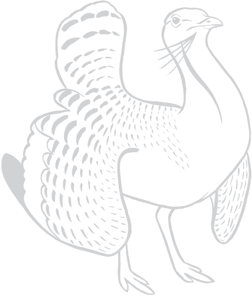

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Winter field survey of bird feeders in two Hungarian cities

Boglárka Bukor[1*], Boróka Kósa[2], András Liker[1,3]
& Gábor Seress[1,3]

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Abstract Bird feeding by people is one of the most popular human-wildlife interactions globally. Urban ecology studies generally recognize that cities offer a more favourable habitat for many wintering birds compared to natural areas, primarily due to the increased availability of the winter food sources provided by people. However, actual field surveys about the residents' bird feeding activity are rare. Here we surveyed bird feeders during the winter of 2021–2022 at 5-5 locations in two cities in Hungary. We recorded the number and type of bird feeders, the type of food offered, the number of bird species and individuals visiting the feeders. The density of feeders was higher in Veszprém, a middle-sized city (range: 60.1–206.1 bird feeders/km^2) compared to Budapest, the capital city of Hungary (23.3–83.0 bird feeders/km^2). The most frequent food types were fat balls, seed mix, and sunflower seeds in both cities. We registered a total of 516 individuals of 24 species on the feeders, and found that the type of the feeder, but not the city, significantly affected both the number of individuals and species visiting bird feeders. These results help to get a more complete picture of how the winter food supplies of birds are shaped by urbanization.

Keywords: urbanization, wildlife feeding, supplementary feeding, human-wildlife interaction, Central Hungary

Összefoglalás Az emberek szerte a világon, így Magyarországon is előszeretettel helyeznek ki eleséget a madarak számára. A városökológiai kutatásokban általánosan elfogadott nézet, hogy az így megnövekedett téli táplálékmennyiség kedvezőbb élőhellyé teheti a madarak számára a városokat a természetes területeknél, legalábbis a téli időszakban. Azonban arról, hogy milyen típusú és mennyiségű madáreleséget helyeznek ki a lakosok, ritkák a tényleges terepi felméréseken alapuló vizsgálatok a szakirodalomban. Ezért jelen vizsgálatunkban ismételt terepi bejárások során mértük fel a madáretetőket 2021–2022 telén, 5 budapesti és 5 veszprémi helyszínen. Feljegyeztük a madáretetők számát és típusát, a kihelyezett táplálék típusát, továbbá azt, hogy milyen madárfajok és mekkora egyedszámban látogatták az etetőket. Az aktív etetők sűrűsége a veszprémi területeken általában magasabbnak bizonyult (60,1–206,1 madáretető/km^2 között mozgott), mint a budapesti helyszíneken (23,3–83,0 madáretető/km^2). Az etetőkön leggyakrabban megfigyelt tápláléktípus mindkét városban a cinkegolyó, a magkeverék és a napraforgómag volt. Összesen 24 faj 516 példányát figyeltük meg. Az etető típusa szignifikáns hatást gyakorolt az azt látogató madarak egyed- és fajszámára, míg a két város között ezekben nem találtunk különbséget. A jelen vizsgálatunkban gyűjtött adatok segítségével pontosabb képet kaphatunk arról, hogy miként alakítja át az urbanizáció a telelő madarak táplálék forrásait.

Kulcsszavak: urbanizáció, madáretetés, téli élelem, ember-vadvilág kapcsolat, Közép-Európa

[1] *Behavioral Ecology Research Group, Centre for Natural Sciences, University of Pannonia, 8200 Veszprém, Egyetem utca 10., Hungary*
[2] *Hungarian University of Agriculture and Life Sciences*
[3] *ELKH-PE Evolutionary Ecology Research Group, University of Pannonia, 8200 Veszprém, Egyetem utca 10., Hungary*
**corresponding author, e-mail: bukor.boglarka@gmail.com*

Introduction

Food availability stands out as one of the primary regulatory factors shaping avian communities in all types of habitats (Payne & Wilson 1999, Ferger *et al.* 2014). At the same time, the fluctuations of food availability exert a significant influence on birds, at both individual and population levels, particularly in seasonal environments (Diggs *et al.* 2011, Elo *et al.* 2012). Thus, birds have historically adapted to the natural variations in food supplies, which is particularly notable in temperate zones where seasonal changes in food, such as seeds and arthropods, fundamentally influence birds' foraging behaviour, overwinter survival, and distribution (Roberts 1979, Diggs *et al.* 2011, Pekarsky *et al.* 2021). However, human activities are increasingly altering the natural abundance of these food sources and, consequently, may disrupt the associated ecological processes (Chamberlain *et al.* 2005, Johnson & Munshi-South 2017).

The practice of bird feeding has emerged as a widespread and increasingly popular activity in human settlements, especially as more and more people are living in urban areas worldwide (Reynolds *et al.* 2017). This trend is reflected by the growing market for bird food production and sales (Orros & Fellowes 2015, Plummer *et al.* 2019), establishing bird feeding as probably the most popular form of human-wildlife interactions (Jones *et al.* 2008, Baverstock *et al.* 2019). Typically, people provide food for birds not solely for welfare reasons or to aid conservation efforts, but also for aesthetic enjoyment, with many food-providing nature enthusiasts eager to discover the most preferred types of food to attract more birds to their bird tables (Cox & Gaston 2015, Galbraith *et al*. 2015, Dayer *et al.* 2019). The practice of bird feeding is often encouraged by nature conservation organizations in many countries, particularly those in the Northern Hemisphere (Baverstock *et al.* 2019). This is not different in Hungary either, where urban residents commonly engage in bird feeding, especially during the winter months.

Considering the widespread occurrence of bird feeding, urban ecology studies generally recognize cities as more favourable habitats for many wintering birds compared to natural areas, primarily due to the increased availability of food sources during winter (Robb *et al.* 2008, Chamberlain *et al*. 2009, Evans *et al.* 2015). Beyond this, however, bird feeding has several further potential biological and ecological implications for feeder-visiting birds. Previous research on this topic has largely focused on how winter feeding influences avian community composition at feeding sites (Ferger *et al*. 2014, Galbraith *et al.* 2015, Pierret & Jiguet 2018), health risks including pathogen exposure (Lawson *et al.* 2012, but see: Frątczak *et al.* 2021), mortality factors associated with feeding sites (Robb *et al.* 2008, Lawson *et al.* 2018, Tryjanowski *et al.* 2018), and occasionally the potential impacts of winter feeding on birds' physiology and reproductive success (Plummer *et al.* 2013, Plummer *et al.* 2018). These studies are very important by providing a more comprehensive understanding of the myriad effects of bird feeding on urban bird populations. However, many of these studies, being feeding experiments, may not necessarily provide insights into the prevalence and characteristics of local bird feeding practices. While there have been efforts to assess the extensive scale of bird feeding (Horn & Johansen 2013, Dayer *et al.* 2019) or estimate bird feeder densities and the types of food provided at bird tables in urban environments (Orros & Fellowes 2015, Plummer *et al.* 2019), actual field surveys and studies investigating human residents' bird feeding practices remain rare. Moreover, there is a notable gap in our understanding regarding the structural types and densities of bird feeders (Amrhein 2014, but see: Tryjanowski *et al.* 2015), factors critical in determining the number of bird species and individuals that can effectively utilize these resources. This is particularly true for regions beyond the USA and the UK (Reynolds *et al.* 2017, Baverstock *et al.* 2019), where bird feeding has been a longstanding tradition for decades and is studied most frequently (Cowie & Hinsley 1988, Plummer *et al.* 2019). Therefore, while there has been a prevailing notion that in Europe bird feeding is far more prevalent in North-western European cities (Reynolds *et al*. 2017), research from Central and Eastern European countries is rare. From this region, to our knowledge, research published on human residents' bird feeding habits is only available from Poland where the authors found no significant difference in the number of bird feeders between urban and rural settings, although urban residents tended to fill a higher proportion of bird feeders with food (Tryjanowski *et al.* 2015).

The aim of the present study was to provide an accurate picture of the prevalence of winter bird feeding in Hungary, Central Europe, in areas that considerably differ in their degree of urbanization. Our study objectives were as follows. First, to survey the density and characteristics of winter bird feeders (placed by citizens) in Veszprém (a middle-sized city) and Budapest (the capital of Hungary) and also in nearby peri-urban forested areas with low housing densities. Second, to document the bird species and number of individuals attracted by the different types of feeders.

Material and Methods

Study areas

We conducted our study in two Hungarian cities: Veszprém, a middle-sized city with ~57,100 residents, and Budapest, the capital city with 1,707,000 residents (Hungarian Central Statistical Office, 2021.01.01; https://www.ksh.hu/stadat_files/fol/hu/fol0014.html). For the winter bird feeder surveys, we selected five study sites in each city, comprising four urbanized areas (within the city) and one peri-urban wooded area in the proximity of the city *(Figure 1)*.

A) City centre I (Veszprém): Located in one of Veszprém's central districts, this site surrounds the city's main bus station. It is a bustling area with several high-traffic roads, shops, offices, an urban park, and some residential buildings (47°05'46.3"N 17°54'45.6"E, area: ~0.12 km^2).

B) Office area I (Veszprém): This site is located in the middle of the city near the main campus of the University of Pannonia. It features university buildings, parking lots, a nearby cemetery with mature trees, an urban park, office buildings, and high-traffic roads (47°05'19.1"N 17°54'34.3"E, area: ~0.333 km^2).

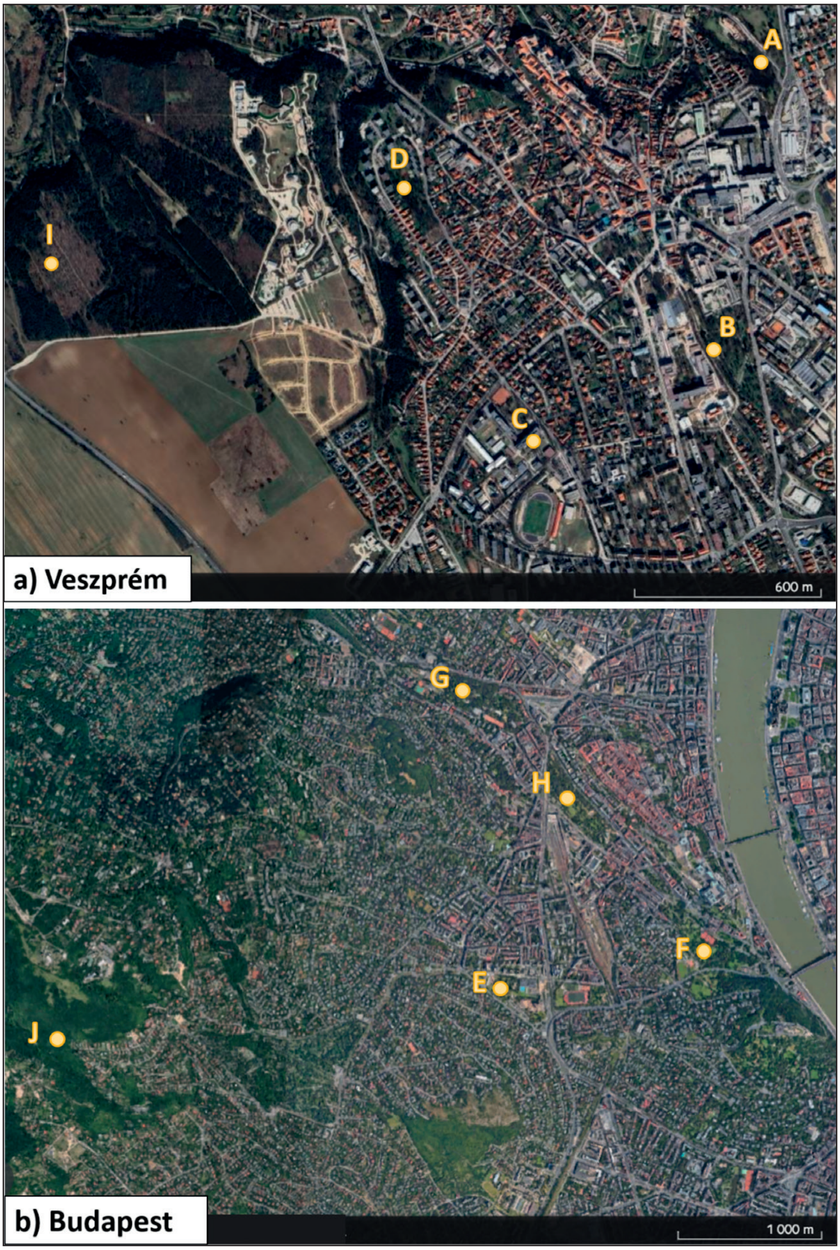

Figure 1. The map of the winter bird feeder survey sites in Veszprém (panel a) and Budapest (panel b) during the winter of 2021–2022. A) City centre I; B) Office area I; C) Residential area I; D) Residential area II; E) Office area II; F) Urban park; G) Residential area III; H) City centre II; I) Peri-urban woodland I; J) Peri-urban woodland II.

1. ábra A téli madáretető felmérés területeinek a térképe Veszprémben (a panel) és Budapesten (b panel), 2021–2022 telén. A) Városközpont I; B) Üzleti negyed I; C) Lakóövezet I; D) Lakóövezet II; E) Üzleti negyed II; F) Városi park; G) Lakóövezet III; H) Városközpont II; I) Városszéli erdős terület I; J) Városszéli erdős terület II.

C) Residential area I (Veszprém): The Egyetemváros neighbourhood is characterized by a mix of green spaces, recreational facilities, and residential buildings, including multi-storey block housing flats and houses with gardens. Another university campus with a large park is also located here (47°05’09.1”N 17°54’11.5”E, area: ~0.209 km^2).

D) Residential area II (Veszprém): The Jeruzsálemhegy neighbourhood is primarily a housing estate with multi-story block housing flats, public green spaces, and an old and relatively undisturbed cemetery with mature broadleaved trees (47°05’36.8”N 17°53’51.2”E, area ~0.131 km^2).

E) Office area II (Budapest): The Gesztenyés-kert park consists of green spaces, a shopping centre, and extensive office and sports facilities (47°29’22.8”N 19°01’14.1”E, area ~0.15 km^2).

F) Urban park (Budapest): The Tabán urban park near the Danube River and adjacent to Gellért Hill’s green area, is covered with large grassy fields, dotted with trees and bushes. It is a popular site for recreational activities among locals and it is surrounded by residential flats (47°29’33.9”N 19°02’16.7”E, area ~0.258 km^2).

G) Residential area III (Budapest): Characterized mostly by residential multi-story blocks of flats and an urban park with green spaces and several recreational facilities (47°30’27.7”N 19°01’06.0”E, area ~0.299 km^2).

H) City centre II (Budapest): This area features one of the main train stations of Budapest, and parking lots, office and residential buildings. A large urban park with green spaces and walking paths is also located here (47°30’03.7”N 19°01’37.1”E, area ~0.265 km^2).

I) Peri-urban woodland I (Veszprém): The Gulya-domb is a semi-natural forest on the outskirts of Veszprém, adjacent to the zoo. This area is very popular for recreational activities with campfire spots and numerous hiking trails. The most common tree species are the native flowering ash *(Fraxinus ornus)*, downy oak *(Quercus pubescens)* and Turkey oak *(Quercus cerris)*, and the non-native black pine *(Pinus nigra)* (47°05’28.2”N 17°52’59.4”E, area ~0.292 km^2).

J) Peri-urban woodland II (Budapest): The Ördög-orom within the borders of Budapest, is a semi-natural forest with weekend houses and hiking trails. This site is mainly characterized by the native common hornbeam *(Carpinus betulus)* mixed with sessile oak *(Quercus petrea)*, English oak *(Quercus robur)* and flowering ash (47°29’09.6”N 18°58’42.2”E, area ~0.346 km^2).

Field methods

We conducted bird feeder surveys during the winter season, between November 25, 2021 and March 1, 2022. Each site was surveyed three times with a minimum two-week interval between the consecutive surveys. Surveying took place only during favourable weather conditions (no snowfall or rain, wind force below 20 km/h [Beaufort-scale 3]) between 8:00 and 14:00. During these surveys, one or two observers equipped with binoculars walked through the study site at a slow pace, following a route that enabled to visually cover all accessible areas as much as possible without cross-passing. We meticulously mapped the location of every bird feeder and documented the following details: the type of the bird feeder (see below), the type(s) of food provided, and the abundance and species of birds visiting the feeders (detailed below).

We differentiated five types of feeders (following Tryjanowski *et al.* 2015): (1) typical bird table often with a roof (having a fixed position e.g. on a pole, fence, or window sill; (2) bottle-type hanging feeders providing seeds (often made from plastic water bottles); (3) fat balls; (4) food scattered on the ground (typically sunflower seeds, but sometimes breadcrumbs or kitchen waste); and (5) mixed feeders where more than one feeder types were present together (e.g. bottle feeders with fat balls).

Furthermore, we categorized the type of food provided at the feeders into seven main categories: (1) sunflower seeds; (2) seed mix; (3) fat ball (fat mixed with seeds); (4) animal fat; (5) nuts; (6) fruits; and (7) human food waste (e.g. bread, oat or cooked rice).

We also recorded the presence of birdbaths. Note however, that we started to record baths only during the first field surveys, and that due to the decreased visibility of baths, this type of data was less accurate than the rest of the data collection protocol. Therefore, the data on the presence of birdbaths is likely incomplete to some degree.

During the surveys, we conducted observations at each feeder for 3–5 minutes (depending on the birds' activity on the feeder), to record all bird species appearing at the feeder. First, we recorded the number of species, estimated as the maximum number of bird species in one feeder per survey. Second, for each species present we also recorded the number of birds as the highest observed count of individuals that were present at the feeder and/or in its immediate vicinity during the observation period.

Statistical analysis

We analysed our data in RStudio (R 4.3.2.). For fitting generalized linear mixed models, we used Template Model Builder automatic differentiation engine (package 'glmmTMB'; Brooks *et al.* 2017). We built generalized linear mixed models with Poisson distribution separately for the number of birds and the number of species (response variables). The models included feeder ID as a random factor. The models contained the following environmental predictor variables potentially affecting the number of birds and the number of species: feeder type (5 levels), the daily minimum temperature (on the day of the survey), the city (Budapest or Veszprém), the date (numeric variable; 1 = 25th of November, the date of the first survey), and the presence of a birdbath on the feeder (present/absent). Snow coverage (present/absent) was not included in the analysis, because snow cover was rare during the surveys and its presence was unbalanced between the study sites: snow coverage during survey days was present only in the two peri-urban sites and the urban sites in Veszprém, but never in the urban sites at Budapest. Removing step-wise the non-significant predictors from the models did not change the results qualitatively, so we present the results of the full models. We tested the fit of the models using the 'DHARMa' R package (Hartig 2019); the fit of all models was acceptable. Finally, we compared the effect of the feeder type on the number of birds and number of species with Tukey's post-hoc tests (using R package "glht").

Results

Density of the surveyed feeders

We completed 30 surveys in total, three at each of the 10 study sites. During these, we mapped the locations of a total of 202 bird feeders that contained food on at least one occasion. The density of the active feeders (i.e. the feeders that contained food on a given field survey) varied highly across study sites and even from one survey to the next within the same site, and was notably lower in the two peri-urban woodland sites compared to the other 8 urban locations *(Table 1)*.

In the urban study sites in Veszprém, the number of active feeders varied between 11–33, translating to a density ranging from 60.1 to 206.1 bird feeders/km^2. The feeder density was usually two times higher in Veszprém than in Budapest where, the number of active feeders ranged between 4–22, extrapolating to a density of 23.3–80.0 bird feeders/km^2. At Veszprém, we found the highest feeder densities in the two residential areas (C and D), during all three surveys. But in Budapest, we found the highest feeder densities in the city centre area (H; *Table 1*). In comparison to the urban sites, bird feeders were much scarcer in the peri-urban forest sites in both cities. The number of active bird feeders ranged between 1–4 with their density spanning between 3.4–13.7 bird feeders/km^2, in the peri-urban woodland at Veszprém (I). Similarly, in the peri-urban woodland at Budapest (J), the number of active feeders was 4–5, resulting in a density of 13.5–14.5 bird feeders/km^2.

Table 1. Density and number of active bird feeders at each site, surveyed in the cities of Veszprém and Budapest, in the winter of 2021–2022

1. táblázat A Veszprémben és Budapesten felmért aktív madáretetők denzitása 2021–2022 telén

	Site	**Area of site (km^2)**	**Number of active feeders**			**Density of active feeders (\km^2)**			
			Survey No.1	Survey No.2	Survey No.3	Survey No.1	Survey No.2	Survey No.3	Mean
Veszprém	**A) City centre I**	0.12	13	15	11	108.3	125.0	91.7	108.3
	B) Office area I	0.333	20	22	26	60.1	66.1	78.1	68.1
	C) Residential area I	0.209	27	33	28	129.2	157.9	134.0	140.4
	D) Residential area II	0.131	23	24	27	175.6	183.2	206.1	188.3
	I) Peri-urban woodland I	0.292	4	3	1	13.7	10.3	3.4	9.1
Budapest	**E) Office area II**	0.15	6	4	7	40.0	26.7	46.7	37.8
	F) Urban park	0.258	8	6	6	31.0	23.3	23.3	25.8
	G) Residential area III	0.299	9	12	11	30.1	40.1	36.8	35.7
	H) City centre II	0.265	14	22	18	52.8	83.0	67.9	67.9
	J) Peri-urban woodland II	0.346	4	5	5	11.6	14.5	14.5	13.5

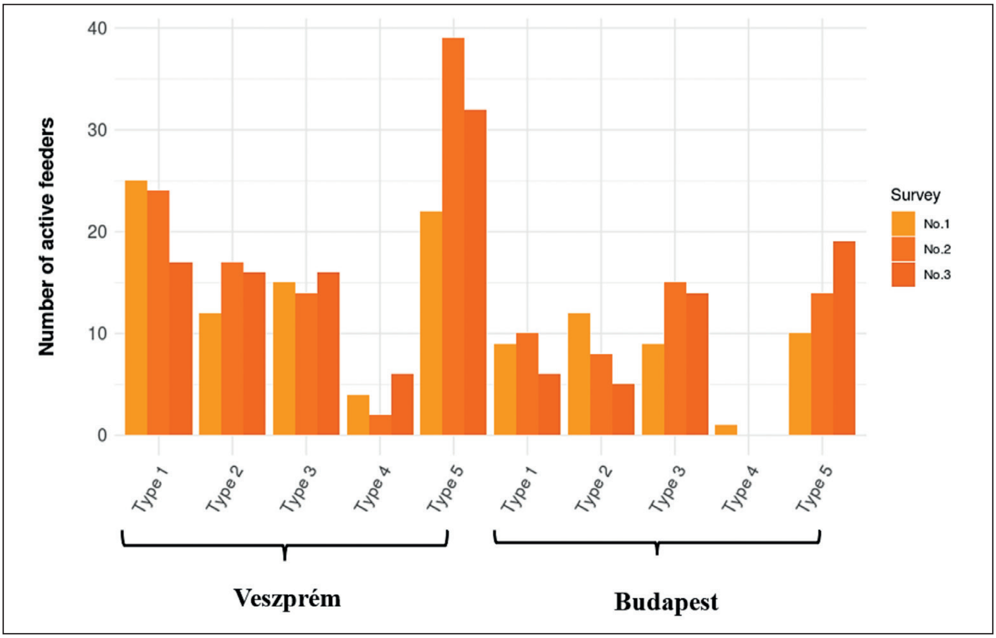

Figure 2. The distribution of the number and type of active bird feeders in Veszprém and Budapest. The feeder types were: (1) typical bird table often with a roof; (2) bottle-type hanging feeders providing seeds; (3) fat balls; (4) food scattered on the ground; (5) mixed feeders where more than one feeder types were present together

2. ábra Az aktív madáretetők száma madáretető típusonként lebontva Veszprémben és Budapesten. Öt féle madáretető típust különböztettünk meg, ezek a következők: (1) hagyományos, tetős, telepített etető; (2) felfüggesztett, palack típusú etető; (3) cinkegolyó; (4) földre kiszórt mag vagy élelmiszer-hulladék; (5) vegyes etető, ahol többféle etető típus is jelen van egyszerre

Feeder and food types

The most frequent type of currently active feeders was type 5 (mixed feeders) and the least frequent was type 4 (food scattered on the ground) both in Veszprém and Budapest *(Figure 2)*. Fat balls, seed mixes, and sunflower seeds were by far the most popular types of food that people provided to birds both in Veszprém and Budapest. However, in Veszprém those feeder types were present in a higher ratio than in Budapest, which were associated with the other four food types (animal fat; nuts; fruits; and human food waste; *Figure 2*). In Veszprém, we registered only eight feeders associated with birdbaths (seven in the Residential area II (D) and one in the City centre I (A), while birdbaths were present at only three feeders in Budapest, all of them in the City centre II site (H).

Number of birds

We recorded a total number of 516 individuals belonging to 24 species visiting the bird feeders (Veszprém: 20 species, Budapest: 14 species; *Table 2*, *Appendix 1*). There was no significant difference in the number of birds present on the feeders per survey between the

Table 2. The number of birds and bird species surveyed in different feeder types in the cities of Veszprém and Budapest, during the winter of 2021–2022. Feeder types are the following: (1) typical bird table often with a roof; (2) bottle-type hanging feeders providing seeds; (3) fat balls; (4) food scattered on the ground; (5) mixed feeders where more than one feeder types were present together

2. táblázat A Veszprémben és Budapesten felmért aktív madáretetőkön megfigyelt madarak egyedszáma és fajszáma 2021–2022 telén. Öt féle madáretető típust különböztettünk meg, ezek a következők: (1) hagyományos, tetős, telepített etető; (2) felfüggesztett, palack típusú etető; (3) cinkegolyó; (4) földre kiszórt mag vagy élelmiszer-hulladék; (5) vegyes etető, ahol többféle etető típus is jelen van egyszerre

	Feeder type	**Number of birds**				**Number of species**			
		Survey No.1	Survey No.2	Survey No.3	Total	Survey No.1	Survey No.2	Survey No.3	Total
Veszprém	**Type 1**	25	36	30	91	2	6	8	8
	Type 2	4	19	13	36	1	7	5	10
	Type 3	8	3	3	14	2	1	2	2
	Type 4	0	2	5	7	0	2	2	3
	Type 5	52	101	51	204	9	13	10	17
Budapest	**Type 1**	9	8	1	18	3	3	1	4
	Type 2	24	7	11	42	6	4	4	7
	Type 3	0	6	5	11	0	4	3	5
	Type 4	4	0	0	4	2	0	0	2
	Type 5	34	32	23	89	6	7	5	10

two cities *(Table 3)*. However, we found significant differences in the number of birds visiting the different feeder types *(Table 3, 4)*: feeder type 3 (fat balls) had the lowest (compared to type 1, 2, or 5 feeders) while the highest number of individuals was observed at feeder type 5 (mixed feeders), but this difference was statistically significant only compared to feeder type 3 *(Table 2 and 4)*. Furthermore, both daily minimum temperature and the date had significantly negative impact on the number of birds, while the presence of a birdbath had a significantly positive effect on the number of birds *(Table 3)*.

Number of species

The number of species per survey significantly differed between feeder types

Table 3. The effect of feeder type, daily minimum temperature, date, the city (Veszprém or Budapest), and the presence of a birdbath on the number of birds observed on winter feeders

3. táblázat A madáretető típusának, a napi minimum hőmérsékletnek, a dátumnak, a városnak (Veszprém vagy Budapest) és a madáritató jelenlétének hatása a madáretetőkön megfigyelt madarak egyedszámára

Predictors	**Chisq**	**df**	**p-value**
Intercept	6.217	1	0.012
Feeder type	42.338	4	**<0.001**
Daily min. temperature	19.995	1	**<0.001**
Date	7.639	1	**0.005**
City	0.355	1	0.551
Birdbath	9.25	1	**0.002**

The type 3 ANOVA (analysis of variance) results are from a generalized linear mixed-effects model using Template Model Builder, with Poisson distribution and feeder ID as a random factor. Statistically significant ($P<0.05$) differences are highlighted in bold. N=516 individuals in 412 active feeders.

Table 4. Pairwise comparisons of the differences in the number of birds surveyed in different feeder types during the winter of 2021–2022 in Veszprém and Budapest. Feeder types are the following: (1) typical bird table often with a roof; (2) bottle-type hanging feeders providing seeds; (3) fat balls; (4) food scattered on the ground; (5) mixed feeders where more than one feeder types were present together

4. táblázat Az eltérő típusú madáretetőkön megfigyelt madarak egyedszámainak páros összehasonlítása. A megfigyeléseket Veszprémben és Budapesten végeztük 2021–2022 telén. Öt féle madáretető típust különböztettünk meg, ezek a következők: (1) hagyományos, tetős, telepített etető; (2) felfüggesztett, palack típusú etető; (3) cinkegolyó; (4) földre kiszórt mag vagy élelmiszer-hulladék; (5) vegyes etető, ahol többféle típusú etető is jelen van egyszerre

Contrast	Contrast ± SE	z ratio	p-value
type 2 – type 1	0.045 ± 0.317	0.143	0.998
type 3 – type 1	-1.346 ± 0.358	-3.757	**0.001**
type 4 – type 1	-0.017 ± 0.557	-0.032	1.000
type 5 – type 1	0.573 ± 0.263	2.176	0.171
type 3 – type 2	-1.392 ± 0.349	-3.982	**<0.001**
type 4 – type 2	-0.063 ± 0.555	-0.114	0.999
type 5 – type 2	0.528 ± 0.223	2.359	0.114
type 4 – type 3	1.329 ± 0.588	2.259	0.143
type 5 – type 3	1.92 ± 0.306	6.267	**< 0.001**
type 5 – type 4	0.591 ± 0.513	1.152	0.759

The table shows the results of linear Tukey contrasts that were calculated from the final model presented in Table 3. Statistically significant (P<0.05) differences are highlighted in bold. N=516 individuals in 412 active feeders.

(Table 5, Appendix 1): there were significantly fewer species in type 3 than in type 1, 2, or 5 feeders *(Table 6)*. There was no significant difference between cities in the number of feeder-visiting bird species. The presence of a birdbath at the feeder had significantly positive effect on the number of feeder-visiting bird species while the date and the daily minimum temperatures had no significant effect on it *(Table 5)*.

Discussion

In this study, we conducted field surveys in two Hungarian cities to assess the prevalence of residents' winter bird-feeding practices. We focused on quantifying the density and

Table 5. The effect of feeder type, daily minimum temperature, date, the city (Veszprém or Budapest), and the presence of a birdbath on the number of bird species observed on winter feeders

5. táblázat A madáretető típusának, a napi minimum hőmérsékletnek, a dátumnak, a városnak (Veszprém vagy Budapest) és a madáritató jelenlétének hatása a madáretetőkön megfigyelt madarak fajszámára

Predictors	Chisq	df	p-value
Intercept	3.713	1	0.053
Feeder type	22.87	4	**<0.001**
Daily min. temperature	0.795	1	0.372
Date	0.652	1	0.419
City	2.843	1	*0.091*
Birdbath	15.105	1	**<0.001**

The table shows type 3 ANOVA (analysis of variance) results from the generalized linear mixed-effects model using Template Model Builder, with Poisson distribution and feeder ID as a random factor. Statistically significant (P<0.05) differences are highlighted in bold and marginally nonsignificant (0.05<P<0.1) differences are highlighted in italics. N=516 individuals (24 species) in 412 active feeders.

Table 6. Pairwise comparisons of the differences in the number of bird species surveyed on the different feeder types during the winter of 2021–2022 in Veszprém and Budapest. Feeder types are the following: (1) typical bird table often with a roof; (2) bottle-type hanging feeders providing seeds; (3) fat balls; (4) food scattered on the ground; (5) mixed feeders where more than one feeder types were present together

6. táblázat Az eltérő típusú madáretetőkön megfigyelt madarak egyedszámainak páros összehasonlítása. A megfigyeléseket Veszprémben és Budapesten végeztük 2021–2022 telén. Öt féle madáretető típust különböztettünk meg: (1) hagyományos, tetős, telepített etető; (2) felfüggesztett, palack típusú etető; (3) cinkegolyó; (4) földre kiszórt mag vagy élelmiszer-hulladék; (5) vegyes etető, ahol többféle típusú etető is jelen van egyszerre

Contrast	Contrast ± SE	z value	p-value
type 2 – type 1	0.085 ± 0.292	0.292	0.998
type 3 – type 1	-1.244 ± 0.372	-3.340	**0.006**
type 4 – type 1	0.017 ± 0.56	0.032	1.000
type 5 – type 1	0.374 ± 0.254	1.472	0.558
type 3 – type 2	-1.329 ± 0.373	-3.565	**0.002**
type 4 – type 2	-0.067 ± 0.565	-0.12	0.999
type 5 – type 2	0.288 ± 0.241	1.194	0.737
type 4 – type 3	1.261 ± 0.612	2.06	0.219
type 5 – type 3	1.618 ± 0.339	4.766	**<0.001**
type 5 – type 4	0.356 ± 0.541	0.658	0.961

The table shows the results of linear Tukey contrasts that were calculated from the final model presented in Table 5. Statistically significant ($P<0.05$) differences are highlighted in bold. N=516 individuals (24 species) in 412 active feeders.

characteristics of winter bird feeders and also recorded the bird species and number of individuals visiting various feeder types.

The mixed feeder emerged as the most common feeder type in both cities, indicating a widespread attempt of the residents to offer a diverse array of bird food, likely to attract a larger number of birds to the bird tables. During the field surveys, we observed the highest number and diversity of birds in the mixed feeders, which supports the effectiveness of this practice. However, it is important to note, that this result could be attributed to the overall larger size and the higher variety of food available in mixed feeders, making them more accessible to a broader range of birds compared e.g. to fat balls, which are generally smaller and offer mostly fat and to a smaller degree, seeds. In addition, our observations revealed that feeders combined with birdbaths, irrespective of the feeder type, attracted the highest number of individuals and species. This finding underlines the importance of water sources, alongside food, for birds during the winter, emphasizing the value of birdbaths in supporting bird populations in urban environments.

The most frequent food types offered at feeders were fat balls and seed mixes, likely due to their easy commercial availability on supermarket shelves. This observation aligns with the findings by Orros and Fellowes (2015), who reported that among the UK citizens who provide food for wild birds, various seed mixes (including millet, barley, and sunflower seeds) are the most common. This food type is accepted and favoured as winter food by several bird species, especially granivores, due to its high energy content (Horn *et al.* 2014, Tryjanowski *et al.* 2018). However, several species that are relatively common in urban environments (like robins, blackbirds, or woodpeckers) do not prefer or cannot utilize seed mixes as food source, therefore making these feeders less suitable for supporting a diverse winter bird community (Horn & Johansen 2013, Galbraith *et al.* 2015, Støstad *et al.* 2017).

Our study revealed a significantly higher density of feeders in the urban sites of Veszprém (a medium-sized town) compared to Budapest (a metropolis, and the capital city of Hungary). We also found that feeder densities were notably the highest in the residential areas of Veszprém (range: 129.2–206.1 bird feeders/km^2). This variation highlights the influence of the urban landscape structure on birds' winter food availability (Ciach & Fröhlich 2017). In Veszprém, these study sites were situated in block housing areas and detached houses with private gardens with interconnected green spaces, whereas, in Budapest, the study sites were in densely built-up areas with green spaces resembling more like small, "isolated islands" within the urban landscape. In addition to the cities' architectural structure, other factors could also play a role in shaping bird feeder densities, such as differences in the mentality of the residents between the cities or city districts, or local regulations that sometimes prohibit bird feeding near apartments due to the attraction of unwanted guests on bird feeders, like city-dwelling pigeons. These type of regulations are present in both Veszprém and Budapest. However, Budapest is a bigger and more densely populated city, also with more pigeons *(Appendix 1)*, thus these types of regulations are probably more frequent and prevalent there, which could also negatively affect the number of bird feeders there. Our results revealed a remarkable and fine-scale (i.e. within-city) variation in the availability of winter bird feeders – and consequently food supply – that probably influence various aspects of birds' biology, including physical condition, physiological stress, behaviour (Broggi *et al.* 2005, Roth & Vetter 2008, Lawson *et al.* 2018), and most importantly, birds' chances of survival during the winter months. Therefore, we suggest that future studies focusing on the survival patterns of urban birds should consider this factor rather than treating distinct parts of the city with different landscape structures as the same.

In contrast to the urban sites, we found no considerable difference in the density of feeders between the two peri-urban woodlands, where feeder density was markedly lower than in the city, similarly to the findings of Tryjanowski *et al.* (2015). Even though, the vegetation of these two sites is quite different, both are characterized by the low rate of built-in areas (mostly weekend houses) and low human population density, which could explain the similarly low bird feeder densities at both sites.

Finally, it is important to acknowledge the limitations of our study. Our chances of detecting bird feeders might have varied between or even within cities, due to the different architectural layout of buildings, green spaces, and private properties. During the surveys, we were looking for bird feeders visually, making it challenging to spot feeders located high above the ground (e.g. on a fourth-floor balcony or windowsill) or completely hidden within private gardens. This difficulty may have had a greater impact on our results regarding food type and the presence of birdbaths, as a good view of the feeding station is important to reliably collect such data. Moreover, the differences we found in the distribution of birdbaths across cities and study sites might partially result from the initial inconsistency among surveyors in recording the presence of birdbaths. Nonetheless, we believe that our feeder density results were less affected by these difficulties, as the presence of an active feeder could be often inferred from birds' activity and vocal cues even if we did not have a clear view of the feeder's exact location.

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Appendix 1. List of surveyed bird species and number of individuals (516 individuals of 24 species in total), in winter feeders in Veszprém and Budapest, in the winter of 2021–2022. Those species that only appeared in one city are highlighted in bold

1. függelék A Veszprémben és Budapesten 2021–2022 telén felmért madáretetőkön megfigyelt madarak egyedszámának és fajainak listája (összesen 24 faj 516 példánya). Azokat a fajokat, amelyeket csak az egyik városban figyelünk meg, félkövér betűtípussal jelöltük

Species	**Number of individuals**				
	Survey No.1	Survey No.2	Survey No.3	Total	
Columba livia f. domestica	1	0	0	1	**Veszprém (total number of species = 20)**
Columba palumbus	**0**	**10**	**2**	**12**	
Streptopelia decaocto	3	0	3	6	
Erithacus rubecula	**1**	**3**	**1**	**5**	
Turdus merula	4	21	9	34	
Regulus ignicapilla	**0**	**0**	**1**	**1**	
Cyanistes caeruleus	6	6	11	23	
Parus major	70	79	48	197	
Periparus ater	**1**	**6**	**4**	**11**	
Poecile palustris	**0**	**1**	**2**	**3**	
Aegithalos caudatus	0	0	2	2	
Sitta europaea	1	4	1	6	
Passer domesticus	0	1	21	22	
Passer montanus	0	0	1	1	
Fringilla coelebs	**1**	**12**	**0**	**13**	
Fringilla montifringilla	**0**	**1**	**0**	**1**	
Carduelis carduelis	0	11	22	33	
Chloris chloris	**0**	**3**	**1**	**4**	
Spinus spinus	**0**	**1**	**3**	**4**	
Coccothraustes coccothraustes	**0**	**2**	**1**	**3**	
Columba livia f. domestica	6	25	12	44	**Budapest (total number of species = 14)**
Streptopelia decaocto	2	0	0	2	
Dendrocopos major	**1**	**0**	**0**	**1**	
Dendrocopos syriacus	**1**	**0**	**0**	**1**	
Turdus merula	0	3	1	4	
Cyanistes caeruleus	0	2	3	5	
Parus major	30	28	15	73	
Sitta europaea	4	1	1	6	
Aegithalos caudatus	0	2	0	2	
Garrulus glandarius	**0**	**1**	**0**	**1**	
Corvus cornix	**1**	**0**	**0**	**1**	
Passer domesticus	21	25	0	46	
Passer montanus	3	5	8	16	
Carduelis carduelis	2	1	0	3	

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Spatiotemporal distribution of Eurasian Spoonbills *(Platalea leucorodia)* outside the Carpathian Basin – the results of the Hungarian colour-ringing project based on twenty years (2003–2023)

Csaba Pigniczki[1]*, Habib Dlensi[2], Mohamed-Ali Dakhli[3], Hichem Azafzaf[4] & Salvatore Surdo[5]

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Abstract The Eurasian Spoonbill *(Platalea leucorodia)* is a migratory waterbird. We used the confirmed observations of colour-ringed individuals (2,735 specimens) of the Hungarian population collected outside the Carpathian Basin between May 2003 and February 2023. 546 Spoonbills occurred in 28 countries. They used mainly the Central Mediterranean Flyway, however, some individuals were seen along the East Atlantic Flyway or the East Mediterranean Flyway. Three individuals were observed north of the Alps, too. A small proportion of Spoonbills crossed the Sahara and they occurred in the Sahel zone, between Sudan in the east and Senegal and Mauritania in the west. A few individuals were observed on Saharan wetlands in Algeria during winter. The most important destination for the Hungarian (Pannonian) population during the migration is Tunisia, where many of them spend the winter, primarily in the tidal area of the Gulf of Gabes. The first adults reached North Africa (Tunisia) on 28 July during their southward migration, while the last ones stayed there until 23 April. The first observation of juveniles in North Africa (Tunisia) happened on 31 August. Immature, 2- and 3-cy-old birds spend the summer in unknown numbers in Tunisia. The majority of Pannonian Spoonbills migrate through the Balkans and Italy and some stay there to winter, mainly in Italy. Some of the immatures spent the summer in Italy. In southern Europe, the peak of the spring migration was in March, and the peak of the autumn migration was in September. There was also a difference in the migration of different age groups: in Southern Europe, the migration peak of adult birds falls between March and April, while most of the immatures were observed in May and June during northward migration. The peak of the southward migration in all age groups was observed in September. In the southern part of Europe, there may still be adults migrating north on 13 May, while other adults may already migrate southward on 15 May. The earliest juvenile migrating south was documented on 30 June in Italy.

Keywords: bird migration, summering, wintering, Mediterranean areas, Sahara, Sahel, Gulf of Gabes, Tunisia, Italy

Összefoglalás A kanalasgém *(Platalea leucorodia)* vonuló vízimadár. Ebben a tanulmányban a magyar populáció színes gyűrűs egyedeiről (2735 pd.) húsz év alatt (2003 május – 2023 február között), a Kárpát-medencén kívül összegyűjtött megfigyeléseket használtuk fel, amelyek 547 egyedről 28 országból érkeztek. A kanalasgémek vonulásuk során elsősorban a Közép-Mediterrán Madárvonulási Útvonalat használták, de néhány példányt a Kelet-Atlanti, vagy a Kelet-Mediterrán Madárvonulási Útvonal mentén is észleltek. Három egyedet megfigyeltek az Alpoktól északra is. A kanalasgémek egy kis hányada átkelt a Szaharán és a Száhel Szudán illetve Szenegál és Mauritánia közé eső területein fordultak elő. Néhány példány télen Algériában, szaharai vizes élőhelyeken került elő. A magyar (pannon) populáció számára a vonulás során a legfontosabb célterület Tunézia, ahol sokan át is telelnek, elsősorban a Gabesi-öböl árapály zónájában. Észak-Afrikát (Tunézia) az első öregek július 28-án érték el az őszi vonulásuk során, míg az utolsók április 23-ig kitarthatnak. A fiatalok első észak-afrikai (tunéziai) megfigyelése augusztus 31-én történt. Az ivaréretlen, 2. és 3. naptári éves madarak ismeretlen mennyiségben átnyaralnak Tunéziában. A hazai kanalasgémek többsége a Balkán-félszigeten és Olaszországon átvonul. A hazai populációból a legtöbb madár Olaszországban telel a dél-európai területek közül, a Balkánon csak néhány tölti a telet. Az ivaréretlen madarak egy része Olaszországban átnyaralt. Dél-Európában a tavaszi vonulás csúcsa márciusban van, az őszi vonulás csúcsa pedig szeptemberre esik. Eltérés van a különböző korcsoportok vonulásában is: Dél-Európában az öreg madarak tavaszi vonulási csúcsa márciusra és áprilisra esik, míg a legtöbb ivaréretlent május és június során észlelték. Az őszi vonulás csúcsa minden korcsoportnál szeptemberre esett. Európa déli részén május 13-án még észak felé vonuló öreg egyedek is lehetnek, míg más öregek május 15-én már déli irányba vonulhatnak. A legkorábbi, déli irányba vonuló fiatalt június 30-án észlelték Olaszországban.

Kulcsszavak: madárvonulás, átnyaralás, telelés, mediterráneum, Szahara, Száhel, Gabesi-öböl, Tunézia, Olaszország

[1] *Kiskunság National Park Directorate, 6000, Kecskemét, Liszt Ferenc utca 19., Hungary*
[2] *Association de Continuité des Générations, Med Chabouni 3027 Sfax, Tunisia*
[3] *Birding Tunisia, 46 Avenue Habib Bourguiba, 8045 El Haouaria, Tunisia*
[4] *Association « Les Amis des Oiseaux » (AAO/BirdLife en Tunisie), Immeuble ERIS, Bureau N°4, 2ème étage. 14, Rue Ibn El Heni – 2080 Ariana, Tunisia*
[5] *Department of Agriculture, Food and Forest Science, Viale delle Scienze 13, 90128 Palermo, Italy*
* *corresponding author, e-mail: csaba.spoonbill@gmail.com*

Introduction

The nominate race of the Eurasian Spoonbill *(Platalea leucorodia)* (hereafter Spoonbill) breeds in a wide zone in Eurasia from the Atlantic coast of Europe east to the Pacific coast of Asia with breeding populations in India and Sri Lanka (Triplet *et al.* 2008). While the population is increasing in coastal West Europe, other European populations are declining (Champagnon *et al.* 2019). The European breeding population comprises at least four flyway populations (Pigniczki 2022). The Hungarian breeding population belongs to the Pannonian breeding population and primarily uses the Central Mediterranean Flyway to reach its most important wintering areas. The majority of Spoonbills marked in Hungary returned to the Carpathian Basin to breed (Pigniczki 2009, Pigniczki & Végvári 2015). The breeders arrive in their Hungarian nesting areas between the second half of February and May (Pigniczki 2021). The Hungarian breeding population reached its lowest size by the middle of the 20th century and was estimated at 280 pairs. Later, this population started to increase and it was estimated at 450–700 pairs in the 1990s, 850–1,300 pairs between 2002 and 2013, and finally 550–900 pairs between 2014 and 2020 (Pigniczki 2021). The bulk of the Pannonian individuals are short-distance migrants and winter in the Central Mediterranean areas, however, there are a few long-distance migrants amongst them, which winter in the Sahel zone, while a few individuals are residents and stay in the Carpathian Basin even in winter (Pigniczki 2010, 2022, Kralj *et al.* 2012).

Spoonbills predominantly depend on shallow wetlands during their life, including breeding, migration, and wintering (Pigniczki & Végvári 2015, Pigniczki 2022). For conservation purposes, it is important to analyse the spatiotemporal distribution of the Hungarian breeding population. In this paper, the observations and recoveries of the colour-ringed Spoonbills are collected from outside the Carpathian Basin.

Material and Methods

2,735 Spoonbill chicks were marked in Hungary with colour rings between 2003 and 2022. For this study, only those records were used that were collected outside the Carpathian Basin between May 2003 and February 2023. Three types of colour-ringing schemes were used in the Hungarian colonies (see details in Pigniczki 2022). The colour-ringed Spoonbills can be identified with telescopes even from large distances (up to 300–400 m). Professional and amateur ornithologists collected the observations of colour-ringed individuals in Europe, the Middle East, and Africa. In several cases, special ring-reading expeditions were organised to Tunisia to find as many colour-ringed Spoonbills as possible.

The dataset was analysed to identify Spoonbills' spatial and temporal distribution outside the Carpathian Basin. For the analysis, three age groups were created: 1) juveniles, 2) immatures, and 3) adults. A bird was treated as a juvenile in the calendar year (hereafter cy) of its hatching. A Spoonbill was an immature if it was 2-cy-old or 3-cy-old. A Spoonbill in 4-cy-old age or older was treated as an adult. Similarly, three time periods were defined to describe the annual cycle of the birds: the winter period lasts between November and February when Spoonbills generally occur in their wintering area. Spring was defined as the period between March and June. During this period, most Spoonbills do their northward migration and on the breeding ground (in the Carpathian Basin), this is the main period of their nesting. Autumn was identified as the period between July and October. During this period, Spoonbills finish their breeding and start their post-natal/post-breeding dispersal, and then, the majority of the birds complete their southward migration.

We created four maps that represent the distribution of Spoonbills. One of the maps is a general map that contains all records (including data with no exact date) that were reported outside the Carpathian Basin. We created maps that show the winter (between November and February), spring (between March and June), and autumn (between July and October) distributions. In these maps, two records were excluded where the inaccuracy in the date of the record exceeded the monthly rate.

The majority of Spoonbills occurred south of the Carpathian Basin. The analysis of the migration of Spoonbills was divided into two large geographic areas: we separately analysed the data of individuals detected in South Europe and North Africa. South Europe was defined as the areas south of the Alps and the Carpathian Basin, generally south of 45 °N, including the observations from Turkey. North Africa was defined as African territories north of 22 °N and the observations from Israel were also added to this area. The data were analysed in a monthly distribution for the three age groups in the case of both geographic areas. If a single immature or adult individual was detected in the same month in multiple years within the same geographical area, each observation was added to the number of monthly observations of the proper age groups in the appropriate geographic area. If a single individual was reported multiple times in the same month in the same year in a geographic region, those records were pooled and treated as a single occasion. Records from sub-Saharan Africa and the northern part of Europe are not available in the proper quantity, thus they were excluded from this analysis.

Finally, we tested the hypothesis that during winter, spring, and autumn, the number of Spoonbills is the same in Europe (outside the Carpathian Basin) and Africa. The chi-square test was applied for given probabilities in the R statistical program (R Core Team 2023). However, the dataset contains a few Asian records from the Middle East, those records were not involved in this test.

Results

Geographical distribution

547 different individuals (20.00%) of 2,735 specimens were observed outside the Carpathian Basin and 1,737 records were collected on them from 28 different countries between May 2003 and February 2023 *(Table 1, Figure 1)*. 525 (19.20%) individuals were reported along the Central Mediterranean Flyway (in the case of Spoonbills, it is alternatively referred to as the Adriatic Flyway), from the central part of south Europe (Italy and the western part of Balkans), the central part of north Africa (east Algeria, Tunisia, and coastal Libya), and the central part of the Sahel (Mali, Niger, and Nigeria). The majority of Spoonbills were found in Tunisia (368 individuals, 13.46%) and Italy (174 individuals, 6.36%).

The most important African sites for Spoonbills based on ring readings of Hungarian specimens lay in the tidal wetlands and salinas of the Gulf of Gabes (Tunisia), with a notable

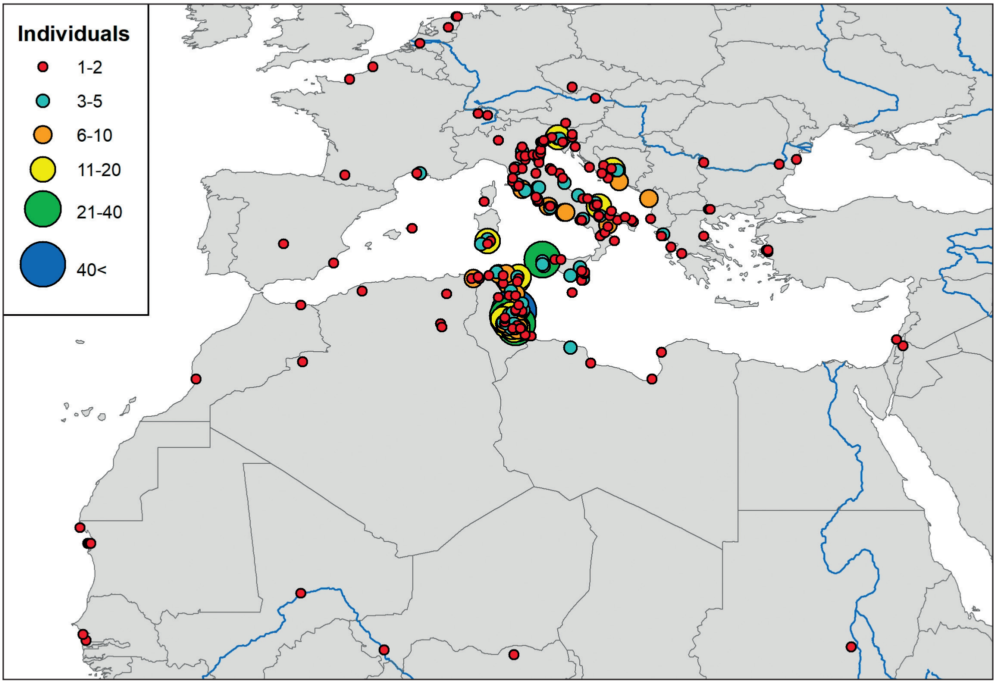

Figure 1. General distribution of Spoonbills marked in Hungary with colour-rings between 2003 and 2023 in Europe (outside the Carpathian Basin), Asia, and Africa.

1. ábra A Magyarországon színes gyűrűvel jelölt kanalasgémek általános elterjedése 2003 és 2023 között Európában (Kárpát-medencén kívül), Ázsiában és Afrikában

Table 1. Number of Spoonbills (individuals) marked in Hungary, occasions of their occurrences, and monthly occurrences in countries, outside the Carpathian Basin. Abbreviations: CB means the Carpathian Basin

1. táblázat A magyar gyűrűs kanalasgémek egyedszáma, előfordulási eseteinek száma és havi előfordulásai országonkénti bontásban, a Kárpát-medencén kívül. Rövidítések: CB jelentése Kárpát-medence

Country	Individuals (%)	Occasions	Months
Germany	1 (0.04%)	4	9
The Netherlands	1 (0.04%)	3	6–7
France	5 (0.18%)	28	5–10
Spain	3 (0.11%)	4	3–4
Switzerland	1 (0.04%)	3	5
Czechia	1 (0.04%)	1	4
Austria (outside the CB)	2 (0.07%)	4	5–6
Italy	174 (6.36%)	618	1–12
Malta	1 (0.04%)	2	6
Slovenia (outside the CB)	3 (0.11%)	3	3–5
Croatia (outside the CB)	17 (0.62%)	20	2–6; 10
Bosnia & Hercegovina (outside the CB)	19 (0.69%)	28	3–4; 8–10
Montenegro	6 (0.22%)	14	3–6; 9
Albania	1 (0.04%)	1	7
Romania (outside the CB)	3 (0.11%)	3	3–5
Greece	10 (0.37%)	18	11–6; 9
Turkey	3 (0.11%)	5	1–2; 5; 9–10
Israel	2 (0.07%)	2	10
Morocco	2 (0.07%)	3	4; 11–12
Algeria	15 (0.55%)	28	9–3
Tunisia	368 (13.46%)	921	1–12
Libya	11 (0.40%)	12	1; 3; 8; 10–11
Mauritania	3 (0.11%)	6	11–1; 6; 9
Senegal	1 (0.04%)	2	3; 10
Mali	1 (0.04%)	1	2 or 3
Niger	1 (0.04%)	1	11
Nigeria	1 (0.04%)	1	2
Sudan	1 (0.04%)	1	2
Total	**547 (20.00%)**	**1737**	

concentration of colour-ringed specimens 1) at Thyna Saltpans near Sfax, 2) the archipelago of Kneiss Island and the coastal areas near to it, and 3) around Djerba together with the Gulf of Boughrara *(Figure 1–4)*. Besides coastal wetlands, the freshwater reservoirs and lagoons of Cape Bon play an important role as well, mainly during the migratory periods, however, some wintering Spoonbills also stayed there. Most African sites are important during winter (between November and February) for Spoonbills *(Figure 2)*. During spring (between March and June), the number of reported individuals is much lower in Africa and most of them are late birds *(Figure 3)*. In the autumn (between July and October), the number of reported Spoonbills is higher *(Figure 4)*, however, it is not as high in winter.

The European sites are generally important during migration as stop-over sites, however, some of them are also essential as wintering sites *(Figure 2–4)*. The most important European sites based on the readings of Hungarian rings are 1) Busko Lake (Bosnia & Hercegovina), 2) the river mouth of Isonzo (Italy), 3) the wetlands of Apulia around the Gulf of Manfredonia (Italy), 4) the wetlands at Trapani (Sicily, Italy), and 5) the wetlands around Cagliari (Sardinia, Italy).

Three (0.11%) Spoonbills were observed or found north of the Alps between April and August. These individuals occurred in Switzerland, Czechia, and Austria *(Figure 1)*. Ten (0.37%) specimens were identified east of the main migratory paths of the Pannonian Spoonbills. They occurred in east Romania, east Greece, west Turkey, Israel and Sudan *(Figure 1)*. These observations come from the East Mediterranean Flyway. 13 (0.48%) individuals were seen west of the main migratory paths of Central European birds in Germany, the Netherlands, France (along the Atlantic coast and in the Camargue), Spain, Morocco, west Algeria, Mauritania, and Senegal *(Figure 1)*. These resightings have been recorded along the East Atlantic Flyway.

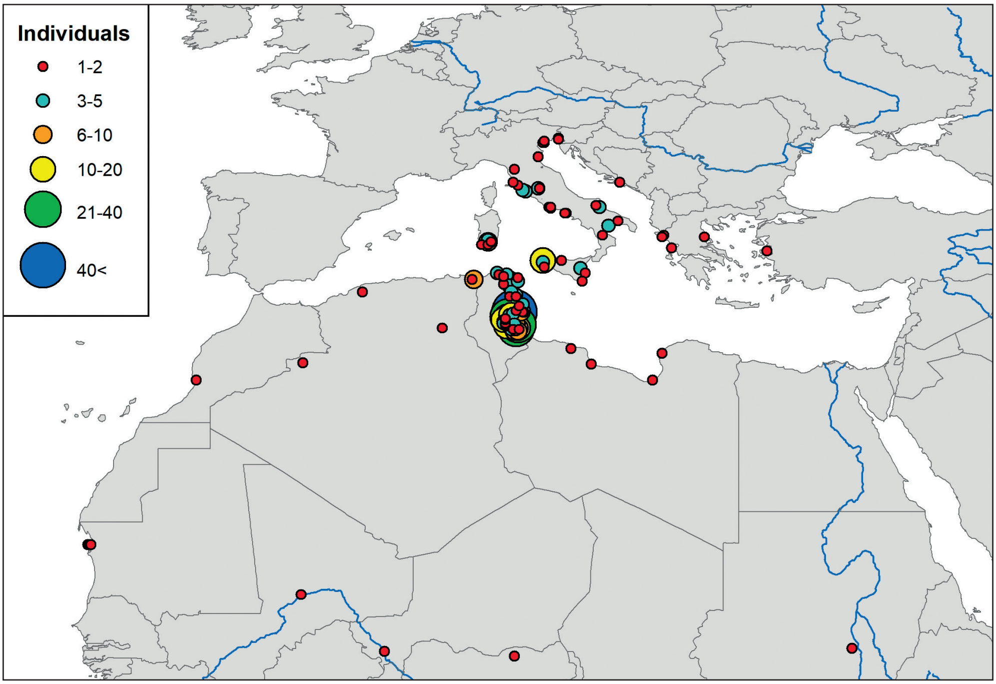

Figure 2. Winter (between November and February) distribution of Spoonbills marked in Hungary with colour-rings between 2003 and 2023 in Europe (outside the Carpathian Basin), Asia, and Africa.

2. ábra A Magyarországon színes gyűrűvel jelölt kanalasgémek téli (november és február közötti) elterjedése 2003 és 2023 között Európában (Kárpát-medencén kívül), Ázsiában és Afrikában

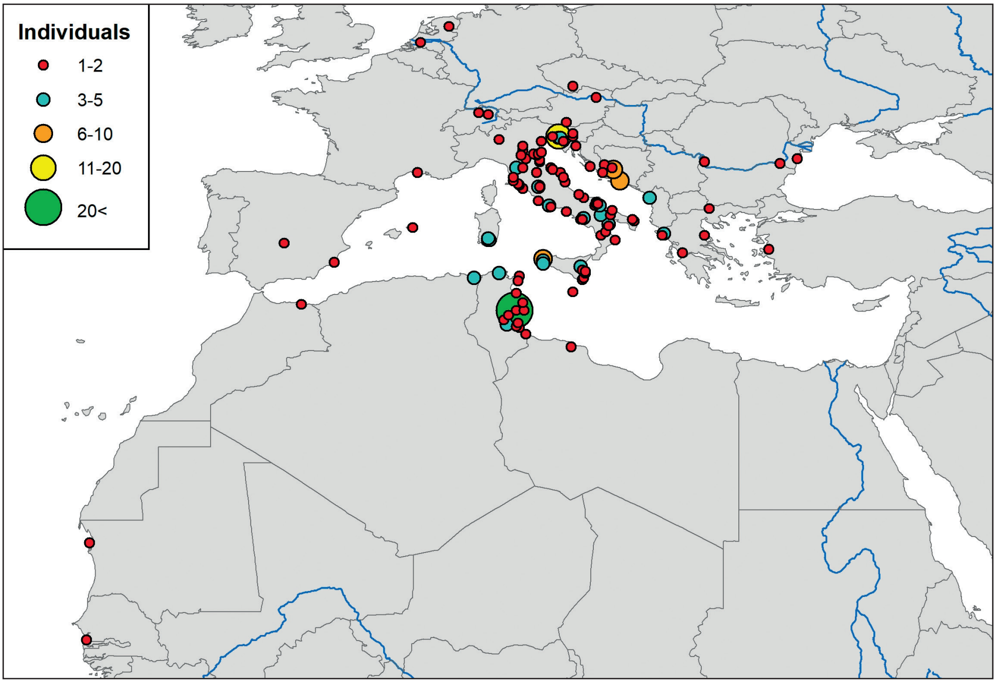

Figure 3. Spring (between March and June) distribution of Spoonbills marked in Hungary with colour-rings between 2003 and 2022 in Europe (outside the Carpathian Basin), Asia, and Africa

3. ábra A Magyarországon színes gyűrűvel jelölt kanalasgémek tavaszi (március és június közötti) elterjedése 2003 és 2022 között Európában (Kárpát-medencén kívül), Ázsiában és Afrikában

Migration dynamics

General movement dynamics

The South European records of Spoonbills had a peak (62 cases) in March then declined slowly until June (from 54 monthly occasions to 38) and finally, steeply reached the minimum value (15 occasions) by July. From August onwards, the number of observations in Europe started to increase and reached its maximum (70 cases) by September. During winter (between November and February), the number of reported events declined (24–42 occasions monthly) *(Figure 5)*. Spoonbills from the winter period were mainly detected in Italy, however, a few were reported from Turkey, Greece, and Croatia (Neretva Delta), too *(Figure 2)*.

Contrastingly, the number of observations was the highest during the winter in North Africa: between November and January, there was a significant peak (154–200 occasions monthly), while their number dropped by February (39 occasions). Wintering individuals were detected in Morocco, Algeria, Libya, and principally in Tunisia. Interestingly, there are two wintering records from Saharan wetlands in Algeria *(Figure 2)*. Between March and September, the number of records was even lower (5–32 occasions monthly) in North Africa and reached its minimum in July. From August onwards, the number of reported Spoonbills

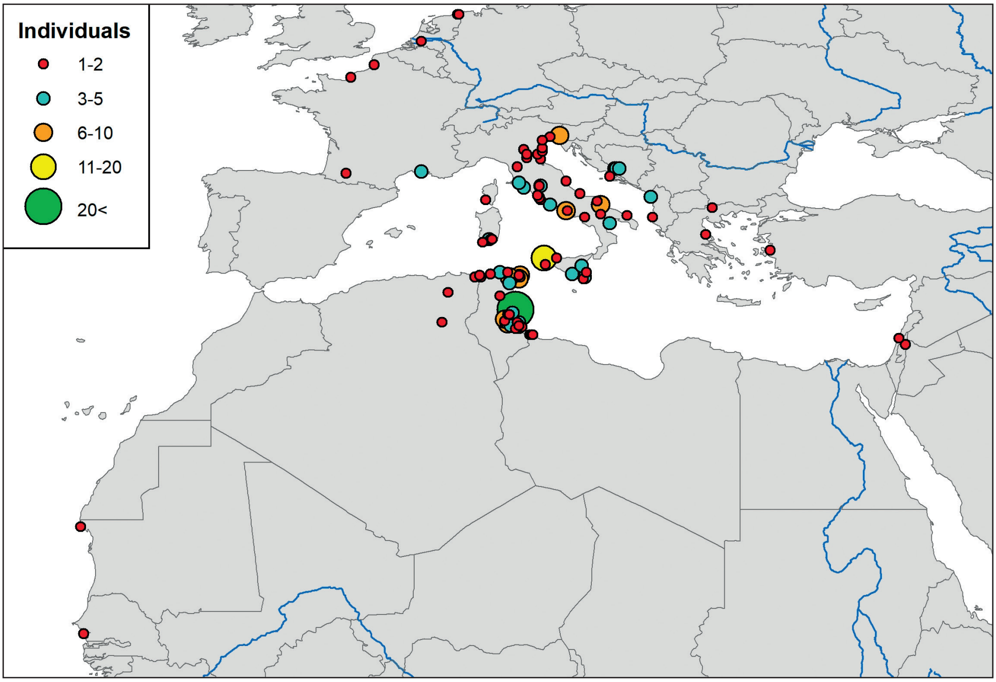

Figure 4. Autumn (between July and October) distribution of Spoonbills marked in Hungary with colour-rings between 2003 and 2022 in Europe (outside the Carpathian Basin), Asia, and Africa

4. ábra A Magyarországon színes gyűrűvel jelölt kanalasgémek őszi (július és október közötti) elterjedése 2003 és 2022 között Európában (Kárpát-medencén kívül), Ázsiában és Afrikában

started to increase and in October, 94 occasions were reported indicating strong autumn migration and arrival in North Africa *(Figure 5)*.

During winter, 320 individuals were reported from Africa, 59 from Europe (outside the Carpathian Basin), and 2 from Asia (the Middle East) *(Figure 2)*. Significantly more Spoonbills were observed in Africa than in Europe (outside the Carpathian Basin) during winter (chi-square test: $\chi^2 = 179.74$, df = 1, $p < 0.0001$). In spring, 50 specimens were observed in Africa, 144 in Europe (outside the Carpathian Basin), and one in Asia (the Middle East) *(Figure 3)*. Significantly more Spoonbills were detected in Europe (outside the Carpathian Basin) than in Africa in spring (chi-square test: $\chi^2 = 45.546$, df = 1, $p < 0.0001$). In autumn, 126 individuals were reported from Africa, 121 from Europe (outside the Carpathian Basin), and 3 from Asia (the Middle East) *(Figure 4)*. The number of reported Spoonbills in Europe (outside the Carpathian Basin) and Africa did not differ significantly during autumn (chi-square test: $\chi^2 = 0.10121$, df = 1, $p = 0.7504$).

Juveniles

Juvenile Spoonbills start to leave the Carpathian Basin after the second half of June:

JA59 was found on 19 June in Austria, north of the Alps and YRa/R(Bf)Y was photographed on 30 June in northern Italy (at Staranzano, Isola della Cona) *(Table 2)*. The first yearling

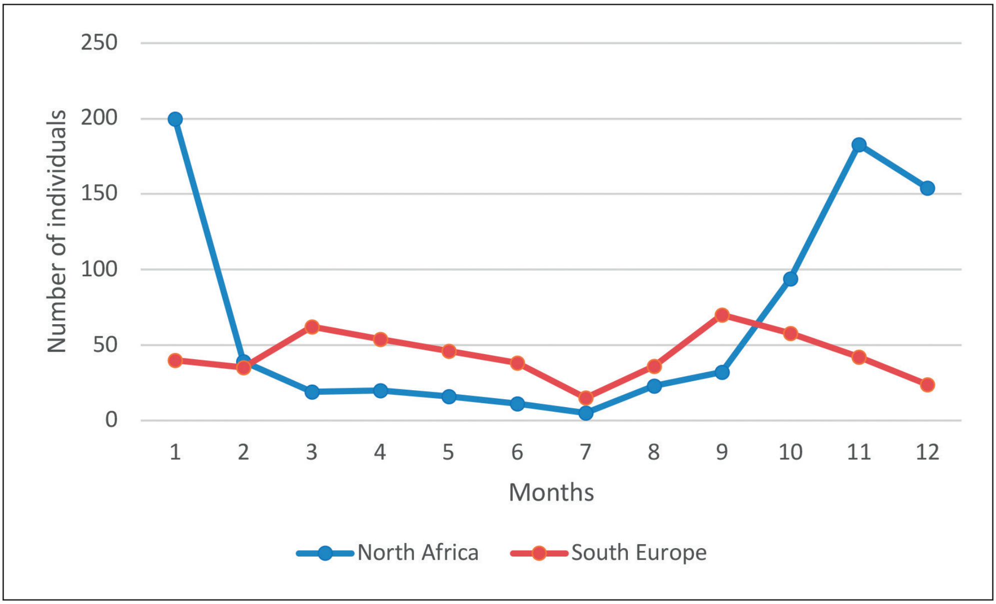

Figure 5. Migration dynamics of Spoonbills in South Europe and North Africa. All age-groups were pooled into the proper geographic groups. Turkey was pooled to South Europe and Israel to North Africa

5. ábra A kanalasgémek vonulási dinamikája Dél-Európában és Észak-Afrikában. Minden korcsoport összevonásra került a megfelelő földrajzi csoporton belül. A török megfigyeléseket Dél-Európával, az izraeli megfigyeléseket Észak-Afrikával vontuk össze

(JP05) was reported on 31 August in North Africa (Thyna Saltpans, Tunisia) *(Table 2)*. Based on observations of the colour-ringed juveniles, their migration mainly fell between August and October with a peak in September in South Europe *(Figure 6)* and they started to reach North Africa in larger numbers from the middle of September *(Figure 7)*. There was a peak in their number in November in North Africa *(Figure 7)*. In the Sahel, a juvenile (JK70) was found dead on 25 November in Niger *(Table 2)*. This is the earliest known observation of a colour-ringed juvenile from sub-Saharan Africa in this project.

Immatures

Immature Spoonbills occurred in North Africa and South Europe in the whole year *(Figure 6, 7)*. Some immatures stay in North Africa even in the summer: ten 2-cy-old and three 3-cy-old specimens were observed in June and July in Tunisia *(Figure 7)*. One of them, a 2-cy-old immature [L/L (GB)] was observed at Lake Ichkeul (Tunisia) on 5 June and 8 August suggesting that likely spent the summer there. L/L (ZN) was observed in Tunisia in June when it was 2-cy-old and 3-cy-old, too *(Table 4)*. The number of reported immatures is low (4–15 occasions monthly) between March and September contrasting with the period between November and January when their number was higher (42–95 occasions monthly) in North Africa *(Figure 7)*. During southward migration, J225 (3-cy-old) reached Tunisia

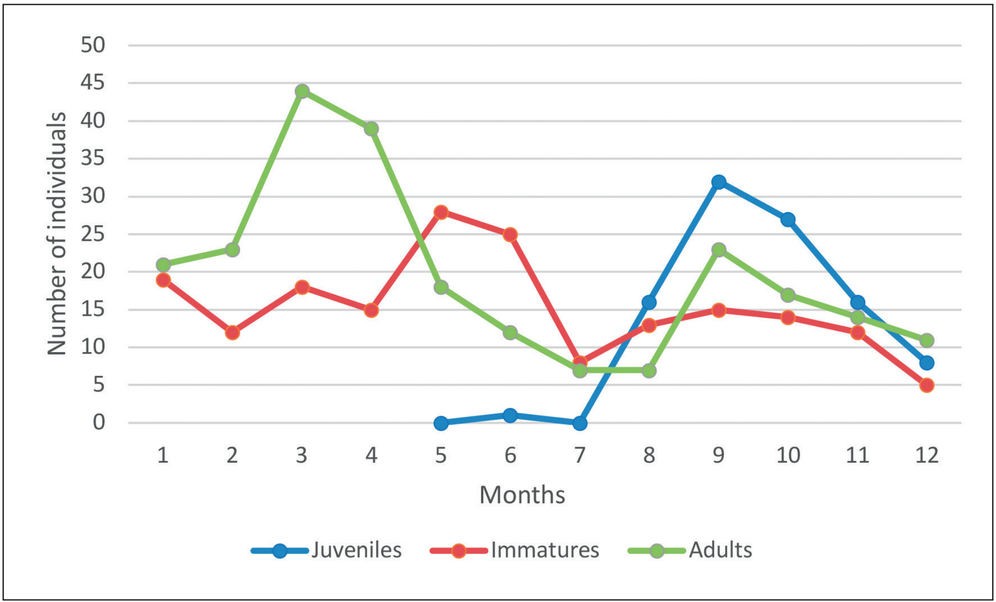

Figure 6. Migration dynamics of juveniles, immatures and adults in South Europe based on monthly observations (occasions in age groups). Note that most adults were mainly observed in March and April during the northward migration while immatures had a peak later, in May and June. All three age groups had a peak in September during their southward migration

6. ábra A fiatal, immatur és öreg kanalasgémek vonulási dinamikája Dél-Európában, havi bontás alapján (az adott korcsoportban megfigyelt alkalmak alapján). Az öregek többnyire márciusban és áprilisban voltak a tavaszi vonulásuk csúcsán, míg az ivaréretlen madarak vonulási csúcsa később, május és június során történik. Az őszi vonulás csúcsa mind a három korcsoport esetén szeptemberre esett

Table 2. Early arrival dates of Spoonbills to Europe (outside the Carpathian Basin), North Africa and sub-Saharan Africa during southward migration

2. táblázat Kanalasgémek korai érkezési dátumai Európában (Kárpát-medencén kívüli területek), Észak-Afrikában és Afrika száheli területein az őszi (déli irányú) vonulás során

Ring code	Age	Country	Date of arrival	Note
J836	5 cy	Italy	15 May 2020	seen on 16 April in Hungary
L/L (HE)	16 cy	Italy	2 June 2019	seen on 10 May in Hungary
YRa/(Bf)YG	6 cy	Italy	7–8 June 2014	seen on 8 April in Hungary
J42H	1 cy	Austria	19 June 2020	ringed on 17 May in Hungary
YRa/R(Bf)Y	1 cy	Italy	30 June 2009	ringed on 22 May in Hungary
aG(Bf)/RGR	7 cy	Tunisia	28 July 2014	seen on 5 May in Hungary
J225	3 cy	Tunisia	28 July 2014	seen on 26 June in Hungary
JP05	1 cy	Tunisia	31 August 2018	seen on 2 July in Hungary
JK70	1 cy	Niger	25 November 2016	found dead; seen on 4 July in Hungary

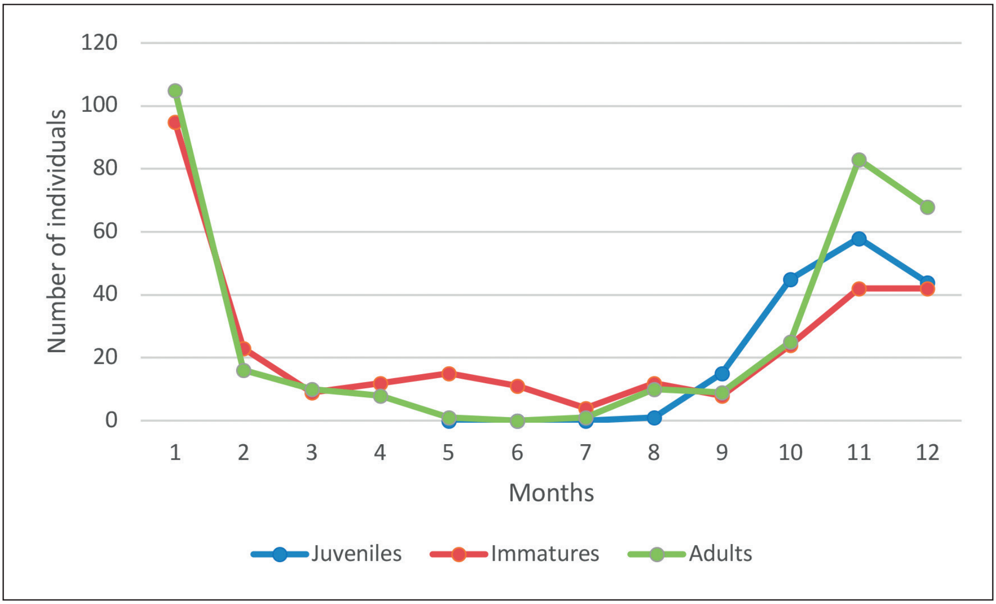

Figure 7. Migration of juveniles, immatures and adults in North Africa based on monthly observations (occasions in age groups)

7. ábra A fiatal, immatur és öreg kanalasgémek vonulási dinamikája Észak-Afrikában, havi bontás alapján (az adott korcsoportban megfigyelt alkalmak alapján)

(Cape Bon) on 28 July *(Table 2)*. That is the earliest African record of an immature moving to the south.

In South Europe, immature Spoonbills had a migration peak in May and their number was still close to the peak in June (28 and 25 occasions monthly, respectively) *(Figure 6)*. They occurred regularly in Italy in June and July, too. Some of the birds observed in June continued their movement and appeared in the Carpathian Basin later *(Table 3)*. Based on regular observations, four individuals likely spent the whole summer in northern Italy *(Table 4)*. Another peak in the number of immatures was detected in January (19 occasions) *(Figure 6)*.

Table 3. Dates of late observations of Spoonbills in North Africa and Europe (outside the Carpathian Basin) during northward migration

3. táblázat Kései kanalasgém megfigyelések Észak-Afrikában és Európában (a Kárpát-medencén kívül) a tavaszi (északi irányú) vonulás során

Ring code	Age	Country	Date	Note
aR(Bf)/GYG	8 cy	Tunisia	23 April 2016	seen on 4 September in Hungary
J718	5 cy	Romania (Danube Delta)	13 May 2017	seen between 23 May and 26 August in Hungary
(Bf)Ga/RYR	3 cy	Italy	12 June 2011	found dead in winter 2011/12 in Hungary
YaR/(Bf)YG	3 cy	Italy	12 June 2011	seen on 9 July in Hungary

Table 4. Irregular summer occurrences and oversummering of Spoonbills in Europe (outside the Carpathian Basin), North Africa, and sub-Saharan Africa. If a single individual stayed long and observed multiple times the summering is very likely

4. táblázat Kanalasgémek nyári előfordulásai Európában (a Kárpát-medencén kívül), Észak-Afrikában és a Száhelban. Ha egy-egy egyed hosszabb ideig tartózkodott egy területen, az ottani átnyaralása nagyon valószínű

Ring code	Age	Country	First observation	Last observation	Days	Note
L/L (HE)	2 cy	Italy (N)	12 June 2005	4 August 2005	54	21 occasions
B/O (ND)	2 cy	Italy (N)	14 May 2007	18 July 2007	66	23 occasions
J027	3 cy	Italy (N)	15 June 2012	18 July 2012	34	5 occasions
J179	3 cy	Italy (N)	19 June 2013	28 July 2013	40	5 occasions in 3 locations; wintered in 2012/13 in Tunisia
L/L (ZN)	2 cy	Tunisia	8 June 2008			1 occasion
L/L (ZN)	3 cy	Tunisia	14 June 2009			1 occasion
L/L (GB)	2 cy	Tunisia	5 June 2006	8 August 2006	65	2 occasions
B/R (VY)	2 cy	Tunisia	25 June 2004			1 occasion
LaY/R(Bf)L	2 cy	Tunisia	25 June 2010			1 occasion
aR(Bf)/GYG	2 cy	Tunisia	23 June 2010	3 July 2010	11	2 occasions
aRY/L(Bf)L	2 cy	Tunisia	26 June 2010	4 July 2010	9	3 occasions
J363	4 cy	Tunisia	29 May 2019			1 occasion
B/W (TN)	4 cy	Mauritania	30 June 2010			1 occasion

Adults

There are no observations of adults in June in North Africa *(Figure 7)*. During the southward migration, the earliest record of an adult [aG(Bf)/RGR] was noted at Oued Lebna reservoir (Cape Bon, Tunisia) on 28 July *(Table 2)*. The number of observations of adults is the highest in North Africa during the wintering time, between November and January, with a peak in November and a higher peak in January (83, 68, and 105 occasions monthly, respectively). The number of observations declined by February and the majority of the adults left North Africa by May *(Figure 7)*. The latest North African observations of adults were recorded on 23 April [aR(Bf)/GYG] and 29 May (J363) (both cases in the Thyna Saltpans, Tunisia) *(Table 3)*. It is unclear whether J363 (4-cy-old) had been in Africa since winter and spent all summer in its wintering site or was an early arrival *(Table 4)*. aR(Bf)/GYG was observed on 23 April and occurred later, in the same year in Hungary *(Table 3)*.

During the northward migration of the adults in South Europe, the observation events had a peak in March (44 occasions) and it was still high in April (39 occasions), then declined sharply by May. The observation events of adults were low between May and August (7–18 occasions monthly) *(Figure 6)*. Interestingly, J718 was on her northward migration in May: she was photographed in the Danube Delta (Romania) on 13 May and appeared in Hungary on 23 May *(Table 3)*. Contrastingly, the southward migration started in several cases as early as May: J836 was in Venezia on 15 May *(Table 2)*. There were further early observations in Italy such as the detection of L/L (HE) at Staranzano (Italy) on 2 June, and the observation of YRa/(Bf)YG in south Italy on 7 and 8 June *(Table 2)*. All three individuals mentioned above started their southward migration in May or early June. They were observed in Hungary previously, in the same year. During the southward migration, there was a peak in September in South Europe (23 occasions). The number of winter observations was smaller than in the peaks of the spring or autumn migration *(Figure 6)*. Furthermore, the observation of (Bf)aG/RLG in the Neretva Delta on 17 and 18 February likely indicated an individual that stopped there during its northward migration *(Figure 2)*.

In sub-Saharan Africa, B/W (TN) (4-cy-old) was observed on 30 June in Mauritania (Banc d'Arguin) *(Table 4)*. That individual was observed there several times in winter, too.

Discussion

We analysed the observations of Spoonbills of Hungarian origin outside the Carpathian Basin, in 28 countries. In those regions, 20% of the Hungarian population was observed and reported. In winter, a significant part of the population occurred in Africa compared to Europe. Africa is the main wintering site of the Central European Spoonbill population: 80% of wintering data came from Africa contrasting the 20% of the European wintering data (Pigniczki 2022). In spring, a significant part of the Hungarian population was reported from Europe (outside the Carpathian Basin) compared to Africa. This result indicates that Spoonbills leave Africa in spring and reach Europe during their northward migration. However, the observation activity is lower in Africa between March and June because there were no ring-reading trips and large-scale waterbird counts. Reports indicate that the majority of Spoonbills leave Tunisia in February/March which is the main African wintering area (Isenmann *et al.* 2005). It means that at the beginning of the spring period, most of the wintering birds should be in Africa but there are only sporadic observations. The increased European observations outside the Carpathian Basin must be the result of the northward migrating Spoonbills. During autumn, no significant differences were found between the African and European (outside the Carpathian Basin) records. It indicates that Spoonbills stopped at several parts of Europe during their southward migration before reaching Africa. Autumn is the main part of postnuptial migration between July/August and October (Isenmann *et al.* 2005). Similarly to the spring period, the observation effort is lower in Africa during the autumn period.

The majority of Spoonbills occurred along the Central Mediterranean Flyway (which is also referred as the Adriatic Flyway) because, in the case of Spoonbills, they cross the Adriatic Sea. Several studies underlined the importance of the Adriatic Flyway for Spoonbills (Schneider-Jacoby 2008, Pigniczki *et al.* 2016). The East Atlantic and the East Mediterranean Flyways are only marginally important for the Pannonian population (Pigniczki *et al.* 2016, Pigniczki 2022).

Three Spoonbills of Hungarian origin were reported from north of the Alps in Austria, Czechia, and Switzerland. Especially, the observations of the single individual in Switzerland may indicate an undescribed migratory flyway that leads north of the Alps. It is known, for example, that a part of the Hungarian populations of Great Egrets *(Ardea alba)* and Mediterranean Gulls *(Ichthyaetus melanocephalus)* follow migration flyways north of the Alps (mme.hu 2024a, mme.hu 2024b, pers. comm. Hungarian Bird Ringing Centre). This flyway seems only marginally important for the Pannonian Spoonbill population. One individual of Hungarian origin occurred in Czechia in April. A bird of Croatian origin was observed in a Czech Spoonbill colony (Kralj *et al.* 2012). It is supposed that the Czech population originated from the Pannonian population and it is likely that a connection between the two populations still exists (Kralj *et al.* 2012, Pigniczki 2017).

Some Spoonbills from the Hungarian population joined the West European population and appeared in Germany, the Netherlands, Atlantic France, and Spain. Furthermore, Spoonbills from the Pannonian population reached Scotland (Kralj *et al.* 2012). At least, a part of the adult Spoonbills of Hungarian origin probably shifted their breeding area and they likely bred in Western Europe, however, the breeding is not confirmed by field observations. Adults from the East Atlantic population (Denmark and the Netherlands) also appeared during the breeding period in Hungary and potentially nested, however, the breeding was not confirmed either in these cases (Pigniczki 2017). These records highlight potential gene flow between the East Atlantic and the Pannonian Spoonbill populations. Interestingly, a Spoonbill marked in the Danube Delta was also observed in Switzerland, Germany, and France in multiple years, however, it is not confirmed whether that bird nested anywhere in West Europe (Kiss *et al.* 2022).

South Europe

The South European areas – especially in Italy – bear valuable importance for the Pannonian Spoonbill population. Individuals of Pannonian origin use the South European sites as wintering areas, stop-over sites to have food and rest during migration, and finally, immatures may stay there to summer (Kralj *et al.* 2012, Pigniczki 2015, 2022, Pigniczki *et al.* 2016).

Our data indicates a peak in March during the northward migration in southern Europe. In spring migration, the peaks of adults and immatures were detected in different months: the bulk of adults were reported in March and April, while the majority of immatures were detected later, mainly in May and June. In the eastern Adriatic region, there is a migration peak in March at the coastal sites, while the spring peak was detected between mid-March and April in Bosnia-Hercegovina (Stumberger *et al.* 2013). In Sicily (Italy), a peak was detected in February and March (Ientile *et al.* 2020). This spring peak may likely be related to the start of migration of Spoonbills wintering in North Africa. In Italy, the spring migration is concentrated between late February and early April (Spina & Volponi 2008).

In this study, we identified four immatures that spent the summer in northern Italy, those birds did not appear in their natal area, in the Carpathian Basin. Summering Spoonbills were regularly seen in Sicily between 2014 and 2018 in June and July, their maximal numbers varied between 5–33 individuals (Ientile *et al.* 2020). Ring readings did not confirm the summering of individuals of Hungarian origin in Sicily.

During the autumn migration, all age groups had peaks in September in southern Europe. Based on surveys, Spoonbills have a peak in September in the eastern Adriatic region, too

(Stumberger *et al.* 2013). In Sicily (Italy), a marked peak was observed in September and October (Ientile *et al.* 2020). This peak is related to the southward migration, when Spoonbills migrate through Sicily to their wintering grounds in North Africa, however, a part of them stay to winter in Sicily as well. Interestingly, our data indicates that the southward migration starts as early as mid-May and early June when individuals that occurred previously in the Carpathian Basin started to move to the south and appeared in Italy. Contrastingly, some adults can be on their northward migration even in May.

The Pannonian Spoonbill population that winters in South Europe has a peak in January, probably because of the wintering waterbird census and the higher observation effort. In the Balkans, the number of Spoonbills is moderate in winter compared to the pre- and post-breeding migrations (Stumberger *et al.* 2013).

Among European countries, the most wintering individuals of Hungarian origin were reported from Italy, however, Spoonbill was a rare species in Italy during winter in the largest part of the country some decades ago. Spoonbills in Italy are still scarcely abundant and quite localised: there are 20–25 coastal sites where the winterers are distributed. The Lagoon of Orbetello and the wetlands of Sicily, Sardinia, and Apulia host the most numerous and stable wintering populations in Italy (Spina & Volponi 2008, Zenatello *et al*. 2014). The colour-ringed individuals of Hungarian origin are mainly reported from the abovementioned localities. In Italy, the number of wintering Spoonbills has increased from max. 99 individuals in the period 1991–1995 to over a thousand individuals recently, and was estimated at 1,027 specimens in 2017, 1,365 in 2018, 1,440 in 2019, and 1,210 in 2020 (Pigniczki 2022, Wetlands International 2024). In Sicily, the first wintering group of Spoonbills was observed in December 1992. Spoonbills have become regular wintering birds there since 1992, and their maximal numbers varied between 40–105 individuals in December or January between 2014 and 2018 (Ientile *et al.* 2020). The system of wetlands in western Sicily (e.g. the salinas of Trapani and Marsala) plays a key role for Spoonbills during winter and other periods of the year as well. In turn, the wintering in south-eastern Sicily is less regular and abundant, probably the abandonment of the practice of salt cultivation may have adversely affected this species. Despite, there are former salinas and natural, temporary ponds in south-eastern Sicily, their fish fauna is absent or has little abundance, therefore, Spoonbills mainly forage on invertebrates such as Branchiopods in those areas (Surdo 2020). Invertebrates have irregular life cycles because they are connected to the water level and their density can be low or they may be totally absent from the area. Therefore, the lack of available food does not make possible a stable or abundant wintering Spoonbill population in most of the wetlands in the southeastern part of Sicily.

Italy is the most significant wintering site of Spoonbills of Hungarian origin in the northern Mediterranean and there are further, known wintering sites in Greece and Turkey with a few wintering individuals from the Hungarian population (Pigniczki 2022). Besides Hungarian individuals, Italy is an important wintering area for specimens from Croatia and Serbia, too (Kralj *et al.* 2012). Probably, the wetlands of the Balkans and Turkey are more important for the wintering Spoonbills of Hungarian origin, however, clarifying this is the task of the future.

North Africa

In North Africa, the quality of data is very likely biased, because the ring-reading effort is definitely higher during the wintering period due to the special Tunisian ring-reading expeditions in November and December, and the survey of wintering waterbirds in January (Pigniczki 2022). Despite that, our data clearly indicate that North Africa holds essential wintering areas for the Hungarian population, especially in Tunisia. The relevancy of Tunisia was confirmed by several studies: the tidal wetlands and Thyna Saltpans in the Gulf of Gabes are very important for the Pannonian population according to ring readings and recoveries (Smart *et al.* 2007, Kralj *et al.* 2012, Pigniczki *et al.* 2017, Pigniczki 2022). Besides the Pannonian population, a massive number of Spoonbills from the Camargue and Italy also winter in Tunisia (Volponi *et al.* 2008, Pigniczki 2022, Ferreira *et al.* 2024, CP, HA, HD & MAD pers. obs.). The number of wintering Spoonbills was estimated at 4,033 in 2008, 3,447 in 2014, and 5,002 in 2023 during the waterbird census in January in Tunisia (Azafzaf *et al.* 2015, 2023, Pigniczki 2022). The tidal wetlands in the Gulf of Gabes provide appropriate foraging areas during all year. We found that the freshwater reservoirs of Cape Bon are also important for Spoonbills, but mainly during migration periods. The freshwater reservoirs are temporary habitats because, in the recent dry years, they dried out (M. A. Dakhli pers. obs.). All these results indicate the outstanding importance of Tunisia along the Central Mediterranean Flyway. In smaller numbers, Spoonbills from the Hungarian population also spend the winter in Libya, Algeria, and Morocco (EGA – RAC/SPA waterbird census team 2012, Pigniczki 2022). Probably the importance of Algeria for the Pannonian Spoonbill population is underestimated, because 830 individuals were observed there in January 2019 (Wetlands International 2024). Despite the valuable number of wintering individuals, the number of reported colour-ringed specimens is relatively small, probably because of a lower ring-reading activity. Interestingly, records on wintering Spoonbills from the Algerian Sahara are known in some cases (Pigniczki 2022), and new observations have been reported recently, too. Two individuals of Hungarian origin were observed on their Israeli stop-over sites indicating the Middle East is marginally important for the Pannonian population (Pigniczki *et al.* 2016, Pigniczki 2022). Despite several old records of Hungarian Spoonbills in Egypt until the 1950s, recent and confirmed data are missing from there (Pigniczki 2010, 2022). Only a single record is known with Pannonian origin in Egypt: a specimen marked in Serbia was photographed at Aswan in 2007 (Pigniczki 2022).

In North Africa, the earliest arrival records of adults and immatures were known from late July, while the first juvenile reached that area in late August. In Tunisia, Isenmann *et al.* (2005) supposed that postnuptial migration takes place between July/August and October. Our results based on ring reading show similar consequences, however, a GPS-tracked adult arrived in Tunisia on 15 June indicating Spoonbills may complete their southward migration quite early (Cs. Pigniczki unpublished data).

Prenuptial migration happens in February/March in Tunisia (Isenmann *et al.* 2005). Our ring-reading data indicate that the majority of Spoonbills leave North Africa by the end of March, however, a few may stay there even in April and these late African individuals do appear in the Carpathian Basin. Furthermore, we know an adult individual that was observed in Tunisia in late May, however, we do not know any other previous and subsequent movement of that bird. These late records indicate that the northward migration of adults on a population level could be a longer process and probably takes place between February and April/May. According to the data of GPS-tracked adults, it is confirmed that the northward migration starts in February and other individuals may start it in the last third of April (Cs. Pigniczki unpublished data).

Ring readings confirmed that immatures may stay in North Africa during the summer period, however, their exact number and detailed movement are unknown because of the lower observation effort. Likely, immatures stay longer in North Africa than adults. Records on colour-ringed adults are missing from June in North Africa. Smart *et al.* (2007) hypothesized that Africa is the 'kindergarten' of the Spoonbills because they occur there during the whole year, however, they mentioned that more evidence is needed to support this hypothesis. Isenmann *et al.* (2005) suppose that the Tunisian observations in May and June are the results of observations of immatures and considered the records from early July as early arrivals. The first Tunisian ring-reading of an adult happened in late July, however, a Spoonbill tracked with a GPS device reached Tunisia on 15 June (Cs. Pigniczki unpublished data). Thus, we rather think that both late/early adults and summering immatures can be observed during summer in the flocks of Spoonbills. Despite having more records on summering immatures in North Africa than fifteen years ago, the situation is still unclear. It seems that immatures follow very different strategies: in unknown numbers, they may spend the whole summer in Tunisia, while some of them migrate northward to summer in Italy (and probably other parts of Europe), and others may reach their natal areas in the Carpathian Basin (Pigniczki 2009).

Sub-Saharan Africa

Only a limited number of data came from sub-Saharan Africa. Records are known from a wide range of the Sahel between Mauritania/Senegal and Sudan (Pigniczki 2022). Spoonbills visit that area to winter there, however, even the adults likely stay there during the summer in certain conditions. In small numbers, Spoonbills of Pannonian origin regularly cross the Sahara (Smart *et al.* 2007, Pigniczki 2010, 2022, Kralj *et al.* 2012).

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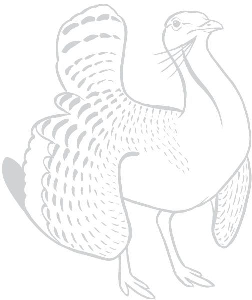

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Sunlight and time of the day affect visual lateralisation in Greater White-fronted Geese

Kseniia A. Kaskova*, Olga A. Babkina & Elmira M. Zaynagutdinova

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Abstract Sensory lateralisation, defined as the separation of functions for processing information from the sensory organs between the hemispheres of the brain, is a variable characteristic of the nervous system influenced by external factors. The plasticity of lateralisation is an important factor influencing the assessment of lateralisation on individual and population levels. We tested the influence of sunlight and time of the day on the visual lateralisation of Greater White-fronted Geese *Anser albifrons* when following their partners. Most of the individuals showed no preference to observe a partner with one of their eyes. Among the lateralised birds, a significant prevalence of right-eyed individuals was revealed. The highest proportion of lateralised individuals was observed in cloudy conditions. Direct sunlight, particularly in the morning, interfered with the emergence of visual lateralisation. Thus, the effect of sunlight and time of the day on lateralisation in birds should be taken into account when evaluating lateralisation in field observations and experiments.

Keywords: sensory lateralization, animal behaviour, environmental factors, weather, monogamy

Öszefoglalás A szenzorikus lateralizáció, melyet az érzékszervek információfeldolgozási funkcióinak agyféltekék közötti elkülönítéseként definiálnak, az idegrendszer külső tényezők által befolyásolt változó jellegzetessége. A lateralizáció plasztikussága fontos tényező, amely befolyással van az egyedi és populációszintű lateralizáció becslésére. Jelen tanulmányban a napfénynek és időnek a nagy lilik *Anser albifrons* fajtársak követésekor tapasztalt vizuális lateralizációjára gyakorolt hatását elemeztük. Az egyedek többsége nem mutatott preferenciát a fajtársának követéséhez használt szemmel kapcsolatban. A lateralizált egyedek esetében a jobb szemüket használó egyedek szignifikánsan nagyobb számban kerültek megfigyelésre. A lateralizált egyedek legnagyobb aránya felhős égbolt idején lett megfigyelve. A közvetlen napfény, elsősorban a reggeli órákban, egybeesett a vizuális lateralizáció megjelenésével. Így a napfény közvetlen hatását és az időt számításba kell venni a lateralizáció terepi vagy kísérletes megfigyelésénél.

Kulcsszavak: érzékszervi lateralizáció, állati viselkedés, környezeti tényező, időjárás, monogámia

Department of Vertebrate Zoology, Faculty of Biology, Saint Petersburg State University, Universitetskaya nab. 7–9, St Petersburg, 199034, Russia
** corresponding author, e-mail: kseniia.kaskova@mail.ru*

Introduction

Sensory lateralisation is the separation of functions for processing information from the sensory organs between the hemispheres of the brain (Rogers *et al.* 2013). It was revealed in most classes of vertebrates and many classes of invertebrates (Rogers *et al.* 2013). The complex interactions between genes, environment, and epigenetic factors determine the lateralised perceptual, cognitive, and motor functions of asymmetrical brains (Güntürkün *et al.* 2020). When considering animal populations, laterality has often been discussed as an evolutionarily stable strategy (Ghirlanda & Vallortigara 2004, Vallortigara 2006, Rogers *et al.* 2013). For a better understanding of the evolutionary path of lateralisation, a continuation of the phylogenetic approach to investigating laterality and a further focus on mechanistic drivers, with special attention to genetic and environmental effects are required (Wiper 2017). Sensory lateralisation is not a static, unchanging characteristic, but one that changes with different factors, and research must move forward with investigations considering environmental effects on lateralisation (Wiper 2017, Frasnelli 2021).

The effect of environmental factors on sensory lateralisation in birds is still poorly studied. Nevertheless, the behaviour of birds was shown to be influenced by environmental factors, including weather and time of the day (Ely 1992, Frederick & Klaas 1982, Paulus 1988). Birds with a small blind area cannot protect their retina from direct sunlight and experience disability glare, which complicates object recognition (Martin & Katzir 2000). The time of the day can affect the amount of social and feeding behaviour in Anatidae (Paulus 1988). As abiotic factors affect many aspects of animal behaviour, they could be essential for visual lateralisation as well.

Much attention was paid to studies on lateralised mating behaviour in birds of both polygamous (Rogers *et al.* 1985, Gülbetekin *et al.* 2007, Vernier 2016) and monogamous species (Ventolini *et al.* 2005). However, interactions between males and females outside the breeding period are poorly studied (Soma 2022).

Geese are a convenient model for studying lateralised relationships in a pair, as partners of all geese species stay together throughout the year, rarely moving away from each other by more than two meters (Akesson *et al.* 1982, Black 2001, Scheiber 2013). Therefore, following a partner during feeding was chosen for this study. This activity takes up most of the daytime in all geese species at spring migration stopovers (Ely 1992, Arzel *et al.* 2006, Chudzinska *et al.* 2013) and may provide a source of lateralised behaviour because, at each moment, the following individual uses only one eye to observe its partner. Due to the lateral position of the eyes in most bird species and the almost complete independence of the visual pathways from the left and right eyes, a large number of studies of visual lateralisation are conducted on birds (Rogers 2011). Geese fall into this category with the binocular visual field of a Canada Goose *Branta canadensis* ranging from 22 to a maximum of 30 degrees (Fernández-Juricic *et al.* 2011). The visual lateralisation of geese was studied in flying, observing the threatening stimulus, and following the mate while feeding in Greater White-fronted Goose *Anser albifrons* and Barnacle Goose *Branta leucopsis*. It was revealed that the majority of juveniles have visual biases in observing the parent on an individual level while flying with parents (Zaynagutdinova *et al.* 2022). The distance to the source of the threat affects the bias in observing the threatening stimulus (Zaynagutdinova *et al.* 2020a). Disturbance from anthropogenic factors, as well as from predators, prevents the manifestation of visual lateralisation in observing the partner (Zaynagutdinova *et al.* 2020b). However, the effect of abiotic environmental factors on visual lateralisation was not yet studied in geese.

As feeding is an everyday activity lasting all day, it gives a good opportunity to study the effect of environmental factors on sensory lateralisation in geese, such as time of the day and weather. Our objective was to investigate the influence of sunlight and time of the day on visual lateralisation in Greater White-fronted Geese following a partner while feeding. We supposed that direct sunlight may interfere with observation of the partner, potentially altering the manifestation of visual lateralisation.

Materials and Methods

Study site and data collection

The study was conducted in 2021 from April 25th to May 15th at the spring migration stopover near Olonets in Karelia Republic, Russia (60°59'N 32°55'E). At this time of the year up to 18,000 Greater White-fronted Geese are present in this area (Artemyev *et al.* 2018).

Geese were video recorded in pairs or groups for 5–30 minutes due to recording conditions and limitations of the equipment. Morning observations were made from dawn (about 4 a.m.) till 7:30 a.m., while the sun was less than 20 degrees above the horizon. Daytime videos were recorded between 12 a.m. and 5 p.m. on April 25th – May 5th and between 12 a.m. and 6 p.m. on May 6th – May 15th with the height of the sun from 20 to 42 degrees above the horizon on the first day of observations (April 25th) and from 20 to 47.5 degrees above the horizon on the last day of observations (May 15th). The duration of morning and daytime observations was the same (3–4 hours). The hourly values of the height of the sun were obtained from web archive (https://voshod-solnca.ru).

A total of 180 pairs was observed in this study. Partners were recorded as a pair of geese staying closer to each other (less than two meters apart) than with other flock members and synchronizing their behaviour (feeding, resting, moving, alert, and aggression).

We determined the position of individuals in pairs relative to each other during feeding from the video footage *(Figure 1)*. Birds were considered feeding when they were walking on the ground and pecking the grass. We counted how long each of the partners followed another partner on the left or right side. Due to the lateral eye position in geese, if an individual followed its partner on the left side, we assumed that the following bird was viewing the leader with the right eye and vice versa.

Figure 1. Focal pair of feeding geese with rear individual viewing its partner with the right eye

1. ábra A megfigyelt táplálkozó ludak, amelyeknél a hátsó egyed jobb szemével figyeli társát

The description of the geese' positions in the video was made by two observers. Inter-rater reliability was assessed for the identification of an individual's position using the kappa coefficient. Three recordings with a total duration of 32 minutes were scored independently by each observer. The kappa coefficient between observers was 0.78±0.01, which indicates substantial agreement.

Geese pairs do not have a permanent leader (Lamprecht 1992), therefore sex of individuals was not considered in the current study. Moreover, it was impossible to determine the sex of the geese from a distance due to the lack of pronounced sexual dimorphism in this species.

Lateralisation assessment

To assess lateralisation in a bird's position, we calculated the number of bouts that an individual spent following its partner on a certain side. Bout was defined as uninterrupted position of the following bird on the left or right side of the leading bird for three or more seconds long. To eliminate the influence of behaviour type on lateralisation, we considered only situations of following the partner while feeding.

We used the number of bouts to assess an individual's eye preference. For this analysis, we used a binomial z-test on the individuals, who had at least 10 bouts, because it is the minimum value for the test we used (binomial probabilities estimated using binomial approximation of the normal distribution). We estimated individual eye preference for 149 individuals in 115 pairs. To reduce the influence of partners on each other, we reorganised the data to represent, which pairs contain at least one lateralised individual and which pairs contain no lateralised individuals.

Influence of the hunting season

The study by Zaynagutdinova *et al.* (2020a) supposed a possible influence of indirect disturbance from hunting on the lateralisation of geese. In the year of the data collection (2021), legal goose hunt in Karelia was allowed from 1st to 10th of May. Observations were made in the protected zone, where geese were not directly influenced by hunting, but could still hear gunfire sounds from the hunting grounds. We included hunting season and time of the day as factors in our analysis. Hunting takes place in the morning, so we checked for the combined effect of the hunting season and time of the day.

Influence of sunlight conditions and time of the day

We defined sunny, cloudy and partly cloudy conditions by their effect on the individual. If an individual was illuminated by direct sunlight throughout the whole video, we considered conditions sunny. If an individual was over shadowed by clouds throughout the whole video, we considered conditions cloudy. Intermediate cases were marked as partly cloudy conditions. Out of 149 individuals with estimated eye preference, seven individuals filmed in partly cloudy conditions were excluded from the analysis of sunlight effect on lateralisation, with a resulting sample of 142 individuals in 108 pairs.

Statistical analysis

We used hunting season, sunlight conditions and time of the day as categorical factors in a model. Hunting season consisted of 3 types: before, during and after the hunting. Sunlight conditions were set as 0 and 1, and time of the day was divided into morning and daytime. We coded pairs without lateralised individuals as y_i=0 and pairs containing at least one lateralised individual as y_i=1. In accordance with binary dependent variable, we fitted a binary logistic regression model as a generalised linear model for binomial distribution with logit link function:

$$y_i \sim Binominal(n = 1, \pi_i)$$

Expected value (E) in this case is a probability that an observed pair would contain at least one lateralised individual, i.e. $E(y_i) = \pi_i$. Logit-transformation was used to linearise the link between predictors and outcome variable. To get predictions in form of probabilities we used inverse logit transformation.

We accounted for possible interactions between factors in the statistical model. To optimize the model, we used the likelihood ratio test (LRT). Tukey test was used to determine which groups of time of the day – sunlight conditions interactions differ significantly. To measure the goodness of fit, we used McFadden's pseudo R^2.

Individual preferences were estimated with a binomial test using the Jupyter Notebook platform with Pandas 1.3.5, Numpy 1.22.3 and Scipy 1.4.1 modules for batch data processing. Statistical analysis was conducted using R v4.3.1 in RStudio with base packages, dplyr v1.1.3, pscl v1.5.5.1, multcomp v1.4-25 and postHoc v0.1.3. For visualisation we used R package ggplot2 v3.4.4. The significance level was set at $P<0.05$.

Results

Population level lateralisation

Out of 149 individuals selected for the binomial test, 111 had no eye preference, and 38 preferred the left or right eye when following a partner. The predominance of individuals without preferences was significant (binomial test, z=5.90, p<0.001). There were significantly more individuals with right-eye preference (26), while only 12 individuals preferred using the left eye to observe their partner while feeding (binomial test, z=2.11, p=0.035).

Influence of the hunting season

Three-level interaction between hunting factor, sunlight conditions and time of the day was excluded during backwards-selection of the model (LRT, p=0.123), as well as the interaction between hunting and time of the day (LRT, p=0.636). Interaction between hunting and time of the day could not be excluded using LRT (p=0.027), although its influence was not found significant. The same was true for hunting factor. The final model contained following parameters: hunting, time of the day, sunlight conditions, interaction hunting and time of the day, interaction between sunlight conditions and time of the day. The McFadden's pseudo R^2 for the model was 0.20, indicating good model fit (McFadden 1979).

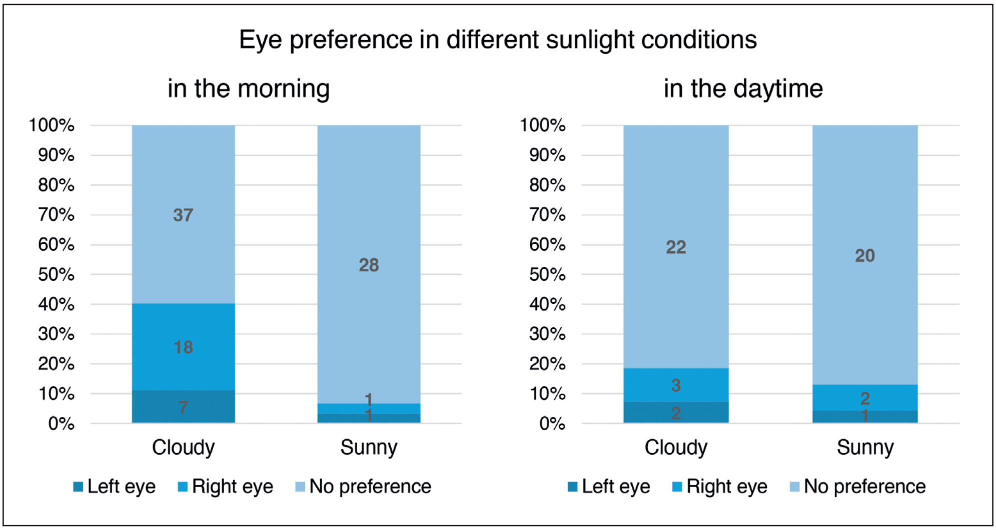

Figure 2. Normalised cumulative histograms showing proportions of left-eyed, right-eyed, and non-lateralised individuals in cloudy and sunny conditions in the morning and daytime. Data labels show the exact numbers of left-eyed, right-eyed, and non-lateralised individuals

2. ábra Normalizált kumulatív hisztogramok, melyek a balszemes, jobbszemes és nem lateralizált egyedek eloszlását mutatják felhős és napos időjárási körülmények között reggel és napközben. A feliratok a balszemes, jobbszemes és nem laterizált egyedek számát adják meg

The effect of sunlight conditions and time of the day

The proportions of individuals with different eye preferences or with no preference in different sunlight conditions and time of the day are shown in the *Figure 2*. The largest proportion of lateralised individuals (40%) was observed in the morning in cloudy conditions.

In our model, the only parameter with significant influence on the response variable was the interaction between time of the day and sunlight conditions (z = -2.69, p=0.007).

Tukey's range test showed that this influence predominantly manifested as the difference between proportions of pairs with lateralised individuals in the morning in cloudy and sunny conditions *(Table 1)*. Predicted probabilities based on interactions of these factors are shown in *Figure 3*.

Discussion

Population level lateralisation

Lateralised behaviour at the population level could be beneficial for social species in interactions with conspecifics and coordination of flock movements (Vallortigara & Rogers 2005). However, one-sided preferences in lateralised behaviour have disadvantages as well, such as the predictability of individuals' behaviour for predators, prey or competitors

Table 1. The result of Tukey's range test on the differences between levels of the interaction between time of the day and sunlight conditions. Estimates and quantiles are presented in fractional form. The last three columns contain z statistics and p-values for pairwise comparisons

1. táblázat A Tukey-féle tartományteszt eredménye a napszak és a napfényviszonyok közötti kölcsönhatás szintjei közötti különbségekről. A becslések és a kvantilisek tört alakban szerepelnek. Az utolsó három oszlop a z-statisztikákat és a p-értékeket tartalmazza a páros összehasonlításokhoz

Category	**Estimates**	**2.5% quantile**	**97.5% quantile**	**Group**	**Morning, cloudy**	**Morning, sunny**	**Daytime, cloudy**
Morning, cloudy	0.48	0.34	0.62	A			
Morning, sunny	0.09	0.02	0.29	B	z=-2.82 p=0.023		
Daytime, cloudy	0.17	0.07	0.38	AB	z=-2.33 p=0.085	z=0.86 p=0.818	
Daytime, sunny	0.11	0.03	0.35	AB	z=-2.46 p=0.063	z=0.26 p=0.994	z=-0.56 p=0.941

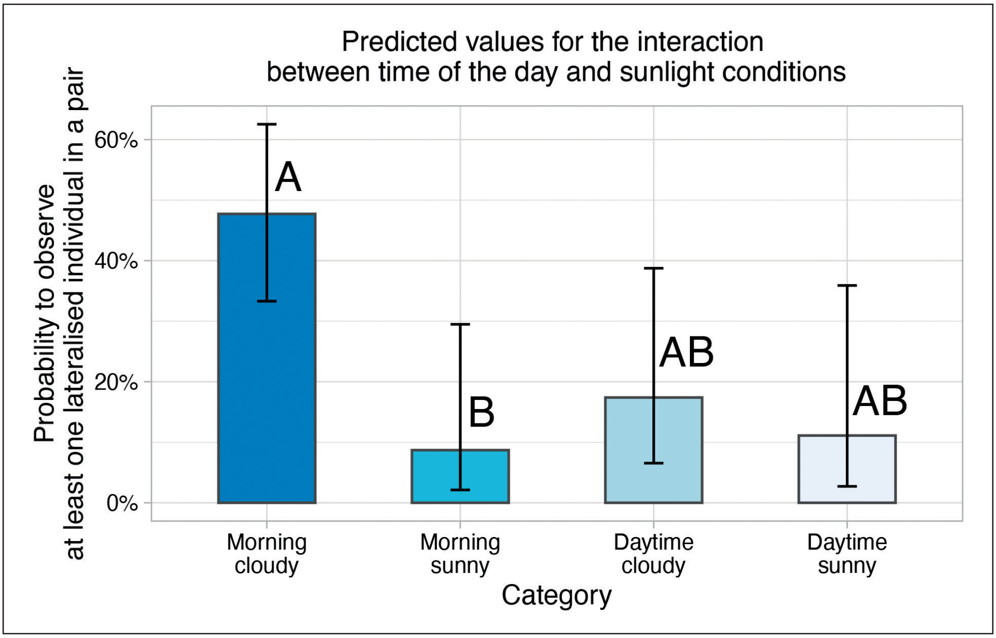

Figure 3. Predicted probabilities to observe a lateralised individual in a pair based on the influence of the interaction between time of the day and sunlight conditions. Labels A, B and AB represent groups of observations determined by post-hoc test

3. ábra Páron belüli lateralizált egyed megfigyelésének valószínűsége az idő és napfény közötti interakció függvényében. Az A, B és AB feliratok a post-hoc teszt által eredményezett megfigyelési csoportokat jelölik

(Vallortigara & Rogers 2005). Therefore, for each population, a ratio of individuals with lateralised behaviour or without preferences may be formed in accordance with specific conditions. Such proportions are explained by the evolutionarily stable strategy (Ghirlanda & Vallortigara 2004, Ghirlanda *et al.* 2009, Tonello & Vallortigara 2023). Most of the individuals in our study were birds with no preference to observe a partner with one of the eyes. This may be due to the highly competitive behaviour in the geese' flocks (Prop 2004) and high levels of threat from predation (Eichhorn *et al.* 2009) or hunting (Mooij *et al.* 1999). Previous research on Barnacle Geese and Greater White-fronted Geese has also shown that high levels of threat prevent the manifestation of visual lateralisation at the population level in geese (Zaynagutdinova *et al.* 2020b). In our study, birds were exposed to the constant noise from the road and only short-term sounds of shooting. As a result, the hunting effect was insufficient in our study.

Although non-lateralised individuals predominated in our study, we observed more right-biased individuals than left-biased individuals. It is known that the left hemisphere (processing information from the right eye) in vertebrates participates in positive interspecies social interactions, categorizing familiar experiences and stimuli, such as food and conspecifics; maintains short-term memory and concentration during routine activities; and can inhibit the right hemisphere processing information from the left eye (Rogers 2011, 2022). Nevertheless, some studies reveal the dominance of left eye – right hemisphere system in social behaviour. Maternal individuals, in many mammalian species, have a preference to keep their offspring on their left side (Karenina *et al.* 2017, 2018). Fish also prefer to keep conspecifics on their left side (Bisazza *et al.* 1999, Sovrano *et al.* 1999, Sovrano *et al.* 2001). Domestic chickens use their right hemisphere, hence showing a left-eye preference, for recognition of companions (Vallortigara 1992, Salva *et al.* 2012). It is necessary to understand the influence of various factors on the processing of social information when comparing the results of different studies.

The effect of sunlight conditions

We have revealed that direct sunlight, especially in the morning, interferes with the manifestation of visual lateralisation. The highest proportion of lateralised individuals was observed in cloudy conditions. Bright sunlight can disturb the observing of the partner preventing the manifestation of visual lateralisation. The low position of the sun in the morning can further enhance this effect. Another reason could be the differences in skylight polarization in morning and noon. It is known that birds are most sensitive to skylight polarization at sunrise and sunset (Muheim 2011). The intensity of UV radiation also differs in the morning and in the daytime. This difference could also affect the perception of visual information as geese, like most birds, have tetrachromatic vision (Moore *et al.* 2012). The influence of the sunlight on partners' relative position was also discovered in hummingbird species (for example, Simpson & McGraw 2018). Dakin and Montgomerie (2009) found that male Indian Peacocks *Pavo cristatus* orient themselves relative to the sun and a female even in cloudy weather, suggesting that the birds remembered the position of the sun or were guided by polarized light. Nevertheless, Domestic (Feral) Pigeons *Columba livia domestica* have no functional lateralisation of sun compass use within the visual system (Ulrich *et al.* 1999, Griffiths *et al.* 2020).

The plasticity of lateralisation is an important factor influencing the assessment of lateralisation on individual and population levels. Our study found the effect of sunlight, specific by time of the day, on lateralisation in birds. These factors should be taken into account when evaluating lateralisation in experiments and field observations.

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Breeding ecology of the endangered Algerian Nuthatch *(Sitta ledanti)* endemic to the Babors′ Kabylia (Northeastern Algeria): Implications of conservation

Adouda Benazouz*, Mourad Zemouri & Abdelazize Franck Bougaham

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Abstract The endemic Algerian Nuthatch *Sitta ledanti*, is classified as an endangered species by the IUCN and protected species by Algerian law. Available information on its nesting and breeding biology is sporadic and incomplete, the purpose of which is to provide additional data on the different aspects of multi-site nesting of the species. 22 nests are monitored across five forests, during the nesting season of 2021. An endoscopic camera was used to monitor eggs and nestlings in the nests during the whole study. Most of the nests (n = 20) were constructed in different parts of the dead trees such as trunks or branches of the Atlas cedar *Cedrus atlantica*, the Algerian oak *Quercus canariensis*, the African oak *Quercus afares* or Cork oak *Quercus suber*. The laying dates were from early April to the end of May when April 28 (± 13 days) is the laying season's median start date. The average clutch size was 4.6 (n = 21). The mean hatching success was 89.2%, while mean fledging success was 88.2%. The nestling sex ratio was 14 males versus 18 females. Data on clutch dates and fecundity of breeding pairs should be considered in any conservation approach and strategy in the context of habitat management and preservation.

Keywords: Algeria, Babors' Kabylia, Algerian Nuthatch, conservation, fecundity, breeding

Összefoglalás Az IUCN szerint az endemikus atlasz-csuszka, *Sitta ledanti* veszélyeztetett faj, melyet az algériai törvények is védettnek tekintenek. A szaporodásbiológiájáról hiányosak a rendelkezésre álló információk. Öt erdei élőhelyen összesen 22 fészket figyeltek meg a 2021-es költési időszakban. Az odúk vizsgálatát endoszkópos kamerával végezték. A legtöbb fészket (n = 20) elhalt fák, például az Atlas-cédrus *Cedrus atlantica*, a Kanári-tölgy *Quercus canariensis*, az afrikai tölgy *Quercus afares* vagy a paratölgy *Quercus suber* törzseiben vagy ágaiban találták. Az első tojás lerakása április elejétől május végéig történt, a medián költéskezdés április 28. volt. Az átlagos fészekaljnagyság 4,6 tojás volt (n = 21). A kelési siker 89,2%, míg a kirepülési siker 88,2% volt (±13). A fiókák esetében az ivarok aránya: 14 hím és 18 tojó volt. A vizsgálat fontos, eddig még nem ismert szaporodásbiológiai adatokat szolgáltatott az algériai csuszkáról, amelyek segíthetik a faj élőhelyeinek megőrzését.

Kulcsszavak: Algéria, Babors Kabila, atlasz-csuszka, természetvédelem, költésbiológia, fekunditás, szaporodási siker

Université de Bejaia, Faculté des Sciences de la Nature et de la Vie, Laboratoire de Recherche en Écologie et Environnement, 06000 Bejaia, Algeria.
**corresponding author, e-mail: adouda.benazouz@univ-bejaia.dz*

Introduction

Monitoring and knowledge of the nesting period, laying dates, brood sizes, and breeding success are important in bird population studies. These kinds of data are very important to determine conservation strategies for threatened species since they might be ancestral features in species adaptation and could also help analyse the viability of passerine populations (Sutherland *et al.* 2004).

There is no complete nesting data for more than 30% of bird species, and most have incomplete or unknown information (Xiao *et al.* 2016). Also, this aspect is well-studied in other groups of birds than in passerines (Xiao *et al.* 2016). The breeding biology of birds can be influenced by environmental conditions, climate change, predation, habitat fragmentation and food resource availability (Crick 2004, Norris *et al.* 2004, Lampila *et al.* 2005, Dunn *et al.* 2010). This is the case for the mesogenic nuthatches group where the nesting is influenced by habitat loss and forest fires (Thibault 2002, 2004), human activities, deforestation, overgrazing, altitude (Ledant *et al.* 1985), and changes in spring temperatures (Albayrak & Erdogan 2005, Thibault & Villard 2005).

In the nuthatches group, studies about the breeding biology of various species in the *Canadensis* and mesogenic group are frequent (Löhrl 1960, Albayrak & Erdogan 2005, Thibault & Villard 2005, Bougaham *et al.* 2017, Ghalambor & Martin 2020). Clutch sizes of the Algerian Nuthatch *(Sitta ledanti)* and Krueper's Nuthatch *(Sitta krueperi)* range from four to seven eggs (Albayrak & Erdogan 2005, Bougaham *et al.* 2017). The incubation period varies between 14 and 15 days in *S. ledanti* (Bougaham *et al.* 2017), from 12 to 15 days for *S. krueperi* (Albayrak & Erdogan 2005) and from 14 to 17 days in Corsican nuthatch *(S. whiteheadi)* populations (Villiard & Thibault 2001). Hatching success ranges from four to seven eggs hatched and fledging success from zero to six chicks fledged for both *S. ledanti* and *S. krueperi* and from three to six chicks fledged for *S. whiteheadi* (Albayrak & Erdogan 2005, Thibault & Villard 2005, Bougaham *et al.* 2017).

The Algerian Nuthatch is a rare and endemic forest bird of Algeria (Hamitouche & Bougaham 2021). It is classified as Endangered species (BirdLife International 2021) and protected forest bird in Algeria since 1983 (JORA 1983, 2012). This species is frequent both in deciduous and evergreen forests in the Babors' Kabylia biogeographical region (Northeastern Algeria), which is distributed in 13 separated habitats (Vielliard 1976, Ledant 1977, Chalabi 1989, Bellatrèche & Chalabi 1990, Moulai & Mayache 2018, Haddad & Afoutni 2019, Bougaham *et al.* 2020, 2021, 2022, Mayache *et al.* 2021). It has been the subject of several studies analysing population densities (Bellatrèche & Chalabi 1990, Bougaham *et al.* 2018, Hamitouche *et al.* 2020, 2021, Hamitouche & Bougaham 2021, Zemouri & Bougaham 2022), the description of habitats (Ledant 1977, Ledant & Jacobs 1977, Vielliard 1978, 1980, Ledant *et al.* 1985, Chalabi 1989, Bellatrèche 1990, Bougaham *et al.* 2017, 2018, Moulai *et al.* 2017, Moulai & Mayache 2018, Hamitouche *et al.* 2020), ecological preferences (Ledant & Jacobs 1977, Vielliard 1978, Ledant *et al.* 1985, Chalabi 1989, Bellatrèche & Boubaker 1995, Bougaham *et al.* 2018, Hamitouche *et al.* 2020) and its diet (Zemouri *et al.* 2021, 2023). However, studies on the Algerian Nuthatch breeding biology remain incomplete by studying only the populations of the Jebel Babor (Vieilliard 1978, Gatter & Mattes 1979, Ledant & Jacobs 1979, Harrap

& Quinn 1996, Monticelli & Legrand 2009) and Guerrouch forest (Bellatrèche & Boubaker 1995, Moulai *et al.* 2017, Bougaham *et al.* 2017).

Our study is conducted on a multi-site scale to provide comprehensive and detailed information on the breeding parameters of the Algerian Nuthatch. We tried to highlight the multifunctional role of this information in the context of the implications of habitat preservation and species conservation.

Material and Methods

Study area

The monitoring of Algerian Nuthatch breeding was conducted in five forests, where the population density of the species was high (Hamitouche & Bougaham 2021) *(Figure 1)*. The monitored populations were found in deciduous forests, aside of Jebel Babor forest. Only the Guerrouch and Babor forests benefit from a protection status (JORA 1984, 2019). Babor forest has an area of 1,268 hectares (Ledant *et al.* 1985) and peaks at 2,004 m. It is dominated by the presence of the Atlas cedar *(Cedrus atlantica)*. However, we also observe the presence of mixed plant formations with Atlas cedar, Algerian oak *(Quercus canariensis)*, Numidia fir *(Abies numidica)* and Aspen popular *(Populus tremula)* (Zemouri & Bougaham 2022). Tamentout forest has an area of 9,688 hectares (Boudy 1955 in Bellatrèche 1999) and reaches altitudes of 1,660 m in Jebel Sidi Salah. The tree stratum of this forest is essentially represented by Algerian oak, African oak *(Quercus afares),* and Blunt-leaved Maple *(Acer obtusatum)* (Hamitouche *et al.* 2022). However, the Guerrouch forest's plant cover is typified by the Algerian oak, African oak, obtuse-leaved maple, and the Cork oak *(Quercus suber)*. This forest covers 10,860 hectares and attains its highest point in M'cid Echta summit at 1,534 m (Bellatrèche 1994). The Algerian oak dominates the vegetation of the Djimla forest while the African oak dominates in the Larbâa forest (Bougaham *et al*. 2018, Hamitouche *et al.* 2021). The areas of these latter forests are 1,000 hectares (Bellatrèche 1994) and 700 hectares (Hamitouche *et al.* 2021), respectively.

Data collection

Preliminary trips began in March 2021. The Algerian Nuthatch's nesting territories were identified by the males' responses to a recording of the species' song (Bougaham *et al.* 2017). Once the nesting territories demarcated, we remotely monitor the nesting behaviour through the observation of the digging activity of the nest cavity, the transport of nest-building materials, and the provision of food to the female who incubates the eggs.

In each forest, the position of the nests found was indicated by GPS points (Garmin map 76 CSx model) *(Figure 1)*. Nesting monitoring was done during the same breeding season in 2021 to prevent bias in the results and to enable data comparisons across the five populations studied.

We were able to locate 22 nests of the species: five nests in the Babor forest, five in the Tamentout forest, four in the Guerrouch forest, four nests in the Djimla forest, and also

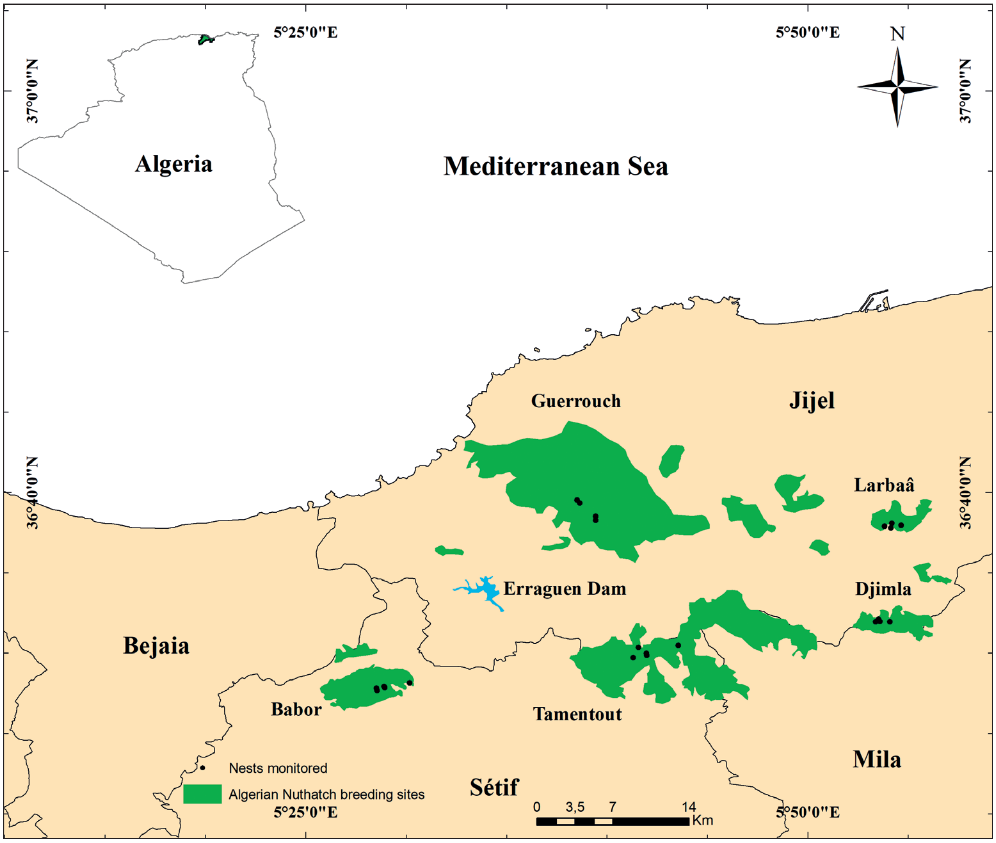

Figure 1. Algerian Nuthatch's nesting sites (green patches) and location of monitored nests
1. ábra Az atlasz-csuszka fészkelőhelyei (zöld foltok) és a megfigyelt fészkek elhelyezkedése

four nests in the Larbâa forest. These nests were monitored from the beginning of April until the end of May using an endoscopic camera (Bougaham *et al.* 2017). In the case of nests inaccessible by the endoscopic camera, we created an opening in the bark and trunk of the tree behind the nesting hole (Pravosudov 1993, Villard & Thibault 2001) to be able to observe the eggs and chicks hidden in the nest out of our field of vision. At the end of each check, we put the extracted piece of wood and bark back in its place using wood glue to avoid all kinds of nesting disturbance.

Nest characteristics

The vertical distance between the ground and the entrance to the nest hole was measured using a tape measure. The purpose of this operation was to calculate in meters the height of the nest hole on the plant support. Our attention sprang from the tree portion (trunk or branch) that the species chose to build its nest. We were also interested in the condition of the plant support alive or dead that was utilised to determine the species' requirements for nesting (Hamitouche & Bougaham 2021).

Nesting season

The dates of the first eggs laid were generally observed directly by inspections of the nests. When the nest was detected with more than one egg laid, the date of the first egg was deduced by the back-calculation method (Norris 2014, Bougaham *et al.* 2017), considering that the Algerian Nuthatch lays one egg every day.

When the nest was discovered at the nestling stage, the date of the first egg laid was determined by estimating their ages using the Norris method (2014) applied for the Red-breasted Nuthatch *(Sitta canadensis)*, where 14.5 days correspond to the duration of eggs incubation in the Algerian Nuthatch (Bougaham *et al.* 2017). The extreme dates of laying was expressed in days of the year where time is expressed as five-day intervals: pentade 1 = 1–5 April (*sensu* Berthold 1973).

Clutch size and breeding success

Clutch size is defined once the number of eggs in a nest has not changed after two consecutive visits. We also calculated the hatching success which corresponds to the percentages of eggs hatched compared to the total number of eggs laid.

$$\text{Hatching succes} = \frac{\text{number of eggs hatched}}{\text{total number of eggs laid}} \times 100$$

Whereas fledging success corresponds to the number of young fledged divided by the number of eggs hatched.

$$\text{Fledging success} = \frac{\text{number of young fledged}}{\text{total number of eggs hatched}} \times 100$$

Thus, total breeding success is calculated by dividing the number of fledglings by the number of eggs laid (Bougaham 2021).

$$\text{Breeding success} = \frac{\text{number of young fledged}}{\text{total number of eggs laid}} \times 100$$

Sex ratio of nestlings

The sex ratio was observed for each brood just before fledging dates, where morphological differences between male and female nestlings were observable. We noticed sexual dimorphism in the Algerian Nuthatch nestlings, including a black cap that starts from the edge of the beak towards the back of the head, thus extending beyond the males’ eyes (Bougaham *et al.* 2017). However, this cap was not observed in young females.

Statistical analysis

The R software (2021) was used to check if there was any variation between dates and clutch sizes, and reproductive success at hatching and fledging. We opted for the non-parametric Kruskal-Wallis test when the raw statistical series are not normal and/or its variances are not equal, it was applied three times, one time to verify whether there was a difference between clutch sizes, second time to verify if there was a difference between hatching success and third time to check the relationship between fledging success in the five forests. We compared between the proportion of males and females by a parametric Chi-square test (χ^2). We also checked if there was a correlation between altitude and laying dates. While in every analysis, statistical tests were considered significant at the $P < 0.05$ level.

Results

Heights and altitudes of nests

The height of the nests ranged between 2 m and 12.4 m with an average of 6.6 m, the altitude varied between 1,054 m and 1,993 m with an average of 1,335.7 m *(Table 1)*.

Table1. Nests height (m) and nests altitude (m) of Algerian Nuthatch
1. táblázat Az atlasz-csuszka fészkek magassága (m) és tengerszint feletti magassága (m)

	Babor	**Tamentout**	**Guerrouch**	**Djimla**	**Larbâa**	**Total**
Number of nests	**5**	**5**	**4**	**4**	**4**	**22**
Nests height (range)	2.6–8.7	2–12.3	3.2–8	4.2–8	5.2–11	**2–12.3**
Nests height (mean ± SD)	5.4±2.2	7.9±5.3	6.1±2.5	6.3±1.6	7.7±2.7	**6.6±2.8**
Nests altitude (range)	1421–1993	1290–1401	1054–1198	1103–1227	1068–1087	**1054–1993**
Nests altitude (mean±SD)	1837.8±235.3	1341±48.9	1080.2±37	1148.2±39.9	1077±9.5	**1335.7±323.9**

Nest supports

The nests were located on different types of trees depending on the habitat type of the forests studied. In the Babor forest, all the nests were built on the Atlas cedar, in the Tamentout forest the nests were located on the Algerian oak and the African oak, in the Guerrouch forest they were on the Algerian oak, African and cork oak, in the Djimla forest all the nests were located on the Algerian oak and lastly, in Larbâa forest, we found the nests on the Algerian and African oak, and one nest on a new species the hybrid oak (African oak × cork oak) *(Table 2)*. The Algerian Nuthatch chose dead wood for the construction of its nesting cavities; in this study, 20 nests were located either on a branch or a dead trunk and 2 were located on living wood *(Table 2)*.

Table 2. Nest support of the Algerian Nuthatch. n: number of monitored nests.
2. táblázat Az atlasz-csuszka fészkek fafajonkénti eloszlása. n: a megfigyelt fészkek száma

Forest	n	Tree	Support types		Dead	Alive
			Trunk	Branch		
Babor	5	*Cedrus atlantica*	3	2	3	2
Tamentout	5	*Quercus canariensis* *Quercus afares*	1	4	5	0
Guerrouch	4	*Quercus afares* *Quercus suber* *Quercus canariensis*	1	3	4	0
Djimla	4	*Quercus canariensis*	0	4	4	0
Larbâa	4	*Quercus afares*	0	4	4	0

Breeding period

The nesting season of the Algerian Nuthatch in the Babor's Kabylia region was characterised by a large spread over time *(Figure 2)*. Most nuthatches of the five habitats studied were laid in April, the average laying date for all forests was April 28. The Djimla forest' nuthatches were the earliest and that of Babor were the latest. There was a positive, but non-significant association between laying dates and the position of the nest in altitude ($t = 1.9786$, $df = 19$, $p = 0.06254$).

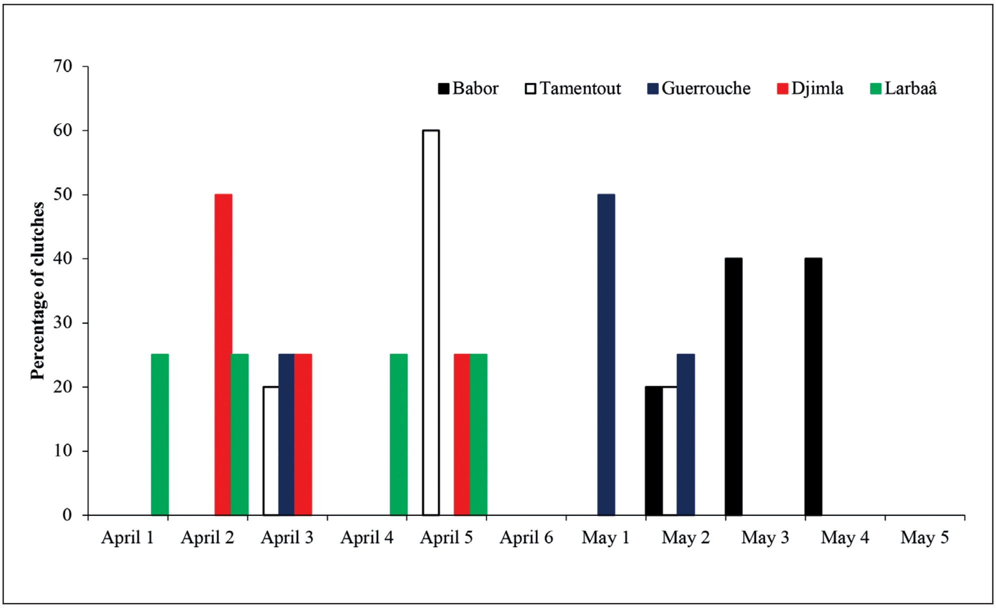

Figure 2. Changes in the first-egg laying pattern of the Algerian Nuthatch clutches in the five forests. Laying time in consecutive five-day periods is presented
2. ábra Változások az atlasz-csuszka felső tojás lerakásának mintázatában az öt erdőben, ötnapos periódusonként

Table 3. The first egg-laying date, clutch size, number of hatchlings and fledglings, hatching success, breeding success at fledging, and sex ratio (male/female) of the Algerian Nuthatch. N: Number of nests found. n: Number of nests monitored. Data is presented as a mean ± SD, with the range in brackets

3. táblázat Az atlasz-csuszka első tojásának lerakási időpontja, a fészekalj mérete, a kikelt fiókák és kirepült fiókák száma, a kelési siker, a költési siker a kirepüléskor és az ivararány (hím/tojó). N: A talált fészkek száma. n: A megfigyelt fészkek száma. Az adatok átlaga ± SD, a tartomány zárójelben

	N	**Laying date**	**Clutch size**	**Number of hatchlings**	**Number of fledglings**	**Hatching success (%)**	**Fledging success (%)**	**Ratio Male/female**
Babor	5	15 May±3 days (10 May–18 May)	5±0 (5–5)	4.5±0.5 (4–5)	4.4±0.5 (4–5)	88	88	2/3 (n = 1)
Tamentout	5	24 April ±9 days (11 April–7 May)	4.2±0.8 (4–5)	3.6±0.5 (3–4)	3.6±0.5 (3–4)	88.2	88.2	5/6 (n = 3)
Guerrouch	4	28 April ±12 days (11 April–8 May)	4.25±0.5 (4–5)	3.7±0.9 (3–5)	3.7±0.9 (3–5)	85.7	85.7	2/5 (n = 2)
Djimla	4	14 April±7 days (8 April–23 April)	4.5±2.4 (3–7)	4.7±1.2 (3–6)	4.7±1.2 (3–6)	86.4	86.4	3/2 (n = 1)
Larbâa	4	28 April ± 10 days (16 April–8 May)	4.25±0.9 (3–5)	4.2±0.9 (3–5)	4±1.1 (3–5)	100	94.1	2/2 (n = 1)
All forests	**22**	**28 April ± 13 days**	**4.6±1**	**4.1±0.9**	**4.1±0.9**	**89.2**	**88.2**	**14/18 (n = 8)**

Fecundity of the Algerian Nuthatch

An average clutch of 4.6 (SD = 1, range: 3–7, n = 21) eggs were noted. There was no significant difference between clutch sizes in the five forests (Kruskal-Wallis = 6.0549, df = 4, p = 0.1951). The average number of eggs hatched per nest was equal to 4.1 (89.2%) (SD = 0.88, range: 3–6, n = 21). The number of hatchlings did not differ between habitats (Kruskal-Wallis = 4.8375, df = 4, p = 0.3044). Fledging success varied between three and six chicks per nest, with an average of 4.1 (SD = 0.92, n = 21) and a percentage of 88.2%. We did not note a significant difference between fledging success in the different forests (Kruskal-Wallis = 4.3533, df = 4, p = 0.3603). The sex ratio of the fledglings was 14 males versus 18 females (n = 8 nests), where the Chi-square test (χ^2) between the proportion of males and females showed no significant difference in all the forests ($\chi^2 = 6.6667$, df = 6, p = 0.3528) *(Table 3)*.

Table 4. Number of Algerian Nuthatch broods that failed in each location

4. táblázat Az egyes helyeken sikertelenül költő atlasz-csuszkák száma

	Number of monitored nests	**Type of brood failures**	
		Number of nests with sterile eggs	Number of nests with dead nestlings
Babor	5	3	–
Tamentout	5	3	–
Guerrouch	4	2	–
Djimla	4	3	–
Larbâa	4	–	1
Total	**22**	**11**	**1**

Nesting failure of the Algerian Nuthatch

Among the causes of breeding failure in the Algerian Nuthatch we noted predation for one nest in the Larbâa forest, another cause was the sterility of the eggs *(Table 4)*.

Discussion

The nest heights noted in our study were lower than those noted in the Guerrouch forest (Bougaham *et al.* 2017) which was between 7 and 15 meters. In the Jebel Babor, the height of the nests was between 5 m and 15 m according to Ledant and Jacobs (1979) and was from 4 to 15 m according to Vieilliard (1978), but they were close to those cited by Gatter and Mattes (1979) which varied between 3 and 13 meters. These results are probably linked to variations in population densities of the species in each forest, which means that the height of the nest location decreases with increasing species density. Indeed, Nilson (1984) showed a negative correlation between nest density and nest height in the European Nuthatch, the Common Starling *(Sturnus vulgaris)* and the Blue Tit *(Cyanistes caeruleus)*. The nest sites of the Algerian Nuthatch reach altitudes of 2,004 meters on the Babor forest (Ledant & Jacobs 1977). Bougaham *et al.* (2017), studied nests located between 707 and 878 meters above sea level in the Guerrouch forest. However, in our study, nests are found between 1,054 and 1,993 meters. The lowest altitudinal position of the nests was noted in the Guerrouch forest and the highest in the Babor forest. In the other nuthatch species, *S. krueperi* the nest sites location reach an altitude of 1,700 m (Albayrak & Erdogan 2005) and those of *S. whiteheadi* at an altitude ranging from 1,000 to 1,600 m (Thibault & Villard 2005).

The nest supports of the Algerian Nuthatch vary between the forests studied depending on the dominant tree type. In the Babor forest, the nests are located on the Atlas cedar, the Numidian fir and the Algerian oak (Vielliard 1978, Gatter & Mattes 1979, Ledant & Jacobs1979). In other deciduous forests, the nests are located on the Algerian oak, African oak and Cork oak (Bougaham *et al.* 2017, Moulai *et al.* 2017). However, the *S. ledanti* had no preference for the dominant tree types, where in the Guerrouch forest nests were also found on the common eucalyptus*(Eucalyptus globules)* (Bougaham *et al.* 2017), the wild cherry *(Prunus avium)* (Mostfai 1990) and the strawberry tree *(Arbutus unedo)* (Kisserli 1992). The nuthatches nests are generally placed on dead wood; only two nests are located on living wood in Babor forest. All previous studies showed the same result (Ledant & Jacobs 1977, Bougaham *et al.* 2017, Moulai *et al.* 2017). These results confirm the importance of dead wood for the nesting of the species (Ledant & Jacobs 1977, Bougaham *et al.* 2017, Moulai *et al.* 2017, Bougaham *et al.* 2018, Hamitouche & Bougaham 2021, Zemouri & Bougaham 2022).

The breeding period of the Algerian Nuthatch extends from April 8 to May 28; April 28 is the average date of the first egg laid. The Algerian Nuthatch in Djimla forest is the earliest during the 2021breeding season. This result was different with the results obtained by Bougaham *et al.* (2017) which give April 5 as the average date of the first egg laid.

The Babor forest's nuthatches remain the latest to lay eggs in our study. The same results were found in the study of Ledant and Jacobs (1977). This differences probably due to the effect of altitude which correlates with the laying dates. Indeed, at higher altitudes the Algerian Nuthatch tends to lay eggs later than other populations of the species living at lower altitudes; this may be linked to temperature variations in Babor's Kabylia which vary from 0 °C to 9 °C in winter and from 28 °C to 31 °C in summer (Seltzer 1946, Ledant & Jacobs 1977, Bellatrèche 1999) such as the case of the Corsican Nuthatch where the effect of altitude was not clear but there was a correlation between the average temperatures of April and the laying dates (Thibault & Villard 2005). The availability of food supply can be another parameter that influences the laying dates of the Algerian Nuthatch (Bougaham *et al.* 2017, Mayache *et al.* 2020) like the case of Corsican Nuthatch (Thibault & Villard 2005).

Clutch sizes described in our study are within the range of results obtained in previous studies, where clutches was varied between 5 and 6 eggs in the Guerrouch forest (Bougaham *et al.* 2017), in the Babor forest, it was between 6 and 10 eggs according to Ledant and Jacobs (1979) and between 3and 4 eggs according to Veilliard (1978). Studies carried out on birds have shown an effect of latitude and length of day on the clutch sizes (Lack 1947, Jetz *et al.* 2008). Also, the Red-breasted Nuthatch *(S. canadensis)* clutch sizes was varied according to food availability, during years when beetles were less available the clutch size decreases with the increase in the laying date (Norris & Martin 2014). Predation can be another factor acting on the clutch size variation (Doligez & Clobert 2003).

The hatching success and fledging success in the five forests were less important than those noted at Guerrouch forest by Bougaham *et al.* (2017). Predation of the nests by the Great Spotted Woodpecker *(Dendrocopos major)* and the frequency of sterile eggs were the main causes of breeding failure in the Algerian Nuthatch (Bougaham *et al.* 2017, Moulai *et al.* 2017).

In this study, we noted a sex ratio in favour of females for the five forests. Several parameters can influence the variation of the sex ratio in birds. Some studies have shown that food availability was a determining factor; parents tend to produce the less expensive sex during the feeding period (Sheldon 1998). Climate variations and the synchronisation of reproduction affected the variation in the sex of the offspring in certain species of birds; pairs that bred early in the season produced more males than females (Dijkstra *et al.* 1990). The age of the parents also contribute to the imbalance in the sex ratio (Daan *et al.* 1996).

Threats and conservation measures for the Algerian Nuthatch

Our study on the breeding ecology of the Algerian Nuthatch provided us with useful information that could help natural area managers and decision-makers in future protection and conservation projects for the species and habitats. The creation of two national parks of Taza and Babor-Tababort (JORA 1983, 2012, 2019) is a less effective protection measure, especially since they only represent a small area compared to the extent of its distribution area which includes 13 isolated forests (Bougaham *et al.* 2022). It would be imperative to create new protected forest areas and to extend, for example, the current limits of the Taza National Park towards other forest cantons of the Guerrouch forest because the current protected area is insufficient for the effective protection of the species, and also the creation of ecological corridors between the different forests, particularly between Djimla and Tamentout and also between Babor and Tababort (Bellatrèche & Chalabi 1990, Bougaham *et al.* 2021). As a result, it would be feasible to increase the size of some populations and to facilitate individual exchanges, which will benefit all populations through genetic exchange. Like the Corsican Nuthatch (Thibault *et al.* 2004), even within these protected areas, the populations of the Algerian Nuthatch remain threatened by the loss of habitat caused by repeated forest fires which remain major threat factors for the species (Ledant 1977, 1981, Ledant *et al.* 1985, Bougaham *et al.* 2018, Hamitouche *et al.* 2021). In addition to forest fires, illegal logging and the recovery of dead wood will reduce the availability of nesting supports (Ledant & Jacobs 1977, Vielliard 1978, Gatter & Mattes 1979, Ledant 1981, Bougaham *et al.* 2017) and food research (Bellatrèche & Boubaker 1995, Zemouri *et al.* 2021, 2023) of which the maintenance of dead trees standing and the control of all silvicultural activities is essential for the protection of this species (Ledant & Jacobs 1977, Bougaham *et al.* 2017, Moulai *et al.* 2017, Bougaham *et al.* 2018, Hamitouche & Bougaham 2021, Zemouri & Bougaham 2022). The opening of passable forest tracks will allow the installation of humans and the fragmentation of forests which causes the disturbance of breeding pairs during the breeding period (Moulai *et al.* 2017, Mayache *et al.* 2018, Hamitouche *et al.* 2021), just like eco-tourists activities such as the creation of the Djimla recreational forest (Bougaham *et al.* 2018). The limitation of access to forests during the breeding season and the development of other forest tracks to avoid nesting territories and all contact with breeding pairs and promote all eco-tourism activities outside the breeding and feeding period may be conservation recommendations that decrease the causes of nesting failure and further improve the breeding success of the Algerian Nuthatch. It would be helpful to map the current climatic vulnerabilities of Algerian Nuthatch's distribution area and include the areas most affected by the factors endangering the species, this could help to develop management plans and actions for the protection and conservation of the Algerian Nuthatch, notably advanced fire-fighting systems, planning for the opening of tracks and roads and the management of tourist activities, etc. (Lipka 2017).

Conclusions

The study on the different parameters of the Algerian Nuthatch breeding biology, which was carried out on five important populations, allowed us to provide complete and precise information on the laying dates, the clutches size, and the breeding success of the species. This information obtained is similar between the different local populations studied and does not record any significant differences. This observation could be linked to the overall bioclimatic conditions of Babor Kabylia, whose local populations of the species are located close to each other in the same biogeographic sector. Like other studies carried out on other groups of nuthatches, our study confirms the importance of the availability of dead wood resources for the nesting of the Algerian Nuthatch, which is a component to consider in any protection and conservation project of the species. The combination of the different threats listed and the information collected on nesting and fertility of this endemic species will help managers of natural environments make appropriate decisions on conservation strategies for the species.

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Diet composition of the Atlas Flycatcher *Ficedula speculigera* in Northeastern Algeria

Lakhdar TEMAGOULT[1*], Abdelazize Franck BOUGAHAM[2]
& Riadh MOULAÏ[1]

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Abstract The diet of the Atlas Flycatcher, an endemic bird species of North Africa is studied in Northeastern Algeria in the forest of Guerrouch in the Taza National Park. The diet analysis was based on the examination of the faecal sacs of the nestlings (n=150) collected in nest boxes installed in a mixed formation of Algerian oak and African oak *(Quercus canariensis* and *Quercus afares)*. A total of 854 food items were identified, representing 49 prey taxa. The analysis of centesimal frequencies by class revealed the clear dominance of Insecta with 85.12%, followed by Arachnida 13.34%, Gastropoda 1.28% and Malacostraca 0.23%. Regarding orders, the diet was constituted mainly of Coleoptera 44.37%, followed by Hemiptera 21.89% and Araneae 13.34%. The size of the prey taxa varied between 3 and 14 mm with an average of 7.11±3.14 mm. The best represented size class was that which varies between 3 and 4.37 mm. To test the homogeneity between the 4 nest boxes sampled, an *ANOVA test* was applied. The results show the presence of 2 distinct groups of nesting boxes concerning the variable number of families / faecal sacs.

Keywords: diet, Guerrouch, prey taxa, oak forest

Összefoglalás Az Észak-Afrikában endemikus Atlasz-légykapó táplálékösszetételét vizsgálták a Taza Nemzeti Park tölgyeseiben (Guerrouch, Északkelet-Algéria). A Kanári-tölgy és az afrikai tölgy kevert állományába kihelyezett négy fészekodú fiókáitól összesen 150 ürülékmintát gyűjtöttek. Az ürülékből 854 táplálékmaradványt azonosítottak, amelyeket 49 taxonba soroltak. A maradványok százalékos megoszlása alapján a rovarok (85,12%) domináltak, amelyeket a pókok (13,34%), a csigák (1,28%) és a szárazföldi rákok (0,23%) követtek. A rovarok többsége a bogarakhoz (44,37%) és a poloskákhoz (21,89%) tartozott. A táplálékdarabok mérete átlagosan 7,11±3,14 mm-esnek (3–14 mm közötti intervallumban) adódott. A tápláléktípusok (családok) előfordulási gyakorisága alapján a négy fészekalj két elkülönülő csoportot alkotott.

Kulcsszavak: táplálék, Guerrouch, zsákmány összetétel, tölgyerdő

[1] *Laboratory of Applied Zoology and Animal Ecophysiology, Faculty of Nature and Life Sciences, University of Bejaia-06000 Bejaia, Algeria*
[2] *Laboratory of Ecology and Environment, Faculty of Nature and Life Sciences, University of Bejaia-06000 Bejaia, Algeria*
** corresponding author, e-mail: ltemagoult98@gmail.com*

Introduction

The Atlas Flycatcher *(Ficedula speculigera)* is an endemic bird of the Atlas Mountains in North Africa. Few studies have been devoted to this species, probably because it was considered a subspecies of the Pied Flycatcher (*F. hypoleuca).* Saetre *et al.* (2001) were the first to suggest, mainly based on molecular genetic data, that the Atlas Flycatcher should be elevated to full species status. They compare mitochondrial DNA sequences within the black and white *Ficedula* species complex. As a result, they found that this species complex contains one more species than previously recognised, which originated from the Atlas Mountains of Morocco. They found that this latter was genetically as distinct from the Pied Flycatcher as from the Collared Flycatcher *(F. albicolis)*. However, since Saetre *et al.* (2001) did not compare *F. h. speculigera* with the morphologically and geographically intermediate form *F. h. iberiae*, their assessment has been widely rejected (e.g. Dickinson 2003, del Hoyo *et al*. 2006, Taylor & Christie 2013), and just a few works have accepted it (e.g. Clements *et al*. 2015). More recently Corso *et al*. (2015) and Robb andThe Sound Approach (2015) analysed plumage and song variation, which clearly showed that *F. speculigera* is different from the designated *F. hypoleuca* but not systematically with the form *F. h. iberiae*. Since then Potti *et al*. (2016) have reanalyzed morphological characters, which led them to conclude that the form *F. h. speculigera* is specifically distinct from the form *F. h. iberiae*.

The Atlas Flycatcher is distributed across Morocco (south to the Middle Atlas Mountains), northern Algeria and northern Tunisia, and winters in West Africa (del Hoyo *et al*. 2006, Clements *et al*. 2015). There are also unconfirmed sightings in Italy and Malta (Corso *et al*. 2015).

Aspects of the biology and ecology of this species still poorly understood in North Africa. In this context, only the work of Boudeffa (2014) can be mentioned, who was interested in the breeding biology and trophic ecology of this species in a cork oak forest *(Quercus suber)* in the region of El Kala in the extreme Northeast Algeria. The diet composition was studied by analyzing the food bolus of the chicks using the collar method.

Our contribution aims to better understand the trophic ecology of this bird, in a humid deciduous oaks forest in the Taza National Park, in North Algeria.

Material and Methods

Study area

The study was carried out in the National forest of Guerrouch inside the Taza National Park (Jijel, Algeria). The Guerrouch forest is located in the northeastern part of Algeria, 30 km southwest of Jijel province (36°41’39.10” N 5°38’55.37” E). It covers an area of nearly 10,860 hectares, from the gorges of the Taza River in the north to the Selma pass in the south. It is 19 km long from east to west and 13 km wide from north to south. Its highest point is the summit of M’cid-Echta at 1,543 m (a.s.l). The Guerrouch forest is characterized

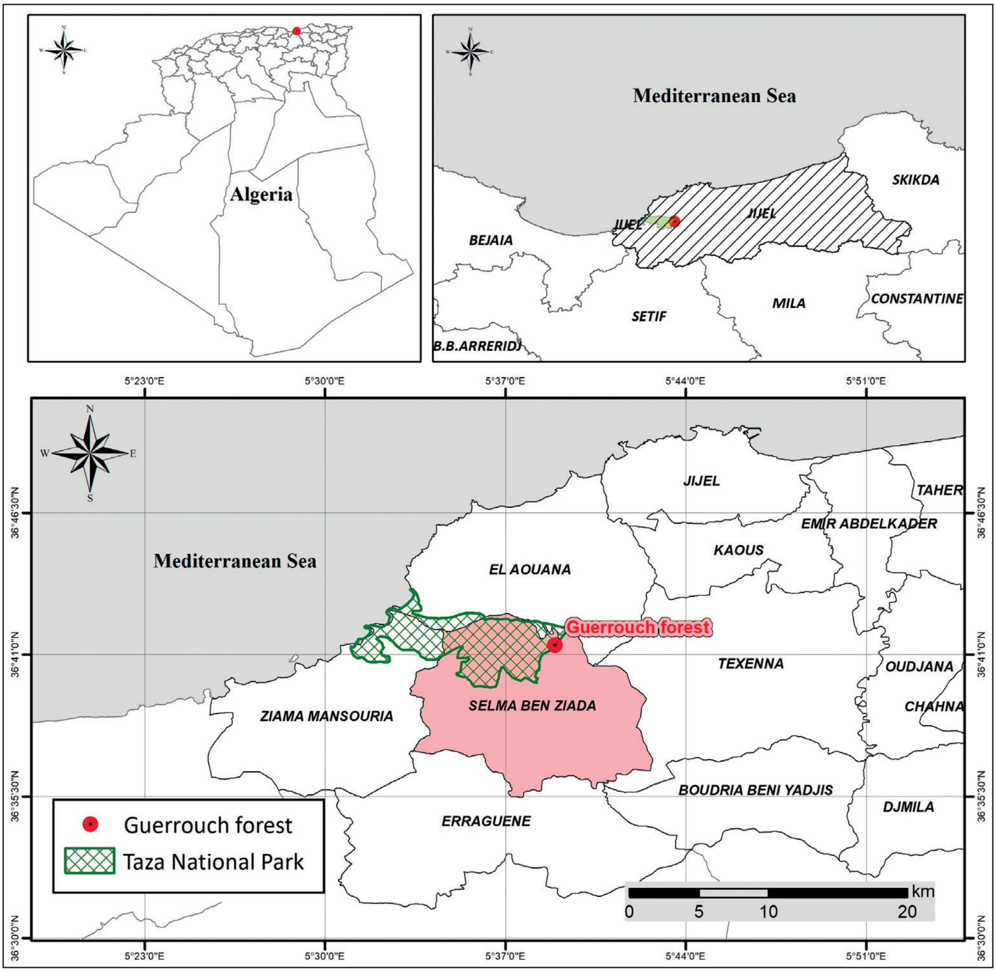

Figure 1. The geographic location of the study area
1. ábra A vizsgálati terület elhelyezkedése Algériában

by the best preserved oak forests in the country, with the presence of the Algerian oak *(Quercus canariensis)* widely distributed from low altitudes up to about 700 m (a.s.l). The African oak *(Quercus afares)* from 900 m (a.s.l), and the cork oak *(Quercus suber)* in low and medium altitudes *(Figure 1)*.

Data collection

The diet of the Atlas Flycatcher was studied by analyzing the content of the faecal sacs of nestlings during the breeding season of 2017. The faecal sacs were recovered directly from nest boxes at the end of the breeding period, towards the end of June. The samples come from four nest boxes (4 locations) installed in the mixed oak forest located at 900 meters (a.s.l).

Data analysis

A total of 150 faecal sacs were collected. The faecal sacs were placed separately in numbered pill boxes and marked with information such as date and place of collection. Before the examination of each faecal sac, the sample was placed inside a Petri dish containing 70° alcohol, which made it possible to easily separate the different fragments found in the faecal sac.

Using entomological forceps and under a binocular magnifying glass (total magnification: 7–10×40), we proceeded to dissect and sort all the fragments contained in the triturated faecal sac (heads, elytra, mandibles, thorax, abdominal segments pronotums and sometimes even complete individuals). These fragments were then arranged by category in another Petri dish lined with blotting paper divided into 6 to 8 boxes.

Prey fragments were determined by referring to various identification guides (Helgrad 1984, DuChatenet 1986, Zahradnik 1988, Leraut 2003), collections of the Department of Applied Zoology, University of Bejaia. Prey taxa were counted and their sizes were estimated either using a strip of graph paper and/or using reference guides.

Ecological indices and statistical methods have been applied to study diet composition and diversity. The total species richness *(S)* is represented by the total number of taxa found in all analyzed faecal sacs. The average specific richness *(s),* which is the average number of species present per sample, was calculated by the ratio between the total number of species identified during each survey and the total number of surveys carried out.

The composition of the diet was expressed as a percentage of centesimal frequency *(cF%)*, which is the ratio between the number of individuals of a given category of prey (n_i) and the total number of prey (*N*), the frequency of occurrence *(Fo%)*, which is the ratio of the number of faecal sacs containing the taxon *i* to the total number of faecal sacs. The frequencies of each taxon were represented in a single graph (Costello 1990), to provide description of the frequency of preys (dominant or rare), the feeding strategy of the predator (specialist or generalist) and the degree of homogeneity of the diet. Thus, prey points that are positioned near 100% occurrence and 100% abundance were considered as dominant prey taxa. A prey group positioned near to 100% of occurrence and 1% of abundance indicated that the predator hunts several prey taxa in low abundance (a generalized diet). Points that are close to 1% occurrence and 100% abundance indicated the specialization on certain taxa by certain predators (Costello 1990).

The Shannon index (Shannon & Weaver 1948) was applied to assess the diversity of the Atlas Flycatcher's diet generally, which was calculated as $H'=-\Sigma p_i \ln p_i$, p_i is the probability of encountering taxon prey *i*, which is given by the following formula $p_i = n_i/N$, where n_i is the number of individuals of taxon prey *i*, and *N* is the total number of individuals.

The equitable or equal distribution index (E) is the ratio between the calculated diversity (H) and the maximum theoretical diversity (H_{max}) which is represented by the log 2 of the total richness (S) (Blondel 1975).

$E= H'/H_{max}$

H': is the index of Shannon

$H_{max}=\log_2 S$

This index vary from 0 to 1:

When it tends towards 0 (E<0.5), it means that almost the entire population tends to be concentrated on a single species. It is equal to 1 when all species have the same abundance (Barbault 1981).

The size classes of the different prey were determined by applying Sturge's rule, and the number of individuals in each class was expressed in centesimal frequency.

To test the homogeneity of the faecal sacs sampled from the 4 nesting boxes, an ANOVA test was performed taking the number of families per faecal sac as a variable. This analysis was performed by the software SPSS.

Results

Diet composition of the Atlas Flycatcher

The number of individuals (N_i), the centesimal frequency (*cF%*) and the occurrence of each species (*Fo%*) are summarized in *Table 1*. The analysis of 150 faecal sacs of young Atlas Flycatchers, collected in the forest of Guerrouch, enabled us to count a total of 854 individuals, divided into 4 classes, 8 orders, 17 families, and 49 species.

Centesimal frequency per class

The class with the largest number of individuals was that of Insecta with 727 individuals (85.12%). The dominant insect groups were: Issidae sp. with 111 individuals, Lepidoptera sp. with 87 individuals and *Otiorhynchus* sp. 3 with 73 individuals. The second largest class was Arachnida with 114 individuals (13.34%) represented exclusively by Araneidae sp. In the third and fourth positions, we found the class of Gastropoda with 11 individuals 1.28% and the class of Malacostraca with 2 individuals only 0.23% *(Figure 2)*. We can note the clear dominance of Insecta (85.12%), which is probably linked to their great availability in this forest.

Centesimal frequency by order

The results of the centesimal frequencies by order of the prey consumed by the Atlas Flycatcher in the forest of Guerrouch are indicated in *Figure 3*.

The order Coleoptera seems to be the most dominant among the 8 identified orders with a centesimal frequency of 44.37%, followed by the order Hemiptera with 21.89%, and Araneae with 13.34%. Then we have 2 orders with similar occurrences: Lepidoptera with 10.18% and Hymenoptera with 8.31%. The three remaining orders are captured with low frequencies, they are: Stylommatophora, Orthoptera and Isopoda with frequencies of 1.28%, 0.35%, and 0.23% respectively.

Table 1. Diet composition of the Atlas Flycatcher *(Ficedula speculigera)* in the forest of Guerrouch (Jijel, Algeria) (*ni:* number of individuals*; cF%:* centesimal frequency*; Fo%:* frequency of occurrence)

1. táblázat Az Atlasz-légykapó *(Ficedula speculigera)* fiókák táplálékösszetétele a Guerrouch erdőben (Jijel), Algériában (*ni:* az *i* tápláléktípus egyedszáma; *cF%: i* tápláléktípus egyedszámának százalékos aránya az össztáplálékban; *Fo%: i* tápláléktípust tartalmazó ürülékminták százalékos aránya az összes ürülékmintához képest)

Classes	**Orders**	**Families**	**Prey-taxa**	***ni***	***cF* (%)**	***Fo* (%)**
Gastropoda	Stylommatophora	Helicidae	Helicidae sp.	11	1.28	7.33
Arachnida	Araneae	Araneidae	Araneidae sp.	114	13.34	76.0
Malacostraca	Isopoda	Oniscidae	Oniscidae sp.	2	0.23	1.33
Insecta	Orthoptera	Gryllidae	*Gryllus* sp.	3	0.35	2.0
	Hemiptera	Issidae	Issidae sp.	111	12.99	74.0
		Coreidae	Coreidae sp.	51	5.97	34.0
		Acanthosomatidae	*Acanthosoma* sp.	25	2.92	16.6
	Coleoptera	Curculionidae	*Otiorhynchus* sp.1	18	2.1	12.0
			Otiorhynchus sp.2	4	0.46	2.66
			Otiorhynchus sp.3	73	8-54	48.66
			Curculionidae sp.1	38	4.44	25.33
			Curculionidae sp.2	34	3.98	22.66
			Curculionidae sp.3	1	0.11	0.66
			Curculionidae sp.4	11	1.28	7.33
			Curculio sp.	15	1.75	10.0
			Pissodes sp.	1	0,66	0,66
		Chrysomelidae	Chrysomelidae sp.1	71	8.31	47.33
			Chrysomelidae sp.2	21	2.45	14.0
			Chrysomelidae sp.3	20	2.34	13.33
		Cerambycidae	Cerambycidae sp.1	1	0.11	0.66
			Cerambycidae sp.2	16	1.87	10.66
			Cerambycidae sp.3	9	1.05	6.0
			Cerambycidae sp.4	3	0,35	2.0
		Carabidae	Pterostichinae sp.1	9	1,05	6.0
			Pterostichinae sp.2	2	0.23	1.33
			Pterostichinae sp.3	1	0.11	0.66
			Carabinae sp.	2	0.23	1.33
			Carabidae sp.	3	0.35	2.0
			Cicindelinae sp.	18	2,1	12.0
		Scarabaeidae	*Onthophagus* sp.	1	0.11	0.66
		Nitidulidae	Nitidulidae sp.	3	0.35	2.0
		Buprestidae	Buprestidae sp.	4	0.46	2.66
	Hymenoptera	Formicidae	*Monomorium salomonis*	11	1.28	7.33
			Camponotus sp.	8	0.93	5.33
			Camponotus laurenti	1	0.11	0.66
			Camponotus truncatus	1	0.11	0.66
			Cataglyphis bicolor	11	1.28	7.33
			Messor sp. 1	5	0.58	3.33
			Messor sp. 2	1	0.11	0.66
			Messor sp. 3	1	0.11	0.66
			Lasius sp.	1	0.11	0.66
			Formica sp.	1	0.11	0.66
			Crematogaster scutellaris	1	0.11	0.66
			Aphaenogaster testaceopilosa	4	0.46	2.66
		Apidae	Apidae sp.	1	0.11	0.66
		/	Apoidea sp.	17	1.99	11.33
		Sphecidae	Sphecidae sp.	5	0.57	3.32
		Pompilidae	Pompilinae sp.	2	0.23	1.33
	Lepidoptera	/	Lepidoptera sp.	87	10.18	58.0
Total 4	**8**	**17**	**49**	**854**	**100**	

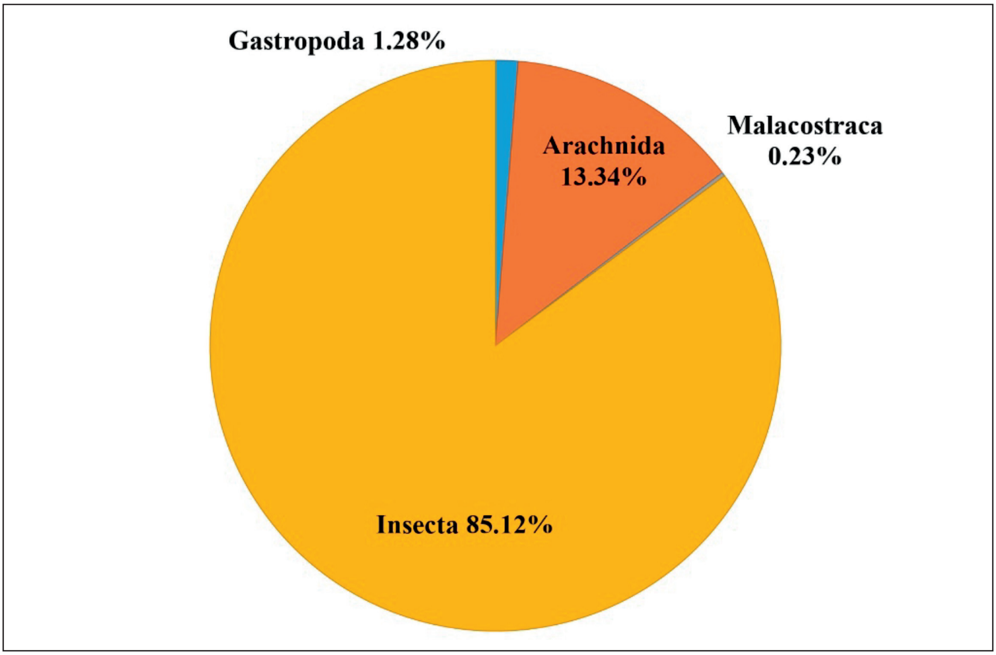

Figure 2. Distribution of the sampled preys by class
2. ábra A tápláléktípusok osztályok szerinti megoszlása

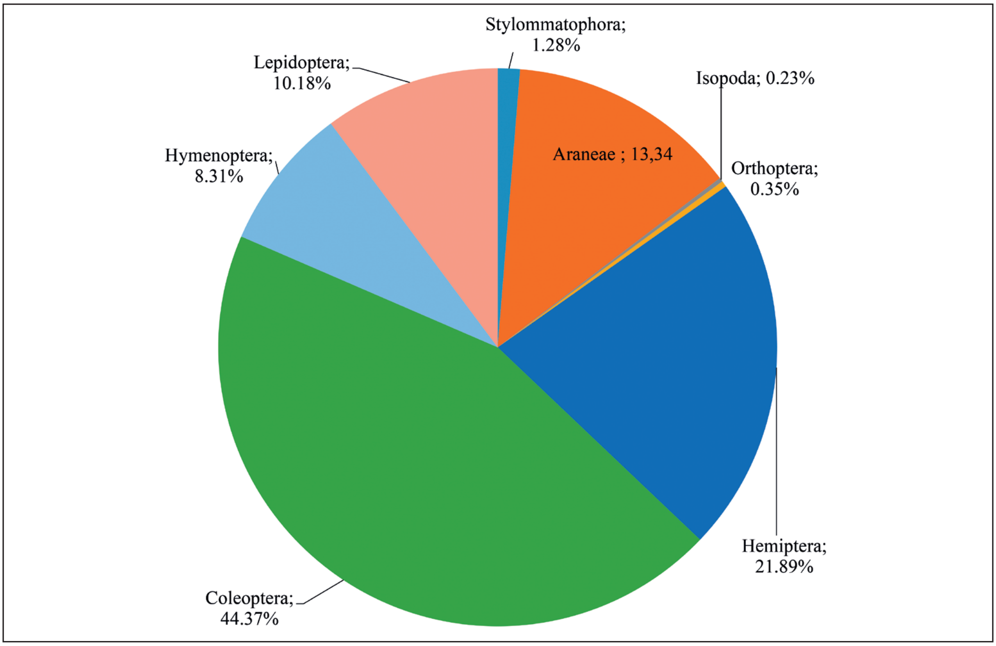

Figure 3. Orders constituting the diet of Atlas Flycatcher in northeastern Algeria
3. ábra A tápláléktípusok rendek szerinti megoszlása az Atlasz-légykapó fészkeknél gyűjtött táplálékban

Prey size

The size of the prey found in the faecal sacs of the Atlas Flycatcher varied between 3 mm (Curculionidae sp 2) and 14 mm (Sphecidae sp.), with an average of 7.11±3.14 mm. The size and the number of prey taxa of the Atlas Flycatcher by class are given in *Table 2*.

Table 2. Distribution of prey numbers among the prey size classes in Atlas Flycatcher (*Ni*: Total number of individuals, c*F%*: centesimal frequency)

2. táblázat A táplálékegyedek eloszlása a táplálékméret kategóriák között (*Ni*: táplálékegyedek száma, c*F%*: százalékos eloszlási arány)

Prey's size (mm)	***Ni***	***cF(%)***
3–4.37	273	31.96
4.37–5.75	6	0.70
5.75–7.12	178	20.84
7.12–8.5	167	19.55
8.5–9.87	4	0.46
9.87–11.25	99	11.59
11.25–12.62	122	14.28
12.62–14.0	5	0.58
Total	**854**	**100**

After applying Sturge's rule, 8 groups were obtained, the first [3–4.37 mm] was the most represented in number of individuals (31.96%). We noted that *Otiorhynchus* sp. 3, Chrysomelidae sp. 1, Curculionidae sp. 1 and Curculionidae sp. 2 were the most present in this group. In the second position, we have the group [5.75–7.12 mm] with a frequency of 20.84%, mainly represented by Issidae sp., Chrysomelidae sp. 3, *Curculio* sp. and Apoidea sp. Then we have the group [7.12–8.5 mm] (19.55%) mainly represented by Araneidae sp., Chrysomelidae sp. 2 and Curculionidae sp. 4. After that we have the group [11. 25–12,62 mm] (14.28%), composed essentially of Coreidae sp., *Acanthosoma* sp., and Cicindelinae sp. Groups [4.37–5.75 mm] [8.5–9.87 mm] and [12.62–14 mm] are represented by a relatively small number of individuals.

Food preference of the Atlas Flycatcher

By using the centesimal frequencies and the frequencies of occurrence of the taxa consumed by the Atlas Flycatcher, we obtained a graphical representation, following Costello (1990) *(Figure 4)*.

This representation shows dominant species such as Araneidae sp. (*Fo*=76%; *cF*= 13.34%), Issidae sp. (*Fo*=74%; *cF*=2.99%) and Lepidoptera sp. (*Fo*= 58%; *cF*=10.18%), rare species such as: Apidae sp. *(Fo*= 0.66%, *cF*= 0.11%), *Gryllu*s sp. (*Fo*=2%, *cF*=0.35%) and Helicidae sp. (*Fo*=7.33%; *cF*=1.28%) and other more or less consumed species such as *Otiorhynchus* sp. 3 (*Fo*=48.66%, *cF*=8.54%), Chrysomelidae sp. 1 (*Fo*=47.33%; *cF*=8.31%) and Coreidae sp. (*Fo*=34%; *cF*=5.97%)

Comparison of the sampled nest boxes

To evaluate the existing differences between the 4 nest boxes studied, the total richness (*S*), the average richness (*s*), the Shannon index (*H'*) and the equitability (*E*) were calculated *(Table 3)*.

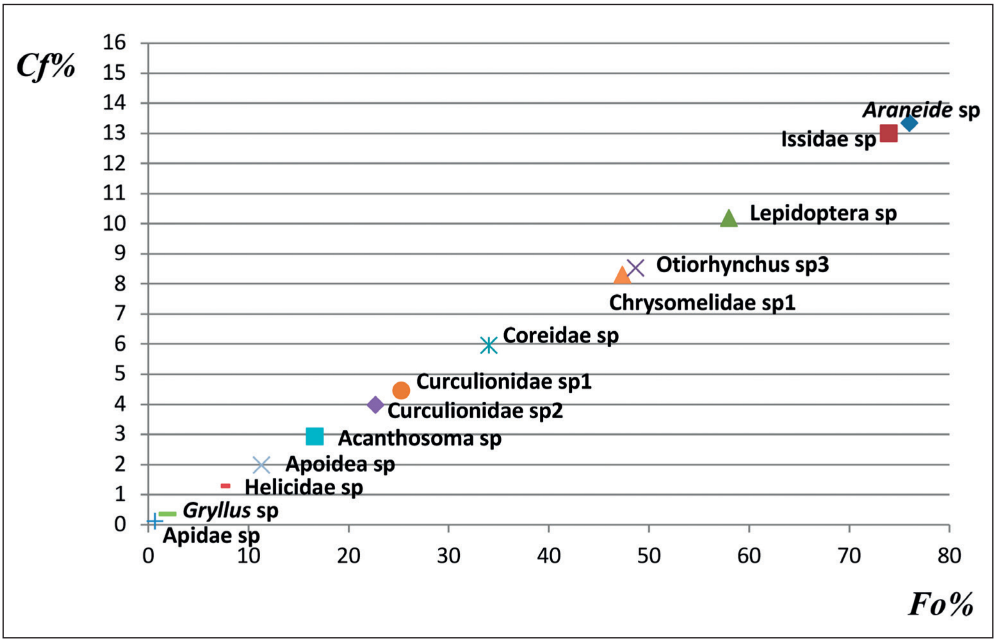

Figure 4. Graphical representation of the potential preys of the Atlas Flycatcher based on Costello's method (*Fo%*= frequency of occurrence; *cF%*= centesimal frequency).

4. ábra Az Atlasz-légykapó táplálékában azonosított főbb tápláléktípusok eloszlása Costello-módszer szerint (*Fo%: i* tápláléktípust tartalmazó ürülékminták százalékos aránya az összes ürülékmintához képest, *cF%: i* tápláléktípus egyedszámának százalékos aránya az össztáplálékban)

The total richness of the 4 nest boxes combined is 49 prey taxa, and in one next box. we recorded 43 species.

The mean richness in nest box 1 is 5.07±1.82, in the nest box 2 is 6.15±1.1; in the nest box3 is 6.15±1.1 and in the nest box 4 is 6.68±2.13.

The value of the Shannon index in nest box 1 is 3.28, in the nest boxe 2 is 2.52 in the nest box 3 is 2.80 and in the nest box 4 is 2.85.

The comparison of the values of each parameter between the 4 nest boxes reveals the existence of 2 distinct groups:

– Group 1: represented by nest box 1
– Group 2: represented by nest boxes 2, 3, and 4.

Table 3. Diet characteristics of the nestling food collected from 4 nest boxes.

3. táblázat Négy Atlasz-légykapó fészkeknél gyűjtött táplálék összetételének jellemzői

Parameters	Nest box 1 n=54	Nest box 2 n=20	Nest box 3 n=44	Nest box 4 n=32
Total richness (S)	43	20	29	23
Average richness (s) (M±SD)	5.07±1.82	6.15±1.1	6.59±1.57	6.68±2.13
Shannon index (H')(Bits)	3.28	2.52	2.80	2.85
Equitability (E)	0.25	0.41	0.32	0.41

Table 4. The result of the ANOVA test applied to the variable: number of prey families/faecal sacs of the 4 sampled nest boxes

4. táblázat Az Atlasz-légykapó négy vizsgált fészkénél gyűjtött táplálék különbözőségére végzett ANOVA teszt eredménye (a vizsgált változó az ürülékmintánkénti táplálékcsaládok száma)

	Sum of squares	**Degree of freedom**	**Mean square**	***F***	***p<***
Between-groups (combined)	56.341	3	18.780	9.473	0.000
Unweighted linear term	38.227	1	38.227	19.282	0.000
Weighted	49.620	1	49.620	25.028	0.000
Deviation	6.721	2	3.361	1.695	0.187
Within-groups	289.452	146	1.983		
Total	345.793	149			

To test the homogeneity of the preys sampled from the faecal sacs of the 4 nest boxes (sites), a statistical test of ANOVA was carried out concerning the 3 variables: Total richness/ faecal sac, number of families /faecal sac and number of orders/ faecal sac. Before this test, we performed a Principal Component Analysis (PCA), to choose the most appropriate variables. According to the PCA, the number of families / faecal sac had the highest contribution (95.5%) to the information on our 4 nest boxes, therfroe, we used it in the ANOVA analysis. According to Levene's statistics, there is no significant difference between the variables of the four nest boxes (P=0.654) so, homoscedasticity is respected and an ANOVA test can be performed because the data follow normal distribution.

According to the ANOVA *(Table 4)* there is a significant difference between the nest boxes (F= 9.473 and P=0.000), so a post-hoc test must be done to find out which nests differ between them and those which are homogeneous; this is the Newman and Keuls test. According to this test, there are two homogeneous groups:

– Nest-box 1 highly differed from the others, with a mean of 4.48 against 5.35, 5.81 and 5.82 which are the means of nest box 2, nest box 3 and nest box 4 respectively, (P= 1.000).

Discussion

The main purpose of the paper was to draw attention to the trophic ecology of the Atlas Flycatcher, a species endemic to North Africa by analyzing nestling's faecal sacs. To our best knowledge, only one study has reported the diet of the Atlas Flycatcher in Algeria, done by Boudeffa (2014) in a cork oak forest in eastern Algeria, using the neck-collar method on nestlings.

Flycatcher faecal samples originated from the forest of Guerrouch during the breeding season of 2017, allowing us to count a total of 854 food items, belonging to 49 prey taxa and distributed between 17 families, 8 orders and 4 classes. Among the 49 prey taxa identified, 3 are consumed with high frequencies: Araneidae sp., Issidae sp. and Lepidoptera sp.

The dietary profile of flycatcher nestlings in our study showed great diversity in the choice and consumption of prey available in the environment. It seems that insects are the most available prey in the environment followed by: Arachnida, Gastropoda and Malacostraca. Researches undertaken on the Pied Flycatcher, a closely-realted species to ours in interest suggest that nestlings are supplied with more digestible invertebrates than those consumed by adults, consisting mainly of Aranea, Lepidoptera, Diptera, Hymenoptera and Coleoptera (Mansfeld 1942, Creutz 1953, Von Haartman 1954, Meidell 1961, Bösenberg 1964, Dornbusch 1981, Silverin & Andersson 1984, Lifjeld & Slagsvold 1988, Lundberg & Alatalo 1992).

In our study, the diet consists mainly of Coleoptera, Hemiptera, Araneae, Lepidoptera and Hymenoptera.

Boudeffa (2014) collected 804 food items, mainly composed of lepidopteran larvae (23.4%) and Hemiptera (17.9%), represented mainly by wood bugs. Diptera occupy the third rank in the composition of the diet with a percentage of 16.5% among the prey brought. The rest of the diet consists of Hymenoptera, Arachnida, and Coleoptera in various stages of development.

We found only fragments of adult butterflies in faecal sacs, which is not the case for the food items collected with the collar method from Atlas Flycatcher nestlings, analyzed by Boudeffa (2014) where he found that caterpillars represent more than 23% of consumed items. The absence of caterpillar traces in the faecal sacs can be linked to two factors: The first relates to digestion because the caterpillars are soft and not very chitinous, so they leave no visible trace after passing through the digestive tract of the chicks. The second is related to the age of the chicks and the phenology of reproduction. Our faecal sacs are certainly from chicks aged between 11 and 13 days. At this time (end of June) there are few caterpillars available in the foliage of trees, most having undergone their metamorphoses (Mayeche *et al*. 2020). Perrins (1979) reports that sometimes an obstacle to the analysis of faecal sacs can occur, in the case of unpleasant or dangerous preys, such as certain caterpillars or the larvae of Hymenoptera, the parents are known to prepare particular elements by decapitating them, it results that the mandibles which are from a diagnostic point of view very important part of the body, are absent in the food brought by the parents and, consequently, absent in the faecal sacs. In addition, Boudeffa (2014), point out that the proportion of caterpillars decreases along the season to the benefit of other prey groups. This decline causes an increase in the size of preys, a diversification of the diet and a reduction in its digestibility.

In our case the Hemiptera occupy the second place with 21.89%, it's also the case of the results of Boudeffa (2014) obtained thanks to the collar method with 17.9%. Diptera seems to be absent from the faecal sacs of the Atlas Flycatcher of the Guerrouch forest, while they occupy the third place (17%) in the constitution of the diet of the Atlas Flycatcher in cork oak forests in eastern Algeria (Boudeffa 2014). This is certainly linked to the difficulty of detecting the remains of Diptera in faecal sacs. In this sense, small Diptera are systematically under-represented in faecal sacs compared to the collar method (Kleintjes & Dahlsten 1992, Moreby & Stoate 2000). The activity rate of prey during the day can also explain the existing differences between food profiles; some birds have adapted their hunting techniques to the activity rate of their prey. For example, the Spotted Flycatcher *(Muscicapa striata)* looks for aphids (Aphidoidea) in the foliage, during the hot hours of the day when Diptera and other winged insects are inactive. Thus, some differences in diets may be due to the time of day when birds are actively foraging (Davies 1977). Spiders seem to be well represented in the trophic menu from the faecal sacs of *F. speculigera* nestlings. This result is in agreement with that of Silverin and Andersson (1984), who found a higher proportion of spider remains in the stomachs of *F. hypoleuca* nestlings than in adults. In general, the differences observed in the food composition of flycatchers are related to the nature of the habitat, the food availability, the phenology of reproduction, in particular the age of the nestlings and the methodology of sampling.

From the research that has been conducted, it is possible to conclude that the Atlas Flycatcher is a species that has a diversified diet, so we think that it can be adapted to different environmental conditions.

The disadvantage of studying bird's diet by analyzing faecal sacs is the advanced state of degradation of prey, only the chitinous parts of the insects remain there, so winged insects and the caterpillars are underestimated in the samples. But this method has the advantage of being non-stressful for the brood and the parents because no individual is taken or touched. As far as possible, it is therefore preferable to combine this method with the neck-collar method to get as close as possible to the food spectrum of this species. The other disadvantage is that sometimes we cannot reach the species level when analyzing certain prey, so it is recommended to use more sensitive methods such as DNA barcoding, which consists of identifying the fragments of degraded DNA that remain in the faecal sacs of birds, to recognise the species that have been consumed (Hebert & Gregory 2005). In perspective to this research, it would be interesting to undertake similar studies on the diet of the Atlas Flycatcher in other humid forests of Algeria, in particular that of Akfadou or Babor which have different habitat characteristics to assess the adaptation of this species to various environmental conditions in North Africa.

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Gut microbiota of Barn Swallow *(Hirundo rustica)* nestlings in Northeast Algeria

Soumia Haddad[1], El-Yamine Guergueb[1], Yassine Nouidjem[3]*, Meriem Rouaiguia[2] & Moussa Houhamdi[2]

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Abstract The intestinal microbiota plays an important role in the digestion of food provided by parents to their hatchlings. Non-pathogenic bacteria in the digestive tract can be significantly beneficial to the host species, while pathogenic bacteria can reduce hatchling survival and lead to a decline in the number of new generation. Microbiological analysis of cloacal microflora of hatchlings revealed a highly diverse microbial load present from hatching until fledging (at 15 days) in Barn Swallow *(Hirundo rustica)*. The intestinal microflora of 15-day-olds was the most diverse, and two groups are dependent on age: CPG and Lactobacilli are mostly present in hatchlings of the second and third ages (10 and 15 days). Our research was conducted to identify certain bacterial species, such as *E. coli*, *Salmonella*, *Pseudomonas*, *Lactobacillus*, *Streptococcus*, and *Staphylococcus*. The presence of most species was related to age, while the presence of *Salmonella* was accidental.

Keywords: Northeastern Algeria, Barn Swallow, cloacal microflora, hatchlings

Összefoglalás A bél mikrobiotája fontos szerepet játszik a szülők által a fiókáknak kínált táplálék megemésztésében. A nem kórokozó baktériumok az emésztőrendszerben jelentős előnyöket nyújthatnak a gazdafajnak, míg a kórokozó baktériumok csökkenthetik a fióka túlélését, és az új generáció egyedszámának csökkenéséhez vezethetnek. Füsti fecske *(Hirundo rustica)* fiókák kloákális mikroflórájának mikrobiológiai elemzése egy rendkívül változatos mikrobiális terhelést mutatott ki a kikeléstől a kirepülésig (15 napig). A 15 napos fiókák bélflórája volt a legváltozatosabb, és két csoport függött az életkortól. A CPG és a *Lactobacillus* főként a második és harmadik életkor kategóriájú fiókákban (10 és 15 naposak) találhatók. Kutatásunk célja az volt, hogy azonosítsuk bizonyos baktériumokat, mint például az *E. coli*, a *Salmonella*, a *Pseudomonas*, a *Lactobacillus*, a *Streptococcus* és a *Staphylococcus*. A legtöbb faj jelenléte összefüggött az életkorral, míg a *Salmonella* jelenléte véletlenszerű volt.

Kulcsszavak: Északkelet-Algéria, fecskefajok, kloákális mikroflóra, fiókák

[1] Laboratoire Valorisation et Conservation des Ecosystèmes Arides (LVCEA), Faculté des Sciences de la Nature et de la Vie et Sciences de la Terre, Université de Ghardaïa, 47000 Ghardaïa, Algeria
[2] Laboratoire Biologie, Eau et Environnement (LBEE), Faculté SNV-STU, Université 8 Mai 1945 Guelma, 401, 24000 Guelma, Algeria
[3] Faculty of Science, University of M'sila P.O. box Ichebilia, 28000 M'sila, Algeria
** corresponding author, e-mail: yacine.nouidjem@univ-msila.dz*

Introduction

Environmental factors, like body mass at fledging (Linden *et al*. 1992), physical conditions, as well as immune competence, are good predictors of individual survival (Møller 2004). The growth of bird species depends on external bioresources, which are fragmented into simple, more easily degradable molecules through the digestive processes (Hooper *et al*. 2002).

In addition to various physical and chemical processes in the digestive tract involved in digestion, a diverse and host-assembled microbiota is of paramount importance for optimal food digestion and, consequently, the nutritional status of hatchlings (Hooper *et al*. 2002). However, pathogenic bacteria can compromise the investment in growth and reduce the likelihood of survival or even kill their hosts (Nuttall 1997, Potti *et al*. 2002).

The migration of certain birds affects the composition of the gastrointestinal tract microbiota, which has a strong environmental component (Lucas & Heeb 2005). Microbial sampling of the cloaca is often considered a good approach to studying the diversity of these microorganisms in the in vivo digestive system, as faces and urine are evacuated at this level (Mead 1997), and microbial cells attached to the intestinal wall make the end of the digestive tract rich and diversified in microbial complexes (Mead 1997).

In this context, we conducted a study aimed to characterize the cultivable cloacal microbiota of Barn Swallow *(Hirundo rustica)* hatchlings nesting in the city of Guelma (Northeast Algeria), through microbial isolation, enumeration and identification.

Material and Methods

Study area

Our study area was located in Guelma province, Northeast Algeria (36°27’40 “N; 7°26’18”’E) at 60 km from the extreme North Algeria at an altitude of 279 m above sea level (Kafi *et al.* 2015), covering an area of 3686.84 km^2, located halfway between the north, the High Plateaus, and the south of the country (Haddad *et al*. 2015). The average annual temperature is 18.7 °C (winter 4.6 °C, summer 36.3 °C) and the mean annual rainfall in the area is 590 mm (Bensouilah & Barrientos 2021).

Sampling method

We studied the cloacal microflora of nestling Barn Swallow *(Hirundo rustica)* nesting in the province of Guelma. Five nests were randomly chosen in three cities (Guelma city, Bouchegouf city and Hammam Debagh city). Guelma city is the capital of the province and it is an urban area, but the others are rural cities with three nestlings each. Samples were collected from hatchlings aged five, ten, and fifteen days. To avoid confusion between chick ages, age was determined using a scale used by McGinn and Clark (1978) *(Table 1)*.

Cloacal samples were collected by swabbing (swab of 5 mm long and 2 mm wide) directly from the cloaca of the nestlings. Then, while observing aseptic conditions, only the cotton

Table 1. Determination of hatchlings age (McGinn & Clark 1978)
1. táblázat A fiókák korának meghatározása (McGinn & Clark 1978)

Age (day)	Determination criterion
First days	Not all eggs have hatched, the hatchlings are blind; the egg tooth is still present on their beaks
4-5 days	The eyes are partly open. Primary and secondary feathers begin to grow
5-6 days	The primary feathers of the tail begin to grow
6 days	The growth of the tarsus slows down. The chicks can be ringed
9 days	The tail feathers have grown
10 days	The growth of the tarsus is almost complete
13 days	Feathers have grown almost all over the body
16 days	Last possible date for ringing
18 days	Capable of flying
20-22 day	The hatchlings leave the nest

of the swab was introduced into 10 ml of appropriate nutrient broth diluted to 10^{-1} (Kyle & Kyle 1993, Lombardo *et al*. 1996).

Clostridia were searched for in the selective VF (Meat-Liver) medium after a heat shock was applied to the samples (at 80 °C for 10 min and then directly transferred to 4°C for 10 min). The resistant forms of these microorganisms, which grow in anaerobiosis at 37±1 °C for 24 h and/or 48 h, give typical colonies that reduce sodium sulphite.

The samples were transported to the laboratory in a cooler (≈4 °C) within a maximum time of 30 minutes (Kyle & Kyle 1993, Lombardo *et al*. 1996). After appropriate dilutions, a volume of 10 ml of the diluted solution was filtered through 45 µm diameter nitrocellulose membranes. These membranes were then placed on selective media *(Table 2)*.

For the examination of bacteria, the samples were incubated for 24 h at 37 °C and yeasts for 72 h at 25 °C. It should be noted that the search for lactobacilli was carried out under anaerobic conditions. After cultivation, the microorganisms were counted and then well isolated and identified based on their enzymatic arsenal and biochemical profiles.

Table 2. Detection of microorganisms in the cloaca of Barn Swallow hatchlings
2. táblázat Mikroorganizmusok kimutatása a füsti fecske fiókák bélcsatornájában

Microorganisms sought	Media used	Dilution
Aerobic bacteria	TSA (Trypticase soy agar)	10^{-4}
Gram-positive cocci	Columbia	10^{-3}
Staphylococci	Chapman	10^{-2}
Gram-negative bacilli	Mac Conkey	10^{-3}
Coliforms	TTC tergitol 7	10^{-3}
Lactobacilli	MRS	10^{-4}
Clostridium	ML (Meat liver agar)	10^{-2}
Yeasts	SAB (Sabouraud agar)	10^{-2}

Data analysis

For presenting the results, the number of microorganisms was multiplied by the dilution factor, and then transformed into log with base 10 (1+n) CFU (colony-forming units) per swab, where "n" is the number of colonies on each filter. This allows us to properly present high numbers of bacteria and also to report negative samples as log with base 10 (1+0) = 0. The results of microbial enumeration were expressed as a percentage of occurrence in the analysed samples and as mean ± standard deviation.

Each nestling was considered as an independent variable in the statistical analysis. The Shannon index, the equitability index, and the species richness were calculated based on the age of the nestlings, and the average of microbial counts for each age group [5 days, 10 days, and 15 days] was calculated before the calculation of the indices. The relationships between the dependent and explanatory variables were assessed using analysis of variance (ANOVA one way).

First, one-way ANOVA was performed to analyse the variation in the number of microorganisms counted as a dependent variable among nestlings. The second analysis aimed to determine whether there was a variation in the number of microorganism species across different ages (5, 10, and 15 days).

Result

Our investigation confirms a fairly significant microbial diversity both quantitatively and qualitatively in the cloaca of Barn Swallow hatchling breeding in the city of Guelma. The one-way ANOVA test showed a highly significant difference in the number of microorganisms counted ($F= 4.3504$, $df = 10$, $P< 0.001$) between nestlings. Therefore, all nestlings possess a more or less individualized microbial flora, they all exhibit unique differences. Practically, all searched microbial genera were isolated and identified in more than 60% of the explored samples, with the complete absence of Clostridium (Anaerobic Sulphate-Reducing bacteria "ASR") in all samples *(Figure 1)*, from nestling hatching to fledging *(Table 3)*.

Gram-positive cocci were the most abundant family, mainly composed of faecal Streptococci (group D) with an average of

Figure 1. Absence of Sulphate-Reducing Anaerobic bacteria "ASR"

1. ábra Szulfátredukáló anaerob baktériumok hiánya „ASR"

Table 3. Main microorganisms isolated from the cloaca of Barn Swallow *(Hirundo rustica)* hatchlings

3. táblázat A füsti fecske fiókák *(Hirundo rustica)* kloákájából izolált fő mikroorganizmusok

Microorganisms detected	**Percentages of positive samples**	**Mean ± standard deviation**	**Most appeared species**
Aerobic bacteria	80%	4.21±1.84	*Pseudomonas* ssp.
***Lactobacillus* spp.**	66.67%	3.94±3.11	*Lactobacillus* ssp.
Gram-negative bacteria	80%	4.39±2.08	*E coli* spp.
Gram-positive bacteria	73.33%	5.24±1.19	*Streptococcus* ssp.
***Staphylococcus* spp.**	93.33%	3.60±1.21	*Staphylococcus aureus*
Yeasts and fungi	66.66%	2.83±2.29	/
***Clostridium* spp.**	0%	0±0	/

Table 4. Estimated ecological indices for the three age groups (5, 10, 15 days)

4. táblázat Becsült ökológiai mutatók a három korcsoportra (5, 10, 15 nap)

Age group of chicks	**Specific richness of microorganisms**	**Shannon index**	**Equitability index**
5 days	8	2.815	0.938
10 days	9	2.901	0.915
15 days	10	3.134	0.944

5.24 (log (n+1) CFU/ml) and a percentage of more than 73% of positive samples, including staphylococci. Gram-negative bacilli followed with an average of 4.21 (log (n+1) CFU/ml) and an occurrence rate of 80%, belonging to the Enterobacteriaceae family, of which coliforms represented the predominant part, namely *E. coli* (the most frequent species) and some simples are positive for *Salmonella* ssp.

Lactobacilli, considered the main protective barrier of intestinal mucosa, were identified in 67% of the samples, as were yeasts, which were present at the same frequency. In each age group, the cloacal flora was very diversified and balanced at the same time *(Table 4)*.

The Shannon index shows a balanced flora in the cloaca of the three age groups, with microbial genera present at very similar frequencies. The most diverse and balanced group is the 15-day-old group, indicating intestinal maturity just before fledging. One-way ANOVA showed that two variables are dependent on age:

1. CGP (Gram-positive cocci) ($F_{1,10}$= 4.400, P= 0.035)
2. Lactobacilli (log(X+1) transformed for processing purposes) ($F_{1,10}$= 6.671, P=0.011)

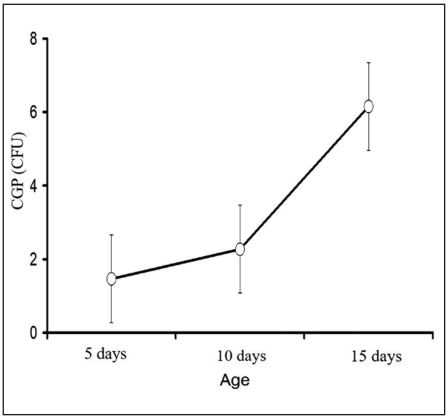

Figure 2. Establishment of Gram-positive cocci (CGP) CFU in the cloaca according to the age

2. ábra A Gram-pozitív cocci (CGP) CFU kialakulása a kloákában az életkor függvényében

For CGP, the post-hoc test (Student-Newman-Keuls) showed that 15-day-old hatchling were the most affected *(Figure 2)*, while for lactobacilli, it was mostly hatchlings of the second and third ages (10 and 15 days) *(Figure 3)*.

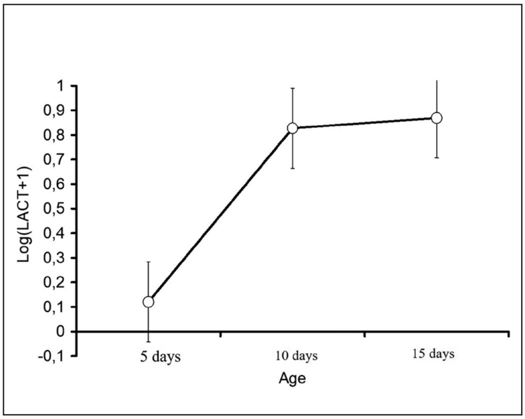

Figure 3. The colonization of lactobacilli in the cloaca according to the age

3. ábra A lactobacillusok kolonizációja a kloákában az életkor szerint

Discussion

In newly hatched chicks, the sudden transition to solid exogenous food is accompanied by allometric growth specific to each portion of the intestine and physiological changes reflecting the maturation of chick digestive capabilities (Quillien & Vidal 2003). The sequence of microbial establishment in the digestive ecosystem ends when a state of equilibrium is established (Savage 1977). In healthy adults, equilibrium is stable unless the environment and diet are altered (Savage 1977, 1987). As with the colonization sequence, the general characteristics of the adult's ecosystem are similar across animal species, and at equilibrium, the microbial species observed in most, if not all, animal species studied are the same. However, each bird's intestinal microbiota is characterized by numerous distinct details. Consequently, the equilibrium state of an adult's intestinal microbial ecosystem is unique.

In the present study, the intestinal microflora of 15-day-old hatchlings reached a specific equilibrium, with the isolated microorganisms, mainly lactobacilli, achieving stability for 10 days after birth, and the presence of other taxa being variable. However, the presence of Gram-positive cocci and conqueror was particularly noticeable at 15 days of age, which may promote a balance between different microbial genera, including Gram-negative bacilli.

The indigenous microbial flora prevents the implantation of pathogenic microbial flora. This phenomenon, called the "barrier effect", is established before the complete maturity of the digestive tube immune system. Thus, lactobacilli exclude coliforms in gnotobiotic animals (Fuller 1977). However, in this study, the effect was much less significant, as was the case in conventional poultry (Watkins & Kratzer 1983), probably due to the presence of other microorganisms that prevent or reduce the action of lactobacilli.

The intestinal microbial flora plays an important role in the digestion of food provided by parents to their hatchlings. Therefore, this flora has a strong environmental component and thus varies between individuals of the same species (Lucas & Heeb 2005). This microflora is also linked to the particular nutritional status (Glünder 1997, Engberg *et al*. 2004) and phenotypic quality of individuals (Moreno *et al*. 2003).

Conclusion

The study of cloacal microflora in hatchlings showed great stability from the first days of life and good defence against pathogenic bacteria. The results obtained from the identification of cloacal simples showed the presence of six bacterial species: *Lactobacillus* spp., faecal Streptococci (group D) and *Staphylococcus* spp. as gram positive cocci. *E. coli* and *Salmonella* as gram negative bacilli, and *Pseudomonas* as an aerobic bacilli. The intestinal microflora of 15-day-old was the more diverse, while some species appeared from the age of 10 days such as *Pseudomonas*, *Staphylococcus* and also affected the 15-day-old category. As for *Salmonella*, its appearance was not related to the age of the individuals we found it with *E coli*, *Streptococcus* and *Lactobacillus* in the first group age of 5 days. It can be said that the appearance and/or disappearance of *Salmonella* is occasional but decrease with age up to 15 days. The diversity of these germs originates from factors that are both extrinsic (environment) and intrinsic (individuals).

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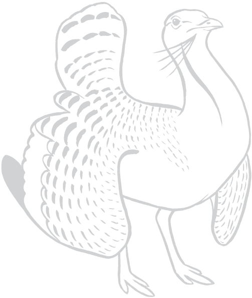

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The White-backed Woodpecker *Dendrocopos leucotos* in Hungary: results of a two-year nationwide survey

Márton Molnár[1]*, Gerard Gorman[2] & András Schmidt[3]

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Abstract This paper summarizes a two-year (2021 and 2022) survey which sought to determine the breeding population of White-backed Woodpecker *(Dendrocopos leucotos)* in Hungary. The survey was initiated by the Hungarian Woodpecker Group of MME/BirdLife Hungary and was the first to be conducted nationwide on this species. All hill ranges where the species was historically known to occur were visited. A total of 31 observers were involved, and 102 UTM squares in which White-backed Woodpeckers were known to breed, or potentially breed, were visited. The results suggest that the Hungarian breeding population of this endangered species ranges between 480 and 800 pairs.

Keywords: White-backed Woodpecker, *Dendrocopos leucotos*, population size, umbrella species, intensive forest management

Összefoglalás A fehérhátú fakopáncs *(Dendrocopos leucotos)* magyarországi állománynagyságának megállapítását célzó két éves (2021–2022) országos felmérés eredményeit összegezzük. A felmérést a Magyar Madártani és Természetvédelmi Egyesület Harkályvédelmi Szakosztálya szervezte. Ez volt a fehérhátú fakopáncs vizsgálatára irányuló első országos léptékű kutatás. Minden olyan régióban zajlott a felmérés, ahol ismert vagy feltételezett volt a faj jelenléte. Összesen 31 önkéntes felmérő vett részt a munkában, amely során 102, 2.5×2.5 km-es UTM négyzetet mértünk fel. Az eredmények alapján e veszélyeztetett faj magyarországi állományát 480–800 költő párra becsüljük.

Kulcsszavak: fehérhátú fakopáncs, *Dendrocopos leucotos,* populáció méret, esernyőfaj, intenzív erdőgazdálkodás

[1] *Coordinator of the White-backed Woodpecker Working Group, Hungarian Woodpecker Group, BirdLife Hungary 1121, Budapest, Költő utca 21., Hungary*
[2] *Independent Picid Researcher, Hungarian Woodpecker Group, BirdLife Hungary 1121, Budapest, Költő utca 21., Hungary*
[3] *Head of Natura 2000 Unit, Department for Nature Conservation, Ministry of Agriculture, 1055 Budapest, Kossuth Lajos tér 11., Hungary*
** corresponding author, e-mail: marcipalkata@gmail.com*

Introduction

The White-backed Woodpecker *Dendrocopos leucotos* is distributed entirely within the Palearctic region. Its range covers three eco-climatic regions: the temperate, Mediterranean and boreal. It occurs from northern Spain and southern France (the Pyrenees) in the west, central Italy (the Abruzzi) and the Balkans in the south, Scandinavia in the north and eastwards through Russia and Asia to Japan (Gorman 2014). The species is polytypic with twelve subspecies recognised (Gill *et al*. 2023). The nominate *D. l. leucotos* occurs in

Hungary. This species has been studied in several countries (although mostly in Europe) and pertinent data from these studies are included in this paper.

The species inhabits a variety of forested habitats across its range, mostly deciduous (Wesołowski 1995, Grangé *et al.* 2002), but also mixed deciduous-coniferous (Fernández & Azkona 1996). In parts of Russia, forests dominated by conifers are sometimes inhabited (Dementiev & Gladkov 1966), but in general, stands of pure conifer, such as plantations of Norway spruce *Picea abies,* are avoided (Hämäläinen *et al.* 2020). White-backed Woodpeckers are strongly associated with stands of mature deciduous trees and deadwood. Numerous studies from different countries have shown that large areas of unmanaged old-growth forest with a high proportion of deadwood, standing and fallen, are typically required for both foraging and breeding (Håland & Ugelvik 1990, Costantini & Melletti 1992, Grangé 1993, Virkkala *et al.* 1993, Hogstad & Stenberg 1994, Bernoni 1995, Mikusiński & Angelstam 1998a, 1998b, Frank 2002, Håpnes 2003, Melletti & Penteriani 2003, Pavelka 2003, Garmendia *et al.* 2006, Czeszczewik 2009, Gerdzhikov *et al.* 2018, Schwaiger & Lauterbach 2019, Urkijo-Letona *et al.* 2020, Bühler 2021). In Hungary, this woodpecker is only found in hill forests (Gorman 2021, Gorman *et al.* 2021), typically where there are native deciduous tree species older than 60–70 years and a minimum volume of 20 m^3/ha of deadwood (Szmorad *et al.* 2018). However, White-backed Woodpeckers also occur in less optimal managed forests in Hungary where there is a close to natural regeneration, with sufficient rotting timber. This is also the case, for example, in Scandinavian forests where management is nominal (Aulén 1988, Aulén & Carlson 1990).

The global population of the White-backed Woodpecker is not precisely known but is considered to be large with most of the population occurring in the eastern part of its range. European populations occupy around 35% of the global range, with a breeding population of 232,000–586,000 pairs estimated (BirdLife International 2023). A preliminary estimate of the total world population size has been made of 1,320,000–3,350,000 adult birds, although validation of this estimate is needed (BirdLife International 2023). The European range is fragmented, particularly in the west of the continent where the species is often very localised and overall trends have often been unclear. Despite some local increases, populations were reported to be declining in several European countries in recent decades, for example in Poland (Wesołowski & Tomiałojć 1986), Sweden (Aulén 1988), Germany (Scherzinger 1990), Norway (Håland & Ugelvik 1990), Finland (Virkkala *et al.* 1993, Martikainen *et al.* 1998), Spain (Fernández & Azkona 1996) and Latvia (Krams 1998). Yet, the overall European trend is now considered to be stable (Lanz *et al.* 2020). The main reasons for the local declines of the species are the loss of old-growth deciduous forests and inappropriate forestry management (Carlson 2000, Håpnes 2003, Sabatini *et al.* 2018). The Red List of the International Union for Conservation of Nature (IUCN) categorises White-backed Woodpecker as *Least Concern* (BirdLife International 2023). Owing to the forest habitat types in which it thrives, the White-backed Woodpecker can be considered an umbrella species, as its occurrence is linked to the presence of many other species (flora, fauna and fungi) of high conservation concern (Roberge *et al.* 2008).

White-backed Woodpecker is the most range-restricted member of the Picidae in Hungary, the only species from the nine that occur to be assigned ‘Strictly Protected Species’ status

(Gorman *et al.* 2021). In Hungary, as elsewhere, intensive forest management, which often involves the introduction of non-native tree species, clear-cutting, fragmentation, felling of mature trees and the removal of deadwood, is a widespread problem (Szmorad *et al.* 2018). For example, in a study of 25 nesting cavities in Hungary, carried out in the Aggtelek, Bükk and Zemplén hills, Gorman (2021) found that all cavities were in dead deciduous trees (snags) or in decaying sections of living trees.

Logging in protected areas, even in the spring during the breeding season, has resulted in a reduction in the number of woodpeckers. Before the survey documented here was conducted, the size of the Hungarian breeding population was estimated to be between 260–670 pairs (Gorman *et al.* 2021).

The survey had two main aims. First, to determine, as precisely as practical, the size of the Hungarian breeding population based on samples from all known subpopulations. Second, to determine the presence or absence of the White-backed Woodpecker in all of the regions where the species was said in the literature to have occurred in recent years, including those places from which it may have later disappeared.

Materials and Methods

Study area

Kőszeg hills

This is the westernmost area of White-backed Woodpecker distribution in Hungary, with an approximate size of 4,400 ha. The nearest population in the country to here is found some 90 km to the east in the Bakony range, hence, within Hungary, Kőszeg can be considered geographically isolated. A large part of the hills is covered by suitable forest, especially beech *(Fagus sylvatica)* stands (Bölöni *et al.* 2011), and a substantial area (4,200 ha) is protected (Kőszegi Tájvédelmi Körzet/Kőszeg Landscape Protection Area).

Bakony hills

The Bakony range is the largest in area of the Transdanubia ranges, covering some 400,000 ha. Thus, we believed that this area had the potential to hold a relatively high population of the species. Although the total area of potential habitat is large, the Bakony is quite isolated owing to the surrounding landscape being mostly open and flat farmland. The climate of these hills is favourable for deciduous tree species, especially beech *(Fagus sylvatica)*, therefore many suitable White-backed Woodpecker habitats are present (Bölöni *et al.* 2011). A substantial part (8,753 ha) of the area is protected (Magas-Bakonyi Tájvédelmi Körzet/Bakony Landscape Protection Area), and thus, it is also favourable for White-backed Woodpeckers as forest management is not overly intensive.

Vértes hills

The Vértes is located to the east of the Bakony hills. We considered the habitats of this area to be suboptimal for White-backed Woodpeckers as there are no large continuous areas of suitable habitat. Although the Vértes is around 31,000 ha in size, stands of mature deciduous trees, particularly beech, only exist in small patches (Bölöni *et al.* 2011). Historically, White-backed Woodpeckers have probably never been common in the area and only a few anecdotal observations have been made in recent decades (Riezing & Gorman 2023). For these reasons, we presumed that the forests here could only support an exceedingly small population, or perhaps no pairs at all. Furthermore, this notion is supported by the fact that the surrounding open habitats mean that the Vértes hills are isolated.

Gerecse hills

The Gerecse is located to the north-east of the Vértes. It can be considered quite isolated as it is mainly surrounded by open habitats except to the south-west where the Vértes hills are located only a few kilometres away. Although the Gerecse is around 85,000 ha in size, favourable forests are found only in isolated patches compared to that of the other regions where stable populations exist (Bölöni *et al.* 2011).

Pilis and Visegrád hills

These hills cover approximately 30,000 ha and include large tracts of suitable beech forests (Bölöni *et al.* 2011). Besides having large suitable habitats, a sizeable proportion of the area is protected (Duna-Ipoly National Park). All in all, the area has the capacity to sustain a remarkable population of White-backed Woodpecker.

Börzsöny hills

The Börzsöny is the westernmost range of Hungary's Northern Hills and covers approximately 60,000 ha. Suitable deciduous forest habitats, particularly with mature beech, are common (Bölöni *et al.* 2011) and a sizeable proportion of the area is protected (Duna-Ipoly National Park).

Karancs-Medves hills

This region is a small, approximately 6,700 ha, area in northern Hungary by the Slovakian border. It is rich in mature beech forests, thus, the capacity to hold a significant population of White-backed Woodpecker exists. A sizeable part of the area is protected (Karancs-Medves Tájvédelmi Körzet/Karancs-Medves Landscape Protection Area). It is also favourable for White-backed Woodpeckers, because forest management is not overly intensive in its protected areas. Furthermore, the population of the species here is not isolated, as there are similar protected habitats close by on the other side of the Hungarian-Slovakian border in a protected area (CHKO Cerová Vrchovina).

Mátra hills

This range of around 90,000 ha is located in the centre of the Northern Hills. Suitable deciduous forest habitats, particularly with mature beech, are widespread and much of the area is protected (Mátrai Tájvédelmi Körzet/Mátra Landscape Protection Area). In addition, the Mátra is favourable for White-backed Woodpeckers, because forest management is not overly intensive in its protected areas. Furthermore, the forests here are not isolated as they are bordered to the north, west and east by other well-forested areas.

Heves-Borsod, Uppony and Putnok hills

In this paper, we discuss these hilly regions together because they are quite similar in their habitats and are adjacent to one another. They are located in the northeast of Hungary and have a combined area of approximately 90,000 ha. They are typified by low average altitudes (300–400 meters) which means that only a few isolated patches of suitable habitat for White-backed Woodpecker exist, usually on northern slopes where there are stands of beech. These hills are surrounded on all sides by other well-forested areas.

Bükk hills

The Bükk is located in the centre of the Northern Hills. Besides being large in size (approximately 100,000 ha), this range also has the largest average altitude in Hungary, with fifty peaks rising above 900 meters. This has resulted in extensive areas of beech forest and hence many suitable habitats for White-backed Woodpecker (Bölöni *et al.* 2011). Thus, one of the largest populations in the country was expected. This expectation was verified by the data in the Hungarian Bird Atlas database. A large area of the range is protected as the Bükki National Park and is connected to other large forest habitats to the north and west.

Aggtelek karst

Aggtelek is located to the north of the Bükk hills and lies on the Slovakian border. It is quite large, approximately 120,000 ha, with many suitable deciduous forest habitats, particularly of mature beech. A sizeable proportion (19,890 ha) of this area is protected by the Aggtelek National Park where forest management is relatively non intensive, and thus, favourable for White-backed Woodpeckers. Aggtelek adjoins the forests of the Slovak Karst protected area, in Slovakia, where extensive suitable habitats for the species also exist.

Zemplén hills

This range is located in the very northeast of Hungary and covers approximately 100,000 ha. Suitable deciduous forest habitats, particularly with mature beech, are widespread (Bölöni *et al.* 2011). The presence of White-backed Woodpeckers in this range is well-known anecdotally, however, no detailed data on the population of the species has ever been published. Nevertheless, on the basis of field observations, a large population was presumed in the Zemplén's forests. The area also adjoins extensive suitable habitats in neighbouring Slovakia. Much of the centre and north of the range is protected as the Zempléni Tájvédelmi Körzet/Zemplén Landscape Protection Area.

Outline of the survey

The methodology used was based on the survey protocol used in the project "Strategic studies to underpin the protection of biological diversity, natural and landscape features" (KEHOP 4.3.0-VEKOP-15-2016-00001) as described in the Bird Atlas of Hungary (Szép *et al.* 2021), with slight adjustments made in order to consider the characteristics of the target species. Sample units were 2.5×2.5 km UTM squares. The UTM squares where White-backed Woodpecker was known to have occurred in recent years were collected for each subpopulation, and surveyors selected the squares to be actually visited. Random selection of squares was not possible as all surveyors were volunteers and the accessibility of squares also had to be considered.

Ideally, a minimum of two surveys were conducted in each selected square, one between 1 March and 20 April, and another between 21 April and 5 June, in the morning hours from dawn to noon. In twenty-six squares, only the first survey was conducted due to a lack of human capacity, and because experience had shown that the first survey period was much more significant in terms of finding the species. During each survey, all parcels of the square (each 2.5×2.5 km UTM square is divided into 25, 500 x 500 m parcels) that potentially held White-backed Woodpecker habitat (parcels covered at least partially by mature, approximately at least 50-year-old deciduous forest based on visual observation and/or Google Maps satellite photos) had to be visited by the surveyor (excluding inaccessible areas, such as fenced areas, restricted access areas, etc.). The two surveys were to be conducted along differing routes, wherever it was possible, and at least one week apart. The aim was to find as many individuals of White-backed Woodpecker as possible and try to establish the number of occupied territories (that is, at least one specimen seen) within the square. The use of playback (of calls and drumming) was allowed as a possibility to increase detection rates, but surveyors' attention was drawn to take care to avoid unnecessary disturbance. The use of playback was not standardised as to instrument or call type used or to spatial distribution of playback use, as the goal was not comparison of detection rate with other surveys, but to achieve as high detection rate as possible while avoiding unnecessary disturbance. All observations (both acoustic and visual) of the species were to be recorded with the following data: date, coordinates and breeding evidence code (the four main categories of which are unlikely, possible, probable and certain) of the Bird Atlas of Hungary project (Szép *et al.* 2021).

After the completion of their surveys, the surveyors were obliged to submit the observation data of the target species, and also an estimate for the minimum number of occupied territories within the square. In some cases, surveyors gave a range for the estimated number of territories (for example, 3–5 territories), in which case the minimum number was used for the calculation of the national population. Surveyors were also asked to upload their data to the online database of the Bird Atlas of Hungary project.

In those regions where the main goal of the survey was to simply determine the presence or absence of the White-backed Woodpecker (such as the Pilis, Visegrád, Gerecse and Vértes hill ranges) the full-scale survey according to the protocol was not obligatory in order to optimise the use of capacities. Rather, the remaining habitats in those areas that were considered to have the highest potential to still hold White-backed Woodpeckers, were to be covered as thoroughly as possible in the breeding season. Nevertheless, eleven squares in these regions were surveyed according to the full protocol.

Methodology for the estimation of the national population and pair densities

Minimum estimation of breeding pairs

The number of occupied territories found within the framework of the survey + the number of further UTM squares in which the species had been seen since 2010 based on the Hungarian

Bird Atlas, assuming that a minimum of one pair still occurred in each of those squares. At the beginning of the survey, it was decided to collect data from the last 10 years because forest management planning works in 10-year cycles in Hungary.

Maximum estimation of breeding pairs

The arithmetic mean of occupied territories within the surveyed UTM squares of each region was multiplied by the number of UTM squares in the given region in which White-backed Woodpecker had been observed since 2010, taking into account habitat suitability of each square in the following way: UTM squares in which more than 75% of the area was considered to be suitable habitat were counted in their entirety (with the arithmetic mean of the observed territories of the surveyed UTM squares). UTM squares in which 25–75% of the area was considered to be suitable habitat were given a factor of 0.5, and UTM squares in which 10–25% of the area was considered to be suitable habitat were counted as holding only one pair.

Habitat unsuitability in the UTMs was estimated from the percentage of open habitats, villages, and other areas based on the map of the Hungarian Bird Atlas. In addition, forest tree species communities were checked from the National Forest Map database (www.erdoterkep.nebih.hu). From this the percentages of unsuitable and suitable habitats were estimated, considering Turkey oak *(Quercus cerris)* woodlands, coniferous stands and black locust *(Robinia pseudoacacia)* plantations as unsuitable habitats for the White-backed Woodpecker. Large clearcuts visible on the satellite map were also omitted from the calculation as unsuitable areas. Area calculations were based on the forest parcel areas provided in the National Forest Map database and using the area gauge function of the database.

Estimation of pair densities and extent of occupied habitats

According to the number of estimated breeding pairs found and the number of surveyed UTM squares, we calculated the average number of breeding pairs in a single UTM in each region. Subsequently, we changed this to a breeding pairs/100 ha of occupied/potential habitat value in order to avoid pitfalls such as multiplying the estimated density with the total area of a region. Using only occupied/potential habitat areas to estimate densities also allowed us to compare densities between the different regions and also with data from other European populations.

In addition, we calculated minimum and maximum densities in each region and the lowest and highest numbers of breeding pairs found in each UTM and changed this to breeding pairs/100 ha of occupied/potential habitat value.

We also estimated the approximate extent of the occupied habitats for White-backed Woodpecker in each region. All squares in which White-backed Woodpecker have been observed since 2010 were considered as occupied.

Finally, the correlation between average density and the approximate extent of occupied habitats was investigated using Microsoft Excel 2013 programme.

Results

According to the Hungarian Bird Atlas database and our survey undertaken in 2021–2022, we found 308 UTM squares in Hungary in which White-backed Woodpecker had been present since 2010 *(Figure 1)*. Breeding evidence is probable in all of these squares except three from the Vértes where we determined that the species is now extirpated (if it ever bred there at all). This decision seemed to be verified by the lack of observations during our survey. In conclusion, we identified 305 UTM squares in Hungary in which White-backed Woodpeckers likely breed.

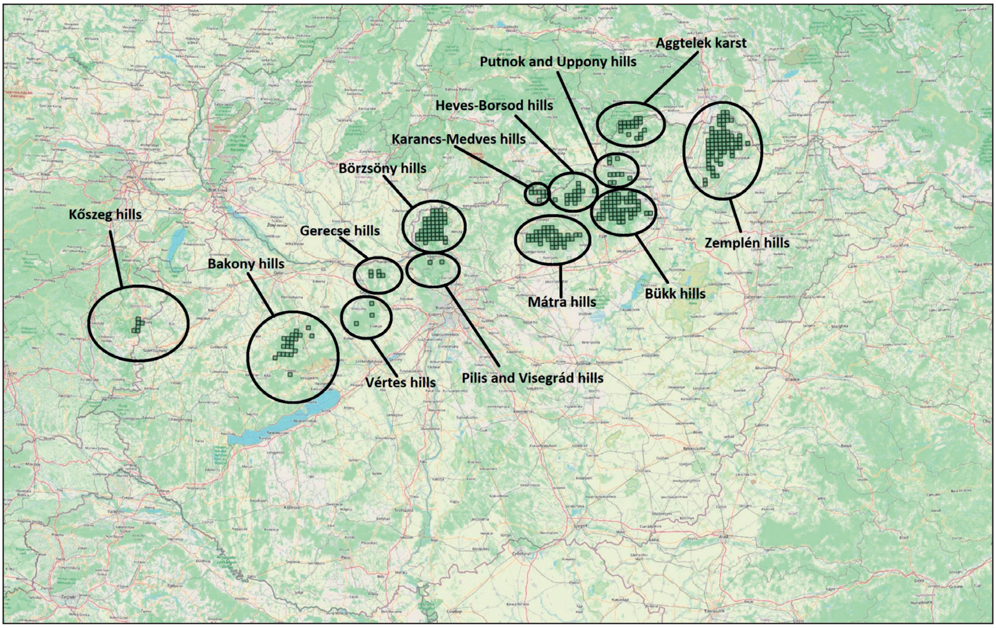

Figure 1. UTM squares by region in which White-backed Woodpecker has been observed since 2010
1. ábra UTM négyzetek régiónként, amelyekben a fehérhátú fakopáncs előfordulása ismert 2010 óta

During the survey, we investigated a total of 85 UTM squares from the 306 in which White-backed Woodpecker certainly breeds *(Figure 2)*. These UTM squares are located in all the regions of Hungary inhabited by the species. We found a total of 267 territories in these squares. A further 17 UTM squares were surveyed in regions from which we had no, or very few, historical observations such as the Vértes, Pilis and Cserhát Hills.

The results of the estimation of the Hungarian White-backed Woodpecker population suggest a breeding size of 480–800 pairs *(Table 1)*. The average density of White-backed Woodpecker in Hungary was estimated at 0.49 breeding pairs/100 ha with a minimum of 0.16 and a maximum of 1.44 breeding pairs/100 ha *(Table 2)*. We found a correlation between the extent of occupied habitat and average breeding pair density *(Figure 3)*. Below we discuss the results from each forested region separately.

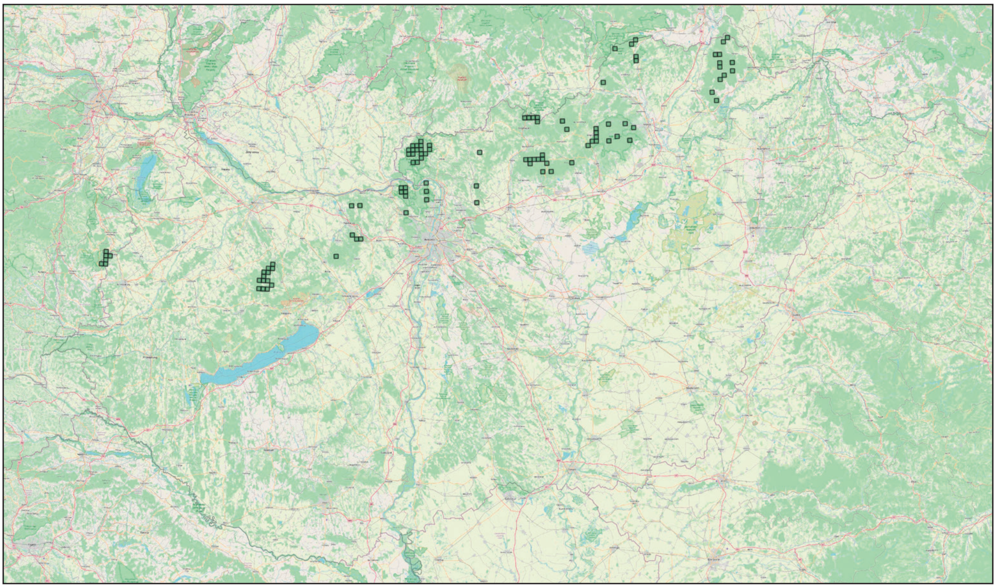

Figure 2. Surveyed UTM squares
2. ábra Felmért UTM négyzetek

Table 1. Estimations of the number of White-backed Woodpecker breeding pairs across Hungary
1. táblázat A magyarországi fehérhátú fakopáncs fészkelő állományok becslése

Region surveyed	**Minimum number of breeding pairs**	**Maximum number of breeding pairs**
Kőszeg hills	16	16
Bakony hills	36	38
Vértes hills	0	0
Gerecse hills	0	5
Pilis and Visegrád hills	0	5
Börzsöny hills	87	129
Karancs-Medves hills	14	16
Mátra hills	69	110
Heves-Borsod, Uppony and Putnok hills	33	47
Bükk hills	85	158
Aggtelek karst	30	47
Zemplén hills	110	229
Total:	**480**	**800**

Table 2. Extent of suitable White-backed Woodpecker habitats and breeding pair densities in the surveyed areas in Hungary

2. táblázat A fehérhátú fakopáncsok számára alkalmas élőhelyek és a felmért területek nagysága régiónként, a költőpárok denzitásával

Region	**Suitable habitat (ha)**	**Surveyed area (ha)**	**Minimum density (pairs/100 ha)**	**Maximum density (pairs/100 ha)**	**Average density (pairs/100 ha)**
Kőszeg hills	3,750	3,750	0.32	0.8	0.43
Bakony hills	13,750	8,125	0.16	0.8	0.33
Vértes hills	–	2,500	–	–	–
Gerecse hills	–	1,250	–	–	–
Pilis and Visegrád hills	–	5,625	–	–	–
Börzsöny hills	30,000	10,625	0.16	1.28	0.54
Karancs-Medves hills	5,625	3,125	0.32	0.32	0.32
Mátra hills	24,375	6,875	0.16	1.28	0.6
Heves-Borsod, Uppony and Putnok hills	16,875	1,875	0.16	0.8	0.48
Bükk hills	35,000	7,00	0.16	1.44	0.53
Aggtelek karst	11,875	3,125	0.16	0.8	0.51
Zemplén hills	45,000	7,500	0.16	1.12	0.67

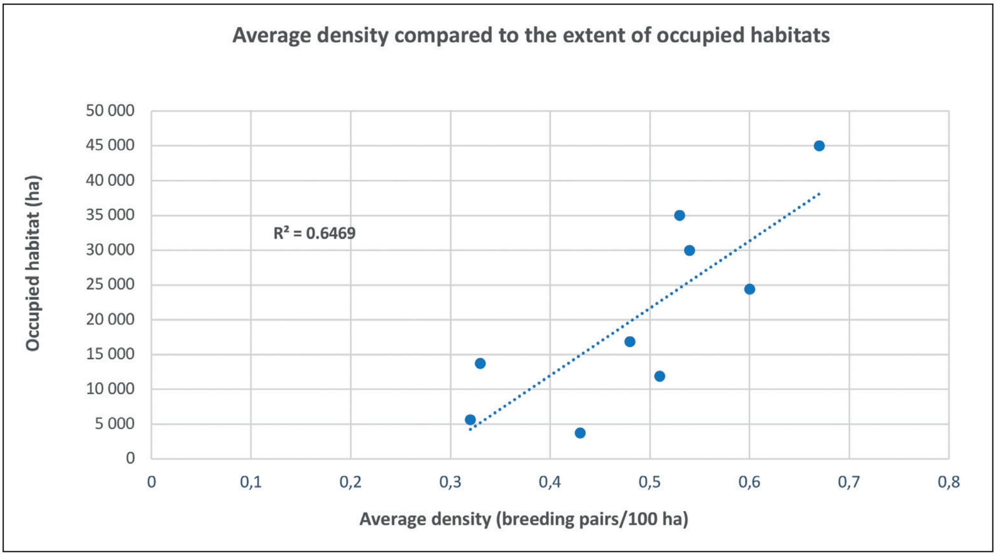

Figure 3. Comparison of the density of White-backed Woodpecker breeding pairs and the extent of occupied habitats in each region

3. ábra A fehérhátú fakopáncs költőpárok denzitásának összefüggése az alkalmas élőhelyek kiterjedésével régiónként

Kőszeg hills

We found 6 UTM squares where the species was likely to breed. All 6 squares were visited, and 16 territories found. Thus, a total of 16 breeding pairs were estimated to reside in this area. Indeed, Kőszeg was the only area where we were able to survey 100% of the potential habitats, and thus, it is likely that the most precise local data of all was from this population. Average density was estimated at 0.43 breeding pairs/100 ha with a minimum of 0.32 and a maximum of 0.8 breeding pairs/100 ha. The extent of occupied habitats was 3,750 ha.

Bakony hills

We identified a total of 22 UTM squares where the species had been seen since 2010. A total of 13 squares were visited and 27 territories found. Taking this data into account, we estimated the average number of pairs in a UTM here to be 2.08. Most of the UTM squares held just 1 or 2 pairs as they were often partly covered by unsuitable habitats. UTM squares at the tops of hills tended to have larger areas of suitable deciduous habitat, mainly beech forests, and hence the highest number of territories (5) was found here.

On the basis of the survey, we estimated a minimum of 36 and a maximum of 38 breeding pairs in this region. Density was estimated at 0.33 breeding pairs/100 ha with a minimum of 0.16 and a maximum of 0.8 breeding pairs/100 ha. 13,750 ha of occupied habitat was determined.

Vértes hills

We found 4 UTM squares where the species had been observed since 2010. A total of 4 UTM squares were visited but no White-backed Woodpeckers were found. We were not able to calculate density and occupied habitat size, owing to the lack of observations.

Gerecse hills

A total of 5 UTM squares were found where the species had been observed since 2010. During the survey, two of these were visited but no White-backed Woodpeckers were found. We were not able to calculate density and occupied habitat size owing to the lack of observations.

Pilis and Visegrád hills

A total of 2 UTM squares were found where the species had been observed since 2010. A total of 9 UTM squares were surveyed, and one adult male White-backed Woodpecker found. We were not able to calculate density and occupied habitat size owing to the low number of observations.

Börzsöny hills

In this region, 47 UTM squares in which the species had been seen since 2010 were identified. A total of 17 UTM squares were surveyed, and 57 White-backed Woodpecker territories were found. The highest number in a single UTM square was 8, which was not surprising owing to the many stands of deciduous forest habitats, particularly with mature beech. The average number of pairs in a UTM was 3.35. Thanks to the high number of participants, the survey in these hills covered a sizeable proportion of the potential White-backed Woodpecker habitat. We estimated a minimum of 87 and a maximum of 129 breeding pairs. Density was estimated at 0.54 breeding pairs/100 ha with a minimum of 0.16 and a maximum of 1.28 breeding pairs/100 ha. 30,000 ha of occupied habitat was determined.

Karancs-Medves hills

In this region, we found 9 UTM squares in which the species had been observed since 2010. During the survey, we visited 5 UTM squares in which 10 White-backed Woodpecker territories were found. The results were the same in all UTM squares surveyed, with 2 territories discovered in each square. Hence, the average number of pairs in a UTM was 2. In this region, we estimated a minimum of 14 and a maximum of 16 breeding pairs. Density was estimated at 0.32 breeding pairs/100 ha. The minimum and the maximum values were the same, and 5,625 ha of occupied habitat was determined.

Mátra hills

A total of 39 UTM squares were found in which the species had been observed since 2010. 11 UTM squares were surveyed, and 41 White-backed Woodpecker territories found. The highest number in a single square was 8. This was most likely due to the extensive mature forest stands in the core area. At the edges of suitable habitat, squares with just 1 or 2 territories were found. The average number of pairs in a UTM was 3.73. According to the results, we estimated a minimum of 69 and a maximum of 110 breeding pairs. Density was estimated at 0.60 breeding pairs/100 ha with a minimum of 0.16 and a maximum of 1.28 breeding pairs/100 ha. 24,375 ha of occupied habitat was determined.

Heves-Borsod, Uppony and Putnok hills

A total of 27 UTM squares were found in which the species had been observed since 2010. During the survey, 3 UTM squares were surveyed and 9 White-backed Woodpecker territories found. The highest number in a single square was 5. One of the squares held a single territory. The average number of pairs in a UTM was 3. In these hills we estimated a minimum of 33 and a maximum of 47 breeding pairs. Density was estimated at 0.48 breeding pairs/100 ha with a minimum of 0.16 and a maximum of 0.8 breeding pairs/100 ha. 16,875 ha of occupied habitat was determined.

Bükk hills

A total of 57 UTM squares were found in the Bükk in which the species had been observed since 2010. 12 UTM squares were surveyed, and 40 territories found. The highest number of territories in a single square was 9. Squares with just 1 or 2 territories were found mainly in forests at the edges of the area. The average number of pairs in a UTM was 3.3. We estimated a minimum of 85 and a maximum of 158 breeding pairs in this heavily forested range. Density was estimated at 0.53 breeding pairs/100 ha with a minimum of 0.16 and a maximum of 1.44 breeding pairs/100 ha. 35,000 ha of occupied habitat was determined.

Aggtelek karst
A total of 19 UTM squares where the species had been seen since 2010 were identified. 5 UTM squares were surveyed, and 16 territories found. The highest number of territories in a single square was 6. Squares with just 1 or 2 territories were also found. The average number of pairs in a UTM was 3.2. In this region, we estimated a minimum of 30 and a maximum of 47 breeding pairs. Density was estimated at 0.51 breeding pairs/100 ha with a minimum of 0.16 and a maximum of 0.8 breeding pairs/100 ha. 11,875 ha of occupied habitat was determined.

Zemplén hills
A total of 72 UTM squares in which the species had been seen since 2010 were identified. This is the highest number of all of the regions surveyed in Hungary. 12 UTM squares were visited, and 50 territories of White-backed Woodpecker found. The highest number in a single square was 7. Squares with only 1 or 2 territories were also found. The average number of pairs in a UTM was 4.16. A minimum of 110 and a maximum of 229 breeding pairs were estimated. Density was estimated at 0.67 breeding pairs/100 ha with a minimum of 0.16 and a maximum of 1.12 breeding pairs/100 ha. 45,000 ha of occupied habitat was determined.

Discussion

Kőszeg hills
The estimations for this area are the most precise from all of the regions surveyed as all potential habitats were visited. However, this is a small and isolated subpopulation with probably no connections to any others in Hungary (the nearest population in the country to here is found some 90 km to the east in the Bakony range) and therefore, can be considered vulnerable. Pair density was found to be lower than the national average in this region, and thus, the population is particularly at risk.

Bakony hills
These estimations are higher than earlier estimations for the area, which were determined during the establishment of the Northern Bakony Natura 2000 site (I1) and suggested 20–30 pairs. This earlier estimation was lower owing to an absence of thorough monitoring. Nevertheless, this subpopulation is small and isolated and therefore can be considered vulnerable. This is also confirmed by the fact that pair density in these hills is significantly lower than the national average, however the extent of occupied habitats is fairly large.

Vértes hills
The results of the survey (no birds found) led us to conclude that the White-backed Woodpecker is extirpated from the Vértes range. Indeed, evidence for this species having ever bred in this area is lacking. Nevertheless, it is possible that wandering individuals may, very occasionally, appear in the region (Riezing & Gorman 2023). To support the chance,

albeit slim, of the "return" of this woodpecker to the Vértes as a breeding species, the overall forest management policy would need to be reevaluated.

Gerecse hills

White-backed Woodpeckers are not known to have ever been common in the Gerecse and additionally very few observations have been reported in recent years. These facts suggested that at best the Gerecse could only sustain a small population of the species, however its total area, approximately 85,000 ha, is large. Being surrounded mainly by open land also means that the area is isolated.

Although no White-backed Woodpeckers were found in this range during surveys, recent observations suggest that a small population may persist. According to the Hungarian Bird Atlas database, breeding was confirmed in 2013 and 2015, and individuals were seen in the breeding season until 2020. In conclusion, we estimated 0–5 breeding pairs in the Gerecse, although further research is needed to clarify the situation.

Pilis and Visegrád hills

Knowledge of the White-backed Woodpecker here is historically scant. Only a few verified observations exist and there are no documented breeding records. Nevertheless, we believed that the paucity of observations did not rule out that a small population of the species could exist, owing to the suitable habitats that are available, and the fact that a fairly large population of 87–158 pairs resides just 10 km away in the Börzsöny range, albeit across the River Danube.

According to the results of the survey, the status of the White-backed Woodpecker in these hills is still unclear. Several areas of suitable habitat were extensively surveyed but no positive results obtained. This suggests that a sizeable population is not present. Indeed, only one individual, an adult male in the Visegrád hills, was found during the survey (Gorman *pers. obs*.). This leads to two scenarios: first, that an exceedingly small breeding population exists; second, that the species does not breed but remnant or vagrant birds occur. In conclusion, we estimated 0–5 breeding pairs for these areas combined, although further research is needed to clarify the situation. In the meantime, to support any potentially remaining small population, the prevailing forest management should be reviewed. Mature forest stands should be preserved, and less intensive practises implemented. Moreover, in those areas of forest where the species was most recently observed, forest management should cease or at least be minimized. Improving the condition of the forests of the Pilis and Visegrád hills is also worthwhile as an important population exists in the nearby Börzsöny range. Although this species is typically sedentary, dispersing individuals could potentially arrive from that area and if that were to occur, may remain if suitable forest habitats are present.

Börzsöny hills

Compared to most of the other ranges surveyed, the Börzsöny hills are well-researched ornithologically. White-backed Woodpecker has been studied here for decades and a fairly large population is known to exist (Schmidt 2000, Selmeczi 2010, Szekeres 2010, 2012).

Our estimation for this area is slightly higher than the earlier official one of 100 pairs, determined during the establishment of the Börzsöny and Visegrád hills Natura 2000 site (I2). The higher number reached probably reflects the more intensive surveying rather than an actual increase in numbers. The significant population size in these hills is complimented by the large extent of occupied habitats and high density of breeding pairs – the third highest of all regions. Therefore, we consider the Börzsöny population to be stable.

The low-intensity forest management practised in protected areas is also favourable for White-backed Woodpeckers. In addition, the forested habitats of the Börzsöny are not totally isolated as they are geographically close to those of the Cserhát, Pilis and Visegrád hills and also to the southernmost forests of central Slovakia.

Karancs-Medves hills

The presence of breeding White-backed Woodpecker in this small region has been known for some time (Drexler 1995, Rozgonyi 2000). Our estimation is slightly higher than the earlier official one which stated 6–12 pairs (Kiss *et al.* 2007). This higher number most probably does not reflect an actual increase in the population, but rather the more intensive surveying conducted. The lowest pair density of all regions was found here and there can be several reasons for this. One is the structure of the landscape: there are large open habitats within the forest. Second, forest management is highly unsuitable. In addition, as the whole area is small, suitable habitat patches are also small, and thus, are prone to being degraded or even totally destroyed. In conclusion, this small population and the small-sized habitats occupied are vulnerable as they are extremely sensitive to human activities. Nevertheless, geographical isolation is not necessarily a serious threat to this population as White-backed Woodpeckers also occur in the forests of neighbouring Slovakia (Kiss *et al.* 2007).

Mátra hills

According to the Hungarian Bird Atlas database and other publications, we presumed that this area would hold one of the largest populations of White-backed Woodpecker in Hungary (Czájlik & Harmos 2000). On the basis of this region's habitat characteristics, it was suspected that this population would be quite large. Our estimation is much higher than the earlier official one of 40–50 breeding pairs, determined during the establishment of the Mátra Natura 2000 site (I3). This considerable difference is a result of the lack of large scale research in the past. The significant population size is combined with a high pair density, the second highest of all regions, and large extent of occupied habitats. In conclusion, this range holds one of the largest populations in Hungary.

Heves-Borsodi, Uppony and Putnok hills

Although the overall combined area is quite large, the territories found are isolated, and thus, the population is vulnerable and threatened. The surveying activity here was the lowest of all areas which resulted in a major difference between the minimum and maximum population estimations. The forested habitat in these hills is very fragmented, and thus, conducting surveys is complex, hence further research is needed to clarify the estimate. The population density in this region is almost the same as the national average, but nevertheless, is very fragmented and vulnerable. This is strengthened by the fact that the size of occupied habitats is also small.

Bükk hills

Surveying activity was low, with only a small proportion of the area covered. This resulted in a significant difference between the minimum and maximum population estimations and further research is therefore needed. Despite this, we found that the size of the White-backed Woodpecker population in the Bükk was slightly larger than the earlier estimation of 80–90 breeding pairs which was determined during the establishment of the Bükk hills Natura 2000 site (I4). The density is close to the national average. Favourable White-backed Woodpecker habitats exist here mainly because of the relatively low intensity of forest management practised in protected areas. In conclusion, this area has much occupied habitat (the second largest in the country) and a significant population of the species which can remain stable over the long term if the appropriate forest management is maintained.

Aggtelek karst

The presence of White-backed Woodpeckers in this hilly area was confirmed several decades ago (Bankovics 1987), but until recently, the population size of the species was still unclear. In 1999, only 3–6 pairs were estimated for the whole area (Horváth *et al.* 1999).

The estimation here is slightly higher than the official estimation of 30 pairs, determined during the establishment of the Aggtelek karst Natura 2000 site (I5). Such a survey of this species had previously never been done in this area which may explain the significant difference between the two estimations. The forest habitats at Aggtelek are connected to adjacent extensive forests in Slovakia and consequently the White-backed Woodpecker population here is not isolated. Thus, this population can probably persist and remain stable in the long term if its habitats are maintained. This is supported by the fact that the population density is a little higher than the national average.

Zemplén hills

Our survey supports the belief that this region holds the largest population of White-backed Woodpecker in Hungary. The figures estimated are significantly higher than the recent official estimation of 51–100 pairs, determined during the establishment of the Zemplén hills, Szerencs hills and Hernád-valley Natura 2000 site (I6). As in other regions, this difference can be explained by the lack of earlier large-scale surveys. The stark contrast between the minimum and maximum numbers is owing to the widespread distribution of White-backed Woodpeckers in this region and by the fact that due to the Zemplén's large size the coverage of our survey was relatively low. Further research is needed in order to enhance the estimation. As this local population is the largest in Hungary, its importance cannot be overstated. Population density and the extent of occupied habitats were both found to be the highest in this region and consequently can most likely remain stable in the long term.

The results of the first nationwide survey of the Hungarian White-backed Woodpecker population suggest an estimated population breeding size of 480–800 pairs. The survey revealed that there are several, most likely stable, populations in the northern ranges of Börzsöny, Aggtelek, Mátra, Bükk and Zemplén. These populations form the bulk of Hungary's total population of this species. Smaller populations also inhabit the adjacent, less extensive and lower Karancs-Medves, Heves-Borsod, Uppony and Putnok hills. In addition, several geographically isolated populations exist in Transdanubia (Visegrád, Gerecse, Bakony and Kőszeg hills). All of Hungary's White-backed Woodpecker populations are vulnerable to changes in their habitats owing to the prevailing and widespread intensive forestry management methods. However, those in Transdanubia are particularly at risk as they are small in size and isolated (Schmidt 2009), which means that immigration into the gene pool is problematic (del Hoyo *et al.* 2020). Such isolated populations are susceptible to decline, as examples from elsewhere in Europe have shown (Aulén & Carlson 1990, Virkkala *et al.* 1993, Carlson 2000, Håpnes 2003). Consequently, decisive conservation action is needed in those areas. General forestry management methods should be reconsidered. Ideally, this would mean ceasing intensive forestry management entirely in areas where White-backed Woodpeckers occur. If this is not possible, then detrimental forestry practise should at least be reduced. For example, mature deciduous stands, especially beech dominated forests older than one hundred years, should not be logged but preserved and deadwood always left in place (Garmendia *et al.* 2006, Roberge *et al.* 2008, Frank 2018). Furthermore, in areas where White-backed Woodpeckers have become scarce, with only a few recent observations of individual birds, such as the Gerecse and Visegrád hills, forest management should be revised and, ideally, ended.

The overall population density of White-backed Woodpecker in Hungary turned out to be low (0.32–0.67) when compared to most other regions in Europe. A study from neighbouring Austria found 1.0–1.28 and 1.5–1.87 pairs/100 ha densities in two different regions of the Northern Limestone Alps (Weiβmar & Pühringer 2015). Here the White-backed Woodpecker occurs in deciduous and mixed forests at altitudes between 400 and 1400 m, mainly between 600 and 1200 m. In the old beech forests of the Central Balkan Range, breeding density is estimated to 1.2 pairs/100 ha (Gerdhzikov 2022). In Slovenia, at Gluha loza SPA, 0.6–0.9 pairs/100 ha density was estimated (Denac & Mihelič 2015). The results led us to two possible explanations. One is that the Hungarian population is an isolated population as the Great Hungarian Plain and connected open habitats are huge barriers for the species (Schmidt 2009). The suitable habitats (mainly beech or mixed forests) do not cover as large, continuous areas as those in higher elevation or northern regions. Such a peripheral population, with smaller suitable habitat sizes, can support pairs only at low densities. The second explanation is that forestry management is too intensive in Hungarian forests which results in suboptimal habitat conditions and subsequently lower densities. Ultimately, it is likely that the low densities of breeding pairs in Hungary is resultant from these two combined factors. Nevertheless, low density values are known from other countries, too. For example, in two areas in Slovenia 0.1–0.2 and 0.4 breeding pairs/100 ha were estimated (Denac & Mihelič 2015). In these cases, the low densities were probably also due to the edge-effect and unsuitable forest management, as in Hungary. In the Spanish Pyrenees a density of 0.38 breeding pairs/100 ha was reported (Fernandez & Azkona 2010).

In our study, we found that there is a correlation between the extent of occupied habitats and pair density. Quite simply, smaller population patches hold White-backed Woodpecker pairs at lower densities. This fact reveals that some subpopulations are particularly at risk. Geographic isolation is apparent in all subpopulations of the Transdanubian region, as well as in some of the northern subpopulations, as these hills are surrounded by open habitats, lowlands or intensively managed forests. This isolation renders them highly vulnerable (Ellegren *et al.* 1999), and as the White-backed Woodpecker is an extremely sedentary species (Schmidt 2009, Kirwan *et al.* 2022), immigration is unlikely. In addition, the small size of inhabited areas and low density of breeding pairs make these populations even more threatened.

In conclusion, the Transdanubian subpopulations and those in the Karancs-Medves, Heves-Borsod, Uppony and Putnok hills, face multiple threats. Thus, significant changes in forest management methods are urgent in these regions.

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The spring migration and distribution of Common Crane *(Grus grus)* in the Carpathian Basin during the late 19th and early 20th centuries

László Bozó[1*], Tibor Csörgő[2] & Zsolt Végvári[3]

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Abstract During the early 21st century, the Carpathian Basin was recognised as one of the world's most important migratory area for the Common Crane, but it is not completely clear, what was its status during the late 19th and early 20th centuries. Between 1897 and 1916, a total of 1487 field observation data were published in the journal Aquila from the Carpathian Basin. Our work analysed the timing of the spring migration, how it differed between years and geographical regions, and how the temperature and geographical variables reported above influenced the timing of the migration. The results show that the migration routes of the species have changed significantly over the last century. During the study period, the migration concentrated in the eastern part of the Carpathian Basin, and was particularly rare in the Great Hungarian Plain. There was on average a two-week difference in the timing of migration between the western and eastern parts and between different years. The start and peak of migration were weeks later than today, and this change is mainly due to the effects of climate change. Geographical factors did not influence the migration of the species, whereas higher air temperatures advanced the timing of the migration.

Keywords: climate change, *Grus grus*, short-distance migration

Összefoglalás A Kárpát-medence a 21. század elején a darvak egyik legfontosabb vonulási útvonala, de nem teljesen világos, hogy mi volt a helyzet a 19. század végén és a 20. század elején. Az Aquila című folyóiratban 1897 és 1916 között összesen 1487 terepi megfigyelési adatot közöltek a fajról a Kárpát-medencéből. Munkánkban azt vizsgáltuk, hogy a tavaszi vonulás időzítése hogyan különbözött akkoriban az egyes évek és földrajzi régiók között, és hogy a különböző hőmérsékleti és földrajzi változók hogyan befolyásolták a vonulás időzítését. Az eredmények azt mutatják, hogy a faj vonulási útvonalai jelentősen megváltoztak az elmúlt évszázadban. A vizsgált időszakban a vonuló madarak a Kárpát-medence keleti részén koncentrálódtak, a Tiszántúlon csak ritkán fordultak elő. A nyugati és keleti részek, valamint a különböző évek között átlagosan kéthetes különbség volt a vonulás időzítésében. A vonulás kezdete és csúcsa hetekkel későbbre esett, mint ma. Ez a változás valószínűleg az éghajlatváltozás hatásainak köszönhető. A földrajzi tényezők nem voltak hatással a faj vonulására, míg a magasabb hőmérséklet egyértelműen korábbi vonuláskezdést eredményezett.

Kulcsszavak: klímaváltozás, *Grus grus*, rövidtávú vonulás

[1] *Eötvös Loránd University, Department of Systematic Zoology and Ecology, 1117 Budapest, Pázmány Péter sétány 1/C, Hungary*
[2] *Eötvös Loránd University, Department of Genetics, 1117 Budapest, Pázmány Péter sétány 1/C, Hungary*
[3] *Institute of Aquatic Ecology, HUN-REN Centre for Ecological Research, 1113 Budapest, Karolina út 29., Hungary*
** corresponding author, e-mail: bozolaszlo91@gmail.com*

Introduction

The Common Crane *(Grus grus)* is a monotypic bird species. Its isolated populations in Turkey, Georgia and Armenia were previously considered a separate subspecies due to morphological differences (Meine & Archibald 1996), although its taxonomic status is still unclear. Its breeding range extends from Northern and Western Europe, through Eastern Europe, Russia, Northern Kazakhstan and Mongolia, to Lake Baikal and the Far East. The southern limit in 2023 of its breeding range within Europe is reached in Northern France, Hungary, Ukraine (Archibald *et al.* 2020). The Baltic Sea region (Sweden, Finland, the Baltic States) and Russia include the central part of its range within Europe, but Germany and Poland also have significant populations (Prange 2005, Schepers 2020).

It is mainly a nesting species of extensive and undisturbed wetlands (Haraszthy 2019). Due to habitat loss and hunting, its population declined in a large part of its European range by the 19th century, and it disappeared as a nesting species from Central Europe (Oláh & Ecsedi 2004, Schepers 2020).

In the Carpathian Basin, it was a regular but rare breeder until the mid-19th century (Schenk 1938a), when it declined and then became extinct as a breeder due to river regulation and draining of marshes (Oláh & Ecsedi 2004, Hadarics & Zalai 2008, Bende 2023). Its last nesting sites were found in the 1940s, and its eggs were found in 1952 (Béczy 1974). In the 21st century, in parallel with its expansion in Central Europe, it has become a nesting species again in Hungary (Kaufman *et al.* 2017, Végvári 2021).

Until the end of the 20th century it was migratory throughout its range, but now wintering areas are shifting further north (Fintha 1993, Végvári 2009, Ojaste *et al.* 2020). Individuals from populations nesting in Western Scandinavia and Central Europe are mostly wintering in Spain and Southern France, while those nesting in Finland, the Baltic and Western Russia migrate through the Carpathian Basin and winter in North Africa and along the Nile (Spina *et al.* 2022).

There is a long tradition of ornithological data collection for scientific purposes in the Carpathian Basin. Between 1894 and 1926, the Hungarian Ornithological Centre set up an extensive observation network covering the whole region. Its task was to record the spring return data of all bird species and send them to the Centre. The raw data were then published annually in the journal Aquila. Schenk (1938a, 1938b) published two short summaries of the species' migration. However, these only outlined the migration of the species. This was the first publication dealing with the migration of the species in the Carpathian Basin, no earlier description is available. The database therefore remains unprocessed in several respects. As we have seen so far, the migration of the species varies almost from decade to decade, it is important to analyse the earliest available data. This was the aim of our present work, and we sought to answer the following questions.

1. Was there a difference in the timing of the species' migration between years?
2. In which region of the Carpathian Basin did the species migrate in the greatest numbers, and were there differences in the timing of migration between regions?
3. Did the geographic location, elevation and temperature of the observation site have an effect on the timing of migration?

Materials and Methods

The original historical data have published in the annual reports of the Hungarian Ornithological Centre (Gaal 1898, Schenk 1899, 1901, 1905, 1906, 1907, 1908, 1909, 1914, 1915, 1916, Vezényi 1902, 1903, 1905, Greschik 1910, Lambrecht 1911, 1912, 1913). The first report was based on data from 1894, while the last one was based on data from 1926 (Bozó 2017). The first three years did not provide enough data, while after 1916 the World War I resulted in the collapse of the observation network, and after 1920, the Carpathian Basin as a geographical unit was divided into several countries. The observers who survived the war sent data in the same way, but the intensity of observation never returned to what it had been before the war. For this reason we decided to process only the data from 1897 to 1916.

Various “identification guides” were prepared for observers to collect data on the more difficult to identify species. Since the Common Crane cannot be confused with any other species, and was known to everyone at the time, there is no uncertainty about the validity of the data. Each observation includes the day of the year, the altitude and coordinates (latitude, longitude) of the observation site. The number of individuals and migration direction were not reported.

We divided the Carpathian Basin into categories of different scales for data processing, so that the 1487 observation data were collected from 11 large regions, 65 smaller administrative units (counties) and 536 settlements *(Table 1, Supplemental material 1)*. This

Table 1. Geographical distribution of the observation data between 1897 and 1916 within the Carpathian Basin. After the number of small regions, we also gave the number of smaller regions where the species was not observed during the study period

1. táblázat Az 1897 és 1916 közötti megfigyelési adatok Kárpát-medencén belüli földrajzi eloszlása. A nagyobb régiókon belüli kisebb régiók esetében zárójelben megadtuk azoknak a kisebb régióknak is a számát, amelyekben nem volt megfigyelése a fajnak

Large region (Recent country)	N. of data	N. of small regions	N. of settlements
Burgenland (Austria)	12	4 (5)	6
S-Transdanubia (Hungary)	9	4 (0)	8
Transylvania (Romania)	635	14 (1)	235
N-Transdanubia (Hungary)	26	6 (0)	13
N-Hungary (Hungary)	8	3 (0)	7
Upper Hungary (Slovakia)	49	6 (3)	28
Croatia	4	2 (12)	3
Transcarpathia (Ukraine)	280	7 (1)	70
Great Hungarian Plain (Hungary)	110	6 (0)	32
Partium (Romania)	272	5 (5)	90
Vojvodina (Serbia)	50	8 (3)	21
unknown	32	–	21

analysis also includes most of the parts of Croatia, as it was also part of the former Kingdom of Hungary. Looking at the data for all species between 1897 and 1916, 26% of the smaller administrative units does not include observations of Common Cranes at all. We have also included these administrative units in *Table 1*. This confirms what we have just said, that it is possible and important to examine the geographical distribution of the data.

We used the median date of the data to describe the start, peak and end of the migration.

Since the species was present in the Carpathian Basin throughout the year at that time, we did not specify a time limit for data collection, but instead used all data from 1 February to 31 May. This allowed us to show the differences between years. Some of the data from May may have overlapped with over-summering and nesting birds, but due to the negligible number of these birds, this did not significantly affect the results.

To analyse the differences in the timing of the migration between years and large regions, we used Kruskal-Wallis test. We tested whether there were any outliers in the number of observations in the regions. The result was, that Transylvania stands out because its sample size is a significant outlier (Mahallanobis distance = 2.57, UCL = 2.12, $p < 0.05$). We found no further outliers after excluding Transylvania. The frequency distribution of the regional sample sizes was significantly different from an exponential distribution before excluding Transylvania and was not significantly different after excluding Transylvania. However, due to insufficient observations in some regions, the timing of migration cannot be compared across regions and years. As there were regions with few observations, we included regions with at least 20 observations (Transylvania, North Transdanubia, Upper Hungary (Slovakia), Transcarpathia, Great Hungarian Plain, Partium, Vojvodina). This threshold was arbitrary, but suitable for calculating a median migration date over the study period. However, all data have been taken into account for comparisons between years, regardless of the region it comes from.

Further, to analyse the effects of year and region on the onset of annual migration waves measured as the median date of the days with reported migrant flocks for each year and region, as the first step we fitted a linear regression on the median migration day as a function of year and region. As the following step, we aimed at investigating the effect of year on the median migration day with a control for regional differences by we fitting a Linear Mixed Model (LMM) on the median migration day as a function of year treating region as random effect term.

We used multiple regression analysis to see if there was a correlation between the geographical location of the smaller geographical units (counties) and the total number of observations over 20 years. We then analysed how different environmental factors (elevation, latitude, longitude) affected the timing of migration. We used general multiple regression analyses to do this. We also investigated the relationship between the mean temperature of the whole period between February and April as well as the mean monthly temperature data and the median date of the migration, using simple linear regression. Elevation data were available for all municipalities, latitude and longitude data were only available at the county scale, and temperature data were only available at the larger regional scale. The source of the temperature data is the annual reports of Kabos Hegyfoky (Hegyfoky 1903, 1905a, 1905b, 1906a, 1906b, 1907, 1908, 1909, 1910, 1911, 1913, 1914, 1915).

Data analysis was performed using PAST 3.14 (Hammer *et al.* 2001).

Results

The median date of migration was on 25 March, based on 20 years of data. The median for the first sightings of the year was 28 February and the median for the last sightings was 26 April. The timing differed significantly between years ($H = 130.8$, $p < 0.001$). The earliest median date of the migration was in 1910 (20 March) and the latest was in 1907 (4 April) *(Figure 1)*. The timing of the onset of migration also differed between larger regions ($H = 67.04$, $p < 0.001$). The arrival of birds was as follows: Vojvodina (15 March), Northern Transdanubia (21 March), Partium (24 March), Upper Hungary (Slovakia) and Transcarpathia (26 March), Great Hungarian Plain (27 March), Transylvania (30 March).

The linear regression fitted on the median migration day as a function of year and region showed that i) the year had a non-significant, albeit advancing trend ($b = -0.1737$, $p = 0.1351$) and ii) the only significant level of the region was exhibited by Vojvodina ($b = -14.3259$, $p \leq 0.0007$). If we removed the records from Vojvodina from the dataset, we

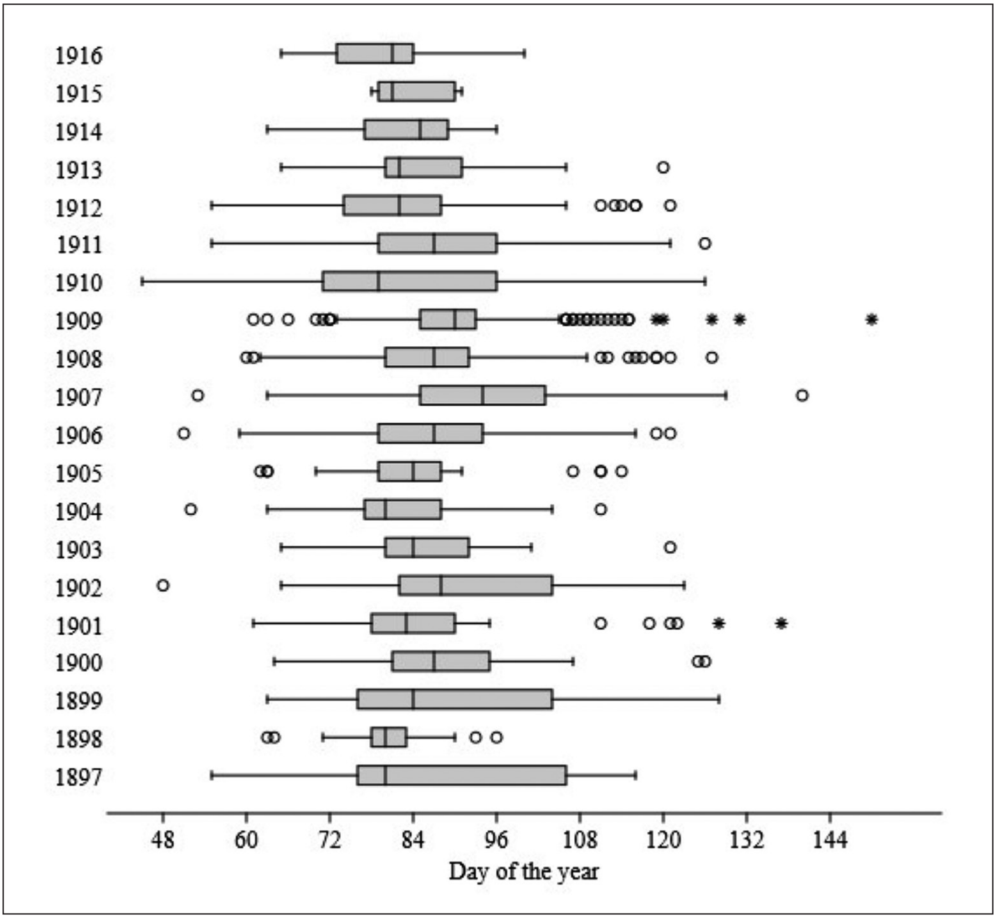

Figure 1. Annual differences in the migration timing of the Common Crane in the Carpathian Basin
1. ábra Évenkénti különbségek a daru Kárpát-medencei vonulásának időzítésében

obtained qualitatively similar data: the onset of migration showed an advancing but non-significant trend with the year (b = -0.2537, p = 0.1013) and the median migration days did not differ among regions ($p \geq 0.1612$).

The LMM fitted on the median migration day as a function of year treating region as random effect term indicated again that the onset of migration non-significantly advanced with years (b = -0.1796, p = 0.219) and region explained only v = 11.20% of the total variance in the variance of the median migration days. The removal of the Vojvodina records from the dataset showed a qualitatively similar pattern: the onset of migration trended to advance with years (b = 0.2704, p = 0.0731).

Elevation ($R^2 = 0.022$, t = 4.285, $p < 0.001$) had a significant positive relationship with day of observation (very weak correlation), while latitude ($R^2 = 0.004$, t = 2.542, p = 0.611) and longitude ($R^2 = 0.007$, t = 0.231, p = 0.817) had no effect on the timing of migration (F = 13.025, $p < 0.001$).

There was no significant correlation between number of observations and latitude of observation ($R^2 = 0.0021$, t = -0.307, p = 0.759), but there was a correlation with longitude ($R^2 = 0.247$, t = 4.505, $p < 0.001$). Most observations occurred in the eastern regions *(Figure 2, Supplemental material 2)*.

Mean temperature between February and April showed a significant negative correlation with migration timing (R = -0.658, p = 0.0016), especially for March (R = -0.564, p = 0.0095).

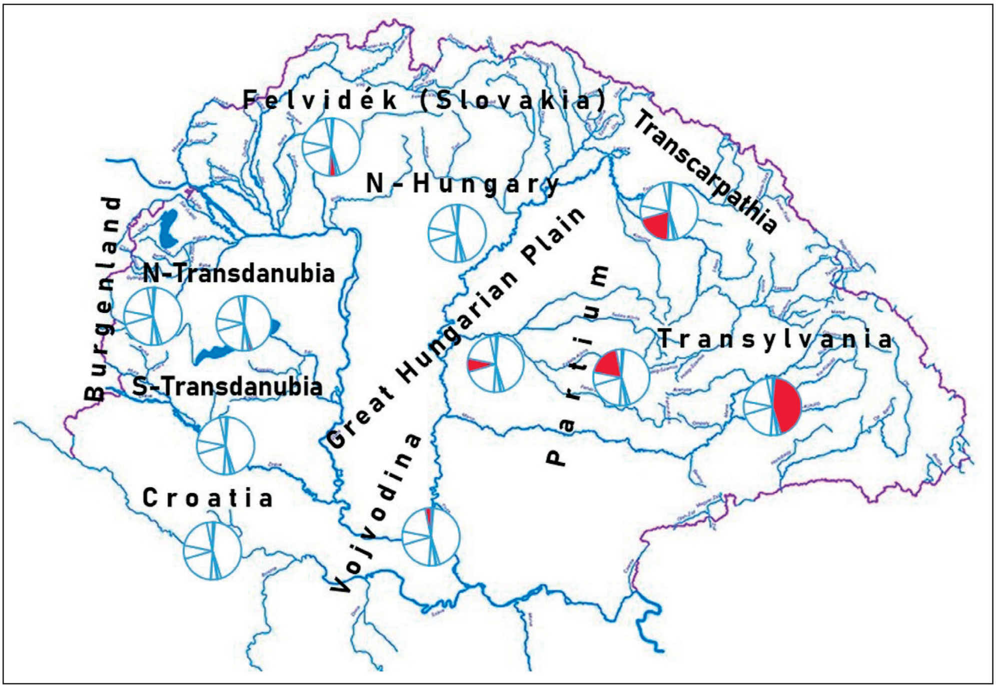

Figure 2. Spatial distribution of the Common Crane observations by large regions. Graphs indicates the rate of the observations at the given region

2. ábra A darumegfigyelések térbeli eloszlása a Kárpát-medencében nagyobb régiónként. A diagrammok a megfigyelések arányát jelzik

Discussion

The migratory behaviour of short-distance migratory bird species is much more flexible than that of long-distance migrants (Calvert *et al.* 2012). This may be due to their ability to adapt more quickly to the effects of climate change. We now know that the timing of migration of many short-distance migratory bird species has changed over the past decades and that these changes have not stopped. In several cases, this has been supported by century-long data series (Sparks 1999, Kullberg *et al.* 2015). Such data series are exceptionally rare, but they provide a much more accurate indication of the extent of change.

The Common Crane is a common migrant throughout the Carpathian Basin (Hadarics & Zalai 2008, Végvári 2009), and is also easily recognisable by the ornithologists. Only in the last two decades, changes were detected in both abundances and routes of birds that would be unimaginable for most species. In this paper, we have analysed data dating back more than a century and the results show that there have been significant changes compared to even before the second half of the 20th century.

The earliest descriptive, non-quantified analyses in the late 1930s pointed to the fact that the migration of the species concentrated in Transylvania (Schenk 1938a, 1938b). Our analyses fully support this finding. It was possible to show that the number of sightings decreased in a west-southwest direction. Considering that there was an extensive observing network in the northern and western parts of the Carpathian Basin, this result is certainly not an artificial one. The role of the Great Hungarian Plain is less clear, as there were far fewer observers. Therefore, it is not possible to say exactly to what extent the Hortobágy, nowadays the most important stopover site in the world for the species, was used by Common Cranes. However, the peripheral area of the Great Hungarian Plain (Partium) was clearly an important migration route. By the first third of the 20th century, these areas were already the most important resting sites for the species (Béczy 1974), but it is possible that they had already played a prominent role in the migration of the species before that time. The areas north, west and south of the Tisza river are clearly outside the migratory range of the species. It was even rare between the lowlands of the Danube-Tisza rivers and was hardly observed in the Transdanubian, Croatian and Burgenland region. The role of the Transdanubian region was not prominent even in the early 2000s (Oláh & Ecsedi 2004), so it is not surprising that it was exceptionally rare there at that time. The data do not provide any insight into where the species' most important spring roosting sites were. The landscape of Central Transylvania is essentially hilly and mountainous, but some major wetland habitats were present in the area both now and then. It is also possible that, as today, they migrated through these regions more quickly and in smaller numbers than in autumn, so that they did not need longer stopover periods (Oláh & Ecsedi 2004). Landscape morphology (at least elevation) may therefore not have had a significant effect on the timing of the species' migration.

The first birds typically arrived in early March, weeks later than today. This practically coincides with the peak of the present-day migration (Végvári 2021), which in the early 20th century and even two decades ago fell at the end of March (Végvári 2009). The last birds departed at the end of April, which is similar to the present trends (Végvári 2009, 2021). In this respect, there is probably no difference because it is difficult to separate the true migrants from the over-summering and nesting individuals. The earlier onset of migration over the last century can certainly be linked to climate change. One of the direct causes is the shortening of migration distances due to increasingly northerly wintering grounds (Nowald *et al.* 2012). This is true not only for Common Cranes but also for other migratory bird species (Ambrosini *et al.* 2011). Although it was non-significant, we found an advancing trend in the onset of migration during the 20 years of the study period, which suggests that the changes of the migration timing of the species already started by that time.

In addition, decreasing rainfall and increasing temperatures may also have an impact through changes in the environmental conditions of resting sites. For this reason, for example, one of the most important stopover sites in Spain had an earlier peak in spring migration of 0.37 days per year between 1973 and 2018 (Orellana Macías *et al.* 2020).

We found a two-week long difference in the timing of the migration between the western and eastern parts of the Carpathian Basin. As the distance between the southwestern and northeastern tips of the Carpathian Basin is about 700 km (www.luftlinie.org), this means that birds may have travelled an average of about 50 km per day during their migration. A similar pattern and difference is observed for the Eurasian Woodcock *(Scolopax rusticola)*, which also has wintering grounds in South-Southwest Europe (Faragó 2009, Bende *et al.* 2023).

There was also a difference of about two weeks in the timing of the migration in different years. Since the air temperature in a given year significantly affected the timing of the migration, it is likely that the difference was caused by weather extremes. They migrated through the Carpathian Basin earlier during mild winters and later during cold winters. Spring migration is in general fast and is determined by not only the air temperature, but also by many weather conditions, such as wind speed and direction, precipitation and cloud cover (Swanberg 1987, Alonso *et al.* 1990a, 1990b, Palm *et al.* 2009). However, these data are not available for the study period, so their impact on migration could not be tested.

The number of migrating birds has also changed significantly over the past decades. While in the early 1980s, the maximum number in autumn in the Hortobágy was less than 10,000 individuals, in the 2010s it reached 160,000 (Végvári 2017) and 195,000 in the autumn of 2023 (Tokody 2024). Unfortunately, in the present study, due to lack of data, it was not possible to compare the historical and recent numbers of Common Cranes.

Overall, the timing of the species' migration is very different from what we see today. The main migration route is hundreds of kilometres further west than in the past and migration route shifts are still occurring in recent time. Different geographical factors have not affected the migration of the species, and this is probably still the case nowadays. In contrast, weather has had a significant effect on the timing of migration, which is typically the case for short-distance migratory species. As the migration of this species changes rapidly, it is important to monitor it, as changes in migration routes and wintering grounds may subsequently affect the population of the species.

Supplemental material 1. Annual number of observations by larger regions
1. függelék A megfigyelések száma nagyobb régiónként

Year	Burgenland	S-Transdanubia	Transylvania	N-Transdanubia	N-Hungary	Upper Hungary (Slovakia)	Croatia	Transcarpathia	Great Hungarian Plain	Partium	Vojvodina
1897	0	0	8	0	0	1	0	5	0	5	0
1898	2	1	8	1	1	5	0	10	4	6	2
1899	0	0	6	3	0	3	0	9	1	6	1
1900	1	1	9	2	0	2	0	8	3	9	1
1901	0	0	13	1	1	2	0	9	1	10	3
1902	0	0	12	1	0	2	0	10	2	3	1
1903	0	0	18	1	0	0	1	8	1	3	1
1904	0	0	11	1	0	1	2	9	1	3	1
1905	2	0	21	1	0	1	0	6	3	8	1
1906	1	2	60	3	1	3	0	22	6	26	1
1907	3	2	85	2	2	7	0	31	17	37	4
1908	1	1	73	3	2	4	0	39	12	38	5
1909	2	2	87	3	0	8	0	36	16	30	8
1910	0	0	63	2	1	4	1	26	14	24	6
1911	0	0	60	1	0	3	0	20	6	24	7
1912	0	0	62	1	0	3	0	18	7	24	4
1913	0	0	25	0	0	0	0	6	5	5	0
1914	0	0	8	0	0	0	0	6	7	4	1
1915	0	0	3	0	0	0	0	1	1	3	0
1916	0	0	3	0	0	0	0	1	3	4	0

Supplemental material 2. Number of observation data by smaller administrative units (counties)
2. függelék A kisebb közigazgatási egységenkénti megfigyelések száma

County	Large region	Number of data
Kovászna	Transylvania	181
Ungvár	Transcarpathia	159
Brassó	Transylvania	109
Arad	Partium	89
Szeben	Transylvania	82
Bihar	Partium	75
Temes	Partium	73
Máramaros	Transylvania	56
Hargita	Transylvania	51
Huszt	Transcarpathia	42
Técső	Transcarpathia	36
Beszterce-Naszód	Transylvania	35
Szabolcs-Szatmár-Bereg	Great Hungarian Plain	35
Hajdú-Bihar	Great Hungarian Plain	28
Beregszász	Transcarpathia	26
Maros	Transylvania	26
Hunyad	Transylvania	24
Kassa	Upper Hungary (Slovakia)	22
Dél-Bánság	Vojvodina	21
Fehér	Transylvania	21
Kolozs	Transylvania	19
Krassó-Szörény	Partium	18
Szatmár	Partium	17
Békés	Great Hungarian Plain	16
Bács-Kiskun	Great Hungarian Plain	15
Csongrád-Csanád	Great Hungarian Plain	15
Komárom-Esztergom	N-Transdanubia	12
Szilágy	Transylvania	12
Mehedinti	Transylvania	10
Rahó	Transcarpathia	9
Bákó	Transylvania	8
Eperjes	Upper Hungary (Slovakia)	7
Nyugat-Bácska	Vojvodina	7
Besztercebánya	Upper Hungary (Slovakia)	6
nagymarton	Burgenland	6

County	Large region	Number of data
Pest	N-Transdanubia	5
Somogy	S-Transdanubia	5
Szerémség	Vojvodina	5
Torontál	Vojvodina	5
Vas	S-Transdanubia	5
Zsolna	Upper Hungary (Slovakia)	5
Borsod-Abaúj-Zemplén	N-Hungary	4
Munkács	Transcarpathia	4
Ökörmező	Transcarpathia	4
Belgrád	Vojvodina	3
Dél-Bácska	Vojvodina	3
Eszék-Baranya	Croatia	3
Felsőőr	Burgenland	3
Nagyszombat	Upper Hungary (Slovakia)	3
Baranya	S-Transdanubia	2
Győr-Moson-Sopron	N-Transdanubia	2
Heves	N-Hungary	2
Kismarton	Burgenland	2
Közép-Bánság	Vojvodina	2
Nógrád	N-Hungary	2
Észak-Bánság	Vojvodina	1
Fejér	N-Transdanubia	1
Jász-Nagykun-Szolnok	Great Hungarian Plain	1
Pozsony	Upper Hungary (Slovakia)	1
Suceava	Transylvania	1
Sziszek-Monoszló	Croatia	1
Szlovénia	Burgenland	1
Tolna	S-Transdanubia	1
Veszprém	N-Transdanubia	1
Zala	S-Transdanubia	1

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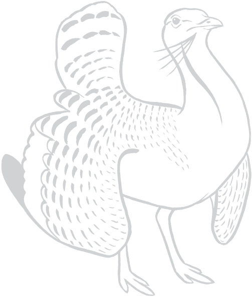

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Additional data to the historical breeding of the Eurasian Woodcock in the Carpathian Basin

László Bozó[1]* & Attila Bende[2]

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Abstract The Eurasian Woodcock is a regular breeder in the wooded areas of the Carpathian Basin. In the past, several literature reviews on the distribution and breeding biology of the species in the Carpathian Basin have been published, but these have ignored the annual reports on spring returns collected between 1894 and 1926 under the coordination of the Hungarian Ornithological Centre. These included 379 nesting records from the present area of Austria, Croatia, Hungary, Romania, Serbia, Slovakia, Slovenia, and Ukraine. The majority of the data came from the Carpathians, with a smaller number from forested areas in the lower mountains and hills. It was particularly rare in lowland areas, with most of the records coming from floodplain forests. The spatial distribution of the data is somewhat at odds with that described in recent summary works. From the Northern Carpathians and the Eastern Alps, however, these sources report fewer nestings, and most of the data come from Transylvania. The temporal distribution of the data is consistent with previously published results. In some cases nestings were found in late February and early March. The peak of nesting was in April, with only a small number of nestings reported in the second half of May. Breeding occurred significantly later in areas at higher altitudes. Nevertheless, it can be concluded that knowledge of the species' nesting in the Carpathian Basin is still incomplete.

Keywords: Austria, Croatia, historical bird observation data, Hungary, nesting, Romania, *Scolopax rusticola*, Serbia, Slovakia, Slovenia, Ukraine

Összefoglalás Az erdei szalonka rendszeres fészkelő a Kárpát-medence erdős vidékein. Az elmúlt évszázadban több szakirodalmi feldolgozás is napvilágot látott a faj kárpát-medencei elterjedésére és költésbiológiájára vonatkozóan, ezek azonban figyelmen kívül hagyták az 1894 és 1926 között a Magyar Ornitológiai Központ koordinálásában gyűjtött tavaszi visszaérkezési adatokat közlő éves jelentéseket, amelyekben 379 fészkelési adatot is említettek Ausztria, Horvátország, Magyarország, Románia, Szerbia, Szlovákia, Szlovénia és Ukrajna mai területéről. Az adatok többsége a Kárpátokból, kisebb része középhegységi és dombvidéki erdős területekről származik. Síkvidéki területeken kifejezetten ritka volt, az ottani adatok többsége ártéri erdőkből ismert. Az adatok térbeli eloszlása némiképp ellentmond az utóbbi évek összefoglaló munkáiban leírtakkal, ugyanis az Északi-Kárpátokból és a Keleti-Alpokból ezek a források kevesebb fészkelésről számolnak be, ellenben a legtöbb adat Erdélyből származik. A fészkelési adatok időbeni eloszlása megegyezik az eddig publikált eredményekkel, néhány esetben február végén és március elején is találtak fészket, de a fészkelések csúcsa áprilisban volt, május második felében pedig már csak kis számban jelezték fészkelését. A tengerszint felett magasabban fekvő területeken szignifikánsan későbbre estek a költések, mint az alacsonyabban fekvő régiókban. Az újabb eredmények mellett is megállapítható, hogy a faj kárpát-medencei fészkeléséről még napjainkban is hiányosak az ismereteink.

Kulcsszavak: Ausztria, fészkelés, Horvátország, Magyarország, Románia, *Scolopax rusticola*, Szerbia, Szlovákia, Szlovénia, történelmi madártani adatatok, Ukrajna

[1] *Eötvös Loránd University, Department of Systematic Zoology and Ecology, 1117 Budapest, Pázmány Péter sétány 1/C, Hungary*
[2] *Institute of Wildlife Biology and Management, University of Sopron, 9400 Sopron, Bajcsy-Zsilinszky út 4. Sopron, Hungary*
** corresponding author, e-mail: bozolaszlo91@gmail.com*

Introduction

The breeding range of the Eurasian Woodcock *(Scolopax rusticola)* extends from Norway, the British Isles, Western France to Northern Spain, and from the Azores, Canary Islands and Madeira eastwards to Hokkaido and Northern Honshu (Van Gils *et al.* 2020). In recent years, it has also been recorded as a breeding species in Iceland and Northern Finland, and has generally expanded eastwards and northwards. In contrast, its distribution has become patchy in the western and southern peripheral areas (Sørensen 2020). Hungary is not a typical nesting area for this species (Bende 2021), but small numbers of nesting records are known from year to year, with a population estimated at only 50–100 'pairs' in 2017–2018 (Hadarics 2021).

Data on the nesting of the species in the Carpathian Basin were first reviewed in detail by Schenk (1943). He published 409 nesting records in a map, mainly from the period between 1908 and 1917. At that time, the Hungarian Ornithological Centre sent out questionnaires to forest authorities to collect spring return and nesting data. As pointed out by the author, the forestry staff were able to access even the most untouched forests, so that the data collection effectively covered the most important potential nesting sites. Unfortunately, he did not provided the database on which the study was based, but according to his own summary, the species nested in the highest numbers in forested areas, which basically covers the mountainous areas of the Carpathian Basin. He also pointed out that the areas around Budapest had a high number of nesting records because the data collection work of the monitoring network was more active there.

The next – and so far the last – analysis of distribution patterns was carried out by Bende (2021) and Bende and László (2020a, 2020b). In their studies, they processed nesting data published between 1846 and 2019, including the data of the map published by Schenk (1943). In the data collection, they treated separately the publications on nests found, chicks and summer roding. In the period 1846–1921, 72% of the nesting records fell in the Northern, Eastern and Southern Carpathians (Romania) and Western Transdanubia (Hungary), while in the period 1921–2019, nesting records were mainly found in the Northern Central Highlands (Hungary) and Transdanubia (Hungary).

Information on the breeding biology of the species was first reviewed by Haraszthy (2019). On the basis of egg collections, publications and personal communications, he concluded that the species breeds typically only once in the present-day area of Hungary, but occasional second broods may occur. The main egg-laying period is in April, but complete broods have been found as early as the first ten days of March, and the first broods may be laid in early June. Broods after early June until August are likely to be second broods.

Bende and László (2020b), based on the ornithological and hunting literature between 1846 and 2019, also found that the breeding of the species is prolonged, but the main period is April – May. Based on the available data, they could not clearly confirm the second breeding either.

These publications were very detailed in reporting the available data, but they did not use all the sources. In Hungary, at the turn of the 19th and 20th centuries, ornithological work was outstanding on a global scale. One of the best examples is the spring bird migration monitoring initiated by Ottó Herman in 1894. Between 1894 and 1926, data on migratory birds in the Carpathian Basin were collected in an organised way during the spring period and published in the form of annual reports. The data collection covered the whole area of the Carpathian Basin, including the entire or part of the present area of Hungary, Slovakia, Ukraine, Romania, Serbia, Croatia, Slovenia and Austria. Each year, thousands of returning records of more than 150 migratory bird species were published, including data on Eurasian Woodcock. Given that a large part of the data was provided by foresters, more observations of Eurasian Woodcocks were published than for most species (nearly 15,000 records), and not only spring return data were published, but often nesting information was also provided. This certainly overlaps with Schenk's (1943) published map, but on closer examination the overlap is not complete. Accordingly, the annual reports also include nesting data that were previously unknown or at least unprocessed. In addition, the exact location and date are also given in these data, which further clarifies the breeding biology of the species within the Carpathian Basin.

The aim of this short communication is to present a detailed account of the nesting data reported in the annual reports, and to compare them with the results of the papers and book chapters published so far.

Material and Methods

The dataset, spanning from the years 1894 to 1926, was collected manually from published annual reports of the Hungarian Ornithological Centre (MOK) (Magyar Ornitológiai Központ 1895, Gaal 1896, 1897, 1898, Schenk 1899, 1901, 1905, 1906, 1907, 1908, 1909, 1914, 1915, 1916, 1919, 1920, 1921, Vezényi 1902, 1903, 1905, Greschik 1910, Lambrecht 1911, 1912, 1913, Hegyfoky 1917, Warga 1922, 1924, 1926, 1928). No information was given by the data providers in these reports as to the stage of nesting at which the birds were found, it was only stated that they were „at the nests". The Carpathian Basin was divided into 11 major regions for the purpose of data processing. We have plotted the temporal distribution of the data and also compared median values of nesting times for Transylvania (Romania) and Upper Hungary (Slovakia) using the Mann-Whitney U test.

We also looked at whether there were differences in breeding timing between lowland (< 200 m a.s.l.), hilly (200–500 m a.s.l.), mountain (500–1500 m a.s.l.) and high mountain (> 1500 m a.s.l.) areas. For this purpose, in addition to the data we collected, we also used the data processed by Bende (2021) from 1863 to 1947 with specific location and date designation from 14 March to 25 May (n = 75). For comparison, we used the Kruskal-Wallis test.

Results

A total of 379 nestings were reported between 1894 and 1926. The data collection was concentrated on the period 1906–1912, from which 98.7% of the data originate. The data come from a total of 269 different settlements. 203 settlements have data from 1, 39 from 2, 18 from 3, 6 from 4, 2–2 from 5 and 6 different years *(Table 1)*. Most data come from

Table 1. The number of data by settlements
1. táblázat Az adatok száma településenként (mennyiségi csökkenő sorrendben)

Location	Data	Location	Data	Location	Data
Köblér (Kiblari)	6	Budatin (Budatín)	1	Nagymaros	1
Torja (Turia)	6	Bustyaháza (Bustino)	1	Nagysomkút (Şomcuta Mare)	1
Szvarin	5	Chizsné (Chyžné)	1	Nagyszeben (Sibiu)	1
Valkó	5	Czeméte (Cemjata)	1	Nagyvárad (Oradea)	1
Gyergyóborszék (Borsec)	4	Csém	1	Németújvár (Güssing)	1
Gyertyánliget (Kobilecka Poljana)	4	Csertés (Certege)	1	Nyárad	1
Karatnavolál (Turia)	4	Csikósgórond (Csikos-Goronda)	1	Nyárádremete (Eremitu)	1
Nagyhalmágy (Hălmagiu)	4	Csíkszentkirály (Sâncrăieni)	1	Nyögér	1
Ökörmező (Mizshirja)	4	Csomorta (Lutoasa)	1	Oása	1
Szikla (Sihla)	4	Csorbató (Štrbské Pleso)	1	Óbozinta	1
Bodzaiszoros	3	Csornarika	1	Óhuta	1
Bulz	3	Darány	1	Ojtoz (Oituz)	1
Dorgos (Dorgoș)	3	Denta (Comuna Denta)	1	Ósáncz	1
Dosz	3	Dipse (Dipşa)	1	Ósva (Olšovany)	1
Élesd (Aleșd)	3	Dobrest (Dobrești)	1	Osztrika	1
Felsőmeczenzéf (Vyšný Medzev)	3	Dobróváralja (Podzámčok)	1	Ótohán (Tohanu Vechi)	1
Görgényüvegcsűr (Glăjărie)	3	Dömös	1	Palánka (Bačka Palanka)	1
Hajdúböszörmény	3	Erdőbénye	1	Parasztdubova (Sedliacka Dubová)	1
Kopacsel (Copăcel)	3	Erdőhorváti	1	Patacskő (Vtáčkovce)	1
Láposmező (Lugi)	3	Erzsébetliget	1	Patkányospuszta	1
Madarasalja (Kľak)	3	Esztelnek (Estelnic)	1	Pécsvárad	1
Márianosztra	3	Fazacsel (Făgețel)	1	Pelyvás (Plevník)	1
Mocsolyás	3	Feketebalog (Čierny Balog)	1	Perhát (Priechod)	1
Ogradina (Eșelnița)	3	Feketevág (Čierny Váh)	1	Petirs	1
Rezsőpart	3	Feketeváros (Purbach am Neusiedler See	1	Pilisszentkereszt	1
Sári (Tajná-Šárovce)	3	Felsőbotfalu (Bzince pod Javorinou)	1	Plasevicza	1
Sebes (Sebeş)	3	Felsődiós (Horné Orešany	1	Poroskő (Poroskovo)	1
Sóskás	3	Felsőszinevér (Szinevirszka Poljana)	1	Pölöske	1
Alsófancsal (Fâncel)	2	Felsőszombatfalva (Sâmbăta de Sus)	1	Prigona	1

Location	Data	Location	Data	Location	Data
Alvincz (Vințu de Jos)	2	Felsővidra (Avram Iancu)	1	Resinár (Rășinari)	1
Apsinecz	2	Felsővisó (Vișeu de Sus)	1	Revisnye (Revišné)	1
Bekényerdő	2	Fenyőháza (Ľubochňa)	1	Románbudák	1
Bikfalva (Bicfalău)	2	Fintvág (Fintoag)	1	Sacza (Šaca)	1
Brusztura (Lopuhiv)	2	Garamberzence (Hronská Breznica)	1	Salgótarján	1
Fehéregyháza (Albești)	2	Garamrudas	1	Sebesváralja (Podhradík)	1
Feketepatak (Čierny Potok)	2	Gömörvég (Gemer)	1	Siter (Șișterea)	1
Felsőapsa (Verhnye Vogyane)	2	Gurahonc (Gurahonț)	1	Solymos	1
Felsővist (Viștea de Sus)	2	Gyergyótölgyes (Tulgheș)	1	Somogyom (Șmig)	1
Garamsálfalva (Šalková)	2	Gyilkostó (Lacu Roșu)	1	Somogyudvarhely	1
Gyergyóbélbor (Bilbor)	2	Gyökeres	1	Sorokpuszta	1
Gyergyóditró (Ditrău)	2	Harangláb (Hărănglab)	1	Sósmező (Poiana Sărată)	1
Gyergyószentmiklós (Gheorgheni)	2	Hátszeg (Hațeg)	1	Stósz (Štós)	1
Hajdúhadház	2	Hédervár	1	Stréza (Cârțișoara)	1
Havasmező (Poienile de sub Munte)	2	Homonna (Humenné)	1	Szakadát	1
Hosszúfalu (Săcele)	2	Hosszúpatak	1	Szalárd (Sălard)	1
Kisbag (Bag)	2	Ipolyság (Šahy)	1	Szászdálya (Daia)	1
Lipót	2	Jászó (Jasov)	1	Szatmárzsadány (Sătmărel)	1
Nagybittse (Bytča)	2	Kallós (Kalište)	1	Székelyvarság (Vărșag)	1
Németlipcse (Partizánska Ľupča)	2	Kálnok (Calnic)	1	Szekszárd	1
Ósánciszoros	2	Kaposvár	1	Szentágota (Agnita)	1
Ozera	2	Kazár	1	Szenterzsébet	1
Párnicza (Párnica)	2	Kelebia (Kelebija)	1	Szentgotthárd	1
Pilisszentlászló	2	Kelecsény	1	Szentmihályfalva (Šarišské Michaľany)	1
Preguz	2	Kelmák (Chelmac)	1	Szeráta	1
Recsk	2	Kéménd	1	Szigetújfalu	1
Sóhát (Csornoholova)	2	Kererhavas	1	Szigetvár	1
Sóslak (Szil)	2	Keresztvár (Teliu)	1	Szkoré	1
Szásznádas (Nadeș)	2	Kisdemeter (Comuna Dumitrița)	1	Szloboda	1
Szil	2	Kisherend	1	Szokolya	1
Tekerőpatak (Valea Strâmbă)	2	Kisterenye	1	Szombathely	1
Teplicska (Liptovská Teplička)	2	Klementka	1	Szomolnok (Smolník)	1

Location	Data	Location	Data	Location	Data
Terebesfehérpatak (Gyilove)	2	Kopács (Kopačevo)	1	Szováta (Sovata)	1
Tömösiszoros (Pasul Timiș)	2	Korbest (Corbești)	1	Teke (Teaca)	1
Vármező (Câmpu Cetății)	2	Kosna	1	Teles	1
Villány	2	Kóspallag	1	Tesmagolvár	1
Znióváralja (Kláštor pod Znievom)	2	Kostéj (Coșteiu)	1	Tesna (Teşna)	1
Aga (Brestovăț)	1	Kovácsfalva (Kováčová)	1	Tjej (Teiu)	1
Ájfalucska (Hačava)	1	Köröshegy	1	Topánfalva (Câmpeni)	1
Alsóhámor (Dolné Hámre)	1	Körösmező (Jaszinya)	1	Tömösvölgy	1
Alsóhunkócz (Choňkovce)	1	Kövesliget (Drahovo)	1	Trencsénpéteri (Petrovice)	1
Alsókomána (Comana de Jos)	1	Lakócsa	1	Turjamező (Turya Polyana)	1
Alsópalojta (Dolné Plachtince)	1	Láposbánya	1	Turjavágás (Turya Pasika)	1
Árok (Jarok)	1	Laposnya (Lăpuşna)	1	Újegyház (Nocrich)	1
Ásvány (Tiszaasvany)	1	Lisza (Lisa)	1	Újmassa	1
Avasfelsőfalu (Negrești-Oaș)	1	Losonc (Lučenec)	1	Újsinka (Șinca Nouă)	1
Bácsordas (Karavukovo)	1	Lövéte (Lueta)	1	Újvidék (Novi Sad)	1
Bakabánya (Pukanec)	1	Luhi	1	Unin (Unín)	1
Bárkány	1	Lunkány	1	Valeamare	1
Berczel (Bercel)	1	Mácsa	1	Varannó (Vranov nad Topľou)	1
Berencsváralja (Podbranč)	1	Magura	1	Vaségető (Železná Breznica)	1
Bobró (Bobrov)	1	Magyarbodza (Întorsura Buzăului)	1	Vaskoh (Vașcău)	1
Bodony	1	Majdánka (Majdan)	1	Veresmart (Roșia)	1
Boldogasszonyfa	1	Maluzsina (Malužiná)	1	Vichodna (Východná)	1
Bolhó	1	Marosnagyvölgy (Valea Mare)	1	Vittencz (Chtelnica)	1
Borosznó (Brusno)	1	Marzsina (Comuna Margina)	1	Vledény (Vlădeni)	1
Borsmonostor (Klostermarienberg)	1	Meczenzéf (Medzev)	1	Vucskómező (Vucskovje)	1
Bős (Gabčíkovo)	1	Mészdorgos (Varnița)	1	Zágon (Zagon)	1
Bráza	1	Mihálytelek (Michalová)	1	Zalatna (Zlatna)	1
Brennbergbánya	1	Nagybocskó (Velikij Bicskiv)	1	Zetelaka (Zetea)	1
Bruckenau (Pişchia)	1	Nagyilva (Ilva Mare)	1		

Table 2. The number and proportion of data by large regions, and the number of settlements within these large regions where nestings were reported

2. táblázat Az adatok száma és százalékos eloszlása nagy régiónként, illetve a nagy régiókon belüli települések száma

Large region	N. of data	Proportion of data	N. of settlements
Burgenland (Austria)	3	0.8	3
South Transdanubia (Hungary)	14	3.7	13
Transylvania (Romania)	130	34.3	91
North Transdanubia (Hungary)	38	10.0	26
North Hungary (Hungary)	17	4.5	13
Upper Hungary (Slovakia)	85	22.4	65
Croatia	1	0.3	1
Transcarpathia (Ukraine)	51	13.5	29
Great Hungarian Plain (Hungary)	5	1.3	2
Partium (Romania)	31	8.1	22
Vojvodina (Serbia)	4	1,1	4

Transylvania (Romania) (n = 130) and the least from Croatia (n = 1) *(Table 2)*. The territory of present-day Hungary accounts for 19.5% of the whole dataset.

The earliest date of reported nesting was on 20 February and the latest was on 25 May. It is important to point out that the survey was primarily aimed at monitoring spring migration, so no data are available for the later period.

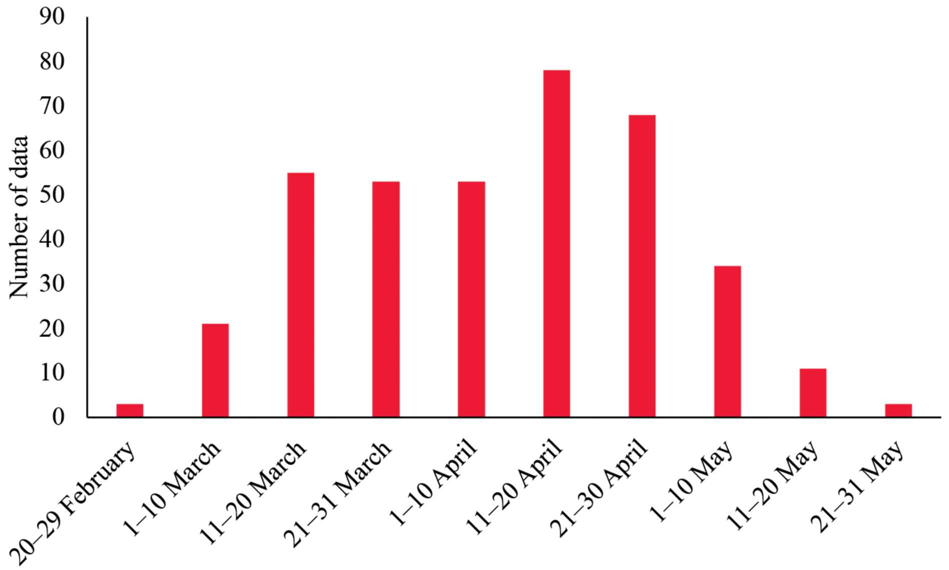

Figure 1. The temporal distribution of the Eurasian Woodcock's breeding data

1. ábra Az erdei szalonka fészkelések időbeni eloszlása

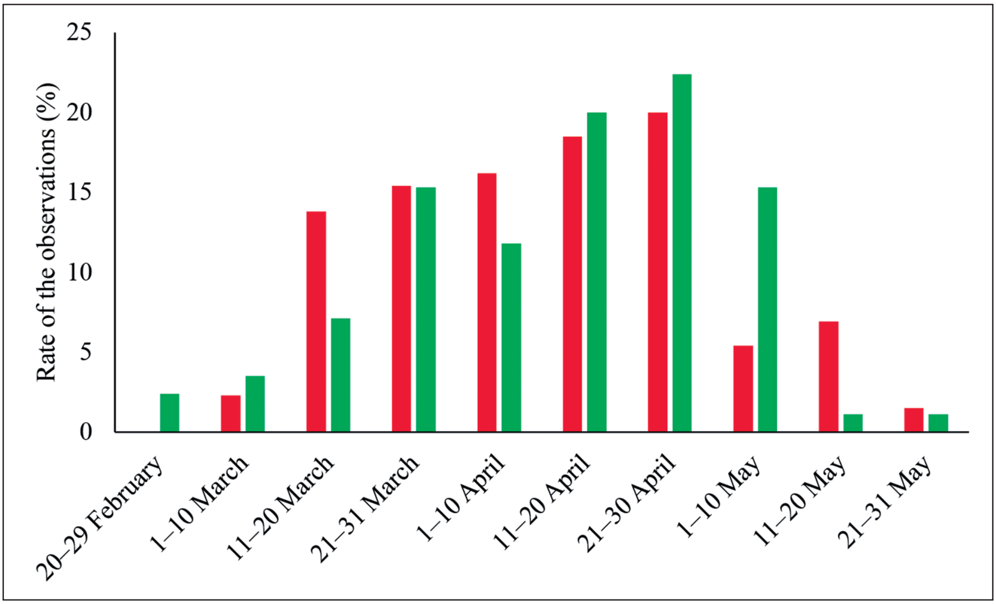

Figure 2. The temporal distribution of the rates of the Eurasian Woodcock's breeding data in Transylvania (Romania) (red bar) and Upper Hungary (Slovakia) (green bar)

2. ábra Az erdélyi (piros) és felvidéki (zöld) fészkelési adatok időbeli százalékos eloszlása

Only three nesting data were reported from the end of February, but the number remained low in the first ten days of March. The month between 11 March and 10 April show roughly the same amount of data, peaking between 11 and 30 April. Relatively high numbers of nestings were still reported in the first ten days of May, but after that the numbers dropped significantly *(Figure 1)*.

There was no significant difference (U = 5140, z = -0.862, p = 0.388) between the data of Transylvania (Romania) and Upper Hungary (Slovakia) *(Figure 2)*.

When examining the spatial distribution of the data, we found that there is a significant temporal shift between nesting data from lower altitudes and higher altitudes (H = 66.49, $p < 0.001$). Our results suggest that the median nesting date in the lowland region was on 4 April (n = 111), in the hilly region on 6 April (n = 160) and 22 April (n = 181) in the lower mountain regions, while we were unable to investigate the question at higher mountains due to low sample size (n = 2).

Discussion

The spatial and temporal distribution of the nesting data we processed also fits well the pattern reported in previous summaries (Schenk 1943, Haraszthy 2019, Bende & László 2020a, 2021). However, some important additions can be made based on the results obtained.

In terms of the spatial distribution of the data, the largest populations of the species were found in the Carpathians, with lower mountain and hilly areas being less frequent. According to Schenk (1943), Bende and László (2020a) and Bende (2021) the Northern Carpathians were also the area with the largest number of records, but this is not supported by the data we have collected. Transylvania (Romania) – and thus the Eastern and Southern Carpathians – may have been a more dominant nesting site than the northern areas. According to the authors of previous studies, the Eastern Alps are not of particular importance for nesting, which is not confirmed by the few nesting records from Burgenland (Austria) and Western Transdanubia (Hungary) in the present study. Both studies mention that the lower forested areas of the Transdanubian region were also suitable for the species, but due to unfavourable climatic and precipitation conditions, no large populations could be established there. The data we have collected are consistent with this. The amount of data from the surroundings of Budapest was not as outstanding as Schenk (1943) reported. Thus, it is likely that the data at that time were in fact so numerous from this region because of the over-representation of the observer network.

It is worth mentioning the lowland nestings. Four nestings were reported from Vojvodina (Serbia) and five from the Great Hungarian Plain (Hungary). In Vojvodina (Serbia), nests were found in Kelebia (Kelebija), Bácsordas (Karavukovo), Újvidék (Novi Sad) and Bácspalánka (Bačka Palanka), while the data from the Great Hungarian Plain (Hungary) come from settlements of the Hajdúság (East Hungary). Schenk's (1943) map probably includes all these records, but the exact settlement names were not known until now. Nesting data from Bácspalánka (Bačka Palanka) were published as early as 1846 (Haraszthy 2015), and suggest that it may have been a regular nesting species in the floodplain forests along the Danube even in the early 1900s. Bende and László (2021) mention nesting of the species in Békés County (Sarkadremete) (Hungary) during the period 1921–2019, but our sources have not mentioned any data from this region. Here, it is worth mentioning an egg collected by Lajos Nemere in 1890 in Székudvar (Socodor) (Romania) (Haraszthy 2015), which provides further evidence for the former nesting of the species along the Körös rivers. These lowland records show that river floodplains were potential nesting site for the species at that time.

The most important result of this data collection regarding the timing of breeding is that nesting could sometimes occur as early as the end of February – beginning of March, but the results clearly show that the main nesting period is April and May. As mentioned above, we do not know at which stage of the nesting period the data providers were referring to. In most cases, the phrase „at the nest" was used, which makes it clear that at least the nest itself was built at the time of observation. Haraszthy (2019) reported the earliest complete brood from 1–10 March (n = 1). However, these were extremely rare, consistent with the results obtained by Haraszthy (2019) and Bende and László (2020b). Nesting was prolonged in the Carpathian Basin, with a peak in April and May, and there was no difference in this between the two regions with the most data. A specific feature of the data set is that there were no data later than the end of May, so we do not have data on second broods. It appears that proportionally far fewer nests were found in the second half of May than in the first half of the month or before. This finding is in line with the results of previous studies (Haraszthy 2019, Bende & László 2020b, Bende 2021).

By examining the relationship between nesting time and the altitude of nesting areas, we found that there is a significant difference in nesting times at higher elevations. We are unable to compare this result with previous data from Hungary, but our finding on the nesting gradient is consistent with the results of a survey in England (Hoodless & Coulson 1998).

Overall, knowledge about the nesting of the species is still incomplete. Accordingly, any sporadic data could contribute to a better understanding of the nesting habits of the Eurasian Woodcock in Hungary and the Carpathian Basin.

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New distribution and breeding location of the Stock Dove *Columba oenas* in Algeria

Mayssara El Bouhissi [1,2], Habib Allah Benhamou [2], Abdelkader Bekkouche [3], Yassine Boulenouar [4], Zouaoui Khacheb [5] & Abdelwahab Chedad [6,7]*

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Abstract Algeria hosts seven species of the Columbidae family, including pigeons and doves, the majority of which have been the subject of numerous studies, but none have been conducted on the Stock Dove *(Columba oenas)*. Data on this species are still scarce, and its distribution is limited only to Kabylie in northern Algeria. Species occurrence data were collected from September 2022 to August 2023 using the point count method. However, the species was recently recorded in several new localities (20 stations) in West Algeria, at Sidi Bel Abbès and Tlemcen. All our observations were made in a semi-arid bioclimatic area at an altitude ranging between 750 and 1,216 m. Nesting sites were located on woodland and forest edges, not far from water sources, and feeding sites were located in open, natural, or agricultural environments where cereal seeds, grasses, flower buds, and young green shoots were consumed. It could also cohabit with other species of pigeons and doves.

Keywords: Columbidae, *Columba oenas*, breeding, range distribution, avifauna, Algeria

Összefoglalás Algériában hét különböző galambfaj él, amelyek többségével számos tanulmány foglalkozott korábban. Kivételt képez ez alól a kék galamb *(Columba oenas)*. Ennek a fajnak szórványos adatai vannak az országból, elterjedési területe az északi országrészben található Kabylie területére korlátozódik. Adatgyűjtés céljából 2022 szeptembere és 2023 augusztusa között végeztünk pontszámlálásokat. A közelmúltban a fajt több új helyen, összesen 20 állomáson észlelték Algéria nyugati részén, Sidi Bel Abbès és Tlemcen környékén. Minden megfigyelésünk félszáraz bioklimatikus területen történt, 750 és 1216 m közötti tengerszint feletti magasságban. A fészkelőhelyek erdőszéleken és erdőkben találhatók, nem messze a vízforrásoktól, a táplálkozóhelyek pedig nyílt, természetes vagy mezőgazdasági környezetben helyezkednek el, ahol a kék galambok gabonamagvakat, füveket, virágrügyeket és fiatal zöld hajtásokat fogyasztanak. Más galambfajokkal is együtt élhet.

Kulcsszavak: Columbidae, *Columba oenas*, fészkelés, elterjedési terület, madárvilág, Algéria

[1] *Laboratory Ecodevelopment of Spaces, University of Djillali Liabes Sidi Bel Abbès, 22000 Sidi Bel Abbès, Algeria*
[2] *Directorate of Forest Conservation of Sidi Bel Abbès (General Directorate of Forestry), 22000 Sidi Bel Abbes, Algeria*
[3] *Independent Naturalist, El Hamadna, 48000 Relizane, Algeria*
[4] *Directorate of Forest Conservation of Relizane (General Directorate of Forestry), 48000 Relizane, Algeria*
[5] *Independent Naturalist, Sidi Bel Abbès, 22000 Sidi Bel Abbès, Algeria*
[6] *Laboratory of Saharan Bio-Resources: Preservation and Valorisation, Ouargla University, 30000, Algeria*
[7] *Directorate of Forest Conservation of Ghardaïa (General Directorate of Forestry), 47000, Algeria*
* *corresponding author, e-mail: agrochedad@yahoo.fr*

Introduction

In the course of evolution, species' ranges have repeatedly contracted and expanded in response to varying environmental conditions (Van der Jeugd *et al.* 2009). The dispersal of birds is linked to major natural phenomena on a geological scale, such as the last glaciation (Blondel 1995), but also to phenomena more limited in time, such as global climate warming in arid environments (Wolf 2000). In spite of this, animals are increasingly being transported beyond their native ranges by human activities and into places where they are alien (Clavero & Garcia-Berthou 2005, Simberloff *et al.* 2013, Blackburn *et al.* 2014). As a result, changes in species distributions are predicted to cause range contractions, alterations in community composition, and increased extinction risk (Thomas *et al.* 2006, Bellard *et al.* 2012).

The movement of organisms is a central process in ecology and evolution, and understanding the selective forces shaping the spatial structure of populations is essential to conservation (Samraoui *et al.* 2023), so that the distribution of species is affected, both in space and time, by environmental, biological, historical, and anthropogenic factors (Lomolino *et al.* 2006). There are two forms of movement in nature: (i) Migration is a form of evolutionary adaptation that allows organisms to undertake a directional and synchronized seasonal movement, either to hunt down fluctuating resources or to escape temporarily unfavorable conditions (Dingle & Drake 2007); (ii) Dispersal is the unidirectional movement of an individual from its native or breeding site; it is also a complex and multidimensional process influencing community structure, population dynamics, and connectivity (Greenwood & Harvey 1982, Levin *et al.* 2003).

The vast area of Algeria, with its diversity of ecosystems, has contributed to plant diversity, which in turn has affected animal biodiversity. In addition to the expansion of scientific research activity, all this has recently led to the addition of many species to the list of Algerian birds, and the announcement of the expansion of the distribution area and also new breeding sites (Chedad *et al.* 2020a, Boulaouad *et al.* 2022, Belakhdar & Chedad 2023). Birds are regarded as bioindicators due to the fact that variations in their population size, behavior, and capacity to reproduce reflect the health of the ecosystem (Harisha & Hosetti 2009, Schrag *et al.* 2009, Zhang & Ma 2011, Egwumah *et al.* 2017, Kurniawan & Arifianto 2017).

There are 352 species of the family Columbidae (regrouped pigeons and doves) that are distributed across most continents (Gill *et al.* 2023). Algeria has recorded seven nesting species, with a distribution between sedentary and migratory: (i) the Rock Dove *(Columba livia)* is considered one of the most commonly distributed species, with several subspecies (Isenmann & Moali 2000); (ii) the Eurasian Collared Dove *(Streptopelia decaocto)* was first observed in northeast Annaba in 1994, and it is considered a very common invasive species (Benyacoub 1998, Isenmann & Moali 2000); (iii) the Laughing Dove *(Spilopelia senegalensis)* has long been confined to the oases of the northeast and east of the country; subsequently, the species extended its range to the west and south in the mid-1960s (Isenmann & Moali 2000); (iv) the European Turtle Dove *(Streptopelia turtur)* is a summer nesting bird throughout the northern gate of the country and is resident practically everywhere in the Sahara region at Hoggar, Tassili, Ménéa, Tindouf, Timimoun and Adrar (Isenmann & Moali 2000, Chedad *et al.* 2020b, Mansouri *et al.* 2022); (v) the Common Wood Pigeon *(Columba palumbus)* is a common resident in Algerian forests, and its populations have increased significantly in previous years (Isenmann & Moali 2000); (vi) the Namaqua Dove *(Oena capensis)* is a sedentary breeding species in the extreme south at Tamanrasset, In Guezzam and Bordj Badji Mokhtar (Isenmann & Moali 2000, Haddad *et al.* 2023); (vii) lastly, the distribution of Stock Dove *(Columba oenas)* is restricted to a specific region in Kabylie in northern Algeria (Isenmann & Moali 2000).

Globally, the Stock Dove is a wild species once found throughout Eurasia and North Africa, while their number of individuals has increased recently (1,400,000–2,600,000) (BirdLife International 2016, Anselin 2020). It is rarely observed in urban areas (Floigl *et al.* 2022), and typically inhabits deciduous forests, farmland, and woodland margins, particularly in the Western Palearctic (BirdLife International 2016, Donegan 2016, Richardson *et al.* 2023). It is capable of breeding in holes excavated by the Black Woodpecker *(Dryocopus martius)* (Kozhova *et al.* 2014), and it is categorized as a species of least concern (LC) on the IUCN Red List of threatened species (BirdLife International 2016, Donegan 2016). But nationally, the latter is protected by Algerian fiat (12-235) in relation to executive fiat 12-235 of 24 May 2012, establishing the list of protected non-domestic animal species. Their distribution is limited only to North Algeria in Kabylie at Djebel Babor, Tigzirt, and Tikjda, with a dubious observation in the south at Tilremt Daïas in Laghouat (probably confusion with Rock Dove) (Isenmann & Moali 2000).

In Algeria, several species of the Columbidae family have taken part in numerous studies, notably on reproduction, distribution, expansion, parasites, and others, but it should be remembered that there have been no studies on the Stock Dove except for a few mentions in Heim de Balsac and Mayaud (1962), Ledant *et al.* (1981), Isenmann and Moali (2000). The current study aimed to fill scientific gaps, document the presence of Stock Doves in new localities with new breeding sites in western Algeria and locations outside the known range, update the map of the national range area and provide an overview of this species' ecology.

Materials and Methods

Study areas

This study was carried out in two departments (Sidi Bel Abbès and Tlemcen), located in West Algeria. The arid bioclimate of these areas is characterized by an annual precipitation of below 50–250 mm. These regions are ecologically significant due to the diversity of ecosystems and their presence on migration routes, which has resulted in important avifaunistic biodiversity. More precisely, they are host to several species of migratory waterbirds and land birds, which makes them an important nesting and wintering area (El Bouhissi *et al.* 2021, 2023).

Data collection

In order to make an updated distribution map of the Stock Dove in Algeria, with a focus on Sidi Bel Abbès and Tlemcen, species occurrence data were collected from September 2022 to August 2023 using the Progressive Frequency Sampling *(Echantillonnage Fréquentielle Progressif "EFP")* method, which is a point count technique (see details in Blondel 1975, Bendjoudi *et al.* 2013, Chedad *et al.* 2021a). Species occurrence data from the current study was supplemented by additional occurrence data from GBIF 2023 (www.gbif.org), as well as from previous studies (Heim de Balsac & Mayaud 1962, Ledant *et al.* 1981, Isenmann & Moali 2000). Counts were undertaken by direct observation using a Nikon Coolpix P600 on a regular basis, with monthly surveys reinforced with additional surveys, especially during the main postnuptial (September and October) and prenuptial (March and April) bird migration seasons in various biotopes (Chedad *et al.* 2021b). ArcGIS (version 10.4 for Desktop: Esri®) was used to produce species distribution maps.

Results

Throughout the various seasons from September 2022 to August 2023, the Stock Dove has been spotted multiple times in Sidi Bel Abbès and Tlemcen; all our observations were reported on a semi-arid bioclimatic at an altitude ranging between 750 and 1,216 m *(Table 1, Figure 1)*.

Table. 1. Range distribution of the Stock Dove in Algeria
1. táblázat A kék galamb állományának eloszlása Algériában

References	Department	Sectors	Number of stations	Altitude (m)	Bioclimatic stage	Max. Obs.	Date	Ph. St.
Current study	Sidi Bel Abbès	Merine, Dhaya, Oued Taourira, Bir El Hammam, Tafissour, Telagh and Mezaourou	19	750–1216	Semi-arid	19	27/01/2023	RB
	Tlemcen	El Gor	1	1150	Semi-arid	37	21/01/2022	U
GBIF	Sétif	Serdj El Ghoul, Djbel Babor, Oued El Bared, Aïn Sebt, Hammam Guergour	10	685–1996	Subhumid/ Semi-arid	4	08/07/2021	RB
	Jijel	Selma Ben Ziada	1	614	Humid	NI	08/07/2021	U
Isenmann & Moali 2000	Sétif	Djbel Babor	1	939	Subhumid	NI	NI	RB
	Béjaïa	NI	1	48	Humid	NI	NI	RB
	Tizi Ouzou	Tigzirt	1	471	Subhumid	NI	13/4/1962	W
	Bouira	El Asnam	1	1435	Subhumid	10	25-26/10/1981	W

Max. Obs.: Maximum observed; Ph. St.: Phenological status (RB: resident breeder, W: wintering, U: status uncertain); NI: unidentified

In Sidi Bel Abbès, this species has been spotted at 20 stations in seven distinct sectors: Merine, Dhaya, Oued Taourira, Bir El Hammam, Tafissour, Telagh, and Mezaourou *(Figure 2b, 4)*. All observations were recorded at different seasons, and the number of individuals ranged from 1 to 19; the highest number was recorded on 27 January 2023. Individuals were typically observed in groups of 2–4, and occasionally in flocks of 12–19. It preferred woodland and forest edges (Aleppo pine *Pinus halepensis*, evergreen oak *Quercus ilex*, barbary thuja *Tetraclinis articulata*, Mediterranean cypress *Cupressus sempervirens* and silver poplar *Populus alba*) and was often observed feeding on open areas such as farmlands *(Figure 2b, 3a)*.

Additionally, there have been reports of a propensity for the species to reproduce; at the start of April, we observed the formation of couples and multiple males that were singing. Additionally, we discovered a number of holes in old evergreen oak trees, which are supposed to have nests, especially since every time we found several individuals near them. Following this, we obtained photographic evidence of the species' reproduction, specifically capturing an immature specimen at the late of August *(Figure 3b)*.

In Tlemcen, we have only observed the species at one site in the El Gor in all seasons, but there was no evidence of nesting *(Figure 2a)*. It often existed in colonies of 20 to 37

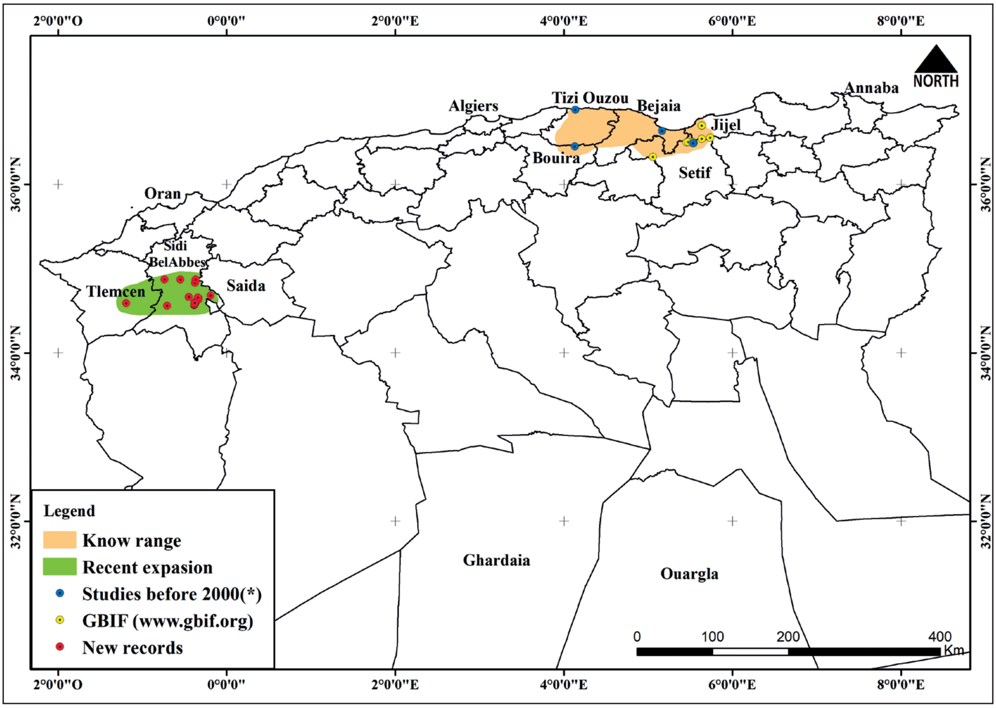

Figure 1. Map showing previous and updated distributions of the Stock Dove *(Columba oenas)* in Algeria. *: previous studies before 2000 included Heim de Balsac & Mayaud (1962), Ledant *et al.* (1981) and Isenmann and Moali (2000)

1. ábra A kék galamb *(Columba oenas)* elterjedése Algériában korábbi és újabb adatok alapján *: korábbi tanulmányok 2000 előtt: Heim de Balsac & Mayaud (1962), Ledant *et al.* (1981) és Isenmann and Moali (2000)

Figure 2. General view of the biotope preferable for the Stock Dove *(Columba oenas)*; a: El-Gor (Tlemcen, Algeria); b: Bir El Hammam (Sidi Bel Abbès, Algeria)
2. ábra A kék galamb *(Columba oenas)* által preferált élőhely; a: El-Gor (Tlemcen, Algéria); b: Bir El Hammam (Sidi Bel Abbès ons, Algéria)

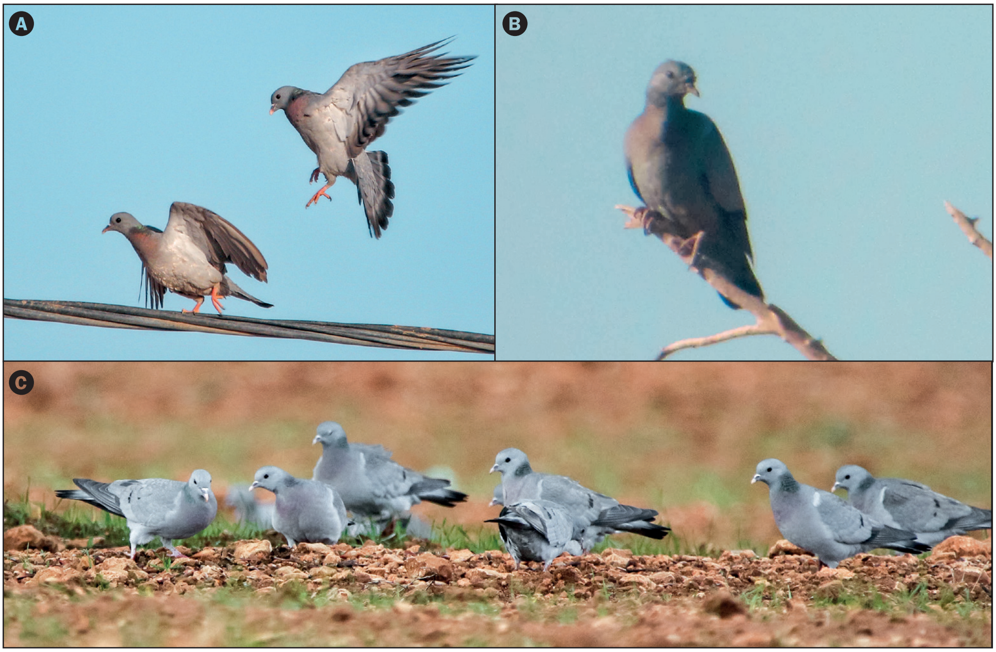

Figure 3. Stock Doves *(Columba oenas)* in their natural environment; a: a couple; b: an immature individual; c: a flock feeding in a ploughed field
3. ábra Kék galambok *(Columba oenas)* természetes környezetükben; a: egy pár; b: immatur példány; c: mezőgazdasági területen táplálkozó csapat

individuals; the highest number was recorded on 21 January 2023 *(Figure 3c)*. It frequented an agricultural area adjacent to a sparse evergreen oak forest.

Generally, the species fed in mixed colonies with Common Wood Pigeons, Eurasian Collared Doves, and occasionally Rock Dove and European Turtle Doves.

It fed on the ground in open environments, whether natural, such as meadows and fallows, or artificial, like agricultural fields. It consumed seeds of cereals and grasses, flower buds, young green shoots, etc., according to the seasons, and was also interested in the lost parts

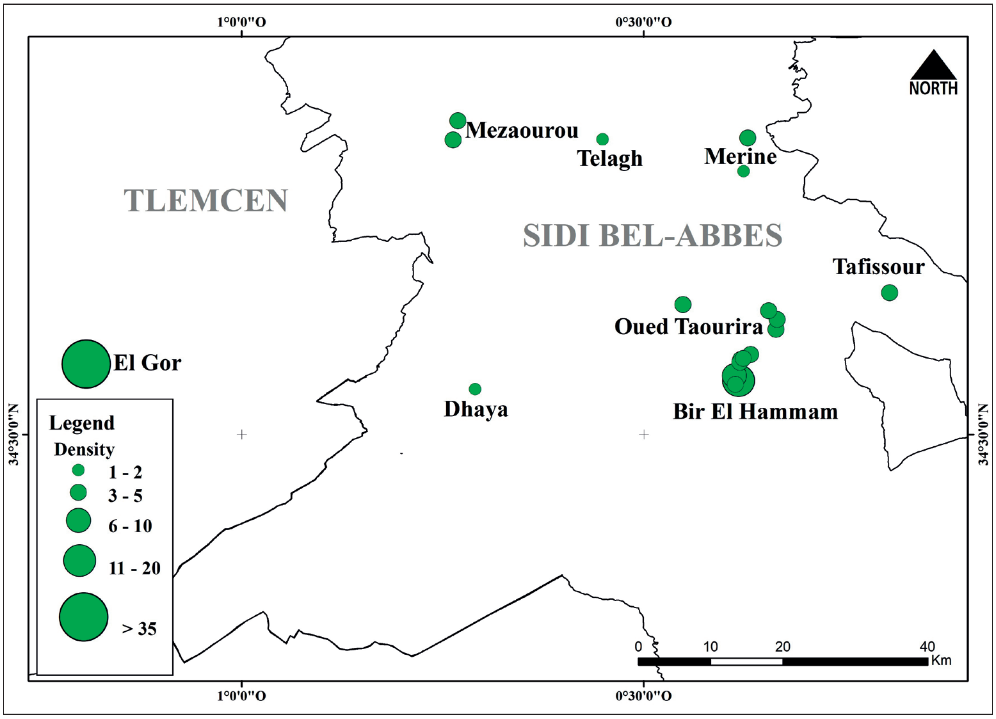

Figure 4. Geographic location of sites where the Stock Dove *(Columba oenas)* was newly recorded in Algeria

4. ábra Azon területek földrajzi elhelyezkedése Algérián belül, ahol újonnan észleltük a kék galambot *(Columba oenas)*

of harvests (wheat, barley, alfalfa, and legumes in general). During periods of repose, they congregated primarily atop old trees and over medium-voltage cables, and in all areas of their presence, they were in close proximity to water sources.

Although most of the Stock Dove sightings in both Sidi Bel Abbès and Tlemcen have been recorded in state forests, which fall under the authority of the Directorate of Forest Conservation (General Directorate of Forestry) of the Ministry of Agriculture and Rural Development, they were exposed to many natural and anthropogenic threats, including fires, overgrazing, logging, diseases, and the scarcity of rains. In addition to all the above, nomads and military barracks are distributed on the edge of the forest, which prevents access to extended areas.

Discussion

Species distribution and phenological status

Our results show new information about the distribution of the Stock Dove in western Algeria in Tlemcen and Sidi Bel Abbès, which is spread out over 20 stations in a semi-arid bioclimatic stage at an altitude of 750 to 1,216 m. This distribution has not been talked about in these areas before, but nomads have said that this species has been there since the 1980s at Oued Taourira. Moreover, it was only found in Kabylie at Tizi Ouzou, Béjaïa, Jijel, Bouira, and Sétif, at 15 stations with different bioclimatic stages ranging from humid to subhumid and altitudes from 48 to 1,996 m (Isenmann & Moali 2000, GBIF 2023). We conclude that the distribution of this species is limited only to two distinct areas; the distance between them is more than 400 km, the first to the north in Kabylie and the other to the west at Tlemcen and Sidi Bel Abbès. It should also be noted that all the regions adjacent to the new distribution locations have been the subject of periodic surveys (Oran, Saida, Relizane, Tiaret, and Tissemsilt), but we have not recorded the presence of this species.

The number of individuals differs from region to region and season to season, with the greatest number recorded during the wintering period: 19 individuals in Sidi Bel Abbès and 37 in Tlemcen in January 2023. In the study area, the phenological status is resident breeder because we found several nesting clues, such as the formation of pairs, singing males, several holes in the trees, and a young. Isenmann and Moali (2000) also reported the species and likely nesting in northern Algeria in June 1977, July 1982, and, between 1989 and 1991, in Djbel Babor (Sétif) and elsewhere in little Kabylie (Béjaïa).

The winter increase in the number of birds can be attributed to the presence of resident populations that are supplemented by migrant birds for the duration of the season. This is particularly significant given that this area is considered an essential stopover site for migrating birds and an important wintering and breeding ground (El Bouhissi *et al.* 2021, 2023). As is the case with the Kabylie region, where its population increases significantly during the winter months (Isenmann & Moali 2000). Alternatively, it could be due to the fact that this species congregates during the winter and then disperses to neighboring regions during the breeding season (partial migration). Numerous avian species, such as the Trumpeter Finch *(Bucanetes githagineus)* and House Bunting *(Emberiza sahari)*, use this behavior as a balancing mechanism for searching for other food and water sources as well as nesting areas (Chedad 2021, Chedad *et al.* 2021a).

Living environment

We have found that the life of the Stock Dove is divided between two areas that can be adjacent to each other or separated and distant from each other: (I) nesting and roosting sites, often in woodland and forest edges (Aleppo pine, evergreen oak, barbary thuja, Mediterranean cypress, and Silver poplar); and (ii) earnings sites that form open areas such as farmlands and clearings. But this species is not registered in urban and peri-urban areas. Perrins (1998) reported that the activity radius during the breeding season reached 15–20 km.

These data correspond to what was previously concluded: Stock Dove is listed as a forest-dwelling species, is mainly present in deciduous and mixed forests, and depends on old beech trees for nesting (Gibbs *et al.* 2010, Koleček *et al.* 2010, Koschová *et al.* 2014, Floigl *et al.* 2022). Others believe that it is a bird of agricultural lands and forest edges and is rarely encountered in urban areas. However, in London, Stock Doves appear to be maintaining a healthy population in some parks because these large mature areas could provide more suitable habitat with more natural cavities in older trees (Richardson *et al.* 2023).

In the breeding sites at Sidi Bel Abbès, we found several holes, especially in old holm oak trees; the majority are natural holes but are also probably dug by the Levaillant's Woodpecker *(Picus vaillantii)*, because the latter is considered a nesting species in these regions. Nesting holes dug by woodpeckers are frequently used by species nesting in secondary holes (Wesołowski 2001, Martin *et al.* 2004, Remm *et al.* 2006, Badis *et al.* 2023). According to Kosiński *et al.* (2011), Stock Dove prefers to breed in holes excavated by the Black Woodpecker, and it avoids dead trees, preferring those with multiple cavities and holes located higher up. Recent research suggests that holes in living wood are better insulated than those in dead wood. They have more consistent temperatures (smaller daily fluctuations) and are warmer during the night (Wiebe 2001, Coombs *et al.* 2010).

Generally, we have noted overlap between the ranges of five species of Columbidae, especially on the earnings site: the Common Wood Pigeon, the Eurasian Collared Dove, and sometimes the Rock Dove and the European Turtle Dove. This is because they are competing for the same resources. If their habitats overlap, this competition can lead to the local extinction of a less effective competitor (Reif *et al.* 2018) and/or niche partitioning (Finke & Snyder 2008). This process also allows competing species to use the same resources in different ways, and thus, promotes the co-existence of species (Vacher *et al.* 2016). Moreover, Floigl *et al.* (2022) confirmed the hypothesis of a high overlap of habitat between the five species of Columbia in agricultural areas in the Czech Republic. The same situation was found in Hungary between the European Turtle Dove and the Eurasian Collared Dove in the early 20th century, and this is the situation recently in the case of the Eurasian Collared Dove and the Wood Pigeon (Csathó & Bozó 2022). Also in terms of habitat overlap, Stock Dove overlapped with European Turtle Dove, the second highest habitat overlap of all other species after Common Wood Pigeon, which is not surprising since these species feed on agricultural land.

Feeding ecology

The method of direct visual observation is used to examine trophic behavior and provides a swift qualitative assessment of the diet of the observed species (Blagosklonov 1987). Compared to other diet analysis techniques, such as the analysis of fecal sacs, droppings, and/or regurgitate pellets, this technique makes it easier to identify ingested species, matter, or items when investigating diet composition (Chedad *et al.* 2021a). Stock Doves are primarily granivorous species, feeding mainly on the seeds of cereals and grasses, flower buds, young green shoots, etc., on the ground in open environments according to the seasons, and they are also interested in the lost portions of the harvests. Previous studies have discussed this information and how it can be consumed by many species of the Araliaceae family, including Asteraceae, Boraginaceae, Brassicaceae, Amaranthaceae, Fabaceae, and others (Murton *et al.* 1965, Möckel 1988, Schumm *et al.* 2023). Additionally, certain insects, including Cecidomyiidae larvae and earthworm cocoons, can be consumed (Schumm *et al.* 2023). This is particularly true during the feeding period of the young or even during the critical period when plant-based food resources are scarce, as is the case with many birds, including the House Bunting (Chedad 2021, Chedad *et al.* 2021a).

The expansion of distribution areas for certain bird species in Algeria can be attributed to various factors, such as climate change, overexploitation of natural resources, fires, urban development, agricultural expansion, pollution of different types, the establishment of green spaces, and the emergence of new wetlands, particularly artificial wetlands (Chedad *et al.* 2020a, 2020c). In addition, the vastness of Algeria, with its rugged terrain and the impossibility of reaching others due to private or military properties, prevented researchers from investigating and following certain species.

In conclusion, the world, including Algeria, has experienced several enlargements or shrinkages of the range of species and breeding sites, following several factors both natural and artificial. This study documents the presence of Stock Doves in new localities with new breeding sites located outside the known range, in western Algeria, and also on the national distribution map, and we have given a contribution on behavior, distribution, and food.

Twenty new distributions and breeding points have been reported in western Algeria, in Sidi Bel Abbès and Tlemcen. Roosting and nesting sites are in forests and wooded edges, not far from water sources, and feeding sites are in open environments, natural or agricultural, where it consumes seeds of cereals and herbs, flower buds, and young green shoots. It cohabits with other species of pigeons and doves.

More research is necessary to compare the species' origin, distribution, and abundance in Algeria's north at Kabylie and west in this study, using phylogenetic analysis. Also, we expand the monitoring to find new sites, begin monitoring reproduction to better comprehend the life cycle of the species, and estimate the classification of certain areas as national reserves in order to preserve this species.

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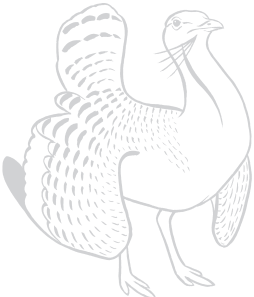

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Phalacrocorax bakonyiensis n. sp., a new species of cormorant from the Late Miocene of Hungary

Ida Horváth[1]*, János Futó[2] & Jenő (Eugen) Kessler[3]

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Abstract We describe *Phalacrocorax bakonyiensis* n. sp. an extinct member of the cormorants (Phalacrocoracidae). The fossil was found in 2021 by geologist János Futó in the sediments of a small cave cavity on the side of Várhegy in Sümeg, a part of the Bakony Mountains of West Hungary, where Late Miocene (MN11–12) vertebrate fossils have been found in the past decades. The total number of bone fragments collected was 14, of which only three can be identified. Two of these belong to adults and one, due to its poor preservation and size, to a very young specimen.

Keywords: West Hungary, Sümeg, Várhegy cave no. 2., Late Miocene, cormoran

Összefoglalás A kormoránfélék (Phalacrocoracidae) egy kihalt képviselőjét, a *Phalacrocorax bakonyiensis* n. sp.-t mutatjuk be. A leletre a Ny-Magyarországi Bakony-hegységhez tartozó Sümegről, a sümegi Várhegy oldalán lévő kis barlangüreg üledékében talált rá Futó János geológus 2021-ben, ahonnan már korábban is kerültek elő késő-miocén korú (MN11–12) gerinces fosszíliák az elmúlt évtizedekben. Összesen 14 csonttöredéket sikerült begyűjteni, melyek közül csupán három azonosítható. Ebből kettő kifejlett egyedhez tartozik, egy pedig elmosódott jellege és mérete miatt egy nagyon fiatal példányhoz.

Kulcsszavak: Nyugat-Magyarország, Sümeg, Várhegy 2 sz. barlang, késő-miocén, kárókatona

[1] *University of Sopron, Faculty of Forestry, Institute of Wildlife Management and Biology, 9400 Sopron, Bajcsy-Zsilinszky utca 4., Hungary*
[2] *LAPILLI Természetrajzi Kutató Bt. 8420 Zirc, Péch Antal utca 2/b, Hungary*
[3] *Department of Paleontology, Eötvös Loránd University, 1117 Budapest, Pázmány Péter sétány 1/c, Hungary*
* *corresponding author, e-mail: idahorvath03@gmail.com*

Introduction

In 1991, cave explorers from Veszprém collected several bird bones from the sandy sediment of cave No. 2 of Várhegy in Sümeg, at a depth of 2 m, which were brought to the Natural History Museum of Hungary for the paleontologist Dénes Jánossy. Preliminary examination revealed that they were dealing with Late Miocene fossil *Phalacrocorax* finds, which included several specimens of different ages. Unfortunately, the material was not further identified, Dénes Jánossy retired in 1997 and died in 2005, and the material was lost when the Museum moved to its new building in 2003.

In 2021, the geologist János Futó visited the cave and managed to collect 14 bone fragments from the remaining sediment and bring them to us. Three of these specimens proved to be identifiable, and two of them, similar to the 1991 finds, were found to be skeletal parts of a cormorant species of smaller size than the great cormorant, of a size intermediate between the extant *Phalacrocorax auritus* and *Microcarbo pygmaeus*.

More recently, the little cormorant is classified in the genus Microcarbo (formerly *Phalacrocorax pygmaeus*) (Worthy 2011).

Geological and geomorphological environment

The Cretaceous Tatai Limestone, on which late Miocene (Pannonian) abrasion conglomerate was cemented in the mountain lobe zone (Haas *et al.* 1984), forms the insular structure of the hill of Vár, which rises about 50 m above the surrounding area. The original site is the shaft-like cave (Schäfer *et al.* 1995), located at 250 m above sea level on the southern edge of the hill's roof. In the immediate vicinity, the remains of several fossil spring channels with a karst thickness are still visible in the limestone. The sediment, completely excavated from the cave, was deposited on the steep slope in front of the cave mouth during excavation. This has been largely washed away by the rains since then, but there may still be further bone fragments in the remains.

The evolutionary history of the former archaeo-geographical setting can be reconstructed as follows (unfortunately, no detailed analysis of the stratigraphy of the excavated sediment fill was made during the excavation of the cave, and only minimal material remains in the cavity).

Lake Pannon gradually flooded the island cone of the Castle Hill and covered it with clay and sand as a result of the general rise in water levels in the Carpathian Basin 10 million years ago. In the meantime, the upwelling paleo-karstic waters have created a cavity a few metres deep, at the bottom of which half a metre of coarse-grained sand mixed with rock silt was washed in from the surrounding terrain. At this point, bird bones may have been deposited, and after a pause in sedimentation, another two metres of rock chippings almost completely filled the shaft. At this stage, the area was probably already dominated by the river plain that had replaced Lake Pannon. During the subsequent tectonic uplift of the region, which continues to this day, all the correlative sediments from Castle Hill were eroded away, with the exception of the material preserved in the cave.

Background

The early members of this distinctively fish-eating bird family belong to the subfamily Graculavinae and are known from the North American Palaeocene with two species of *Graculavis* (*G. velox* Marsh 1872 and *G. pumilus* Marsh 1872) (Brodkorb 1963). The earliest member of the subfamily Phalacrocoracinae, which includes extant cormorant species, is known from the Eocene in England (*Actiornis anglicus* Lydekker, 1891) (Brodkorb 1963), based on the proximal epiphysis of an *ulna*. The *Actiornis anglicus* fossil was described in the Phalacrocoracidae (Harrison & Walker (1976a)). They transferred it to the Threskiornithidae. But Olson (1981) observed that its holotype is neither from a cormorant, nor from an ibis. Mlíkovský placed this specimen in the category Aves incertae sedis.

Another specimen from this period, also from England (MP17) (Mlíkovský 2002), was described on the basis of an incomplete upper beak fragment, described by Harrison and Walker (1976b) as *Piscator tenuirostris*, but Mlíkovský also placed this specimen too in the category Aves incertae sedis, thus suggesting that the affinities of the taxon are questionable.

The genus *Phalacrocorax* was first indicated from the Early-Middle Oligocene of North America (USA) by Shufeldt through the proximal end of a metacarpal bone (*Phalacrocorax mediterraneus* Shufeldt, 1915) (Brodkorb 1963). It was indicated from the Early-Middle Oligocene from the Jebel Qatrani Formation, Fayum, Egypt, based on a characteristic beak remains (Rasmussen *et al*. 1987) and from the Late Oligocene (MP30) several representatives of the *Borocarbo* genus from France and Germany (Mayr 2001, 2007, 2009, Mourer-Chauviré *et al*. 2004, Göhlich & Mourer-Chauviré 2010), *Praecarbo strigoniensis* Kessler & Horváth, 2023, from the Late Oligocene of Hungary (MP25–30), (Kessler & Horváth 2023). The other known species have all been described from the Neogene as *Oligocorax littoralis* (Milne-Edwards 1863) and *P. intermedius* (Milne-Edwards, 1867) from the Early and Middle Miocene (MN3–4 and MN7–8) of France, Germany, and the Czech Republic (Milne-Edwards 1863, 1867, Cheneval 1984, Mlíkovskỳ, 2002), and *P. ibericus* Villalta, 1963 from the Late Miocene of Spain (MN9), *P. lautus* Kurochkin & Ganea, 1972 from the Late Miocene of Moldova (MN9), *P. longipes* (Tugarinov, 1940) from the Late Miocene of Ukraine (MN11–13) and *P. serdicensis* Burchak-Abramovic & Nikolov, 1984 from the Late Miocene of Bulgaria (MN13–14) (Tugarinov 1940, Villalta 1963, Kurochkin & Ganea 1972, Burchak-Abramovic & Nikolov 1984, Mlíkovskỳ 2002). Of the later Middle and Late Miocene finds, only the Bulgarian one shows a proximal epiphysis of the *humerus* (*P. serdicensis* Burchak-Abramovic & Nikolov, 1984), but much larger than that of Sümegi (*P. aristotelis* size). *P. serdicensis* and *P. aristotelis* are considered to be the same size (Göhlich 2002). In addition to the above, several fossil species have been described from the Neogene of other continents (Asia, America, Australia) (Watanabe *et al.* 2018). *Nectornis miocaenus* is also relevant. In their paper, Göhlic and Mourer-Chauviré (2010) discuss several late Miocene cormorant species (such as *Phalacrocorax ibericus* Villalta, 1963 from Spain; *Phalacrocorax lautus* Kurochkin & Ganea, 1972 from Moldova; *Phalacrocorax serdicensis* Burchak-Abramovic & Nikolov, 1984 from Bulgaria; *Phalacrocorax longipes* (Tugarinov, 1940) from Ukraine), however, no size tables are given in the article. All of these species are much larger species than the *P. bakonyiensis* we are presenting.

Material and Method

Three of the 14 bone fragments collected were identified: a left *humerus* proximal epiphysis *(Figure 1/1–2)*, a small juvenile *humerus* proximal epiphysis *(Figure 2/1–2)* and a fragment of an incomplete left *humerus* diaphysis *(Figure 2/3–4)*. To identify morphological features, we used the handbook of Baumel *et al*. 1979. The method of measurement was adapted from Kessler 2013. The finding was compared with *humerus* of extant species. We used the corresponding bone of a Great Cormorant *(Phalacrocorax carbo) (Figure 1/3–4, 2/5–6)* and Pygmy Cormorant *(Microcarbo pygmeus) (Figure 1/5–6, 2/7–8)*.

Concerning size, we would like to emphasize that we have not found in the literature any data on small cormorant *humerus* that could serve as a basis for our comparison. All the data we know are either from significantly larger species or from much earlier finds.

Abbreviations: C-width of proximal epiphysis; C1-width of *caput humeri*; E-thickness of *diaphysis*; a. *caput humeri;* b. *incisura capitis;* c. *tuberculum dorsale;* d. *sulcus lig. transversus;* e. *impressio coracobrachialis;* f. *intumescentia humeri;* g. *crista delto pectoralis;* h. medal view of *incisura capiti;* i. *tuberculum ventrale;* j. *fossa pneumotricipitalis;* k. *crista bicipitalis;* l. *margo caudalis.*

Systematics

Class Aves Linnaeus, 1758
Order Pelecaniformes Sharpe, 1891
Family Phalacrocoracidae (Reichenbach, 1849)
Subfamily Phalacrocoracinae (Reichenbach, 1849)
Genus: *Phalacrocorax* Brisson, 1760
Species: *Phalacrocorax bakonyiensis* n. sp.

Site and age: Sümeg, Várhegy Cave No. 2. (Veszprém county, Veszprém district, Hungary), Late Miocene (MN11–12).

Materials: left *humerus*, proximal epiphysis (holotype) *(Figure 1/1–2*); a small juvenile *humerus* proximal epiphysis *(Figure 2/1–2)*; *humerus* diaphysis fragment *(Figure 2/3–4)*; diaphysis fragment (paratype) *(Figure 1/3–6)*; a small juvenile *humerus*, proximal epiphysis (paratype). Material not yet catalogued.

Dimensions (in mm): *P. bakonyiensis n.* sp.: C-22.54, C1-10.84

Dimensions of comparative materials (in mm): *Phalacrocorax carbo* (Linnaeus, 1753) C-24.22–27.00, C1-16.29–19.00, E-8.35–11.00; *P. auritus* (Lesson, 1831) C-22.31, C1-11.03, E-7.25; *M. pygmaeus* (Pallas, 1773) C-16.20–19.00, C1-9.4–10.02, E-6.10–7.00.

Name etymology: *Phalacrocorax* = genus name; *bakonyiensis* = from the Bakony Mountain.

Diagnosis: a species of cormorant smaller than the extant large cormorant, of intermediate size between the extant *Phalacrocorax auritus* and *M. pygmaeus*:

- *caput humeri* (a) is prominent, separated at ventral end by *incisura capitis* (b) from prominent middle part, unlike extant species;
- *tuberculum dorsale* (c) is rounded, damaged;
- *sulcus lig. transversus* (d) is deep, long and curved;
- *impressio coracobrachialis* (e) is deep, long and wide;
- *intumescentia humeri* (f) is broad, distally narrowing ovate, slightly convex;
- *crista delto pectoralis* (g) is damaged;
- *incisura capitis* (h) is wide and deep;
- *tuberculum ventrale* (i) is well developed, prominent;
- *fossa pneumotricipitalis* (j) is wide, deep, elongated and undivided (no *crus fossae*);
- *crista bicipitalis* (k) is less prominent;

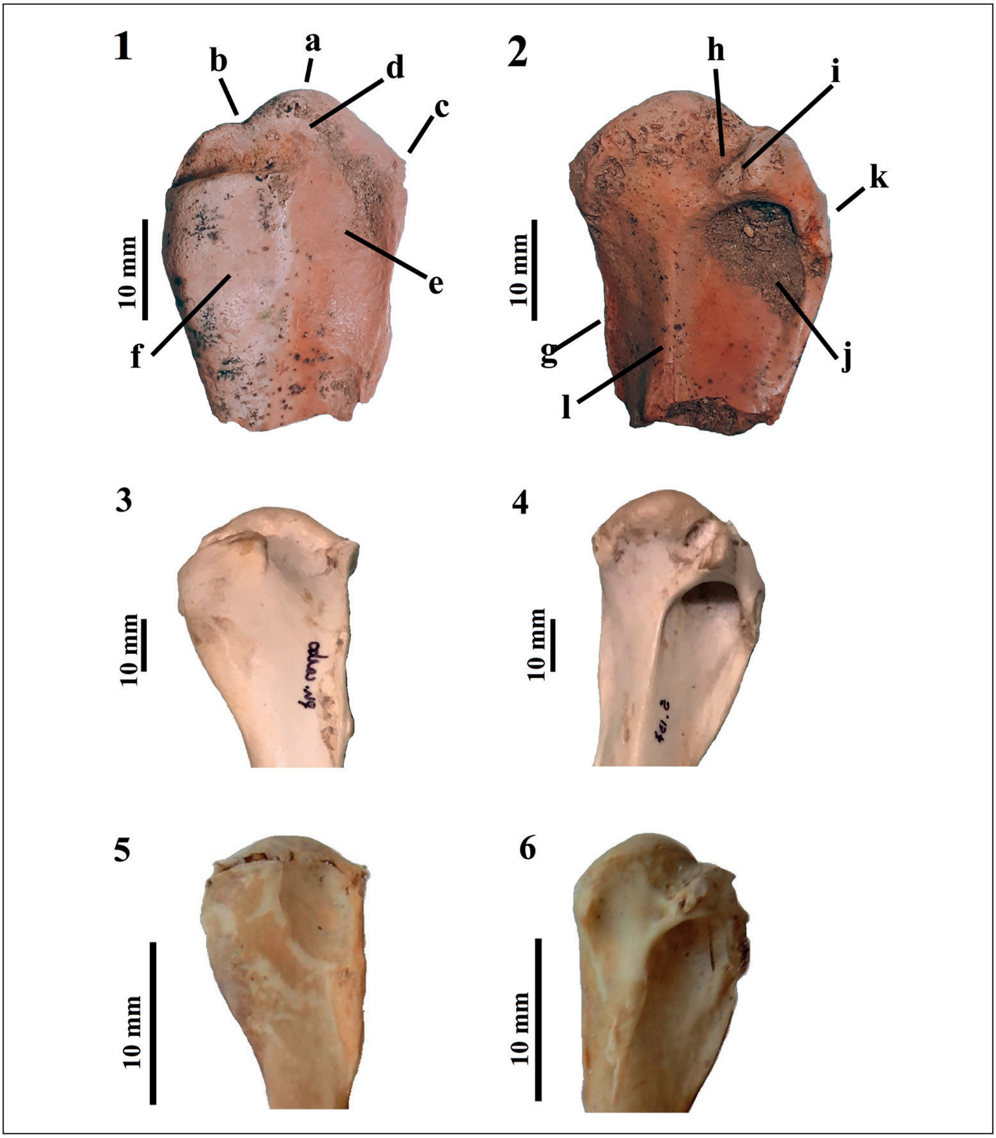

Figure 1. 1. *Phalacrocorax bakonyiensis* n. sp., left *humerus*, proximal epiphysis, lateral view: a. *caput humeri;* b. *incisura capiti;* c. *tuberculum dorsale;* d. *sulcus lig. transversus;* e. *impressio coracobrachialis;* f. *intumescentia humeri*; 2. *Phalacrocorax bakonyiensis* n. sp. left *humerus*, proximal epiphysis, medial view: g. *crista delto pectoralis;* h. *incisura capiti;* i. *tuberculum ventrale;* j. *fossa pneumotriccipitalis;* k. *crista biccipitalis;* l. *margo caudalis*; 3. *Phalacrocorax carbo* extant, left *humerus*, proximal epiphysis, lateral view; 4. *Phalacrocoax carbo* extant, left *humerus*, proximal epiphysis, medial view; 5. *Phalacrocorax pygmaeus* extant, left *humerus*, proximal epiphysis, lateral view; 6. *Phalacrocorax pygmaeus* extant, left *humerus*, proximal epiphysis, medial view. Scale mark: 10 mm

1. ábra 1. *Phalacrocorax bakonyiensis* sp. n. baloldali felkarcsont, proximális epifizis, laterális nézet: a. *caput humeri;* b. *incisura capiti;* c. *tuberculum dorsale;* d. *sulcus lig. transversus;* e. *impressio coracobrachialis;* f. *intumescentia humeri*. 2. *Phalacrocorax bakonyiensis* sp.n. baloldali felkarcsont, proximális epifizis, mediális nézet: g. *crista delto pectoralis;* h. *incisura capiti;* i. *tuberculum ventrale;* j. *fossa pneumotriccipitalis;* k. *crista biccipitalis;* l. *margo caudalis*. 3. *Phalacrocorax carbo* recens, baloldali felkarcsont, proximális epifizis, laterális nézet; 4. *Phalacrocorax carbo* recens, baloldali felkarcsont, proximális epifizis, mediális nézet; 5. *Phalacrocorax pygmaeus* recens, baloldali felkarcsont, proximális epifizis, laterális nézet; 6. *Phalacrocorax pygmaeus* recens, baloldali felkarcsont, proximális epifizis, mediális nézet. Méretarány: 10 mm

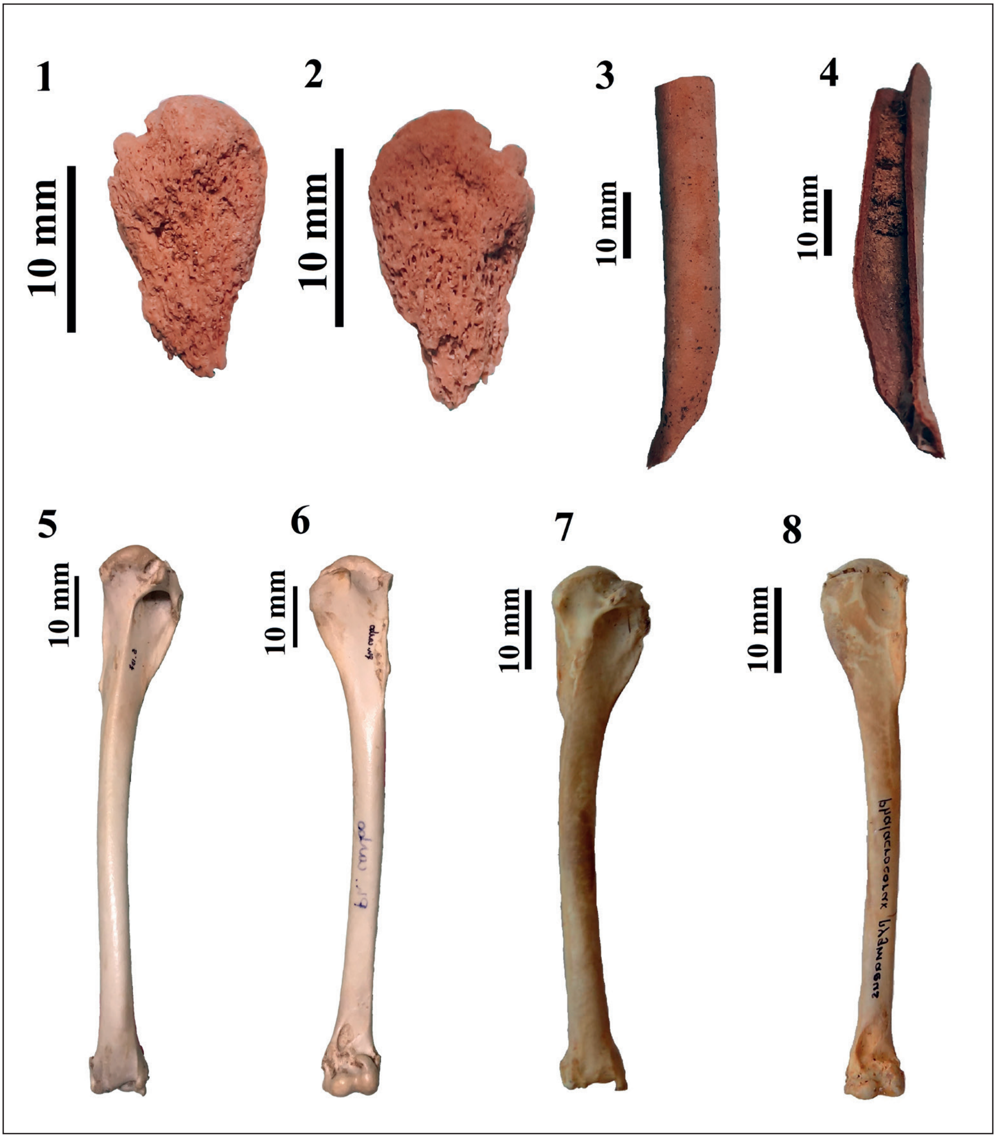

Figure 2. 1. juvenile *Phalacrocorax cf. bakonyiensis* left *humerus*, proximal epiphysis fragment, lateral view; 2. juvenile *Phalacrocorax cf. bakonyiensis* left *humerus*, proximal epiphysis fragment, medial view; 3. *Phalacrocorax cf. bakonyiensis* left *humerus* diaphisis fragment, lateral view; 4. *Phalacrocorax cf. bakonyiensis* left *humerus* diaphisis fragment, medial view; 5. *Phalacrocoax carbo* extant, left *humerus*, diaphisis fragment, medial view; 6. *Phalacrocorax carbo* extant, left *humerus*, lateral view; 7. *Phalacrocorax pygmaeus* extant, left *humerus*, medial view; 8. *Phalacrocorax pygmaeus* extant, left *humerus*, lateral view. Size mark: 10 mm.

2. ábra 1. Fiatal *Phalacrocorax cf. bakonyiensis* bal felkarcsont, proximális epifízis töredék, oldalnézet; 2. Fiatal *Phalacrocorax cf. bakonyiensis* bal felkarcsont, proximális epifízis töredék, mediális nézet; 3. *Phalacrocorax cf. bakonyiensis* bal felkarcsont diafízis töredék, oldalnézet; 4. *Phalacrocorax cf. bakonyiensis* bal felkarcsont diafízis töredéke, mediális nézet; 5. *Phalacrocoax carbo* bal felkarcsont, diafízis töredéke, mediális nézet; 6. *Phalacrocorax carbo* extant, bal felkarcsont, laterális nézet; 7. *Phalacrocorax pygmaeus* bal felkarcsont, mediális nézet; 8. *Phalacrocorax pygmaeus* bal felkarcsont, laterális nézet. Méretarány: 10 mm

- *margo caudalis* (l) is curved, well developed, sharp;
- the shape of the diaphysis fragment corresponds to that of the genus.

The proximal epiphysis of the *humerus* is preserved to the distal end of the *crista delto pectoralis*. The marks indicated in the diagnosis of the species in the two extant species (*Phalacrocorax carbo* and *M. pygmaeus*) are as follows:

In *Phalacrocorax carbo* extant:

- *caput humeri* is flat, ventral end not separated by a small strap on the lateral side;
- *tuberculum dorsale* is prominent;
- *sulcus lig. transversus* is deep, short, broad;
- *impressio coracobrachialis* is less deep, long and wide;
- *intumescentia humeri* is broad, distally narrowing ovate, flat;
- *crista biccipitalis* is bulging;
- *incisura capiti* is ovate;
- *tuberculum ventrale* is well developed, prominent;
- *fossa pneumotricipitalis* is narrow, deep, elongated and slightly divided with *crus fossae*;
- *crista delto pectoralis* is slightly concave straight;
- *margo caudalis* is straight, well developed, sharp.

In *Microcarbo pygmaeus* extant:

- *caput humeri* is flat, ventral end on lateral side not separated by a small ligament from the apical part;
- *tuberculum dorsale* is prominent;
- *sulcus lig. transversus* is long, straight;
- *impressio coracobrachialis* is deep, short, ovate;
- *intumescentia humeri* is proportionally narrow, elongated, flat;
- *crista bicipitalis* is slightly curved;
- *incisura capitis* is wide and deep;
- *tuberculum ventrale* is well developed, prominent;
- *fossa pneumotricipitalis* is narrow, deep, elongated and slightly divided with *crus fossae*;
- *crista deltopectoralis* is forms a straight edge;
- *margo caudalis straight* is well developed, blunt.

Compared with known fossil cormorant species, it has the following morphological characteristics, but differs slightly from the extant species. The known European species of the Late Miocene do not have a *humerus*, and we were unable to compare the Bulgarian *P. serdicensis*, but the dimensions of the Sümeg find suggest that it is smaller than this species.

Conclusions

The new fossil species indicates a small-sized cormorant with the characters of the genus, with the differences listed in the diagnosis compared to the extant large and small cormorants. Its presence at the cave site indicates a former wetland habitat and the remains are part of the prey of a larger owl. The fact that both adults and juveniles are present in the much richer specimen collected earlier suggests the former existence of a larger population in the vicinity of the site. The presence of a juvenile specimen was based on the fact that a single species was recovered from the cave sediments and that there were juveniles among the lost bones, and that the characteristics of the bone fragment, despite its juvenile state, were consistent with the *humerus* of a cormorant. Considering that cave bird fossils can only be dried from owl droppings, this is supported by the discovery of bird bones of different ages.

The stronger indentation of the *incisura capiti* on the lateral side (b) compared to the extant species may suggest a better flight ability, as the tendon of the *m. coracobrachialis* enters the *impressio coracobrachialis* on the medial side through this, where it attaches and moves the *humerus* forward *(anteflexion)*.

Phalacrocorax carbo, *Microcarbo pygmaeus* and *P. bakonyiensis* were used to indicate differences, but we do not have enough fossil and recens material for deeper conclusions. As regards the size, we would like to stress once again that we have not found any data in the literature that would allow us to make a comparison with small cormorant *humerus*.

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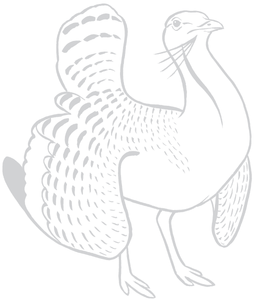

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Observation of a Middle Spotted Woodpecker *Dendrocoptes medius* with aberrant, brown-coloured plumage

Gerard Gorman

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Abstract Birds with atypical colours in their plumage are not uncommon however, the potential causes of such aberrations have not been widely examined. Aberrant brownish-rufous phaeomelanin is one type of plumage colour that has been recorded in numerous bird species, including those which essentially contain only eumelanin (black) pigments, including several European woodpeckers. A Middle Spotted Woodpecker *Dendrocoptes medius* with aberrant phaeomelanised plumage observed in the Bükk Hills, Hungary, is detailed here and an evaluation of the possible nature of this form of plumage discussed.

Keywords: woodpeckers, *Dendrocoptes medius,* aberrant plumage, phaeomelanised

Összefoglalás Az atipikus színű tollazattal rendelkező madarak nem ritkák, azonban az albinizmus és a leucizmus kivételével az ilyen rendellenességek lehetséges okait nem vizsgálták széles körben. A rendellenes barnás-vöröses phaeomelanin a tollazati pigmentek egyik típusa, amelyet számos madárfajnál, európai harkályoknál is feljegyeztek, beleértve azokat is, amelyek tollazata lényegében csak eumelanin (fekete) pigmenteket tartalmaz. Itt egy a Bükk-hegységben megfigyelt közép fakopáncsot *(Dendrocoptes medius)* mutatunk be rendellenes feomelanizált tollazattal, és értelmezzük a tollazat e formájának lehetséges kialakulását.

Kulcsszavak: harkályok, fakopáncsok, *Dendrocoptes medius,* rendellenes tollazat, feomelanizált

Independent Picidae Researcher, Hungarian Woodpecker Group (HVSZ), MME/Birdlife Hungary, 1121, Budapest, Költő utca 21., Hungary
e-mail: picidae.gerard@gmail.com

Introduction

Melanism is defined as an increase of dark pigment in the plumage, resulting in a blackish appearance. However, there is often no increase of pigment and melanism does not necessarily involve dark pigment alone. Also, many different mutations in many different genes promote melanism, which may explain why it is the commonest colour aberration in birds. The main pigments that influence plumage colour are melanins, and these can be divided into eumelanin and phaeomelanin (van Grouw *et al.* 2021). In many bird species, feather colour is determined by eumelanin alone, but eumelanin does not always occur as black, but can also show as different shades of brown or grey. Phaeomelanin creates reddish-brown to pale-buff feathers. When both eumelanin and phaeomelanin are present, a variety of greyish-brown colours result. The intricate patterns that often embellish feathers are due to variations in the type, extent and dissemination of these melanin pigments. This type of plumage colour has been documented for several members of the European Picidae, including the Black Woodpecker *Dryocopus martius* (Gorman 2011) and the Great Spotted Woodpecker (Blume 1977). However, little has been published on this subject for the Middle Spotted Woodpecker *Dendrocoptes medius* (van Grouw *et al.* 2021). We might note, however, that there are documented cases of all-black melanistic Middle Spotted Woodpeckers (Konieczny 2000).

Middle Spotted Woodpecker – background

The Middle Spotted Woodpecker occurs in the Western Palaearctic region where it is resident and sedentary and typically inhabits mixed temperate deciduous woodlands, especially with old oaks *Quercus*, hornbeams *Carpinus* and elms *Ulmus* (Pasinelli 2000). It is also found in riverine woods, parkland, parks and rural gardens (Gorman 2004). The bulk of the population is in south-east Europe, and in recent years it is considered to have expanded its distribution and increased in number elsewhere on the continent (Robles & Pasinelli 2020). In Hungary, Middle Spotted Woodpeckers are locally common, and the population assessed as showing a slightly increasing trend (Gorman *et al.* 2022).

Middle Spotted Woodpecker – description of usual plumage

Middle Spotted Woodpeckers are around 20–22 cm in length with a wingspan of 33–34 cm. Both adults are essentially black and white. The throat and upper breast are white with a cream, buff or greyish tinge. There is a thin black malar stripe which on some birds may be lacking entirely. Even when a malar stripe is present, it never starts from the lower mandible, but begins a little way short. The ear-coverts are cream-white, often dusky, and crossed only partially by a black post-auricular stripe. Black stripes run from each side of the throat down to the upper sides of the breast where they merge into black streaks on the upper flank. The flanks are heavily streaked black. The lower breast, belly and flanks are basically white though often yellowish, especially in the spring. This yellow wash may reach the leg feathering. The lower belly, under-tail coverts and ventral area are pink. The mantle, inner scapulars, back, rump and upper tail coverts are matt black. The outer scapulars are white and form ovals patches. The primaries and secondaries are black, heavily dotted and barred white. Some of the rows of white spots on the flight feathers may join to form bars. The upper wing-coverts are black. The inner median wing-coverts white with black bases. The greater coverts are black with white tips. The axillaries are dusky white. Most of the tail is black though the outer two rectrices have white dots. Males and females overlap in measurements and indeed, this species is only slightly sexual dimorphic in plumage. An all-red crown is characteristic of both males and females, but it is marginally longer in males and in the nesting period brighter and juts out at the rear like a crest. In addition, the red crown of females is often tinged orange, yellowish or rusty at the rear. However, crown colour and size are frequently variable and without good views these features can be difficult to judge in the field (Gorman 2004).

Observation of an aberrant individual

During the first week of May 2023, in the village of Noszvaj, Bükk Hills, Hungary, I observed a pair of adult Middle Spotted Woodpeckers at their nest. The pair were feeding small nestlings and regularly visited with food. During my first observation, on May 1st, an adult landed at the nest cavity entrance with food and made a few quiet calls. Owing to the brevity of the view, I was at first unable to verify the sex of this individual. Almost at once, its partner came out of the cavity and briefly landed on an adjacent tree. I immediately noticed that the exiting bird was abnormally coloured. Instead of having a black back, the bird was coloured brown in that area of plumage. Other areas of black plumage (wings, tail, facial stripes) and white and red areas were unaffected, retaining their usual colourations. During the next change-over at the nest, the aberrant bird landed below the cavity entrance and remained motionless until its mate came out. I was then able to verify that the waiting bird was the male, owing to it having the crown features mentioned above, and being able to compare it to its mate on numerous subsequent occasions.

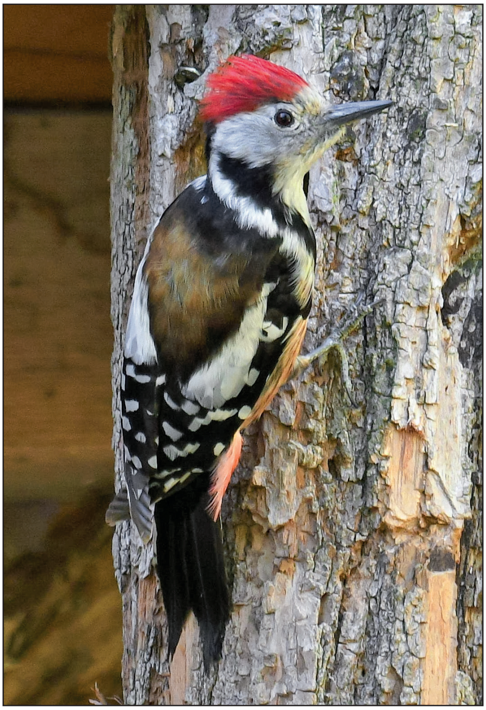

Figure 1. Male Middle Spotted Woodpecker *(Dendrocoptes medius)* with aberrant, brown, phaeomelanised plumage. Noszvaj, Bükk Hills, Hungary, 01.05.2023.

1. ábra Közép fakopáncs hím *(Dendrocoptes medius)* rendellenes, barna, feomelanizált tollazattal. Noszvaj, Bükk-hegység, Magyarország, 2023.05.01.

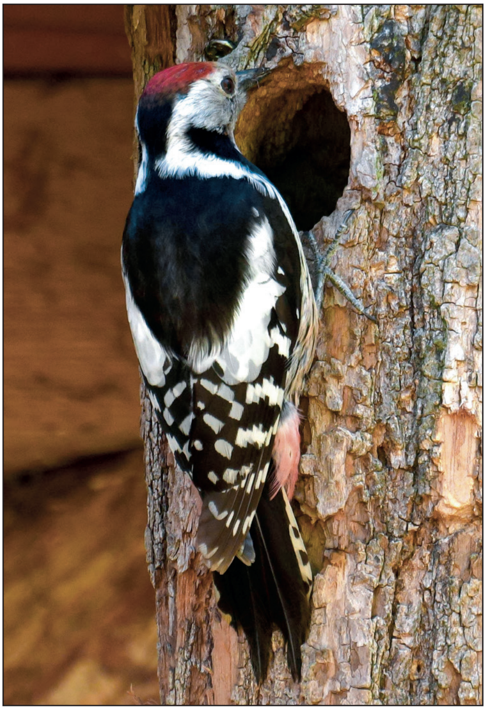

Figure 2. Female Middle Spotted Woodpecker *(Dendrocoptes medius)* with normal black plumage. Noszvaj, Bükk Hills, Hungary, 01.05.2023.

2. ábra Közép fakopáncs tojó *(Dendrocoptes medius)* normál fekete tollazattal. Noszvaj, Bükk-hegység, Magyarország, 2023.05.01.

Figure 3. Male (with aberrant brown back) and female (with normal black back) Middle Spotted Woodpeckers *(Dendrocoptes medius)* changing over at the nest cavity. Noszvaj, Bükk Hills, Hungary, 01.05.2023.

3. ábra Hím (rendellenes barna hátú) és tojó (normál fekete hátú) közép fakopáncs *(Dendrocoptes medius)* váltja egymást a fészkelőhelyen. Noszvaj, Bükk-hegység, Magyarország, 2023.05.01.

Discussion

Numerous occurrences of colour aberrations in birds, involving melanism, leucism, albinism and others, have been documented for a wide range of species. For example, Coppersmith Barbets (Gayen *et al.* 2022), Greater Coucals (Alby *et al.* 2023), Indian Pied Starlings (Jangir *et al.* 2013) and House Sparrow and several other species (van Grouw 2021). In nature, 'brown' male woodpeckers are rare because they can only be born from a 'brown' mother and a normally-coloured father that is heterozygotous for this mutation and, of course, from parents that are both 'brown'; with that colour defined as a heritable mutation which affects the synthesis of the eumelanin (van Grouw *et al.* 2021). Among the array of plumage aberrations described, brown plumage aberration, which is characterized by a qualitative reduction of eumelanin, has attracted been studied (Zbyryt *et al.* 2021). Several explanations for aberrant coloured plumages in woodpeckers are possible. The first concerns exposure to sunlight, which is bleaching of the feathers. When birds are seen in strong light, especially in flight, they may seem to be brown coloured as the light shines through their feathers; alternatively, some observers have suggested that birds with brownish tones are those that have lived in more open areas such as clear-cuts and have thus been exposed to more direct sunlight, thereby causing their plumage to fade from black to brown. In some cases, this might be true, as bleaching by the sun can occur, but it does not adequately explain why birds that spend all of their time in the shady interior of forests, as most woodpeckers do, can have brownish plumage. Neither does it answer the question of why some individuals, which are sedentary and inhabit the same area all year round (which are presumably subject to the same light exposure), are brown one year, but black the next.

A second hypothesis relates to the fact that woodpeckers use tree cavities. It is sometimes suggested that the aberrant colour could be the result of tree sap wearing or colouring the feathers. However, the extent of affected plumage found in many individuals, including the Middle Spotted Woodpeckers detailed in this paper, exceeds the degree likely to make regular contact with sap seepage at a nest hole. The argument that siblings from the same brood are unaffected also suggests pigmentation rather than colouring or abrasion by tree sap as the cause (van Grouw *et al.* 2021).

Diet has also been suggested as a possible cause of aberrant plumage colour. It is thought that aberrant feather colouration is related to poor condition, being provoked by poor diet during the moulting period. Nutrition not only influences the quality of feathers but also their colouration. In the case of the Black Woodpecker, individuals with brown plumage are almost always seen during the second half of the annual moult cycle, that is, between March and August (Gorman 2011). After moulting in the autumn, all Black Woodpeckers have fresh black plumage and the majority of birds in most years stay black throughout the year. But certain individuals in some years show brown tones by the end of winter. Such birds are often even paler by spring, and in late summer just before they moult, they are often at their palest. Other individuals are more or less black throughout the spring but become brownish during the summer. This pattern suggests that the poorer the quality of the feathers, the earlier they start to turn brown and the paler they end up. Regarding the

Great Spotted Woodpecker, Blume (1977) stated that birds that had brownish plumage when caught for ringing had normal black plumage when re-trapped a year later. It was assumed that a ‘disturbed’ moult may have been the cause for the aberration in colour. Indeed, such colour aberrations have been found only in adults and appear to be temporary, with normal plumage being attained once more during the next moult.

Conclusion

Plumage aberrations in birds are intriguing owing to the potential insights they provide into genetic and physiological processes (Hill & McGraw 2006, Guay *et al.* 2012, Price-Waldman & Mary 2021). So far, this type of brown colour aberration has been found only in adult woodpeckers and appears to be temporary, with normal plumage being grown again during their next moult. This subject has not been widely studied, but it is assumed that a ‘disturbed’ moult may be the cause for such aberrant coloured feathers. The cause of brown feathering in areas where they should black is most likely to be external, not due to ageing or genetics as the production of phaeomelanin is not permanent To conclude, this case of brown plumage aberration in the Middle Spotted Woodpecker draws attention to the variability and complexity of avian plumage aberrations.

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First photographic record of a colour aberrant Spotted Dove *Spilopelia chinensis* from the Brahmaputra valley of Assam, India

Neeraj Bora[1*], Chiranjib Bora[2], Smiti Rekha Sharma[3] & Jyotismita Das[4]

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Abstract Colour aberrations are rare conditions in birds that are caused by genetic as well as environmental factors. Among the colour aberrations in birds, albino, leucism, progressive greying, brown, dilution, ino, and melanism are the best known. This report describes an observation of colour aberration in a Spotted Dove *(Spilopelia chinensis suratensis)* from India. It was recorded in the Deobali Jalah (an IBA site) of Nagaon district, Assam. The recorded individual exhibited a pale plumage with normal eyes and some light brown colour in some of the feathers, indicating this to be a form of dilution. The report also represents the first photographic documentation of colour aberration in Spotted Doves from Brahmaputra Valley of Assam, India. Further research is necessary to comprehend the causes of colour aberration in Spotted Doves.

Keywords: colour aberration, Spotted Dove, IBA site, Assam, India

Összefoglalás A madaraknál ritkák a normálistól eltérő színváltozatok, amelyeket genetikai és környezeti tényezők egyaránt okozhatnak. E színezeti aberrációk közt a madaraknál a legismertebbek az albinizmus, a leukizmus, a progresszív szürkülés, a barna, a ‘hígulás’, az ino és a melanizmus. Tanulmányunk egy a melaninhoz kapcsolódó színeltérés legelső feljegyzését írja le Indiából származó gyöngyösnyakú gerle *(Spilopelia chinensis)* esetében. Az esetet az asszami Nagaon körzet Deobali Jalahjában (egy IBA-terület) észleltük. Az egyed fehéres tollazattal rendelkezett, néhány tollazata világosbarna volt, a szemei viszont normális színűek, vagyis az albinizmustól elkülöníthető volt az eset. Esettanulmányunk a gyöngyösnyakú gerle színeltéréseinek jövőbeli kutatásához szolgálhat alapul. A faj színeltérésének genetikai hátterének feltérképezése további vizsgálatokat igényel.

Kulcsszavak: színaberráció, gyöngyösnyakú gerle, IBA, Asszám, India

[1] *Department of Zoology, Nagaon University, Old A. T. Road, Nagaon-782001, Assam, India*
[2] *Department of Zoology, Gauhati University, Gopinath Bordoloi Nagar, Jalukbari, Guwahati-14, Assam, India*
[3] *Department of Zoology, Gauhati University, Gopinath Bordoloi Nagar, Jalukbari, Guwahati-14, Assam, India*
[4] *Department of Zoology, Nagaon University, Old A. T. Road, Nagaon-782001, Assam, India*
* *corresponding author, e-mail: neerajbora15@gmail.com*

Introduction

Plumage colouration in birds appears to have evolved for a variety of possible purposes, such as camouflage, social and sexual signalling, etc. (LaFountain *et al.* 2015). Birds' plumage coloration is primarily caused by accumulation of pigments in their feathers (e.g. Izquierdo *et al.* 2018). In addition to variations in colour between species, pigment-related colour aberrations are also occasionally observed among different species (van Grouw 2013, Alby *et al.* 2023). Colour aberrations in birds have always fascinated bird watchers and ornithologists. This may be because the bird feathers have distinct colour characteristics that allow for easy species identification, and any deviation from the norm apparently piques people's interest. Typically, plumage coloration comes from biological pigments known as biochromes. Melanin and carotenoids are the main pigments influencing the colour of a bird's plumage (van Grouw *et al.* 2016). Colour aberration in birds is usually caused by genetic mutations that affect the synthesis or distribution of these biochromes (van Grouw *et al.* 2016). However, environmental and dietary factors can also result in aberrant bird colour (Martins-Silva *et al.* 2016). According to van Grouw *et al.* (2021), the different colour aberrations typically observed in birds are albino, leucism, progressive greying, brown, dilution, ino, and melanism. Albino, leucism, progressive greying, brown, and ino are colour aberrations resulting from a reduction or complete lack of melanin pigments, whereas dilution and melanism are caused by abnormal deposition or abnormal production of melanin (van Grouw *et al.* 2021). Typically, albinism, leucism, and progressive greying cause white feathers in birds (van Grouw 2006, van Grouw 2013).

The occurrence of albino is rare in nature. Aberrant white feathers are commonly caused either due to leucism or progressive greying (Martins-Silva *et al.* 2016). Leucism is present at birth. It is the complete or partial absence of both melanin in the entire plumage or selected feathers (van Grouw 2013). Progressive greying is characterised by a gradual loss of pigment cells that accumulates with each moult (van Grouw 2013). Initially scattered randomly across the bird, it is possible the plumage eventually turns white. Although the cause of progressive greying is still unknown, it is the most common reason of white feathers in birds (van Grouw 2016, 2013). Dilution is a quantitative decrease in melanin that gives birds a distinctively paler appearance. In dilution, reduction of one or both melanin (eumelanin and phaeomelanin) is observed. While quantitative reduction of only eumelanin in known as Isabel, quantitative reduction of both phaeomelanin and eumelanin is known as Pastel. In both cases, due to decrease in pigment concentration a diluted colour is observed in the individual (van Grouw 2006).

Van Grouw *et al.* 2016 made a compilation of all colour aberrations in birds from India but did not report any abnormally coloured Spotted Dove from the Brahmaputra valley of Assam, India. Thus, the present study in the first to report colour aberration in a Spotted Dove from Assam's Brahmaputra valley.

Notes and Observation

Spotted Doves *(Spilopelia chinensis suratensis)* are small birds belonging to the Columbidae family that range from the Indian subcontinent to the Indo-Malayan region of southeast Asia. They are not particularly gregarious and are typically observed in pairs or small groups (Garrett *et al.* 2023.). They are easily recognised by their long, square-tipped tail and black and white lacelike pattern of spots (chequered patches) on the sides of the neck (Grimmett *et al.* 2011, Garrett *et al.* 2023).

The colour aberrant Spotted Dove was observed in the Deobali Jalah (26°13’58.42”N 92°35’36.21”E; Elevation 81m MSL) of Nagaon district of Assam, India *(Figure 1)*. Deobali Jalah is an Important Bird and Biodiversity Area (IBA), identified through the BirdLife International IBA programme. The area is mostly composed of tall grasses and wetlands.

On 16th January 2024, while we were surveying water birds in the Deobali Jalah, a white bird flew over by us and perched on a nearby tree branch. At first glance, we thought of it as a Eurasian Collared-Dove, but after close observation with binoculars, we were confirmed that it was an abnormally coloured Spotted Dove. The field observations and notes were made with Nikon Prostaff (10×42) binoculars, and photos were taken with a Nikon P900 point-and-shoot camera. In our case, the size, shape, beak structure, and lace-like spots on the bird’s neck all led to the identification of the bird as a Spotted Dove. It was not considered to be leucism or progressive greying as there was no presence of any white

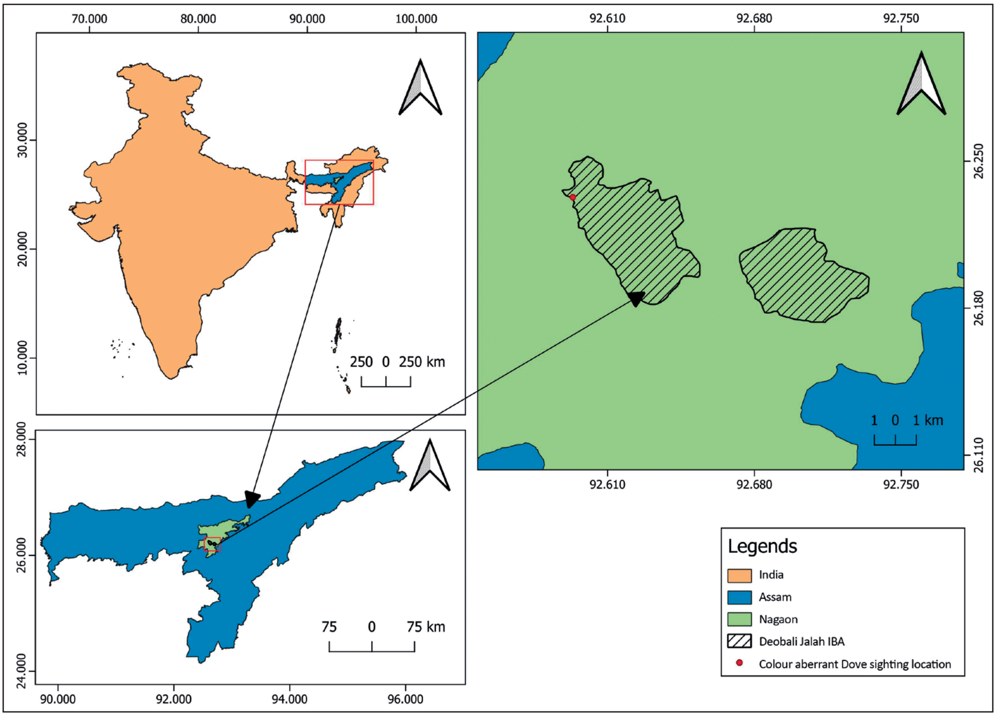

Figure 1. Map representing the recorded location of the colour aberrant Spotted Dove
1. ábra A térkép az abnormális színezetű gyöngyösnyakú gerle észlelési helyét mutatja

Figure 2. The recorded colour aberrant Spotted Dove (left) compared with a normal conspecific (right) (Photo: © Chiranjib Bora)

2. ábra Az észlelt abnormális színezetű gyöngyösnyakú gerle (balra) összehasonlítva egy normális fenotípusú fajtársával (jobbra)

feather. The bird appeared to have a pale plumage, and some brownish colour with normal pattern on its wings was clearly visible *(Figure 2)*. In other words, the colour of the bird appeared to be strongly bleached. Hence, the aberration here may be a form of dilution.

The occurrence of colour aberration in the Spotted Dove is a unique and intriguing observation. Based on available literature, the present study represents the first photographic report of colour aberration in Spotted Dove from the Brahmaputra valley of Assam, India. Further study is necessary to investigate more such cases as well as uncover the causes of colour aberration in Spotted Doves.

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