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Editorial

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A NEW LIFE FOR AVOCETTA BEGINS IN 2025

Avocetta was born in 1953 thanks to an effort by a team of Italian ornithologists who decided to found the Italian Centre for Ornithological Studies (CISO www.ciso-coi.it), with its scientific journal. This means that, formally, our journal recently celebrated its 72nd anniversary. Avocetta has experienced alternating periods of varying activity throughout its long history, but it has been published without interruption since 1978.

Such a long history implies **a great**

adaptive capacity which is an undoubted merit of the Chief and Associate Editors who have alternated in the journal management over the decades. As for a punctuated equilibrium model, periods of calm are alternated with periods of intense, continuous changes. Indeed, the Editorial Board led by Roberto Ambrosini represents one of these ‘changing periods’. Since 2019, we have launched a new website and expanded our presence on social media. We have then redesigned the journal, which became printed in full colour and completely published in English. We have revised our Open Access pol-



icy to become a full diamond open-access (free for readers and authors) and made **the entire publication history available on the journal website**. We have created new columns, such as the Bird News and the review of the ornithological PhD Theses. We have been indexed in DOAJ and FJN, two networks promoting high-quality open-access science against predatory journals. All of this has been done while strengthening our efforts to maintain a rigorous peer review and ensuring the fastest possible publication online after acceptance, with the introduction of the early-view publication format. Moreover, during these years, we focused on progressively raising publication standards, implying the harsh decision to reject a growing proportion of the submissions. As more recent advancements, in 2023 Avocetta moved to an online-only format and adopted a continuous publishing system, with a single issue per year.

It must be acknowledged that **all of this work has been and is still done on a completely voluntary basis** by an enthusiastic group of Editors who believe in this project and want to maintain it completely free of charge.

As a result of these efforts, Avocetta's ranking in Scopus has improved, **enhancing the journal's reputation within the global ornithological community**. Over the past two years, the submission rate to our journal has tripled, prompting the need to elevate our journal to align with the established workflows of international scientific publications.

We are thrilled to announce we are

embarking on an exciting new phase.

Starting this year, Avocetta will be published by the Milano University Press (MUP), an open-access publisher, thanks to an agreement between Milan University, which provides the MUP services free of charge, and CISO, which remains the journal's owner. This change allowed us to introduce several much-needed improvements in the journal editorial system to serve our authors, readers, and the broader scientific community better.

As part of this transition, we are introducing:

1. A New Website - <https://riviste.uni-mi.it/index.php/avocetta>

Adhering to the MUP policies, we will move to a new website, hosted by their servers and with a structure **that integrates the archive and the submission system**. Please note that **www.avocetta.org will permanently remain a valid link to reach our journal's homepage**. The complete journal archive will continue to be accessible to readers. Currently, during the transition period, both of the websites will be active.

2. Simplified and Automated Submission System

Our new editorial system will streamline the submission and review process through enhanced automation, reducing the administrative burdens for authors while ensuring a smooth and efficient publication experience.

3. Print-on-Demand Option

For the readers who prefer physical copies, we are introducing a print-on-demand service, offering the flexibility to

obtain printed versions of their favourite articles or entire issues.

Our partnership with Milan University Press builds on Avocetta's rich legacy of promoting ornithological research while ensuring that the journal remains at the forefront of modern scientific publishing. These changes reaffirm our commitment to providing a global platform for high-quality, accessible research that supports the advancement of ornithology for generations to come.



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Documentation of avian deformities in Algeria

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Abstract

Elevated occurrences of major deformities in wildlife populations are frequently seen as signs of deeper environmental health issues. This study represents the first comprehensive effort to document avian deformities in Algeria, including abnormal beaks and colours, leucism, albinism, and melanism. Notably, some of the observed beak deformities may be indicative of underlying pathological conditions, such as Avian Keratin Disorder (AKD). Over ten years, 50 cases of deformities were documented in 20 provinces. Cases belonged to thirty species, eighteen families and ten orders. Leucism, both partial and complete, was the most common aberration, detected in 34 cases, with partial leucism being most frequent ($n = 23$). Albinism and melanism were rare and observed in one and two cases, respectively. Passeriformes exhibited the highest number of deformities, particularly the House Sparrow *Passer domesticus* ($n = 5$) and the Common Blackbird *Turdus merula* ($n = 3$). Additionally, multiple cases of leucism were observed in the Eurasian Collared Dove *Streptopelia decaocto* ($n = 6$). Abnormal beaks were observed in 13 cases, including conditions such as crossed mandibles, elongated mandibles, and misaligned beaks, which might significantly impact the birds' ability to feed and groom effectively. Notably, deformities were recorded in both resident (23) and migratory (7) species, with a significantly higher number of cases observed in resident species. This study highlights the importance of continuous monitoring and further research to understand the underlying causes of these deformities and their implications for avian conservation in Algeria.

Keywords: Aberration, Abnormal Beaks, Leucism, Albinism, Melanism, Passeriformes, Environmental Health Indicators

INTRODUCTION

High rates of gross deformities in wild-life populations often serve as indicators of underlying environmental health problems (Ohlendorf et al. 1986, Ludwig et al. 1996, Johnson et al. 2007). Among the various categories of aberrant colouration, the most frequently reported cases include individuals exhibiting albinism, brown dilution, melanism, schizochroism, leucism, and progressive greying (van Grouw 2012, Corrêa et al., 2017, Petry et al. 2017, Pradhan & Shrestha 2023). Leucism, caused by the absence of melanin, leads to feather depigmentation, resulting in white feathers that can be either partial or total. In rare instances, this depigmentation can also affect bare parts such as the beak, tarsus, and skin (van Grouw 2006, 2014, Pradhan & Shrestha 2023). Partial leucism in birds often affects feathers on the head, chest, and wings. Pastel dilution, due to decreased melanin in darker hues, may vary among individuals and can occur with distinct patterns, including grey tones, yellow-brown, cream-brown, and even reddish hues (van Grouw 2006, 2013).

Phenotypic mutations in birds have been reported across various groups, with numerous types of variations recognised (e.g., Gross 1965, Everitt & Miskelly 2003, Urcola 2011, van Grouw et al. 2011, van Grouw 2014, Missagia et al. 2016, Pradhan & Shrestha 2023). Cases of birds with aberrant plumages, in particular, have been frequently documented in specialised literature (van Grouw 2012,

Corrêa et al. 2017, Petry et al. 2017). Such plumage anomalies, including leucism and albinism, often compromise an individual's ability to survive in the wild by increasing visibility to predators, reducing camouflage, in the case of complete albinism, even impairing vision due to the absence of melanin in ocular structures, which causes light sensitivity and reduced visual acuity (Kirkpatrick et al. 1990, Van Grouw 2013, Konter 2015). Additionally, these individuals may suffer from reduced social acceptance within their own species, affecting mate selection and overall fitness (Koparde et al. 2014, Araújo-Silva et al. 2023).

Deformed beaks can manifest in various forms, including crossed mandibles, downward-curved upper and/or lower mandibles, upward-curved upper and/or lower mandibles, or elongated mandibles that are often curved downward (Craves 1994). Such deformities can pose significant health risks by impairing a bird's ability to feed and groom effectively (Van Hemert et al. 2012, Gorosito et al. 2016). Additionally, these deformities may result from epizootic conditions such as Avian Keratin Disorder (AKD), which can be caused by *Picornavirus* (Zylberberg et al. 2021).

In Algeria, there have been rare individual reports of avian deformities, including cases of leucism in the White-crowned Wheatear *Oenanthe leucopyga*, the House Bunting *Emberiza sahari*, the Eurasian Jackdaw *Coloeus monedula*, the Common Blackbird *Turdus merula* and Great Grey Shrike *Lanius excubitor*

(Chedad et al. 2019, Chedad et al. 2022, Haddad 2024, Mairif & Hamicha 2025). Additionally, albinism has been observed in hybrid sparrows *Passer domesticus* × *hispaniolensis* and the African Chaffinch *Fringilla spodiogenys* (Chedad et al. 2021, Mairif & Benzohra 2024).

While avian deformities are documented globally, comprehensive records of such deformities in Africa remain scarce. Most existing studies focus on specific bird species or particular abnormalities. In Algeria, deformed birds have been opportunistically observed across various locations and species. This study provides records of avian deformities in Algeria and represents the first effort to compile data on this important issue within the country.

MATERIALS AND METHODS

Study Area

Observations and ornithological trips were conducted across Algeria, the largest country in Africa. Algeria is located in the northern part of Africa with a 1,200 km Mediterranean coastline. Positioned between latitudes 19.5°N and 37.5°N and longitudes 9°W and 12°E, the country features diverse topography, with altitudes ranging from sea level to over 3,000 meters. The landscape consists of mountain chains, depressions, and plateaus, including the Tellian and Aurès chains, as well as Saharan depressions. These varied elevations create a gradient of climates

and vegetation zones, transitioning from temperate environments along the coast to arid desert conditions in the south. The climate and vegetation vary significantly across Algeria, influenced by its geographical features and atmospheric phenomena. This variation leads to a mix of temperate and desert climates, contributing to diverse biotope compositions and ecosystems (Amrouni et al., 2022; Huebner and Fadhil Al-Quraishi, 2024). The country features a variety of habitats, including coastal regions, mountains, forests, wetlands, and desert areas, which support a rich biodiversity of bird species.

Data collection

The study utilised observations and photographs collected by members of the Algerian Wildlife Watchers Association over ten years. These observations were conducted during ornithological trips across various provinces in Algeria. The association members, who are experienced wildlife watchers, documented bird species and any deformities observed in their natural habitats over a ten-year period. Members conducted regular field trips to various habitats, including forests, wetlands, coastal areas, and desert regions. Each trip involved observation and documentation of bird species present in the area.

Photographs of birds exhibiting deformities were taken to provide visual confirmation and for further analysis. High-resolution cameras and binoculars were used to ensure accurate identifica-

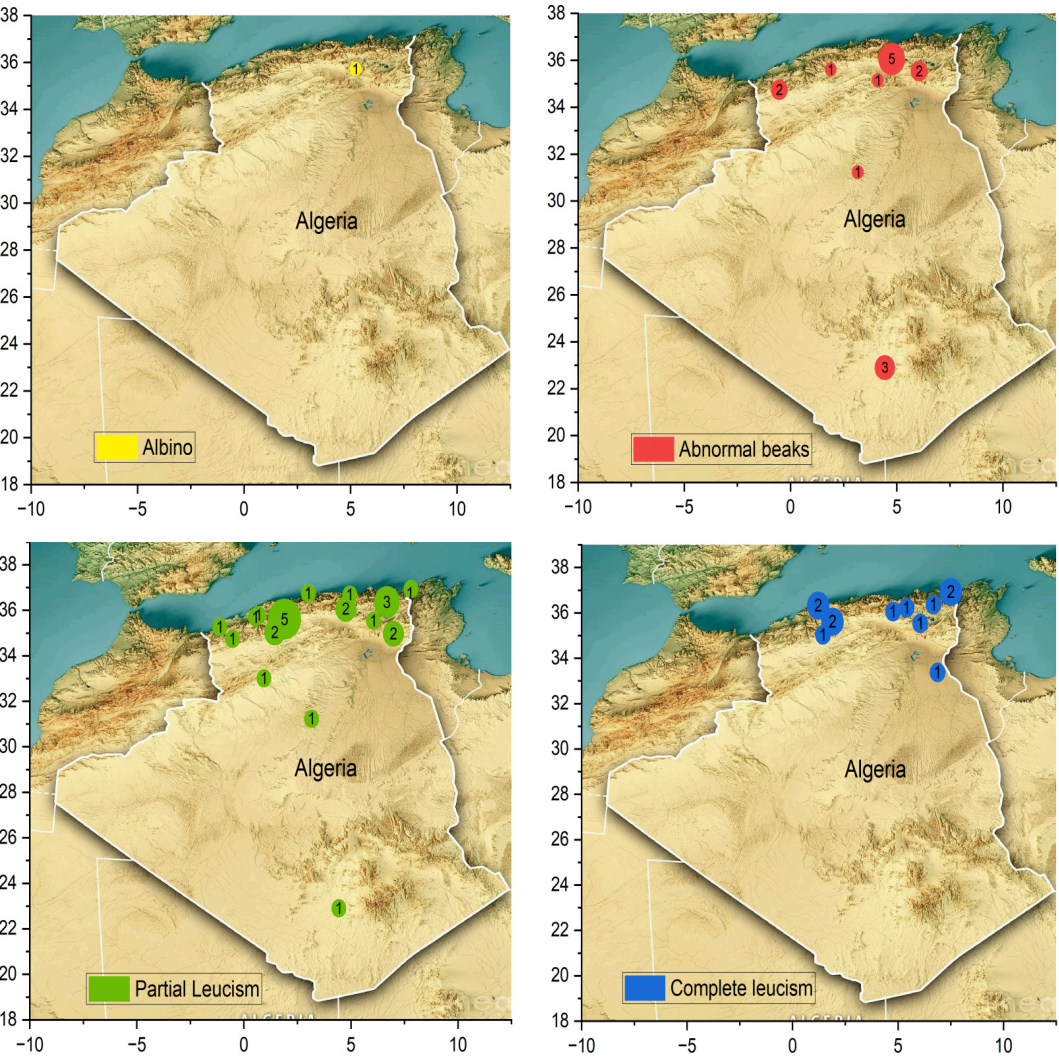


Figure 1. Distribution of Avian deformities recorded in Algeria

tion and documentation. Details such as species, location, and type of deformity were recorded systematically.

Due to the opportunistic nature of the field observations conducted during this study, detailed records of all individuals across the various species observed were

not collected. As a result, we are unable to estimate the proportion of abnormal individuals across the species observed during the numerous trips undertaken.

The observations reported here are therefore qualitative, highlighting noteworthy cases of abnormalities when



Figure 2. A–E: representative abnormalities in Algerian birds (**A:** Beak deformity in a Common Kestrel *Falco tinnunculus* in El Achir, 36°03'36"N 4°38'49"E, May 2021, photo by Bachir Harzallah. **B:** Beak deformity in a White-throated Bee-eater *Merops albicollis* in Tamanrasset, 22°42'33" N 5°37'38" E, December 2021, photo by Belkacem Aimene Boulaouad. **C:** Complete leucism in a Common Raven *Corvus corax* in Bougaa, 36°20'51.3"N 4°59'35.1"E, November 2016, photo by Bachir Harzallah. **D:** Partial leucism in a Little Stint *Calidris minuta* in Tissemsilt, 35°34'14.0"N 1°54'38.2"E, April 2018, photo by Mohamed Mairif. **E:** Albinism in an African Chaffinch *Fringilla spodiogenys* in Méliana, 36°18'26"N 2°11'05"E, October 2022, photo by Mohamed Nadjib Benzohra. **F:** Melanism in a Little Owl *Athene noctua* in Oran, 35° 41' 28.00" N 0° 38' 30.01" E, August 2022, photo by Ibrahim Cheikh.

they were encountered. Future, more structured monitoring or dedicated field studies would be necessary to assess the frequency and patterns of abnormalities within the populations of interest.

The deformities were categorised into the following types (Fig.2):

Abnormal Beaks: Deformations or unusual growth patterns in the beaks of birds (Valdebenito et al. 2018).

Leucism: Congenital absence of melanocytes in some or all feather follicles, which leads to white or pale feathers but does not affect pigmentation in the skin or eyes. Contrary to popular usage, leucism does not refer to diluted or washed-out plumage, which is often the result of other mutations (van Grouw, 2021). It was further categorised into:

- Complete Leucism: All feathers are white due to the absence of melanin, though the eyes and soft parts retain normal colouration.
- Partial Leucism: Only some feathers are white; the rest have normal colouration. White feathers are often symmetrically distributed.

Progressive greying: A distinct and common condition where birds are born normally pigmented but gradually lose melanin in their feathers as they age, resulting in increasing whiteness over time. Unlike leucism, the pigment loss progresses with successive moults and may begin in a localised area (Corrêa 2020, van Grouw, 2021).

Albinism: Total absence of melanin, resulting in white feathers, pink eyes, and pale skin. It is caused by mutations that

block melanin production (van Grouw 2006, 2021).

Melanism: An overexpression of melanin pigments, especially eumelanin, leading to a bird appearing much darker than usual or even completely black. True melanism is genetically inherited and differs from soiling or feather wear (van Grouw 2017, 2021).

RESULTS

From a total of 50 cases of deformities, 13 cases (26%) of abnormal beaks were documented. These deformities can include a range of conditions such as crossed mandibles, elongated mandibles, and misaligned beaks (Tab. 1).

Leucism was the most frequently observed colouration abnormality, with a total of 34 cases (11 for complete and 23 (partial)). Complete leucism, characterised by a total lack of melanin, was observed in 11 birds (22%), while partial leucism was recorded in 23 birds (46%) (Tab. 1). Only one case of albinism (2%) was recorded during the study, and two cases of melanism (4%) were observed (Fig. 3).

Among the recorded cases of avian deformities, some species were more frequently implicated. The Passeriformes order exhibited the highest number of deformities, with 27 out of the 50 documented cases (54%). Within this order, the House Sparrow *Passer domesticus*, a resident species, showed a notable occurrence of abnormalities, including 2 cases of complete leucism, 2 cases of

Table 1. List of bird species recorded with deformity in Algeria

	Order	Family	Scientific name	Common Name	Abnormal beaks	Complete Leucism	Partial leucism	Albino	Melanism
1	Falconi-formes	Falconidae	<i>Falco tinnunculus</i>	Common Kestrel	1				
2	Columbi-formes	Columbidae	<i>Columba palumbus</i>	Common Wood Pigeon			1		
3			<i>Streptopelia decaocto</i>	Eurasian Collared Dove		4	2		
4	Pteroclidiformes	Pteroclididae	<i>Pterocles orientalis</i>	Black-bellied Sandgrouse	1				
5	Strigiformes	Strigidae	<i>Athene noctua</i>	Little Owl					1
6	Gruiformes	Rallidae	<i>Fulica atra</i>	Eurasian Coot			2		
7	Charadriiformes	Scolopacidae	<i>Calidris minuta</i>	Little Stint			1		
8	Coraciiformes	Meropidae	<i>Merops albicollis</i>	White-throated Bee-eater	1				
9			<i>Merops apiaster</i>	European Bee-eater	1				
10	Passeriformes	Muscicapidae	<i>Oenanthe leucura</i>	Black Wheatear			2		
11			<i>Oenanthe leucopyga</i>	White-crowned Wheatear	1		1		
12			<i>Oenanthe deserti</i>	Desert Wheatear	1				
13		Passeridae	<i>Passer domesticus</i>	House Sparrow		2	2	1	
14		Turdidae	<i>Turdus merula</i>	Common Blackbird			3		
15			<i>Turdus torquatus</i>	Ring Ouzel			1		
16		Alaudidae	<i>Galerida cristata</i>	Crested Lark	1				
17			<i>Galerida macrorhyncha</i>	Maghreb Lark	1				
18		Corvidae	<i>Pica mauritanica</i>	Maghreb Magpie	2				
19			<i>Coloeus monedula</i>	Eurasian Jackdaw			1		
20			<i>Corvus corax</i>	Common Raven	1	1			
21		Emberizidae	<i>Emberiza sahari</i>	House Bunting			1		
22			<i>Corn Bunting</i>	Emberiza calandra	1	1			
23		Laniidae	<i>Lanius excubitor</i>	Great Grey Shrike		1	1		1
24		Fringillidae	<i>Loxia curvirostra</i>	Red Crossbill			1		
25			<i>Linaria cannabina</i>	Common Linnet			1		
26			<i>Chloris chloris</i>	European Greenfinch	1				
27		Hirundinidae	<i>Hirundo rustica</i>	Barn Swallow			2		

28	Anseri- formes	Anatidae	<i>Anas platyrhynchos</i>	Mallard duck		1			
29			<i>Tadorna ferruginea</i>	Ruddy Shelduck			1		
30	Pelecani- formes	Ardeidae	<i>Ardea cinerea</i>	Grey heron		1			

partial leucism, and 1 case of albinism. The Eurasian Collared Dove *Streptopelia decaocto*, another resident species, also presented several occurrences, with 4 cases of complete and 2 cases of partial leucism. The Common Blackbird, also sedentary, had 3 cases of leucism, making it one of the most affected species. The White-crowned Wheatear *Oenanthe leucopyga* had 1 case of abnormal beaks and 1 case of partial leucism. The Black Wheatear *Oenanthe leucura* showed 2 cases of partial leucism.

The Eurasian Coot *Fulica atra*, a species that includes both sedentary and migratory populations, was recorded with 2 cases of partial leucism. Mallard *Anas platyrhynchos* and Grey Heron *Ardea cinerea* were each recorded with one case of complete leucism. Finally, one case of partial leucism was recorded in Ruddy Shelduck *Tadorna ferruginea*.

The bar plot illustrates the relative frequency (%) of observed different phenotypic abnormalities across avian orders. Overall, Passeriformes shows the highest

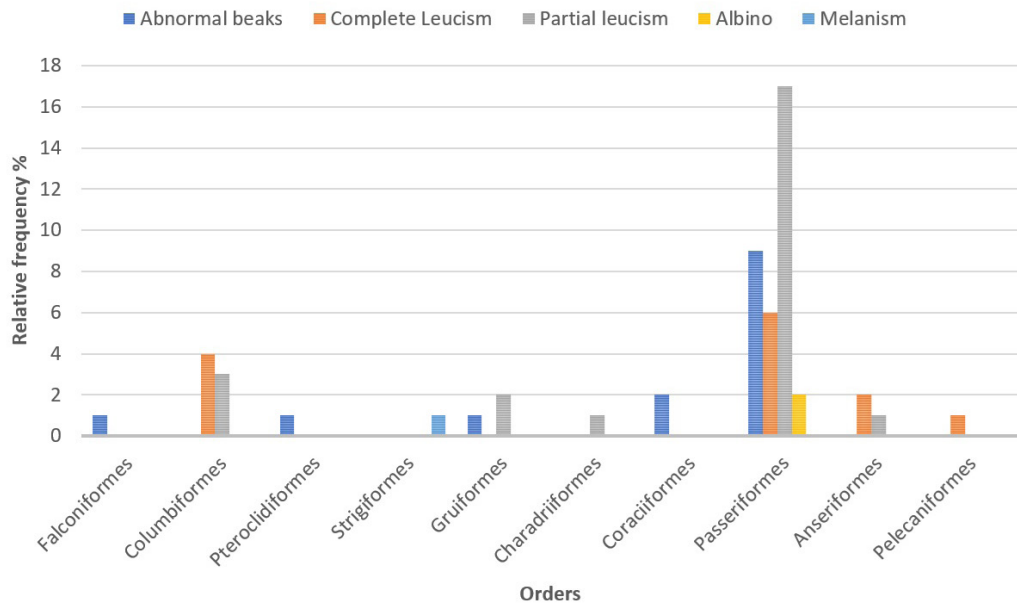


Figure 3. Distribution of Avian Deformities by Order in Algeria

number of abnormalities, particularly partial leucism, followed by notable occurrences of abnormal beaks and complete leucism. This dominance may reflect both the ecological abundance of passerines and higher detectability due to their frequent observation in human-dominated environments. Columbiformes also display multiple types of abnormalities, especially complete leucism. In contrast, the other orders exhibit only rare cases, suggesting either lower susceptibility or reduced observation bias.

DISCUSSION

The observations presented in this study reveal a diverse array of deformities, including abnormal beaks, leucism (both partial and complete), albinism, and melanism. These deformities were observed in a wide range of bird families, reflecting both genetic and environmental factors impacting avian populations in Algeria. The study documented 50 cases of avian deformities across different orders in Algeria. The results provide valuable insights into the prevalence and types of deformities affecting bird populations in the region. Here, we discuss the implications and potential causes of these findings, focusing on the most affected orders: Passeriformes and Columbiformes, specifically found near human settlements. The high prevalence of deformities and colour abnormalities in these orders highlights the need for focused research on them. In Passeriformes, especially Passeridae, Muscicapidae and Turdidae, the diversity

and widespread distribution of deformities and colour abnormalities make them a key group for studying the effects of environmental and genetic factors on bird health. Columbiformes, with their close association with human habitats, provide valuable insights into the impacts of urbanisation and pollution on wildlife.

By understanding the underlying causes of these deformities, conservation efforts can be better directed to mitigate the impacts of environmental stressors and preserve the health of bird populations in Algeria. In this study, the records were found near and far from the human settlements

Albinism has been associated with poor vision and hypoactivity in birds (Lee & Keeler 1951). Chedad et al. (2021) reported a case of a male sparrow in the region of Metlili, with a remarkably whitish colour in addition to three cases of total albinism observed in Algiers. This species was also observed with colour aberrations by Corrêa et al. (2011) in Brazil and van Grouw (2012) from 22 Museum bird collections. In addition, beak deformities were reported by Valdebenito et al. (2018). Colour aberrations in other species of doves were reported, such as Ruddy Ground Dove *Columbina talpacoti*, the Eared Dove *Zenaida auriculata* and the Spotted Dove *Spilopelia chinensis* (Missagia et al. 2016, Rödel et al. 2020, Bora et al. 2024).

Several factors could explain the high incidence of deformities within this order. High species diversity and abundance make Passeriformes naturally prone to

exhibiting a higher number of deformities and therefore a higher probability of observation (Gill 2007). The diverse habitats of Passeriformes and Columbiformes, ranging from forests to urban areas, expose them to different environmental stressors, including pollutants, pesticides, and habitat degradation, which can contribute to genetic mutations and deformities. According to Gorosito et al. (2023), beak deformities increase with urbanisation and flocking behaviour. Additionally, due to their abundance, widespread distribution and the effects of environmental toxicants (Haag-Wackernagel, 1995; Gaston et al. 2003), Passeriformes and Columbiformes are more frequently observed and reported by bird watchers and ornithologists. This higher observation rate can lead to a greater detection of deformities compared to less observed orders (Bibby et al. 2000, Van Hemert 2012). The genetic diversity within Passeriformes could also predispose them to conditions like leucism and albinism, where genetic mutations affecting melanin production are more prevalent (van Grouw 2013). An unusually high prevalence of beak deformities has been observed among Black-capped Chickadees *Poecile atricapillus* and Northwestern Crows *Corvus caurinus* in Alaska and Shiny Cowbird *Molothrus bonariensis* with an elongated maxilla has been reported in Brazil (Handel et al. 2010, Van Hemert & Handel 2010, Purificação 2019). A widespread epizootic of beak deformities consistent with AKD has been documented in dozens of avian species

in North America, caused by picornavirus (Van Hemert 2012, Zylberberg et al. 2021). Izquierdo et al. (2018) studied factors associated with leucism in the Common Blackbird and found that there are more leucistic blackbirds in cities than in non-urban areas. It is also possible that the apparent frequency of leucism in this species is partly influenced by a detection bias. Since males are predominantly black, even minor depigmentation contrasts sharply against the dark plumage, making leucistic individuals visually more conspicuous than in species with lighter or more variegated coloration. Therefore, the higher number of reported cases may reflect greater detectability rather than a true biological prevalence.

While Passeriformes and Columbiformes appeared particularly prone to deformities, various other avian orders were also affected to varying degrees. Observations in Falconiformes and Coraciiformes suggest that deformities such as abnormal beaks may be linked to environmental stressors, including pesticide exposure or nutritional deficiencies, especially in rural and agricultural landscapes. The presence of melanism in Strigiformes, Gruiformes, Anseriformes, and Pelecaniformes could reflect underlying genetic mutations potentially triggered or maintained by environmental pressures such as habitat degradation or pollutant exposure. Nocturnal and elusive species like owls may be underrepresented in observational data, yet their deformities could signal subtle environmental disturbances that are not easily detect-

ed (Mikkola 2013). Similarly, waterbirds such as herons and ducks may accumulate contaminants from aquatic systems, increasing the likelihood of pigment-related abnormalities (Del Hoyo 1996). Leucistic individuals among Charadriiformes suggest that shorebirds, often exposed to polluted wetlands and altered coastal habitats, may also face increasing physiological stress (Piersma & Lindström 2004). Species found in arid ecosystems, like Pteroclidiformes, may exhibit pigment anomalies due to environmental extremes and potential genetic drift in small populations (Winkler et al. 2020). Overall, these deformities in non-urban birds underscore the need for broader ecological surveillance, as they may reflect habitat-specific risks related to environmental quality, chemical exposure, or genetic vulnerability.

The prevalence of different deformities, such as abnormal beaks, leucism, albinism, and melanism, highlights the diverse impacts of environmental and genetic factors on bird populations in Algeria. The high percentage of partial leucism suggests that environmental stressors significantly affect melanin production in birds. Environmental stressors like pollution, habitat destruction, and pesticide use are likely contributing factors to the observed deformities. Birds in urban and agricultural areas are particularly vulnerable to these stressors (Ohlen-dorf et al. 1986). Genetic predisposition plays a crucial role in the occurrence of conditions like leucism and albinism (Alby et al. 2023). The documentation of these

conditions across various orders underscores the importance of genetic diversity studies in avian populations (van Grouw 2006, 2014). Understanding the causes and prevalence of avian deformities is essential for conservation efforts. Protecting bird habitats from pollution and other environmental threats can mitigate the occurrence of deformities (BirdLife International 2018).

Individuals with aberrant colours are often at a disadvantage in the wild. Their colouration makes them more visible to predators, limiting their chances of survival. Furthermore, the predators themselves may be less effective at hunting because their atypical colouration makes them more easily detectable by their prey (Tissier 2020). Even within their own species, these individuals can be rejected or attacked, making reproduction difficult (Withgott & McMahon 1993). It is important to note, however, that some individuals may show a temporary white colouration, which disappears after moulting (Nogueira & Alves 2011). Due to the opportunistic nature of our observations, it was not possible to determine whether such cases represented permanent or temporary colour aberrations.

The high occurrence in sedentary species like the House Sparrow, Eurasian Collared Dove, and Common Blackbird could indicate localised environmental issues affecting these populations. Conversely, the presence of deformities in migratory species suggests that these issues may also extend beyond local environments, potentially affecting these birds during

migration or in their breeding and wintering grounds. Further research is needed to explore the underlying causes and mechanisms leading to these deformities.

This study, while providing valuable insights into the prevalence of avian deformities in Algeria, has several limitations that should be acknowledged. First, the observational nature of the study means that the data collected are based on reported sightings, which may not capture all cases of deformities, especially those in remote or less-observed areas. The absence of a genetic analysis in this study also limits our understanding of the hereditary nature of these deformities. Environmental factors contributing to the deformities, such as pollution or pesticide use, were not systematically measured, and therefore, causal relationships cannot be conclusively established. Lastly, the absence of a longitudinal study means that the impact of environmental changes over time on bird deformities could not be assessed.

CONCLUSION

This study provides the first comprehensive overview of avian deformities observed across Algeria over ten years, documenting 30 bird species affected by various anomalies, including abnormal beaks, leucism, albinism, and melanism. The diversity of deformities recorded across different avian families and regions suggests a complex interplay of genetic factors and environmental influences, such as pollution, habitat degradation,

pesticide exposure, and possibly climate change. These deformities are more than physical irregularities: they serve as important bioindicators of ecosystem stress and the broader environmental health of the regions in which these birds live. The findings underscore the need for increased ecological monitoring and more targeted studies to better understand the underlying causes, whether hereditary, pathological, or induced by anthropogenic pressures. Moreover, raising awareness about these deformities can inform conservation efforts and public engagement in biodiversity protection. Future research should prioritise the integration of genetic analyses, toxicological screening, and habitat assessments to explore causal links and long-term trends. Ultimately, this work contributes to a growing body of knowledge on avian health in North Africa and highlights the urgency of implementing effective conservation strategies to mitigate ongoing threats to Algeria's avifauna and its ecosystems.

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Communal post-breeding roost of Lesser Kestrels *Falco naumanni* and Common Kestrels *Falco tinnunculus* in southern Kosovo

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Abstract

Raptors display a variety of social behaviours. Species like the Lesser Kestrel *Falco naumanni* engage in social behaviour during both the breeding and post-breeding periods, forming communal roosts. Other species, such as the Common Kestrel *Falco tinnunculus*, exhibit a more solitary lifestyle, displaying territorial behaviour towards conspecifics throughout the year, rarely forming large aggregations. In this study, we present observational data from a communal roosting site of the two kestrel species in Kosovo. The aggregation was predominantly comprised of Lesser Kestrels with up to four Common Kestrels joining the roost. The kestrels gathered around sunset at the roosting site and emerged 15-20 minutes before sunrise in the mornings. Lesser Kestrels exhibited higher levels of aggression, frequently displacing their congeners from the core roosting area. The site hosted over 50 birds and represents the first documented occurrence of the Lesser Kestrel in Kosovo and the first description of a communal post-breeding roost of the two kestrel species.

Keywords: interspecific interactions, Balkans, raptor ecology, pre-migratory roosts, intermittent migration

INTRODUCTION

Communal roosting is a well-documented phenomenon among some kestrel species. For instance, Lesser Kestrels *Falco naumanni* are known for forming large aggregations throughout the breeding and non-breeding season. They are colonial breeders (Minias et al. 2009) and migratory birds, breeding in southern Europe and wintering in sub-Saharan Africa (Sarà et al. 2019, Orta & Kirwan 2020). Their migration takes place from early August to early October, peaking in mid-September (Bounas et al. 2016a). Before migrating to their wintering grounds in Africa, Lesser Kestrels undertake staging movements to specific areas that may also be located in the opposite direction of the primary migration route. This behaviour is called intermittent or intermediate migration (Sarà et al. 2014). At the pre-migration roosts, the Kestrels engage in communal roosting and foraging (Newton 2008). Such pre-migratory roosts are known for many countries of the Balkan, including Greece, Macedonia and Albania (Bounas et al. 2016b). Albania harbours one of the most important roosting sites for this species in south-eastern Europe. In the Drino Valley, 4,000 to 6,000 individuals roost together on power lines each year (Minias et al. 2009), although the breeding population in Albania has declined to just 0-20 breeding pairs (Burfield & Bommel 2004). During the pre-migration period, Lesser Kestrels mainly feed on large species of Orthoptera and Coleoptera (Krištín et al. 2020). It is com-

monly stated that the abundance of invertebrates is the main factor in selecting communal roosting sites, as it allows individuals to meet energy requirements for moulting and building up fat reserves for long-distance migration (Olea et al. 2004, Sarà et al. 2014). As pre-migration roosts attract massive aggregations of Kestrels on a small space, these pre-migratory areas are of great importance for conservation (Krištín et al. 2020).

The European Lesser Kestrel population underwent severe decline in the 20th century (Minias et al. 2009, Iñigo & Barov 2010) and the species even became extinct in Austria, Slovenia and Slovakia (BirdLife International 2024). The population decline was mainly attributed to the transformation of herbaceous and cereal crops into intensively used, irrigated land (Donázar et al. 1993, Catry et al. 2013). Together with pesticide use, this led to a reduction in food availability, particularly of large orthopterans (Aparicio et al. 2023). As a result of rigorous conservation efforts, the population has increased since the year 2000 and the Lesser Kestrel was downlisted from “vulnerable” to “least concern” in 2011 (BirdLife International 2011). However, since 2012, the population trend has reversed again, with numbers decreasing, particularly in Spain (Aparicio et al. 2023). In Kosovo, there is insufficient data on the breeding status and occurrence of the Lesser Kestrel. The few observations of the Lesser Kestrel are limited to occasional, random sightings, predominantly in August during the pre-migratory period, which are

not sufficiently supported by evidence (<https://observation.org>, accessed on 17/11/2024). In other databases, such as eBird and GBIF, the Lesser Kestrel is not listed for Kosovo (<http://www.ebird.org>, accessed on 12/12/2024; (GBIF.org (12 December 2024) GBIF Occurrence Download <https://doi.org/10.15468/dl.mqkd8k>)). Despite the lack of documented breeding attempts, it is plausible that undocumented breeding colonies exist within the country, particularly as the species is common across several areas of the Republic of North Macedonia bordering Kosovo to the south (Birdlife International 2011).

Unlike the Lesser Kestrel, the Common Kestrel *Falco tinnunculus* is more frequent and widespread. It is distributed across the entire West Palearctic (Orta et al. 2020). Common Kestrels are partial migrants, with long- and medium-distance migration occurring in northern European populations, while southern and western European birds are sedentary (Costantini & Dell’Omo 2020, Morganti, M. 2021). In northern populations, migration begins in September and October, while juvenile dispersal begins earlier in August. Southern populations of the Common Kestrel prey on large insects but consume a substantially higher amount of vertebrates in contrast to Lesser Kestrels (Van Zyl 1994, Orihuela-Torres et al. 2017). During the breeding season, both sexes of Common Kestrels show aggression towards conspecifics, defending their territories. This aggressive intraspecific behaviour is maintained during the non-breeding season,

when family associations break up and the Kestrels become solitary (Wiklund & Village 1992).

During a summer school programme focused on the fauna of Kosovo, conducted by the University of Konstanz (Germany) in late summer 2024, we discovered and observed a mixed roost of Lesser and Common Kestrels in the country’s southern region. This represents the first documented report of Lesser Kestrels in Kosovo. The presence of both species provided the opportunity to gather new information about the intra- and inter-specific roosting behaviour.

MATERIALS AND METHODS

Over a period of two weeks (22.08.2024-03.09.2024), we observed the kestrels emerging from the roosting site in the morning and arriving in the evening. Observations were conducted every 1-3 days. Emergence was observed from 5:30 to 6:30 am and arrival from 6:30 to 7:30 pm. Kestrels were counted during emergence, while species, sex and age ratios were determined in the evening. Observations were carried out from a distance of 60 m using binoculars and a Kowa TSN-773 scope combined with TE-11WZII lens and TSN-EX16 1.6x extender. Photos of the birds were taken from an elevated position, i.e. the 3rd floor of a former barrack building with a Nikon D500 and Tamron 150-600 mm g2 telephoto lens.

After the emergence counts, the ground underneath the roost trees was examined

for shed feathers. They were collected and subsequently identified by comparison with comprehensive feather collections on FEATHERBASE (<https://www.featherbase.info/de/home>, accessed on 11/09/2024).

RESULTS

The roosting site is located in southern Kosovo at the Prizren Innovation and Training Park (ITP) (42.218249, 20.754337) (Fig. 1A). It comprises 52 buildings, including 23 former barracks, on the 39-hectare former military site. Between the scattered buildings and paved surfaces are green areas, groups of trees and scrubland. The site is enclosed by a fence and, due to the restricted access, it is not frequented by many people and therefore human disturbance of local fauna is minimal. The ITP is surrounded by residential and commercial areas to the north, east and south. To the west,

there is open terrain, comprising the lower slopes of the Sharr Mountains. This area is characterised by low deciduous forests (mainly *Quercus*), scrubland, extensive pastures and fallow land (Fig. 1A). The open sub-Mediterranean grassland and herbaceous areas inside and outside the ITP are rich in insects and harbour numerous species of large orthopterans (e.g. *Calliptamus italicus*, *Oedipoda caerulescens*, *Decticus albifrons* and *Pachytetrachis gracilis*), including suitable prey for the Lesser Kestrel.

As a roost site, the Kestrels chose a row of black pines *Pinus nigra* adjacent to the former barracks (Fig. 1B). The roost size increased from 33 Kestrels on the 23rd of August to a maximum of 53 individuals by the 3rd of September (Fig. 2A). Most of the individuals were Lesser Kestrels. Additionally, an average of two (maximum four) Common Kestrels joined the roost almost every day, likely originating

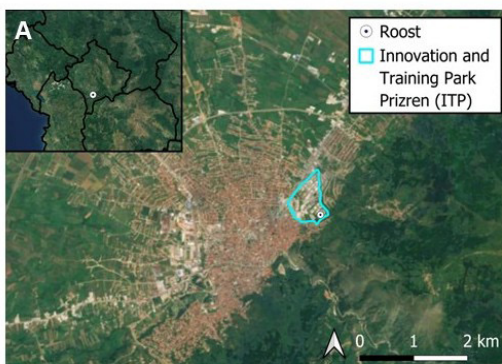


Figure 1: (A) The mixed communal roost of Lesser and Common Kestrels is located in Southern Kosovo on the premises of the Innovation and Training Park (ITP) in Prizren (42.218249, 20.754337). Background image: Sentinel-2 satellite data (© ESA, 2024). (B) The Kestrels used a row of black pines (*Pinus nigra*) adjacent to a former barracks as sleeping trees.

from a local family group. In the morning, the Kestrels began to emerge from the trees 15 to 20 minutes before sunrise. The Common Kestrels were among the first individuals to leave the roost. They were consistently observed leaving the site with vocalisation, which facilitated field identification. They immediately left the vicinity of the roost and different individuals flew off in different directions. The emergence pattern of Lesser Kestrels was highly dependent on whether there were any disturbances in and around the roost at the time of emergence. Corvids, such as Eurasian Jays *Garrulus glandarius* or Eurasian Magpies *Pica pica*, actively chased away the Lesser Kestrels, whereas other species, such as Eurasian Collared Doves *Streptopelia decaocto*, primarily caused disturbance within the roost, both resulting in a sudden simultaneous departure of numerous Kestrels. Without any apparent disturbance, the Lesser Kestrels left in groups ranging from single individuals to flocks of approximately 30

birds. Following emergence, the Lesser Kestrels gathered on nearby power lines to the east, adjacent to the ITP grounds. They continued as a cohesive group for several hours after sunrise before leaving the vicinity of the roost site.

In the evening, arrival peaked around sunset. However, some single individuals and smaller groups of both species were already present in the vicinity of the roost a few hours before sunset. Subsequently, larger flocks of up to 15 birds continued to arrive at the site, until 30 minutes after sunset. Arriving birds lingered in the surrounding area of the roost site, circling above the site and perching on the roost trees as well as surrounding structures. Within the roost, we observed frequent competition for perching sites, with interspecific conflicts often resulting in the displacement of Common Kestrels, which subsequently settled down on the shutters of nearby barracks.

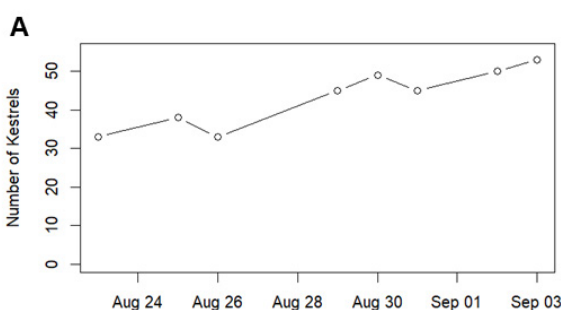


Figure 2: (A) Emergence counts for the communal roost. The kestrels were counted each morning between 5:30 and 6:30 am. The count data include both Lesser and Common Kestrels. (B) Juvenile and adult female Lesser Kestrel in the roost trees.

DISCUSSION

Our observations provide the first reliable evidence of Lesser Kestrels in the Republic of Kosovo, thereby extending the known distribution range of the species to a little-explored region of southeastern Europe. Additionally, it is the first documented case of a mixed roost of Lesser and Common Kestrels. The aggregation of both species at the roosting site allowed us to examine behavioural patterns and interspecific differences. The presence of Common and Lesser Kestrels highlights that larger flocks of kestrels require careful observation, as distinguishing between the two species can be difficult in the field, especially in poor light.

Lesser Kestrels are known to form large aggregations throughout the year (Olea et al. 2004, Bounas et al. 2016b). After the breeding season, they flock at pre-migratory roosts located in areas with abundant and accessible prey (De Frutos & Olea 2008, Sarà et al. 2014). Besides conspecific aggregations, mixed roosts with Amur Falcons *Falco amurensis* and Red-footed Falcons *Falco vespertinus* have also been reported (Kopij, 2012; Topić et al., 2019), likely coinciding with high local prey abundance. A higher dilution effect may also favour the formation of mixed roosts. In our study, the roost predominantly comprised Lesser Kestrels. A maximum of four Common Kestrels (one male, one female and two juveniles) suggests that the Common Kestrels belonged to one resident family group opportunistically joining the roost. Common Kestrel families remain co-

hesive for several weeks after the young have fledged. During that time, parental care continues, including the training of hunting skills. Even after the parents stop feeding the juveniles, they typically remain close to the nest, rarely dispersing more than one kilometre during the day (Boileau & Bretagnolle 2014). Beyond this family cohesion, little is known about the social behaviour of Common Kestrels, which are usually considered solitary and territorial (Village 2010). There are cases of colonial breeding Common Kestrels across Europe and North Africa (Ille et al. 2002, Dietzen 2016, Tulis et al. 2017), sometimes in association with Lesser Kestrels. However, most of the studies focus not on social interactions, but on different aspects of the breeding biology. Bustamante (1994) reported such a case, where both species bred together in a mixed colony. In that instance, aggressive interactions were either allospecific or among Lesser Kestrels, this being consistent with our observations. The departure of the Common Kestrels following a conflict over a perching site may reflect the generally more solitary behaviour of this species.

Communal roosts of Lesser Kestrels are well known and documented in many parts of southeastern Europe. Despite the breeding range being restricted to some countries, i.e. Greece, Albania, Croatia and Bulgaria (Culina et al. 2013, Gradev et al. 2015, BirdLife International 2024), Lesser Kestrels regularly appear in other countries during autumn migration (Saveljić & Jovičević 2015, Topić et al. 2019). Ring recoveries and data from tagged Lesser Kestrels

have shown that individuals travel long distances, even in the opposite direction of migration, in order to reach pre-migratory roosts (Olea et al. 2004). Given that intermittent migration mainly occurs between early August and early October with a peak in mid-September (Bounas et al. 2016a), and that the number of birds present at the roosting site increased over the course of the observation period, the aggregation of Kestrels can probably be explained as pre-migratory gathering. The area around the roost displays a high abundance of Orthopterans, which may be the reason for the choice of this roosting site. Some grasshopper species, such as the Common Pincer Grasshopper *Calliptamus italicus*, tend to form high population densities (as evidenced by observations made in 2023 in Krivenik, near Hani I Elezit, in southern Kosovo). The Lesser Kestrels, which mainly feed on large crickets and grasshoppers during the pre-migration period (Sarà et al. 2014, Krištin et al. 2020), exploit this abundant food source in order to fill their energy reserves. Observations of large numbers of Kestrels from the 2023 summer school programme, the year before our study, support the assumption that the identified roost is used every year. Unfortunately, in 2023 the Kestrels were neither counted nor identified at the species level, but since Kestrels usually show high roost fidelity (Olea et al. 2004, Riegert & Fuchs 2011), it may reasonably be assumed that the same phenomenon occurred the year before. Because the pre-migration period is a sensitive time for Lesser Kestrels, during which they are compelled to fuel up

for the energy-consuming flight to their wintering grounds (Martin et al. 2007, Sarà et al. 2014), localising and protecting such sites is of major importance for conserving this species (De Frutos & Olea 2008). Moreover, autumn pre-migration aggregations could service as a guide in the search for undiscovered breeding colonies, demonstrating the need for more rigorous field research in order to extend knowledge of the breeding distribution of the Lesser Kestrel in southeastern Europe.

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First genetic survey on the Montagu's Harrier *Circus pygargus* breeding population in Italy

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ABSTRACT

Investigating genetic variability and differentiation in target populations of conservation concern is pivotal, as poor genetic variability may further threaten their survival and persistence over time. Here we present the first genetic data for the Italian breeding population of the Montagu's Harrier *Circus pygargus*, a declining migratory raptor species typical of steppe and agricultural landscapes, ranked as vulnerable at the national level. We analyzed four mitochondrial genes, the cytochrome oxidase gene (*COXI*), control region (*D-loop*), 16S RNA subunit gene (*16S*), and NADH dehydrogenase 2 gene (*ND2*), in six individuals from central Italy to estimate their phylogenetic relationships with European populations and assess local genetic variation. We recorded low genetic nucleotide diversity ($\pi = 0.0009$), but relatively high haplotype diversity ($h = 0.8$) compared to Central European populations and a close phylogenetic relationship of Italian Montagu's Harriers with both western and eastern European populations. This study can serve as a baseline to study genetic variability and conservation of this vulnerable raptor species in Italy.

Keywords: Accipitridae, breeding population, *Circus pygargus*, migration, mitochondrial DNA.

INTRODUCTION

Assessing genetic variability in target populations of conservation concern is important to detect limited genetic variation (e.g. Frankham et al. 2002). Low genetic variability can further threaten the survival and persistence of populations already affected by anthropogenic threats or in decline (e.g. Lande 1998), making their conservation even more challenging. Conservation efforts should therefore focus on reducing both direct and indirect human threats while promoting the maintenance of genetic variability and structure among populations. Raptors represent one of the most threatened groups of birds (Buechley et al. 2019), with 52% of global species in decline (McClure et al. 2018). Among them, migratory populations are especially vulnerable (Bildstein 2006; De Pascalis et al. 2020), mainly because of the high mortality they often experience during hazardous long-distance migratory journeys (Strandberg et al. 2009; Klaassen et al. 2014).

The Montagu's Harrier (*Circus pygargus*) is a long-distance migratory raptor species typical of steppe habitats and open agricultural landscapes, which is declining across its range because of habitat loss and fragmentation (Corbacho et al. 1997; Butet & Leroux 2001) and other human-related threats (De Pascalis et al. 2020). It breeds throughout most of the Western Palearctic and part of the Maghreb in North Africa (Garrido et al. 2021) and extends as far East as Central Asia (BirdLife International

2024). In the Western Palearctic, the largest concentration of Montagu's Harriers occurs in Spain and France (e.g. Soutullo et al. 2006), accounting for approximately two-thirds of the entire European population (excluding Russia: Simmons 2000). Within this region, 45–90% of breeding pairs utilize cultivated crops as their nesting grounds. Being a ground-breeding species, it is highly susceptible to impacts arising from harvesting activities and land-use changes (Simmon 2000; Limiñana et al. 2006; Gameiro et al. 2024), particularly in Europe where nearly 40% of the land area is occupied by farmlands (Rigal et al. 2023).

In Italy, the Montagu's Harrier has a fragmented distribution across several central-northern regions (Brichetti & Fracasso 2018, Ravasini 2022; Fig. 1). Breeding nuclei are present in Emilia Romagna, Tuscany, northern Latium and the hilly areas of western Marche (Morelli et al. 2012, Ravasini 2022). Other breeding pairs have also been reported in the Po plain and North-Eastern areas, whereas it is more localized and/or with discontinuous breeding in Piedmont, Sardinia and Apulia (Ravasini 2022). At the country level, the breeding population is estimated at 260 to 380 breeding pairs (Ravasini 2022) and is ranked as vulnerable (VU), due to the reduced number of mature individuals and the presence of threats, such as those linked to cereal and fodder threshing operations, destroying nests (IUCN RedList - Rondinini et al. 2022).

Previous satellite telemetry studies have identified three main migratory

routes at the Afro-Palearctic scale, with Italy crossed by the central route (Trierweiler et al. 2014, Schlaich & Klaassen 2021). Rutkowski et al. (2014) provided a preliminary analysis of genetic variability for Spanish and Polish Montagu's Harrier populations using molecular markers and found a low but significant level of genetic differentiation between these two populations. Successively, Rutkowski et al. (2015) analyzed part of the mitochondrial control region in 158 individuals from Central Spain, Germany, the Czech Republic and Poland and observed high genetic diversity in the European breeding population of Montagu's Harrier. This finding aligns with the species' extensive distribution range, low level of philopatry and high dispersal capabilities (Limiñana et al. 2012; but see Janowski et al. 2018). Garcia et al. (2011) recorded the highest genetic variation in Southern Europe, i.e., where migration routes of individuals from different northern European countries concentrate. No genetic information is available yet from Montagu's Harrier populations breeding in Italy.

As low levels of genetic variability within a population may threaten its survival and viability over time, understanding the level of genetic variation represents an important useful basis for planning effective conservation measures (e.g. Monti et al. 2018). This study aimed to provide the first baseline genetic data on the Italian Montagu's Harrier breeding population. We analyzed fragments of four mitochondrial genes: the cytochrome oxidase gene (*COXI*), control region (*D-loop*), 16S RNA

subunit gene (*16S*), and NADH dehydrogenase 2 gene (*ND2*), in six samples from the breeding population of Central Italy (Tuscany), an area located in the middle of the central migratory route at the Afro-Palearctic scale (Schlaich and Klaassen 2021). We also investigated the phylogenetic relationship of Italian Montagu's Harriers with other European populations and assessed the genetic variation at the local level as a starting point for further sampling campaigns.

MATERIALS AND METHODS

Study area and population monitoring

In Tuscany, the breeding population of Montagu's Harrier is estimated at 50-100 pairs (thus 19.2-26.3% of the entire Italian population), with strongholds mainly located in the Pisan mountains in the north and the hill areas of the province of Grosseto in the south (Tellini Florenzano et al. 1997; Ravasini 2022). Our study was carried out in the latter area (Fig. 1a).

Starting from sites of known historical presence (e.g. Tellini Florenzano et al. 1997), suitable areas for the species were checked from 0 to ca. 1500 m above sea level, from mid-April to mid-late September, between 2020-2023. Further information on the presence of the species was obtained through citizen science records (e.g. www.inaturalist.org; Accessed on 08 March 2020). When the presence of a harrier was recorded, we checked on the area through repeated daily stakeouts (by binoculars



Figure 1. Montagu's Harrier breeding range in Italy and study area in Tuscany. a) The species' breeding range (light yellow) (BirdLife International 2022; IUCN 2023); the shaded grey area shows Tuscany (regional administrative boundaries), while the red triangle is for the study area location within the region. b) Unatched eggs from the same nest found after nest abandonment in 2022, in the province of Grosseto (Tuscany). c) Flight interaction between a breeding male and a juvenile in the proximity of a nesting site in Grosseto's District. All pictures by Marco Brandi ©.

©Leica - Geovid R 10×42) with a minimum hourly interval of four hours, to confirm the utilization of the area by the harriers over time. Checks were repeated twice a week for at least two months before excluding an area. Following Berger-Geiger et al. (2019), nests were located by observing the females landing at the nest site after a food pass. When nesting was ascertained (e.g. Fig. 1b), daily surveys were organized and repeated at least once a week from vantage points at a distance of > 500 m from nest sites, throughout the season (Fig. 1c). The census of the areas and the search for nest sites involved volunteer ornithologists that,

overall, monitored ca. 2000 km² between 2020 and 2023. Eleven breeding pairs/nest sites were found (mean nest sites per year: 6.5 ± 3.6 s.d.) during the study, but only a few of them at the end of the breeding season contained samples suitable for molecular analyses (see below).

Sample collection and molecular analyses

To limit disturbance to breeding individuals, samples were collected at nest sites only at the end of the breeding season, as accessing active nests to collect a

high number of samples would have been challenging and would have required specific authorizations. Biological monitoring samples, collected through non-destructive methods, were utilized to assess mitochondrial lineages and investigate levels of genetic variation at the local level. Three unhatched eggs were found and collected from the same nest that was abandoned in July 2022. Only one of these eggs (randomly chosen) was used for subsequent analyses. After collection, eggs were kept at -20 °C until lab analysis. Five shed feathers from different nests were found and stored in 96% ethanol in 15 ml tubes at room temperature until analyses. In addition, a road-killed individual was found in the surroundings of a territory in 2023 (Tab. 1), and feathers were kept and stored in 96% ethanol for being analyzed.

For the amplification of four genes, the total genome DNA was extracted from six individuals/samples of the nine collected: one unhatched egg, four feathers and

one road-killed individual. These samples come from six different nests from four different localities/sites within the study area. DNA was extracted using the Qiagen Qiaamp Tissue and Blood kit (©Qiagen, Inc, Tokyo, Japan). For feathers, we extracted DNA from blood clots as remnants of the axial artery (when available; Proctor & Lynch 1993, Horvath et al. 2005) or from calamus tips. As for the unhatched egg, the DNA of the adult breeding harrier was extracted by scraping the outside of the egg's shell with a razor blade. After DNA extraction, the 5'end of the mitochondrial DNA control region (hereafter, *D-loop*), cytochrome oxidase I (*COXI*), 16S RNA subunit (16S), and NADH dehydrogenase 2 (*ND2*) genes were amplified using primers already used for Montagu's Harriers and other birds (Hebert et al. 2004; Spicer and Dunipace 2004; García et al. 2011): CIRC RF (5'-CACTAACCGGAGCCCTAGAA-3') and CIRC RR (5'-CATATGTGAGGGCCACCTGT-3') for *D-loop*, BirdF1 (5'-TTCTCCAAC-CACAAAGACATTGGCAC-3') and BirdR1 (5'-

Table 1. Samples of *Circus pygargus* used for this study and collected in the Grosseto District (Tuscany). Acc N: Genbank Accession Number

Collection year	Location	Acc N (COXI)	Acc N (ND2)	Acc N (16S)	Acc N (D-loop)
2021	Site1 – [feather]	OR523521	PQ238359	PQ238358	PQ238361
2021	Site1 – [feather]	OR523526	PQ238359	PQ238358	PQ238360
2021	Site2 – [feather]	OR523520	PQ238359	PQ238358	PQ238360
2022	Site2– [feather]	OR523724	PQ238359	PQ238358	PQ238360
2022	Site3 – [egg]	OR523594	PQ238359	PQ238358	PQ238360
2023	Site4 – [road- killed]	OR523522	PQ238359	PQ238358	PQ238360

ACGTGGAGATAATTCCAAATCCTGG-3') for COXI, 16SAR (5'-CGCCTGTTTATCAAAAA-CAT-3') and 16SBr (5'-CCGGTTTGAAC-TAGATCACGT-3') for 16S, H6313 (5'-ACTCT-TRTTTAAGGCTTTGAAGGC-3') and L5758 (5'-GGCTGAATRGGMCTNAAYCARAC-3') for ND2. PCR reactions were carried out with an Applied Biosystems 2700 thermal cycler in 25 µl mix, including 100 ng of each DNA sample, buffer 10X, 2 mM MgCl₂, 200 µM dNTPs, 0.2 µM of each primer, and one unit of Taq polymerase (©Life Technologies, Waltham, Massachusetts, USA). PCR conditions included initial denaturing at 94 °C for 2 min, followed by 35 cycles of 94 °C for 45 sec, annealing at 50 °C (COXI), 51 °C (16S and ND2) and 53 °C (D-loop) for 30 sec, extending at 72 °C for 1 min, and a final extension to 72 °C for 10 min. PCR products were run by electrophoresis on 1.5% agarose gel, containing 0.5 mg/ml of SYBR gel staining. PCR amplifications were then purified (ExoSAP-IT PCR clean-up Kit, ©Applied Biosystems, Foster City, California, USA) and sequenced through the Sanger method at the BMR Genomics (<https://www.bmr-genomics.it/>, Padua, Italy). Electropherograms were displayed on the Chromas 1.45 software (<http://www.tech-nelysium.com/au>). Sequences were manually corrected and analyzed with the Mega XI software (Tamura et al. 2021).

The dataset analyzed for Montagu's Harrier is shown in Tab. S1. (Supplementary Electronic Material). Nucleotide diversity, haplotype diversity, and number of polymorphic and parsimony-informative sites were computed through DNAsp vers. 5 (Librado & Rozas 2009). Nucleotide pair-

wise genetic divergences were calculated for COXI data using K2P distances and including populations of *C. pygargus* from other European regions (Tab. 2). Median-joining networks were built up for *C. pygargus* Italian haplotypes using all genes (16S+D-loop+ND2+COXI) and for the entire dataset including *C. pygargus* COXI Italian sequences and all available on GenBank, through the TCS software (Clement et al. 2000) based on Maximum Parsimony and graphically visualized by TCBuntu (dos Santos et al. 2016). JModelTEST 3.04 (Posada & Crandall 1998) was used to test the most accurate model of substitution using the Bayesian Information Criterion (BIC) and Akaike Information Criterion (AIC), corrected for the heterogeneity between sites (gamma) (Schwarz et al. 1978). Sequences obtained in this study were aligned with previously published Montagu's Harrier genetic sequences available in GenBank (<http://www.ncbi.nlm.nih.gov>). Since Genbank sequences of *Circus* spp. comprising COXI+16S+Dloop+ND2 are very few (four mitochondrial whole genomes, which did not include *C. pygargus*), a separate dataset involving all *Circus* sequences available in Genbank was created. A phylogenetic reconstruction Bayesian (hereafter, BI) analysis was performed separately using only the COXI and the D-loop, given that they were the most represented genes on GenBank for *C. pygargus*. The BI analysis was performed with MrBayes v.3.12 (Ronquist & Huelsenbeck 2003), using the best model selected for the two genes separated. We used the Markov chain Monte Carlo (MCMC) theory approach in BI, run-

ning 10,000,000 generations, drawing one sample every 1000, running four chains per analysis, and removing the top 25% of the data with the other parameters as the default. The results were checked using Tracer 1.7.2 (Rambaut et al. 2018). We obtained effective sample size (ESS) values > 250 for both genes. We inferred the phylogenetic relationships of the haplotypes related to this study with sequences of all the other *Circus* species obtained from Genbank. Related accession numbers are reported in the phylogenetic trees. Other *C. pygargus*, Western Marsh-Harrier *C. aeruginosus*, Hen Harrier *C. cyaneus*, Long-winged Harrier *C. buffoni*, Swamp Harrier *C. approximans*, Eyles's Harrier *C. teauteensis* (extinct) and Pallid Harrier *C. macrourus*, were included. The Eurasian Sparrowhawk *Accipiter nisus* was used as an outgroup (Tab. 1).

RESULTS

The *D-loop*, *16S*, *ND2* and *COXI* gene portions (2089 bps in total, five polymorphic sites, five parsimony-informative

sites, four for *COXI* and 1 for *D-loop*) for the six samples showed four haplotypes (Tab. 1; Fig. 2). The nucleotide diversity (π) for the whole 2089 bp fragment was 0.0009 and the haplotype diversity (h) was 0.800. The *ND2* and *16S* genes were monomorphic in our population (Accession numbers: PQ238358- PQ238359). Calculating the genetic diversity for the two other genes, *COXI* and *D-loop*, for Italian Montagu's Harriers was $h = 0.948$ and $\pi = 0.002$ for fragment *COXI* while it was $h = 0.4$ and $\pi = 0.0009$ for *D-loop*. Considering all available haplotypes, the nucleotide diversity of *C. pygargus* in Europe (Italy excluded) was similar to Italy for *COXI* ($h = 0.985$, $\pi = 0.002$) and quite higher for *D-loop* ($h = 1$, $\pi = 0.004$). The average number of nucleotide differences among haplotypes was low ($k = 1.47$, Tab. 1). The K2P distances were low for all pairwise comparisons, also between different described *Circus* species (see between *C. aeruginosus* and *approximans*); the distances among different Italian localities/sites were 0.2-0.3%. Genealogical relationships shown in the net-

Table 2. Mean K2P pairwise genetic among Montagu's harrier populations and *C. approximans* and *aeruginosus* for an interspecific comparison. Rate variation among sites was modelled with a gamma distribution (shape parameter = 1). There was a total of 626 positions in the final dataset

<i>Circus</i>	<i>aeruginosus</i>	<i>approximans</i>	pygSWEurope	pygNEEurope
<i>approximans</i>	0.9%			
<i>Pygargus</i> SW Europe	6%	6%		
<i>Pygargus</i> NE Europe	6%	6.6%	0.5%	
<i>Pygargus</i> Italy	6%	6.5%	0.5%	0.5%

works confirmed the close relations between the different localities/sites of South Tuscany, except for the second haplotype found in Site 1 (red circle on the right) that was more separated from the other Italian samples (Fig. 2a). In the *COXI* network including other European sampling localities, the Italian haplotypes are in close relationships with the

other SW European samples sharing the same haplotypes with these populations (Fig. 2b).

Haplotypes showed the same relationships in the phylogenetic reconstructions. Montagu's Harriers from Central Italy were strongly phylogenetically related to other populations from Southern Europe. All *C. pygargus* sequences from Europe

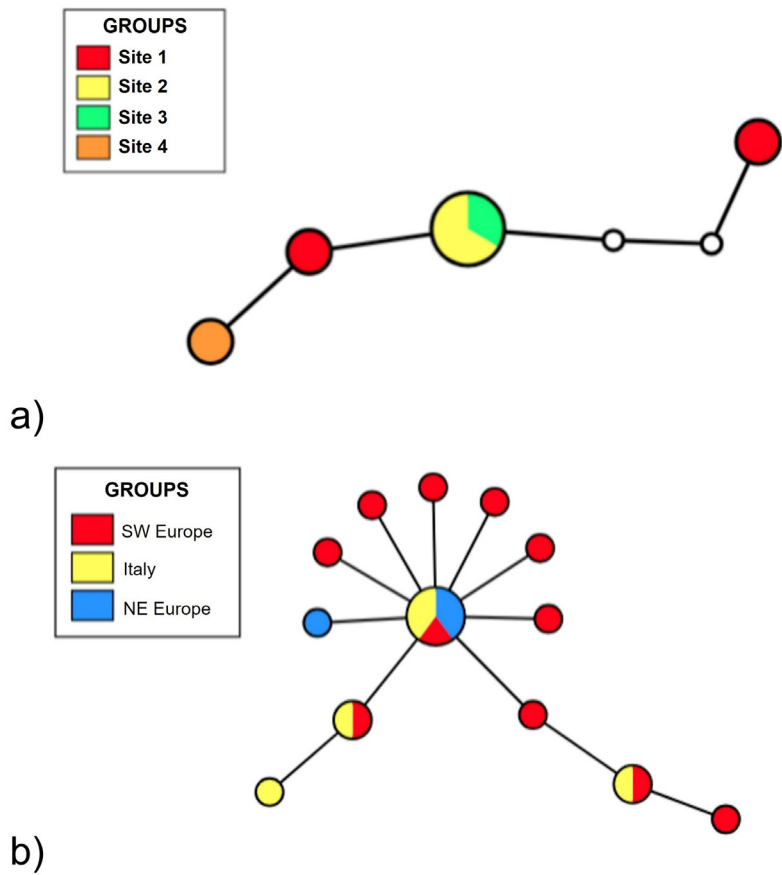


Figure 2. TCS Parsimony Network showing the relationship among a) all mitochondrial (16S+D-loop+ND2+COXI) haplotypes of *C. pygargus* and b) *COXI* data including other available sequences of *C. pygargus* named as in Garcia et al. (2011). Circles represent different haplotypes. Circle size is proportional to the number of samples for each haplotype. Median vectors, which represent extant either unsampled or extinct ancestral sequences, are indicated by white circles.

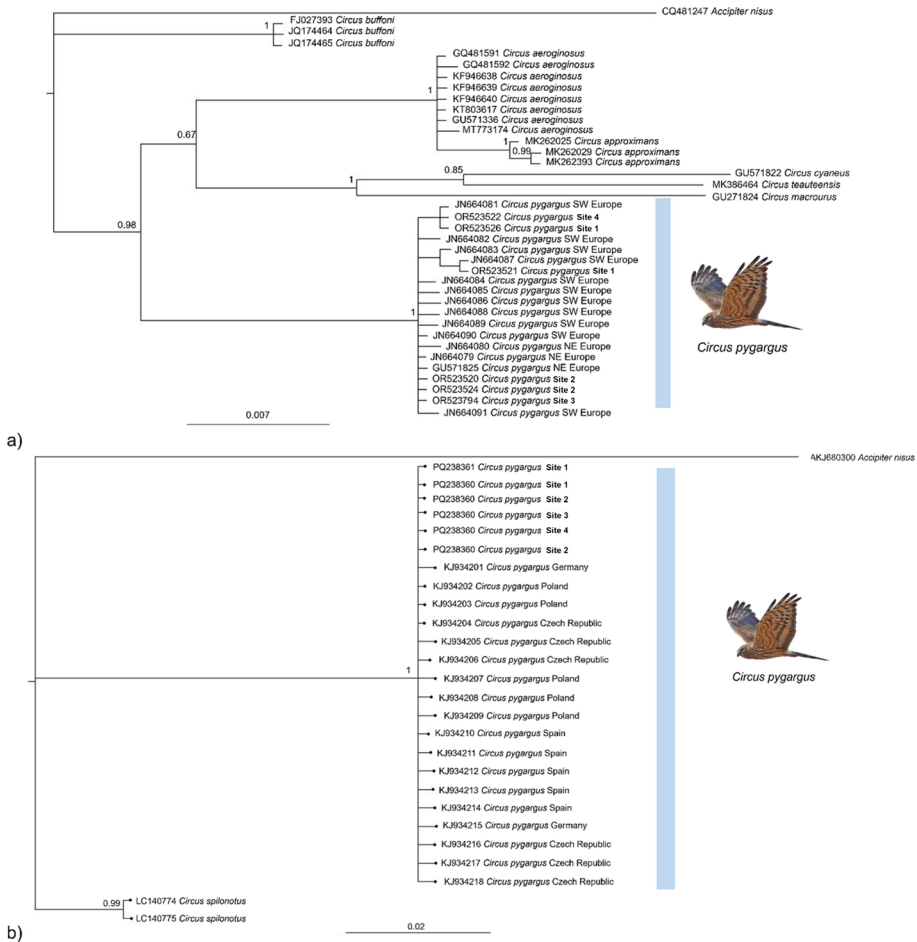


Figure 3. Phylogenetic relationships within the *Circus* species, estimated by a) *COXI* (633 bp) and b) *D-loop* (526 bp) sequences. Posterior probabilities (BI MCMC=10,000,000) are indicated at each node. The blue band indicates the clade *Circus pygargus*. Sequences from this study are red framed. Image of the Montagu's Harrier is by Wikimedia Commons: CC-BY-SA-3.0.

formed a unique highly supported monophyletic clade (Fig. 3).

DISCUSSION

The nucleotide diversity found in this study was lower than that usually reported for both threatened and

non-threatened birds (0.001-0.006; e.g., Bartolomé et al. 2011, Arbabi et al. 2014, Petit-Marty et al. 2021), including *C. pygargus* (García et al. 2011; Rutkowski et al. 2015), for all genes. The only exception was for the *COXI* marker which showed similar values throughout all of Europe. However, pair haplotypes differed by a

single substitution, on average, as found for other Montagu's Harrier populations (Rutkowski et al. 2015). This indicates that there is little variation in the population at the nucleotide sequence level among the sampled individuals. This could be in line with the species' vulnerable status nationwide and the multiple human-related threats currently affecting its populations. On the other hand, however, despite the low nucleotide diversity, haplotype diversity was relatively high in our sample, indicating some variability among them at the population level, similar to values of other European populations (e.g. García et al. 2011; Rutkowski et al. 2015). Despite the small sample size (six) preventing any strong conclusion, these preliminary data suggest that Central Italy is an admixture of different haplotypes of Montagu's Harrier, which may contribute to the genetic variability recorded, comparable with Spanish and French populations. In this sense, our preliminary results may indicate that the Montagu's Harrier population of Central Italy could be an important genetic resource for the species. Different not-mutually exclusive hypotheses may explain such variability: in the Holocene, Southern Europe (including Italy) was mostly characterized by open areas, while most of the rest of Europe was covered with forests (Mitchell et al. 2005). This may have secured remnant populations of *C. pygargus* in these southern regions, contributing to the preservation of their genetic pool (e.g. García et al. 2011). At the same time, the species is known to have a high natal dispersal capacity (for both sexes) potentially favour-

ing high genetic mixing between populations (Limiñana et al. 2012). For example, in a review of five tagging programs in different sites in continental Spain, the percentage of philopatric individuals was lower than 5% (Limiñana et al. 2012). Furthermore, the Italian breeding population is in the middle of one of the main migratory routes at the Afro-Palearctic scale, which is mostly used by central-northern and central-eastern Montagu's Harriers (Schlaich & Klaassen 2021), during both autumn and spring migration (García & Arroyo 1998; Schlaich et al. 2017). This may promote encounters between individuals from even distant populations. All these points probably contribute to explaining the co-presence of genetically different individuals of both Western and Eastern origin.

In contrast, the low nucleotide diversity found would indicate genetically limited variability at the sequence level, thus potentially worrying from a conservation point of view for this population. In the future, polymorphic nuclear markers, possibly on a larger sample size, should be considered together with current results, to deepen knowledge of the current genetic structure of this and other Italian breeding nuclei.

The genetic variability observed in this study suggests a potential for local breeding population increase if good management strategies could be applied. As Tuscany hosts relatively high concentrations of confirmed breeding occurrences compared to other parts of the country (Ravasini 2022), this population may be

highly important for the conservation of this threatened species not only for its size but also from a genetic point of view.

This study provides a preliminary baseline for addressing the challenges related to genetic variability and conservation of the Montagu's Harrier. The Italian Red List classified *C. pygargus* as "Vulnerable" both in 2013 and 2022, suggesting that its conservation status has not improved in the last ten years (Rondinini et al. 2022). The continuing population decline, the decrease in natural habitats and the mechanization of agriculture call for alternative agricultural practices and urgent increased conservation efforts for securing the long-term preservation of this declining ground-nesting species.

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Conflicts Of Interest

The authors have no competing interests to declare that are relevant to the content of this article.

Author Contributions

Conceptualization, E.G. and M.Br.; methodology, E.M., A.V. and M.Ba.; software, M.Ba.; validation, E.G. and M.Ba.; formal analysis, M.Ba.; investigation, E.G. and M.Br.; resources, M.Ba.; data curation, E.M.; writing-original draft preparation, E.M.; writing-review and editing, E.M, E.G. and M.Ba; visualization, M.Ba.; supervision, M.Ba.; project administration, E.G.; All authors have read and agreed to the published version of the manuscript.

Ethics and Animal Welfare

Authors certify that no living animal was used for this research.

Data Availability Statement

All sequences used in this work have been uploaded to GenBank (accession numbers are reported in Tab. 1 and Tab. S1) (Supplementary Electronic Material).

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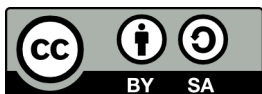
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A photographic approach to monitor spatial dynamics and population trends of Arctic Tern colonies in two touristic bird watching spots in the Westfjords, Iceland.

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Abstract

This study examines the population dynamics and spatial distribution of Arctic Terns in two tourist sites in Iceland's Westfjords: Vigur Island and Súdavík. In 2023, counts revealed 458 terns in Súdavík and 991 in Vigur. We propose a monitoring approach using photography to estimate the population, including non-breeders. Additionally, an interspecies interaction was observed in Vigur, where terns appear to be relocating towards the puffin colony. This behaviour is hypothesised to serve as a defence mechanism against predators, utilising the puffins' frequent, low-altitude flights, as a protective ceiling.

Keywords: Arctic Tern, *Sterna paradisaea*, Iceland, population, ornithology, Atlantic puffin, *Fratercula arctica*

INTRODUCTION

Located just South of the Arctic circle, Vigur Island (geographical coordinates,

WGS 84, -22.828 °E 66.055 °N) is a famous Icelandic touristic place in the Westfjords, known for being home to several iconic bird species, such as the Atlantic Puffin



Fratercula arctica, the Black Guillemot *Cephus grylle*, or the Common Eider *Somateria mollissima*. Amid economic shifts and a declining population, the Westfjords region of Iceland has experienced a downturn in its fishing industry. To counter this, local authorities have promoted tourism and encouraged local entrepreneurship (Vannini 2023). Iceland's blooming tourist industry brings a surge of visitors to regions such as the Westfjords, renowned for their natural beauty and opportunities for wildlife observation, including bird watching. This increase in human presence, while beneficial for the economy, poses significant risks to the delicate balance of local ecosystems (Maher et al. 2022). The impact of tourism is not isolated; it is part of a complex web of global environmental challenges. Human activities, along with global challenges like climate change (Daunt & Mitchell 2013, Paleczny et al. 2015, Bannan et al. 2022) have significantly impacted seabird populations (Croxall et al. 2012). The repercussions of unchecked human activities are many, leading to the degradation of vital habitats and disrupting the breeding cycles of various species, as evidenced by reduced incubation periods (Croxall et al. 2012, Dias et al. 2019). Specifically, the Arctic Tern *Sterna paradisaea* has been adversely affected. Factors such as reduced prey availability significantly impact the breeding success of colonies in a single season (Vigfúsdóttir et al. 2013, Häkkinen et al. 2023). Every year from May to early September, Iceland welcomes 20 to 30% of the world's

breeding population of Arctic Tern (Asbirk et al. 1997), and a notable decline in the Westfjords has already been documented (Petersen et al. 2020). While Arctic Terns are not globally threatened, earning a 'Least Concern' status on the IUCN Red List (BirdLife International 2018), their situation in Iceland is more precarious, classified as 'Vulnerable' on a national level (Náttúrufræðistofnun Íslands 2018, Skarphéðinsson 2018). Consequently, any additional stress, such as tourism, would worsen their population's condition. Human presence is frequently perceived by birds as a predatory threat (Beale & Monaghan 2004a). In Iceland, the collection of eggs is for example permitted until the 15th June (Act No. 64/1994 on the protection, conservation, and hunting of birds and wild mammals).

Although Iceland hosts a substantial population of Arctic Terns and is a critical breeding ground for the species, research focused on understanding these birds in the country remains limited. Arctic Tern populations decline underscores the urgent need for comprehensive studies that can inform effective management, leading to robust conservation strategies. By deepening our understanding of their ecology and the specific challenges they face, research can equip both scientists and local communities with the insights necessary to make informed and effective decisions for the preservation of this species. A first step would be to implement reliable and accurate monitoring methods tailored to the Icelandic context, enabling long-term assessments of the trends in

the targeted populations. This is particularly important in areas where tourism is actively promoted and encouraged.

In the Westfjords, Arctic Terns exhibit flexibility in their nesting choices, often selecting urban areas. Notably, they nest near a supermarket and gas station in Ísafjörður, and close to the town's industrial zone. Similarly, in the village of Suðureyri, part of the same municipality, a smaller colony is found near a playground. These nesting sites are subject to disturbances from non-touristic activities. Conversely, two renowned bird watching spots in the Westfjords, Vigur Island and the Langeyri peninsula in Súðavík (geographical coordinates, WGS 84, -22.991 °E 66.027 °N), are specifically promoted for their bird populations. They provide different levels of protection and various attractions, some related to birds and others not.

Consistent monitoring of these tern colonies is consequently crucial for assessing and improving the effectiveness of their conservation measures. This approach

aligns with the Icelandic Tourist Board (Ferðamálastofa) 2030 policy framework, advocating research-based decision-making in tourism management, including wildlife observation (Ferðamálastofa 2020). Hence, this study details and discusses recent monitoring of the Arctic Tern populations in Vigur Island and Súðavík and emphasises a counting method using photography and GPS data collection for future monitoring of the same populations, with the aim to characterise the spatial and quantitative evolution of Arctic Tern populations.

MATERIALS & METHODS

Study area

This study was carried out in the Westfjord region of Iceland, in two sites, Vigur Island and the Langeyri peninsula in Súðavík (Fig. 1).

The first site, Vigur Island, is a privately owned location renowned as an eider-down farm and a premier bird watching destination. Every year, the island also welcomes, among others, breeding Atlantic

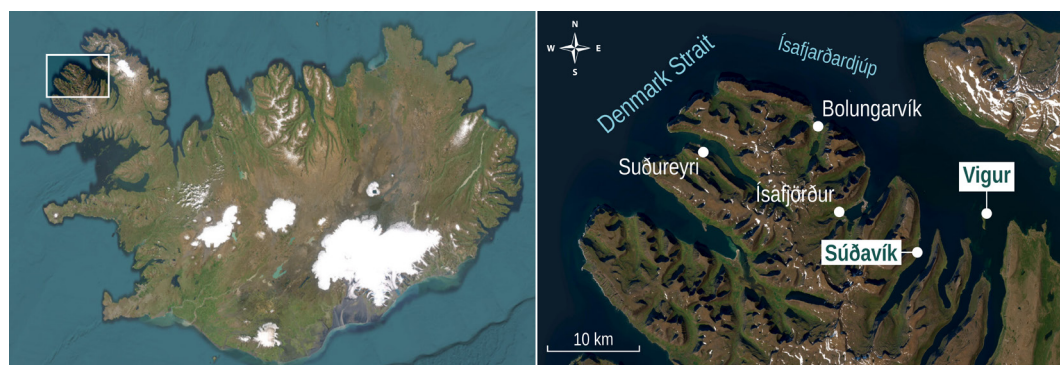


Figure 1. Location of the two investigated sites in Vigur Island and Súðavík, Westfjords, Iceland.

Puffins, Black Guillemots and Arctic Terns. Although primarily tailored for cruise ship tourism, the access to the island is carefully controlled. However, it is important to mention that guided tours in Vigur include visits through the Arctic Tern nesting areas. These tours, which also educate visitors on eiderdown farming and the island's history, invariably traverse the tern colony, following various routes of differing lengths across the nesting grounds (Milesi-Gaches & Lhériaud 2022).

The second site, Langeyri, is a peninsula in Súðavík which mostly remains natural. Alongside a few amenities like storage, and the local rescue team facilities, it's the birds that truly define Langeyri. Encircling a central pond, the area supports breeding colonies of Black-headed Gulls *Chroicocephalus ridibundus*, Common Eiders, and Arctic Terns, together with waders, passerines, and waterbirds such as Mallards *Anas platyrhynchos*, Greylag Goose *Anser anser*, or Red-breasted Mergansers *Mergus serrator* (Milesi-Gaches 2024). While tourism here is not as prominent as in Vigur and access isn't as tightly controlled, the peninsula is private property with open access. Notably, to protect the birdlife, the owner closes off a section from April 10th to July 7th annually, by putting up a sign, close to a dirt road which crosses the nesting ground. Another activity in the peninsula includes gathering of blueberries and crowberries towards the end of summer.

Vigur Island enjoys heightened visibility through its dedicated website, active presence on major social media platforms, and frequent features in tourism-related

press and cruise ship company programs. In contrast, Langeyri in Súðavík, while not hidden, is primarily promoted through local channels, including leaflets and maps. Nonetheless, both sites are recognised as bird watching hotspots on ebird.org (eBird 2023).

Counting by photography

The counts of tern colonies were carried out using photography. Particularly, one observer took photographs from a distance of the flying birds, while another person was walking through the colony, thus fostering birds to take off. In 2023, terns in Súðavík and Vigur Island were counted on the 20th and 22nd of June, respectively, during the incubation period. Before the counts, 10 minutes of casual observations were conducted up to three days prior to the actual counting, in order to gather preliminary insights into the distribution of terns, finalise the walking route, and identify suitable locations for photographing the birds. On Vigur Island, it became evident that the colony was divided into four distinct sections, shaped by both natural and anthropogenic features (e.g., paths, hills), as noted by the owners and observed during our visit to the island. Before counting terns in each perceived section, we waited for the birds to return to their nests to avoid counting birds from another section. When disturbed by a person, most birds, both breeders and non-breeders, take flight. We therefore opted for a photographic method,

as it captures the entire range of colony members, including non-breeders, unlike a nest count, which reflects only the number of breeding pairs. Despite the possibility of some birds being absent from the photographs or not identifiable, photography remains the most suitable methodology for studying rapidly moving flocks, such as those observed in Arctic Terns (Sutherland et al. 2004).

Photographs were obtained with a Canon EOS 60D camera equipped with a MC Granit-11 4.5/80-200 zoom lens. The series of photos was aggregated with the software Inkscape 1.3 (Inkscape Project 2023) to reconstitute the person's path through the colony (Fig. 2). Developed as a graphic design software, Inkscape provides several features, including counting all shapes in the current document, through the key combination CTRL+A. Available in many languages and working on all major operating systems, Inkscape is a free, reliable and open-source desktop application, usable for long-term monitoring of bird populations. In an empty document, the aggregated photograph was imported, and the layer in which it was located was then locked, to later allow Inkscape to only count shapes drawn on terns, and not the background image (Fig. 2). Before proceeding with data analysis, adjustments were made to the photographs to enhance bird detectability, including modifying luminosity, contrast, and sharpness. Additionally, the person walking through the colony as part of the counting process was removed from the images to ensure privacy. No further

alterations were made to the photographs.

We anticipated challenges such as poorly identifiable objects in the photographs and the presence of other bird species or individuals that were difficult to distinguish. Similarly, we expected reduced visibility of birds due to lighting conditions or landscape features in some photographs. To ensure accuracy, only terns that could be confidently identified, either by their distinctive appearance or characteristic shape, were included in the count. The discussion section further explores the full range of how terns appeared in our photographic data.

Due to the distribution of terns on Vigur Island, the colony was sectioned into four distinct areas, primarily based on topography. Several attempts were made to define the boundaries of each section, where bird identification from photographs proved challenging. Before initiating data collection for the counts, we ensured there were no overlaps between sections and that movement through one section would not disturb terns in adjacent areas. Details of the four delineated sections are provided in the results section. The same counting methodology was consistently applied across all sections. Upon completion of the analysis, the bird counts were conducted using the software, facilitated by the key combination CTRL+A.

Evolution of tern populations

Available counts were compiled from existing literature and unpublished data



Figure 2. Screenshots of the counting method, for Langeyri in Súðavík, with Inkscape 1.3 (Inkscape Project 2023). Terns are indicated by red dots.

(courtesy of Pr Ævar Petersen). Due to the use of diverse counting methods, which varied from direct nest counts to flock es-

timations, the population trends of terns in Vigur and Súðavík were characterised in various ways in the results section.

Monitoring of Arctic Tern colony areas

From 2021 to 2023, the shape of the colony area has been monitored during the incubation period in June. We collected GPS coordinates of the nests located at the edge of the Vigur's colony. The shape of the tern colony in Súðavík is only known for 2023 (June). To determine the boundaries of the colony, one author identified the approximate limits based on observations. Then, they systematically walked around the colony, scanning the area to identify the outermost nests. By traversing slightly beyond what appeared to be the colony's edge, they ensured that no nests were overlooked. GPS co-

ordinates of each nest located at the periphery were recorded using the mobile application GPS Point (Grečnár 2023). Recording was halted once a precision of 5m was achieved, or after 20 seconds, to prevent extended disturbances. GPS points were plotted and connected with Inkscape. The area of the Arctic Tern colony was estimated using the online tool SketchAndCalc® (SketchAndCalc 2023).

RESULTS

Data were collected through a series of photographs representing one section in Súðavík and four sections in Vigur, as illustrated in Fig. 3. Wherever possible, the person navigating the colony adhered to

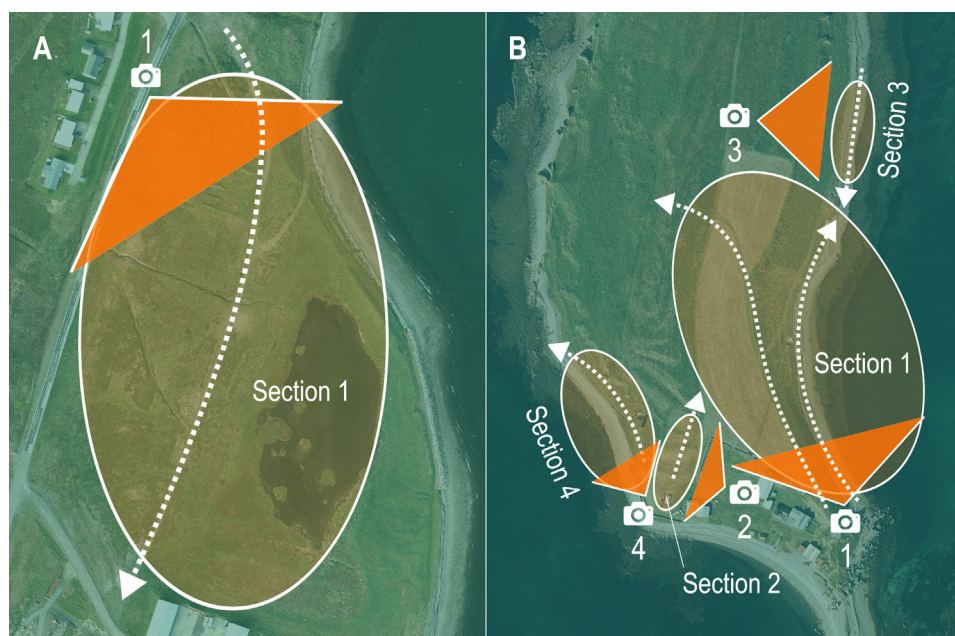


Figure 3. Schematic representation of the Arctic Tern colony photographed sections, with the trajectory taken by the person triggering birds to take off. (A) in Langeyri, Súðavík; (B) in Vigur Island (basemap: Loftmyndir ehf).

existing paths. In Vigur, two people walked through section 1, with one person walking alongside the coastline. To minimise disturbances, photographs were consistently taken from outside the colony boundaries.

Total population counts

In 2023, a total of 458 Arctic Terns were counted in Súðavík. While a relatively important number of non-breeding terns were present on the nearby beach that is part of the colony area (Fig. 3), they all took off during the census. Vigur hosted 991 terns. The counts, based on photographs of the entire flocks of birds taking off during the census, include both breeding and non-breeding individuals. Details of the aggregated photographs used to count birds with the software Inkscape are provided in Fig. 4. In each photographic capture, certain avian species were discernible, yet definitive identification as either terns or another species remained inconclusive. Additionally, several unidentified objects within these images presented the potential to be Arctic Terns. The documentation and analysis of these data are crucial in delineating the boundaries and limitations inherent in our counting methodologies (Tab. 1).

When incorporating the unidentifiable birds and objects as Arctic Terns into the population estimates, the counts for Vigur Island and Súðavík are revised to 1044 and 461 terns, respectively. This adjustment reflects an increase of 5% for Vigur Island and 1% for Súðavík in the estimated tern populations (Tab. 1).

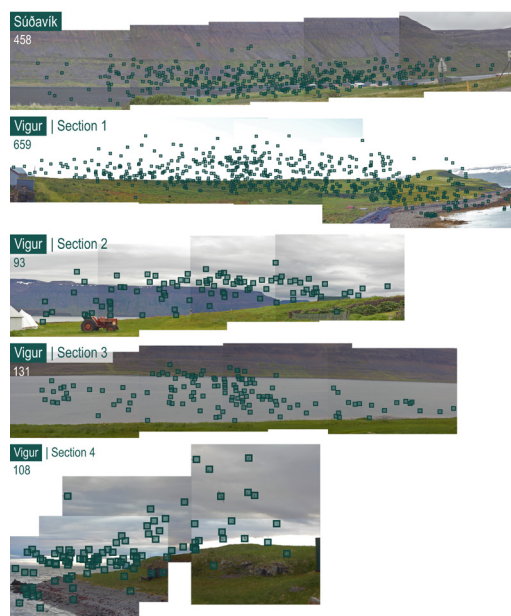


Figure 4. Aggregated photographs and associated counts for Súðavík and Vigur Island in 2023.

In the literature, only counts from the regional research institute, Náttúrustofa Vestfjarða, were found for Súðavík (Gallo et al. 2021, Gallo & Sigurðardóttir 2022). Other counts come from unpublished work made available by courtesy by Pr Ævar Petersen (Tab. 2). The total of 6 counts includes one nest count, four estimations and one count by photography. The censuses cover a 36 year period with an uneven distribution. Examining the development of the colony in Súðavík is evident: the tern population has been increasing (Spearman rank-correlation test, $p = 0.9$, $P = 0.03$), as shown in Fig. 5 (A) despite the use of different counting methods, including estimations, nest counts, and photography.

Table 1. Estimation of the theoretical maximum number of Arctic Terns in Vigur Island and Súðavík, by adding not identified birds and objects

Location		Unidentified Birds (UB)	Unidentified Objects (UO)	UB+UO / Total (%)	Total (theoretical maximum)
Vigur	Section 1	12	21	5%	659(692)
	Section 2	2	2	4%	93(97)
	Section 3	11	0	8%	131(142)
	Section 4	5	0	5%	108(113)
Vigur	TOTAL	30	23	5%	991(1044)
Súðavík	TOTAL	3	0	1%	458(461)

Table 2. Arctic Tern population census (number of individuals) in Súðavík and Vigur Island, including the 2023 counts

Year	Count	Method	Details	Reference
Súðavík				
1987	28	Nest count	14 pairs	Brynjúlfur Brynjólfsson (unpublished)
1991	150	Estimation	Total bird number	Kristinn H. Skarphéðinsson (unpublished)
2003	100	Estimation	Total bird number	Böðvar Þórisson (unpublished)
2020	270	Estimation	135 pairs	Gallo and Sigurðardóttir (2022)
2021	400	Estimation	Total bird number	Gallo et al. (2021)
2023	458	Photography	Total bird number	This study
Vigur Island				
2021	880	Transect line, nest count	440 nests. 60% of the colony covered	Milesi-Gaches and Lhéreau, 2022
2021	1499 ±39	Transect line, nest count, estimation	440 nests. 60% of the colony covered + estimation for the last 40%	Milesi-Gaches and Lhéreau, 2022
2023	991	Photography	100% of the colony covered	Fieldwork
2023	883	Photography	60% of the colony equivalent to 2021	Calculation based on 2023 fieldwork

Prior to 2023, data on tern numbers in Vigur were limited. The 2021 count recorded 440 nests, equating to 880 adult birds, but this only covered 60% of the colony. The whole breeding population was estimated in 1499 ± 39 breeding pairs (min: 1460, max: 1538; Milesi-Gaches & Lhériaux 2022). However, this number may be imprecise due to the uneven distribution of the colonies, particularly as the densest areas were included in the 60% surveyed in 2021. Furthermore, the count only included breeding adults (Milesi-Gaches & Lhériaux 2022). To analyse population changes between 2021 and 2023, we compared 60% of the 2023 count, excluding section 4 (Fig. 3), to the 2021 count. The most detailed count avail-

able is the incomplete 2021 nest census, which covered only 60% of the colony due to adverse weather conditions and hatching eggs (Milesi-Gaches & Lhériaux 2022). However, the 2023 count enables a correction to make it more comparable with the 2021 census. The section 4 of the area covered in the 2023 count corresponds approximately to the missing part of the 2021 census. Therefore, the most accurate method to assess population changes is through a relative population changes is through a relative comparison between the 2021 and 2023 data for equivalent colony portions. Excluding section 4, the 2023 count recorded a total of 883 birds (Tab. 2). This suggests that the Arctic Tern population has remained stable over the 2021–2023 period. However, when considering the

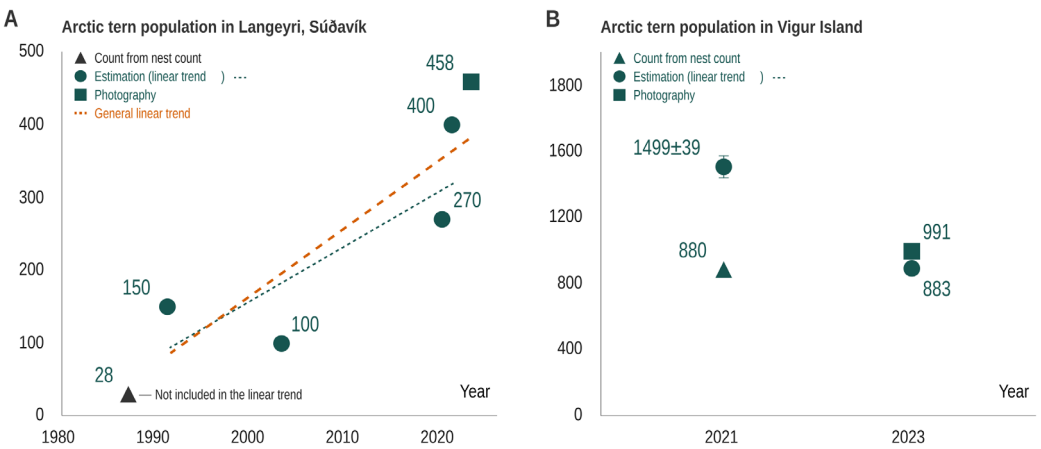


Figure 5. (A) Evolution of the Arctic Tern colony in Langeyri, Súðavík. The nest count performed in 1987 is excluded from the linear trend as it only accounted for breeding terns, while estimates and photo-based counts included all present birds. (B) Evolution of the Arctic Tern colony in Vigur Island. In 2021, the points represent both the count for 60% of the colony and the extrapolated estimate for the entire colony. In 2023, the points represent the total photographic count and an estimation based on 60% of the colony to allow comparison with 2021.

statistical estimation—despite inherent biases in the calculations—a noticeable decline in the Arctic Tern population on Vigur Island is indicated.

Nests distribution

In Súðavík, the colony occupied a surface of 34 727 m² which represents around 31% of the peninsula's natural surface. Arctic Terns were mainly sharing this space with Black-headed Gulls, Common Redshanks *Tringa totanus* and Common Snipes *Gallinago gallinago*. The tern colony is distributed between the main road and the pond, on its western side, and in the southern part of the peninsula, similarly between the pond and the buildings. Common Eiders are mostly nesting on the eastern side of the pond with few overlap

with terns. However, Arctic Terns are using a wider area, including all the shoreline, notably those who are not breeding.

Although few counts were available for Vigur Island, more extensive data exists on the spatial distribution of terns. As an alternative or complement to invasive nest censuses, monitoring colony shape by recording the GPS coordinates of nests at the colony's edge has been proposed (Milesi-Gaches & Lhéreau 2022). From 2021 to 2023, terns used in Vigur the same areas for both pre and post nesting times. The colony remains located close to buildings, in the southern part of the island (Fig. 6). In 2023, more nests were found at the edge of the perceived colony territory, leading to a more chopped shape. A pair of terns were also observed establishing its territory remotely in the

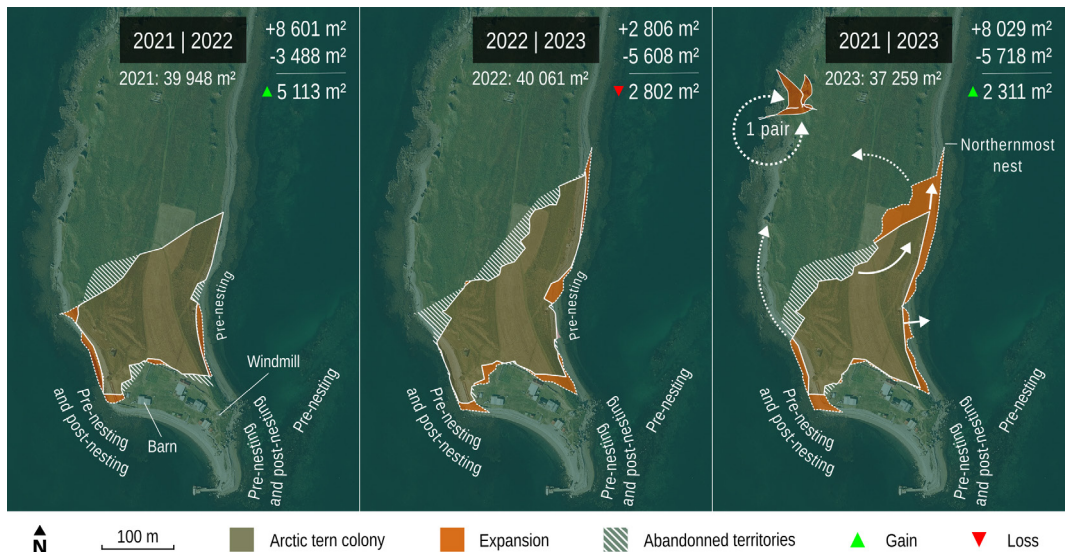


Figure 6. Evolution of the Arctic Tern colony in Vigur Island from 2021 to 2023 (basemap: Loftmyndir ehf).

western side of the island, close to an area dominated by Atlantic Puffins and Black Guillemots. No nest was located but terns displayed a defensive behaviour towards humans and were seen harassing black guillemots to steal their prey.

When comparing the territory between consecutive breeding seasons or over the 2021–2023 period, we can observe that terns abandoned the field area located in the middle of the island. The evolution of the territory shows clearly four trends. Terns are moving northwards and southwards alongside the eastern coast. As well, terns are solidifying their settlement on this coastline, with a more consistent distribution. Terns are also coming closer to buildings in the South west of the island, nesting around storage facilities (Fig. 6). Since 2021, the colony area shows a net gain of 2 311 m² (Fig. 6), with successive gains of 5 113 m² between 2021–2022 followed by a loss of 2 802 m² in 2022–2023. The northernmost Arctic Tern nest, observed for approximately 4 hours as part of a separate study, offers insights into the colony's northward shift since 2021. Adjacent to this nest is a puffin-inhabited territory with small cliffs where puffins also nest. The constant flow of puffins flying at low altitudes, often up to 10 metres (Fig. 7), acts as a protective barrier, shielding the area below from potential threats and hindering predators' access to eggs. Notably, in 2023, while seagull predation was high in Vigur, no predators were seen attempting to breach this, puffin highway' despite flying over the area, displaying no sign of interest.

DISCUSSION

Arctic Terns often display aggressive behaviour and do not hesitate to harass humans walking nearby their territory (Syrová et al. 2020). Thus making them likely to be the most interactive species of the bird spots where they are present. In the Westfjords, Vigur Island and the Langeyri peninsula in Súðavík constitute, to varying degrees, the most important bird watching sites in the north of the region (eBird 2023). With the recent surge in tourism in Iceland, particularly in the Westfjords, it is imperative to monitor bird populations and assess any human-induced impacts. The selection of effective monitoring tools is crucial for stakeholders and policy-makers to make informed decisions. Monitoring techniques of Arctic Tern populations in Vigur Island and Súðavík exhibit distinct characteristics. While few counts exist for Vigur, the area used by terns is well known and documented since 2021. In Súðavík, the situation is the exact opposite. While the tern colony area was only measured in 2023, more counts are available and were done with techniques which encourage comparative analysis. For colonial seabirds that breed in pairs, maintaining consistent monitoring methods is essential. Tern colonies, often unevenly distributed with several high-density areas, pose challenges for proportional estimates, as sampling a section of the colony can lead to misleading results (Heinänen et al. 2008). Comparing the 2021 Vigur census with 60% of the photographic count from 2023 provides insights into population trends but highlights

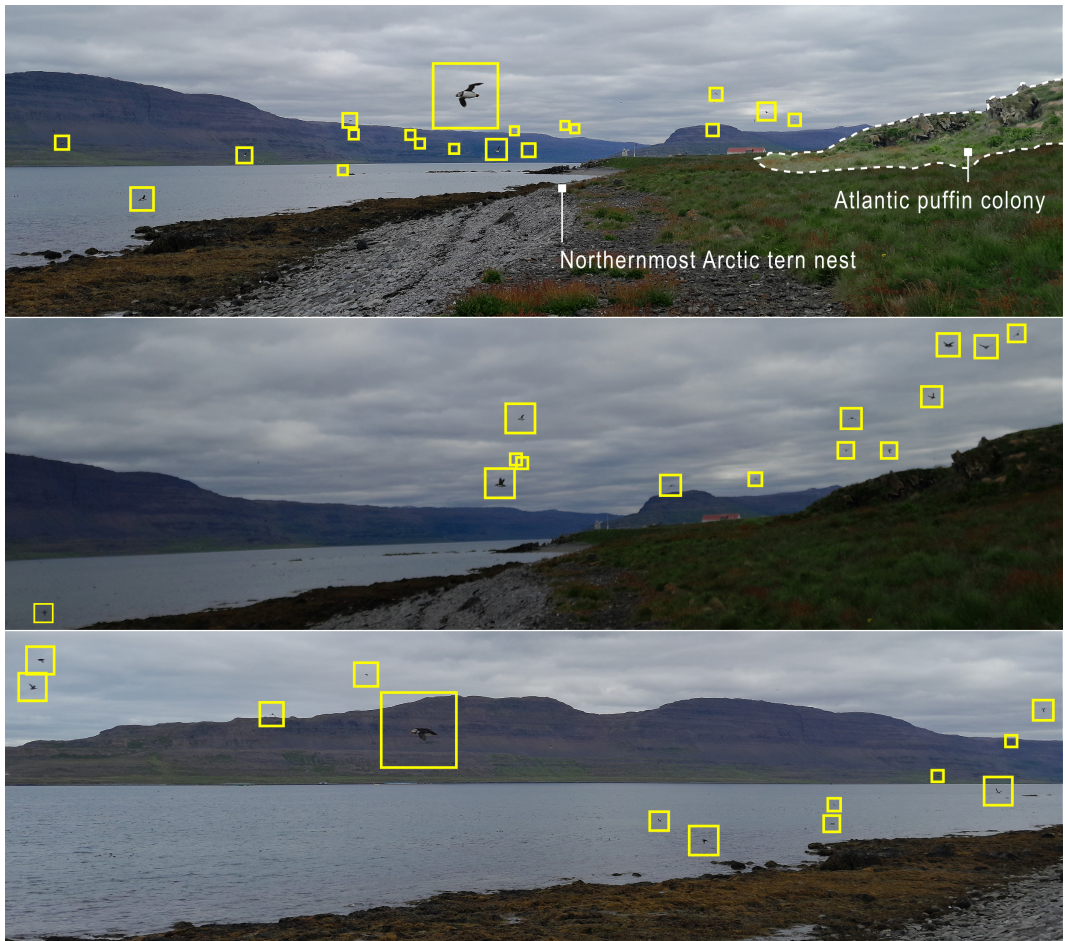


Figure 7. Series of photographs showing Atlantic Puffins flying over the northernmost Arctic Tern nests, in Vigur Island. The three photographs were shot on the 6th of July 2023, at 6:04pm.

the differences in the segments of the population these methods monitor. Nest counting, while invasive and time-consuming, provides limited reliability as it focuses exclusively on nesting pairs, capturing only breeding adults and neglecting non-breeding individuals and other demographic groups (e.g. non-breeders, inter-colony movers, etc.). In contrast, photographic surveys mitigate some of these issues by

reducing operator fatigue, enabling re-counting if needed, and accounting for a broader range of individuals (Milesi-Gaches & Lhériaux 2022). However, challenges persist with this method, particularly in accurately identifying birds in photographs. Factors such as poor visibility or similarity in appearance to other species can hinder identification. This underscores the need for more comprehensive, less intrusive

monitoring techniques to accurately assess the entire bird population.

In the case of Vigur and Langeyri, other species were easy to identify, with the exception of distant birds in Súðavík, with Black-headed Gulls sometimes impossible to distinguish from Arctic Terns (Fig. 8). Occasionally, determining the presence of a bird in the photographs can be challenging, as the subject captured may potentially be a plant or debris, rather than a bird (Fig. 8, D). Even with adjustments made for unidentified birds and objects, these corrections are unlikely to markedly alter the estimated population size of the Arctic Terns. Notably, Section 1 in Vigur exhibited the highest number of unidentified objects (33), a detail that may be attributed to the varying weather conditions, specifically bright and cloudy skies, documented during the fieldwork. Additionally, the geographical nature of Vigur as an island provides expansive landscapes with distant horizons, which is evident in Fig. 4, potentially influencing the visibility and identification of subjects in the photographs.

Hence, we strongly endorse the enhancement of the existing photographic methodology by integrating direct observational techniques. This approach becomes particularly pertinent in areas like Súðavík, where the cohabitation of Arctic Terns and Black-headed Gulls can complicate species differentiation. In Langeyri, for instance, Black-headed Gulls are observed perching on an islet within the pond, a location not contested by Arctic Terns. Within our photographic dataset, the birds in these images are not easily

distinguishable (as depicted in Fig. 8, B). However, through direct field observations, these birds were definitively identified as Black-headed Gulls. This identification was crucial in preventing inaccurate counting of these birds as part of the Arctic Tern population during the photograph analysis. Nonetheless, the photographic approach remains highly recommended due to its versatility, rapid execution, and straightforward implementation. In the majority of scenarios, Arctic Terns are readily identifiable in photographs, typically exhibiting a limited range of appearances (Fig. 8).

The identification of birds becomes most challenging when they are in the process of taking off or landing, as well as when they are sitting or incubating, due to the concealment of key characteristics such as wings in flight position (as demonstrated in Fig. 8, A). Despite these difficulties, it is still feasible and straightforward to record the number of unidentified birds, thereby enabling an estimation of the margin of error and quantifying one limitation of the counting process.

Observations play a key role in accurately determining the number of non-breeders, who often remain outside the nesting area in locations like Vigur Island and Súðavík, effectively forming a detached segment of the colony. Therefore, it's vital to structure observations to account for non-breeders, ensuring they are also included in the count. This requires careful consideration, as non-breeders may not take flight when an observer enters the tern territory, if the area used

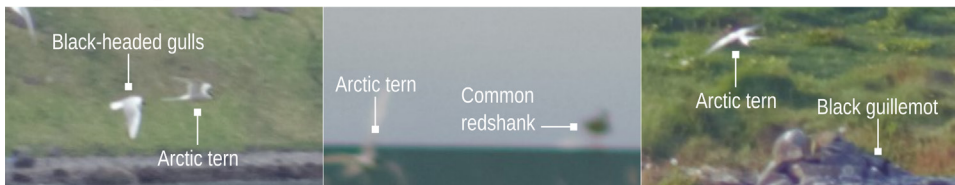
A Arctic tern aspect on photographs



B Other bird species on photographs



C Other bird species close to Arctic terns



D Non identified objects



Figure 8. (A) Other species can be easily identified either by colour or wing and body shape. (B) Certain species are easily identified by colour or body and wing shape, while others require closer observation. (C) In proximity to an Arctic Tern, other species become easier to distinguish. (D) Distant and sitting birds are harder to identify due to fewer distinctive features, such as wing shape, and sometimes their position prevents definitive species identification.

by non-breeders is too far from the nesting ground. To capture an accurate census, one strategy could be to count non-breeders separately, based on their

specific locations and activity levels. Conducting a separate count for non-breeders, which is customised to their distinct behaviours and locations, will enhance the overall understanding of the colony's structure and size. However, it's crucial to synchronise this count with the main colony census. Performing these counts on the same day is vital, especially at the onset of the nesting period, when some non-breeders may simply be late in laying their eggs. Delaying even by a few days between counting non-breeders and the main colony can result in double-counting individuals, thereby skewing the data. Accurate synchronisation ensures a more reliable and accurate representation of the entire colony's population. In 2023, the Westfjords witnessed challenging weather conditions that impacted the Arctic Terns post-migration. A significant number of these birds, particularly in Vigur (estimated between 100 to 200, and around 60 in Súðavík), opted out of the nesting season. Given these circumstances, the photographic census method will account for those birds, allowing also to record, if necessary, detailed numbers about breeders and non-breeders. This technique is not only easier to implement but also less intrusive compared to nest counting (Cutler & Swann 1999). Although the photographic method necessitates human presence within the colony, the duration of disturbance is notably shorter compared to a nest count and fits with the commonly accepted presence limit of 20 minutes (Walsh et al. 1995). This brief intrusion is a reasonable trade-off for the

more accurate data obtained. The method's ability to capture a broader scope of the population, including non-breeders and inter-colony movers, makes it a more comprehensive approach for monitoring tern populations under the challenging environmental and weather conditions experienced in the Westfjords.

Long-term monitoring is indeed vital for accurately understanding the dynamics of Arctic Tern colonies, such as those in Vigur. If assessments were based solely on data from 2021 and 2022, it might erroneously suggest an expansion of the colony beyond its actual extent. Time is a crucial factor in distinguishing between temporary fluctuations and genuine trends. For instance, the poor weather conditions of 2023 influenced a considerable number of terns to forgo nesting, thereby affecting population observations. The apparent slight increase in the Vigur colony's area in 2023, compared to 2021, must be interpreted with caution. Around 200 non-breeding terns were observed on the pebble beach, out of the nesting ground, indicating a shift rather than a true expansion. Furthermore, the observed activity of non-breeders, including at least one pair exploring new territory on the west coast, suggests that these birds may play a role in either expanding the colony or in movements between colonies. Currently, we can only hypothesise about the factors influencing the tern population's changes. In Vigur, the central higher elevation of the island, more exposed to wind, could be leading to the abandonment of nesting sites there. Additionally, the daily influx of tourists might also impact the

terns. In contrast, the tern population in Súðavík, an area theoretically accessible to all and thus potentially subject to frequent human disturbances, seems to be more significantly impacted by the proximity of a diverse array of other bird species nesting nearby. Other crucial factors likely influencing the population include prey availability, the impact of bird flu during migration, and overall survival rates (Petersen et al. 2020). These elements need to be considered in future studies to gain a comprehensive understanding of the health and dynamics of Arctic Tern populations in these areas.

The tern population in Súðavík appears to be on an upward trend, a hypothesis that needs verification through future population counts and detailed analyses of the colony's area. In Vigur, discerning a clear trend is more challenging due to various influencing factors. From a conservation perspective, it is prudent to treat the Vigur tern population as potentially declining, especially considering the atypical conditions brought about by the Covid-19 pandemic. This cautious approach will support more effective conservation strategies under uncertain environmental and biological influences. Before the pandemic, Vigur Island attracted approximately 10,000 tourists annually from mid-June to the end of September. The pandemic years saw a stark decline in these numbers, with only around 300 visitors in 2020, and then a gradual increase to 5,500 in 2021 and 8,000 in 2022 (Aston & Jónsson 2022). As a result, the tern population experienced reduced human disturbances during 2020–2022. This suggests that the context of

our current study may not fully reflect the post-pandemic situation of terns in Vigur, nor in Súðavík, which also experienced reduced tourist activity due to pandemic-related travel restrictions. However, the nature and frequency of tourism-related disturbances are critical factors to consider. In Vigur, intense tourist activity concentrated within a limited timeframe could potentially be more disruptive than the sporadic and unpredictable disturbances at a site like Súðavík, which is accessible around the clock. This difference in the patterns of human presence could have varying implications for the tern populations in these two locations.

Another limit of this study is the lack of historical records about the presence and behaviour of Arctic Terns in the two locations. On the middle of Vigur Island, a small portion of the eastern coast is named Kríuhöll, which could be translated as 'Arctic Tern hill' (National Land Survey of Iceland 2023), suggesting historical nesting or usage by Arctic Terns. To address this gap, it is crucial to initiate and maintain detailed observations.

Finally, observations from 2023 in Vigur hint that Arctic Terns may be nesting near puffins, potentially as a strategy to mitigate predation risks. This behaviour, however, might be specific to areas with low human disturbance. In places with frequent human activity, terns might be frequently disturbed and compelled to cross puffin territories more often, inadvertently heightening their exposure to predators. During our data collection, when approaching their nests, terns, including those from

adjacent nests, were observed to fly away. This action underscores the challenges they face in returning to their nests through areas occupied by flying puffins, often requiring multiple attempts before successfully landing. Such observations underscore the complexity of interactions between different species and the impact of human presence on these dynamics. The colony's shift towards the north of the island or below the windmill, as shown in Fig. 6 and 7, seems to support the idea of terns moving closer to puffins. Moreover, interactions with Black Guillemots, who share part of their diet with terns and are often pursued by terns for food, may be another factor influencing this movement.

We concur with the recommendation to employ straightforward, long-term monitoring techniques for an accurate assessment of Arctic Tern populations in locations like Vigur Island and Súðavík. The utilisation of photographic methods offers a simple yet efficient way to estimate population sizes, capturing both breeding and non-breeding individuals. Complementing this with GPS tracking of the colony locations provides valuable spatial data, fostering the development of explanatory hypotheses and assisting in setting priorities for future research. Furthermore, behavioural observations are a critical component in evaluating the health of tern populations. Traditionally, birds showing minimal reaction to human presence were often interpreted as being unaffected. However, as Beale and Monaghan (2004b) noted, this assumption can lead to erroneous assessments of a population's vulner-

ability or health. In reality, a heightened responsiveness to humans can be indicative of a population in good health. This nuanced understanding of bird behaviour is crucial for accurate evaluations and effective conservation efforts.

This study emphasizes the need for a broader and more holistic perspective in future research. It is essential to consider not only direct observations but also to evaluate anthropogenic impacts, interspecies interactions, and habitat conditions. While the use of photographic methods and direct observations can be valuable tools for monitoring, it is crucial to ensure that such approaches minimise disturbance to the species studied. Some species, particularly those classified as endangered or vulnerable, like Atlantic puffins and black guillemots, may be highly sensitive to human intrusion, especially during critical periods such as incubation. Careful consideration of species-specific sensitivity and habitat conditions is necessary to avoid harmful impacts, such as nest abandonment. For example, colonies of Audouin's Gull *Ichthyophaga atricapilla* in the Mediterranean Basin were reportedly abandoned following human disturbance (Yaylı et al. 2003). Implementing such precautions will allow for effective data collection while safeguarding the welfare of the species and their habitats, thereby contributing to the development of sound conservation strategies.

Data availability statement

The datasets generated during and/or analyzed during the current study are

available from the corresponding author on a reasonable request.

Acknowledgements

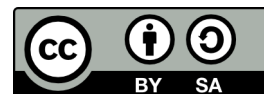
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Pelagic seabirds in coastal waters of the Western Ligurian Sea: occurrence and seasonality

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ABSTRACT

Seabirds are a heterogeneous group of birds that, due to their behaviour and at-sea distribution, remain difficult to study when compared to other avian species. In the Liguro-Provençal basin (Mediterranean Sea), the fragmentary information of presence and number of individuals available fails to capture the variability of occurrence of these species year-round and at smaller regional scales. This study aimed to fill this gap of knowledge in seabirds' presence and phenology for the coastal Western Ligurian Sea. Data were collected opportunistically at sea, year-round, from June 2018 to May 2022. Two hundred and seventy-four surveys were conducted, totalling 1,522.91 hours of observation year-round, during which 12 species of seabirds, excluding seagulls, cormorants, shags, and landbirds, were identified. Observations of species and group size were collected to estimate cumulative seasonal encounter rates (ER) for all species and seasonal ERs (only for the most common taxa). Spring and autumn had the highest ER cumulative for all species, as these are migratory periods for several species. These are also periods of the highest presence of the most sighted species - Yelkouan *Puffinus yelkouan* and Scopoli's Shearwaters *Calonectris diomedea* - at French breeding colonies. Species also observed in large numbers were the Northern Gannet *Morus bassanus* and the Sandwich Tern *Thalasseus sandvicensis*, whose sightings matched their migratory phenology. Other northern breeding species, such as the Atlantic Puffin *Fratercula arctica*, and more rare species like skua spp. were also recorded.

The year-round presence of migratory species indicates the region is an important foraging ground also for individuals that are not taking part in the pre-breeding migration and for shearwaters breeding in the Tyrrhenian Sea. This study highlights the importance of the Western Ligurian Sea for pelagic seabird species, emphasizing the need for specific conservation actions to enhance their protection.

Keywords: Coastal waters, Gannets, Mediterranean Sea, Seabirds, Shearwater.

INTRODUCTION

Seabirds are species adapted to marine environment, spending the majority of their life in offshore areas. Their wide-ranging distribution and often elusive behaviour make them difficult to monitor and, as a result, less studied than many other bird groups. Historically, a vast number of research on seabirds has been conducted at their breeding colonies (Brichetti 1980; Baccetti et al. 2009), and migrating individuals have been recorded either from land (Şahin et al. 2011; Elmerberg et al. 2016) or from opportunistic platforms at sea (e.g. Martín et al. 2020). Although ringing has been performed on several colonies, allowing researchers to monitor birds during reproduction, information on the at-sea ecology and year-round movements of these species have only been obtained by using miniaturised GPS trackers (Bridge et al. 2011; Péron & Grémillet 2013; Bernard et al. 2021; De Pascalis et al. 2022).

The Mediterranean basin, recognised as a biodiversity hotspot (Coll et al. 2010), hosts multiple endemic species of seabirds, and is used as wintering ground (Carboneras 1988) by various species

nesting in northern Europe, such as auks and gannets (Balestrieri et al. 2023, Borgo et al. 2024). The Liguro-Provençal Basin, located in the North-Western portion of the Mediterranean Basin, supports vast breeding colonies of shearwaters (Péron et al. 2012). Two endemic species of Procellariiformes can be found regularly in this area (Spina & Volponi 2008; BirdLife International 2021a, b, d): the Least Concerned (BirdLife International 2021a) Scopoli's Shearwater *Calonectris diomedea* (Scopoli, 1769) - presenting important colonies in the Gulf of Lion, Tuscany, Sardinia, Corsica and Strait of Sicily (Baccetti et al. 2009; Péron & Grémillet 2013) - and the Vulnerable (BirdLife International 2021d) Yelkouan Shearwater *Puffinus yelkouan* (Acerbi, 1827) - breeding along the Mediterranean French coast (Péron et al. 2012) but with a main breeding colony at Tavolara island (Sardinia) (Zenatello et al. 2012). The other species of Procellariiformes present in the area is the Least Concerned (BirdLife International 2021b) European Storm Petrel *Hydrobates pelagicus* (Linnaeus, 1758) largely unstudied in this basin (Baghino et al. 2012; Lago et al. 2019). Within the Mediterranean basin the subspecies Mediterranean Storm

Petrel *Hydrobates pelagicus melitensis* (Schembri, 1843) is also present. The Least Concerned (BirdLife International 2021c) Northern Gannet *Morus bassanus* (Linnaeus (1758)) is also found in the area, particularly during the winter (Spina & Volponi 2008; Baghino et al. 2012), with individuals migrating primarily from British and French colonies (Kubetzki et al. 2009; Fort et al. 2012). Regular and occasional species of skuas and terns are present, with some appearing in smaller numbers year-round or at specified seasons. Atlantic Puffin *Fratercula arctica* (Linnaeus (1758)) and Razorbill *Alca torda* (Linnaeus (1758)) have also been observed to winter in the Ligurian basin (Spina & Volponi 2008; Ballardini et al. 2005; Balestrieri et al. 2023).

Various studies have identified the Liguro-Provençal basin as highly frequented by seabirds, but only limited information on their year-round presence has been obtained over several years (Rufay et al. 2014; Lambert et al. 2017). The Western Ligurian Sea (Central part of the Liguro-Provençal basin), in particular, has not been extensively monitored (Bourgeois & Vidal 2008). This area differs from the adjacent regions – such as the Gulf of Lion and the Eastern Ligurian Sea (Cattaneo-Vietti et al. 2010; Prieur et al. 2020) – due to its narrow continental shelf and the presence of several underwater canyons. According to David and Di-Méglio (2012), these undersea structures provide diverse habitats that support numerous species of cetaceans and seabirds. Despite its ecological significance, com-

prehensive information on seabird communities in the area remains limited.

This study aims to describe the seasonal occurrence of pelagic seabirds in coastal waters of the Western Ligurian Sea over a period of four years. By building upon existing knowledge, it seeks to contribute to a foundational understanding of the area's importance for seabird ecology and to inform future research and conservation efforts.

MATERIALS & METHODS

Study Area

The study area is located within the Liguro-Provençal Basin, more exactly in the Western Ligurian Sea (Western Mediterranean Sea) (Fig. 1).

It covers approximately 812 km² of the coastal area from the Italo-French border (43°47'06"N, 7°31'44"E) to the west and Capo Noli (44°11'53"N, 8°25'30"E) to the east, from the shoreline to the 500 m bathymetric line. The maximum distance from shore ranges from less than 4 km to up to 11 km, encompassing the shallow continental platform (up to 200 m) and the continental slope. This area is characterised by a narrow continental platform that makes space for the continental slope relatively close to the shore. Moreover, there are 11 underwater canyons that cut through the continental platform (Migeon et al. 2011) allowing for steep changes in depth, reaching up to 800 m within the study area.

The area is included in the "Pelagos Sanctuary", established in 1999 for the

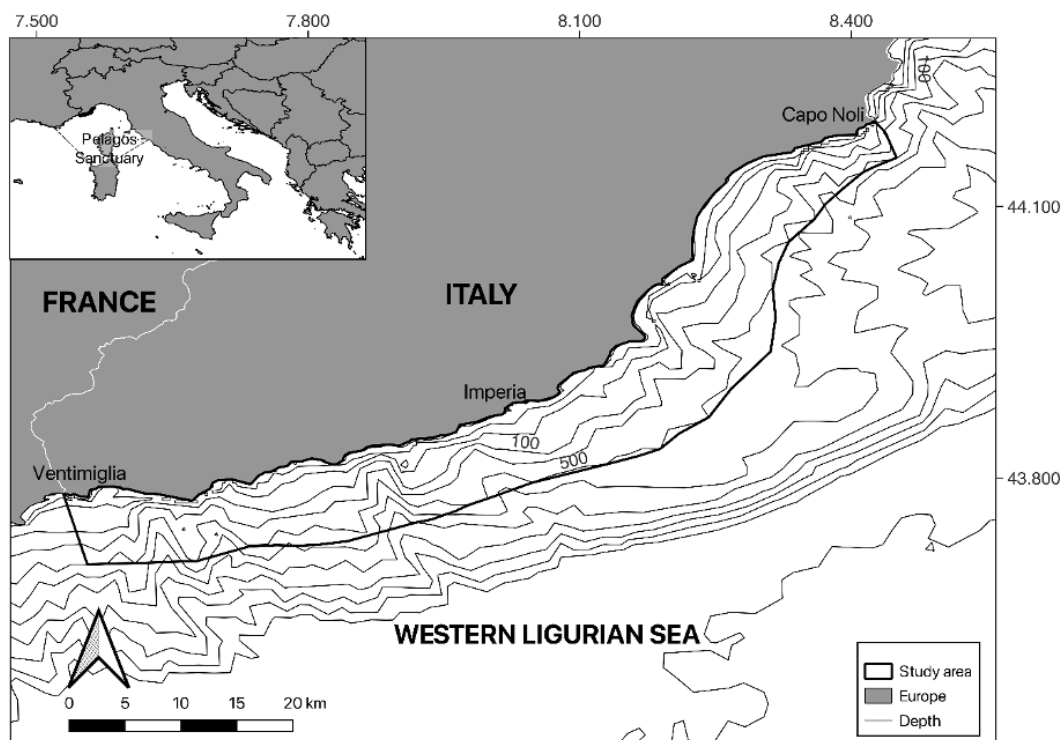


Figure 1. Study area showing bathymetric contour lines, with the 100 m and 500 m isobath highlighted.

protection of marine mammals and listed in 2001 as a Specially Protected Areas of Mediterranean Importance (SPAMIs) (Norrbartolo di Sciara et al. 2008).

Since 2023, it has also been included in the North Western Mediterranean Sea Particularly Sensitive Sea Area (NW Med PSSA) (IMO). Moreover, the study area is close to multiple IBAs (BirdLife, 2023) on the southern coast of France, around Corsica Island and the Tuscan Archipelago.

The Liguro-Provençal Basin is important for cetaceans' conservation and for different seabird species listed within the SPA/BD Protocol (UNEP-MAP-RAC/SPA 2010).

This basin presents a cyclonic circulation with the Liguro-Provençal-Catalan system being its main feature (Casella et al. 2014). This system presents currents of different densities that allow the formation of water fronts and eddies responsible for vertical mixing (Picco et al. 2010) and upwelling phenomena (Poulain et al. 2010; Casella et al. 2014), features that have been linked to the presence of foraging seabirds such as shearwaters and Northern Gannets (Paiva et al. 2010; Sabarros et al. 2014; Scale et al. 2014). This circulation is strongly driven by wind action, mainly the mistral wind regime

(Poulain et al. 2010) and, together with the underwater topography, is responsible for the high biological productivity (Estrada 1996) and biodiversity of the area (Cattaneo-Vietti et al. 2010; Coll et al. 2010). This productivity, together with the heterogeneous morphology found in coastal waters, makes this region important not only for resident, but also for migratory species (Paiva et al. 2010; Péron & Grémillet 2013; Pollonara et al. 2015).

Data collection

Data were collected opportunistically during boat-based surveys from June 2018 to May 2022 with a primary focus on the population of bottlenose dolphins (*Tursiops truncatus*) (Ascheri et al. 2022).

Surveys were conducted onboard a 5.2 metre long zodiac equipped with a 40HP outboard engine and took place year-round, during daylight and with favourable weather and sea conditions (wind speed of Beaufort scale ≤ 3 and sea state of Douglas ≤ 2). The duration of the survey varied from 6 to 9 hours, depending on weather conditions and cetacean sightings. The surveys followed random tracks and depended on the weather conditions as described in Ascheri et al. (2022). Each track consisted of two linear routes parallel to the shore, 2 nautical miles apart, to avoid double counting of cetaceans and seabirds present in the same area.

The study area was monitored as equally and as homogeneously as possible in each season, although the sur-

veying effort could vary according to the weather conditions and cetaceans' sightings. During the survey, the position of the zodiac was automatically recorded every 2 minutes using a portable GPS (Garmin ETrex 32x), with the starting and ending point being the port of Imperia. A constant speed of less than 7 knots (13 km/hr) was maintained throughout. A team of at least two experienced observers with comparable visual skills was onboard, visually scanning the sea with and/or without binoculars (7x50), covering a full 360° around the boat to detect the presence of both cetaceans and seabirds (Ascheri et al. 2022; Fontanesi et al. 2024).

Environmental data including wind and sea conditions, visibility and cloud coverage, were collected at regular intervals as described in Ascheri et al. (2022), to ensure comparable surveying effort and data collection. If the environmental conditions were not favourable (see above) the effort was suspended and data were not collected.

In this study, observers were considered "on effort" when actively scanning the area with and/or without binoculars, under favourable conditions, aiming to identify seabird species to the lowest possible taxonomic level. If cetaceans were sighted, the effort was switched off to allow for the collection of cetacean data as described in Ascheri et al., (2022). The effort and seabird observation was later resumed when the cetacean sighting was concluded. When an individual or group of birds were sighted, the GPS position of

the zodiac, the species and the number of individuals were recorded. To minimise the risk of double counting, observers recorded birds only when they were perpendicular to the boat, following a method similar to the transect sampling (Camphuysen et al. 2004). For foraging flocks, two experienced observers estimated the number of individuals grouping them by species (Spear et al. 2004). To prevent overestimation of individuals, the visual survey was temporarily suspended until the area was clear. However, underestimation is expected for smaller species, such as storm petrels, and less conspicuous individuals, such as stationary birds on the water (Tasker 1984).

The protocol developed for the seabird data collection excluded from the monitoring landbirds and few species of seabirds. The choice of excluding from the data collection seagulls, cormorants and shags was supported by the need to record information on species that are not easily sighted from land. Moreover, for these bird species, census-monitoring activities at breeding colonies are normally conducted (Walsh et al. 1995) and their accounting during boat-based monitoring, due to the large number of Yellow-legged Gull *Larus michahellis* (Naumann, 1840) and Black-headed Gull *Chroicocephalus ridibundus* (Linnaeus, 1766) in the area, might hinder data collection on other, less common species. During the study, 12 species from the families Procellariidae, Hydrobatidae, Sulidae, Stercorariidae, Alcidae as well as individuals of the subfamily Sterninae

were recorded in the field and further analysed. If a bird could not be identified to the species level, it was recorded as an unidentified individual of a specific family (e.g. unidentified tern). For the family Stercorariidae the species was always confirmed through photographs. Data were not collected if the family could not be determined.

Data analysis

Four seasons were considered: winter (December -February), spring (March - May), summer (June - August) and autumn (September - November). In annual analyses, data were grouped by sampling period (I-II-III-IV): period I from June 2018 to May 2019 included, period II from June 2019 to May 2020 included, period III from June 2020 to May 2021 included, period IV from June 2021 to May 2022 included.

The total surveying effort (hour) was extrapolated from the GPS tracks, considering only “on effort” intervals. The encounter rate (ER) was obtained as the number of sightings - within a specific period (e.g. across the study, season or sampling period) and of a specific species and/or across species - per hour on effort (sig h^{-1}) in said period. The presence/absence of a species in a season, and in a sampling period, was recorded. Moreover, the total number of species sighted in a season, and in a sampling period, was obtained.

The cumulative number of individuals and sightings was calculated for the entire study period and for each season.

The seasonal ER – cumulative of all species – was calculated. For each species, the total ER, across the study period, was computed. Additional analyses were performed for species presenting a number of individuals across the study period higher than 100 and for the storm petrel, species presenting relatively large numbers.

For each species with more than 100 individuals recorded (Scopoli's and Yelkouan Shearwaters, Northern Gannet, and Sandwich Tern) the following qualitative and quantitative analyses were performed. A qualitative analysis of the monthly occurrence of the species across years was performed through visual representation. For quantitative analyses the seasonal ERs were obtained and compared using a non-parametric Kruskal-Wallis test, followed, when significant, by a post-hoc Dunn-test to identify significantly different comparisons. Moreover, the seasonal average group size was also calculated and compared using a non-parametric Kruskal-Wallis test, followed by a post-hoc Dunn-test to recognise seasons with significant differences.

For storm petrels only the comparison between seasonal ERs across the study period was performed. The smaller sample size did not allow an effective qualitative analysis of monthly occurrence nor to compare between seasonal average group sizes.

All statistical analyses were performed using the R Software (R Core Team 2022) and statistical significance set at p -value < 0.05 .

RESULTS

Surveying Effort and Species Occurrence

From June 2018 to May 2022 a total of 274 surveys were conducted across all seasons, totalling 1,522.91 hours on-effort (Tab. 1). A total of 4361 sightings of seabirds were collected, amounting to 18,301 individual seabirds belonging to 12 confirmed species (Tab. 2).

The highest seasonal ER - cumulative of all species - was recorded in spring (4.576), followed by autumn (2.354), summer (2.170) and winter (1.805). Except for the Arctic Skua (*Stercorarius parasiticus* (Linnaeus, 1758)), all identified species were sighted during summer. Four species were sighted in winter, five in autumn and seven in spring (ESM1). The sampling period during which more species were identified was period IV (June 2021 - May 2022), with nine species recorded. This was followed by periods II (June 2019 - May 2020) and III (June 2020 - May 2021), with seven species each, and period I with six species (June 2018 - May 2019) (ESM1).

Table 1. Summary of the number of surveys performed by season relative hourly effort (h)

	Number of surveys	Hourly effort
Winter	26	119.65
Spring	75	428.33
Summer	104	597.23
Autumn	69	377.70

Table 2. Summary table on the species sighted with the number of sightings and individuals recorded, and total ER for the study. The species have been divided based on their taxonomy

Common name	Scientific name	Sightings	Individuals	ER
Northern storm petrels				
European Storm Petrel	<i>Hydrobates pelagicus</i>	72	75	0.047
Procellariids				
Yelkouan Shearwater	<i>Puffinus yelkouan</i>	2428	14 573	1.595
Scopoli's Shearwater	<i>Calonectris diomedea</i>	1265	2837	0.831
Sulids				
Northern Gannet	<i>Morus bassanus</i>	421	512	0.277
Terns				
Gull-billed Tern	<i>Gelochelidon nilotica</i>	1	1	0.001
Sandwich Tern	<i>Thalasseus sandvicensis</i>	145	257	0.095
Common Tern	<i>Sterna hirundo</i>	6	14	0.004
Unidentified Tern	-	8	13	
Skuas				
Great Skua	<i>Stercorarius skua</i>	1	1	0.001
Pomarine Skua	<i>Stercorarius pomarinus</i>	2	4	0.001
Arctic Skua	<i>Stercorarius parasiticus</i>	1	1	0.001
Long-tailed Skua	<i>Stercorarius longicaudus</i>	1	1	0.001
Unidentified Skua	-	6	6	
Alcids				
Atlantic Puffin	<i>Fratercula arctica</i>	4	6	0.003
Total		4361	18 301	

Procellariiformes

Scopoli's Shearwater and Yelkouan Shearwater were the species with the most recorded sightings, accounting cumulatively for 17,412 individuals (95.1% of all sightings): 2,839 individuals (15.5%) and 14,573 individuals (79.6%) respectively.

Scopoli's Shearwater

This species was present in the area for the majority of the year but was not recorded during winter. Of the total 2,839 Scopoli's Shearwater observed, 52.9% were sighted in spring. Notably, 1,375 individuals were recorded in May alone,

accounting for 48.4% of all Scopoli's Shearwater's sightings. The record of this species seemed to follow a bimodal distribution with a main peak in May/June and a smaller one in September (Fig. 2A).

The ER for this species during the entire study period was 0.831. It reached a maximum seasonal average of 1.186 during spring and a minimum of 0 during winter. Its ER in summer was 0.980 and in autumn 0.455. The ER differed significantly between seasons (Kruskal-Wallis test: $H(3) = 10.007$, $p = 0.02$). A post-hoc Dunn-test revealed the winter ER to be significantly lower than both spring ($Z = 2.843$, $p < 0.01$) and summer ($Z = 2.618$, $p < 0.01$).

The average group size across the study was 2.2 individuals ($\pm SD = 5.8$, min-max = 1-100). The largest groups were recorded during spring (mean number of individuals $\pm SD$: 3.0 ± 7.5), although most sightings were of single individuals. Group size differed significantly across seasons (Kruskal-Wallis test: $H(2) = 32.651$, $p < 0.001$), with summer and autumn groups being significantly smaller than spring (post-hoc Dunn-test: Summer: $Z = 5.702$, $p < 0.001$; Autumn: $Z = 2.446$, $p = 0.007$).

Yelkouan Shearwater

The Yelkouan Shearwater was observed year-round, although with varying encounter rates across seasons. The highest count was recorded in spring, totalling 10,077 individuals (69.1% of all Yelkouan Shearwaters), with May accounting for the highest number of monthly records with 6,582 individuals (45.2%). In contrast, winter had

the lowest numbers of individuals recorded, with only 257 individuals observed (1.8%). The monthly counts of individuals appeared to follow a bimodal distribution, with a first peak in May and a second one in October (Fig. 2B).

The overall ER for this species across the study period was 1.594. The highest seasonal average ER was observed in spring (2.951) and the lowest occurred in winter (0.476). The ER values for summer and autumn were 0.829 and 1.620 respectively. The ER differed significantly between seasons (Kruskal-Wallis test: $H(3) = 9.640$, $p = 0.02$). Spring ER was found to be significantly higher from summer (post-hoc Dunn test: $Z = 2.302$, $p = 0.01$) and winter (post-hoc Dunn-test: $Z = 2.748$, $p = 0.003$).

Group size comprised, on average, 6.0 individuals ($\pm SD = 11.7$, min-max = 1-200). The largest groups were found in spring, (mean number of individuals $\pm SD = 7.9 \pm 14.5$), but single individuals made up most sightings. The group size differed significantly between seasons (Kruskal-Wallis test: $H(3) = 139.453$, $p < 0.001$) with spring having significantly larger groups than all other seasons (post-hoc Dunn test: Autumn: $Z = 7.814$, $p < 0.001$; Summer: $Z = 10.613$, $p < 0.001$; Winter: $Z = 3.475$, $p < 0.001$). Summer and autumn median group size were also significantly different with larger groups in autumn (post-hoc Dunn test: $Z = 2.944$, $p = 0.002$).

European Storm Petrel

The European storm petrel was the only species of the Hydrobatidae family record-

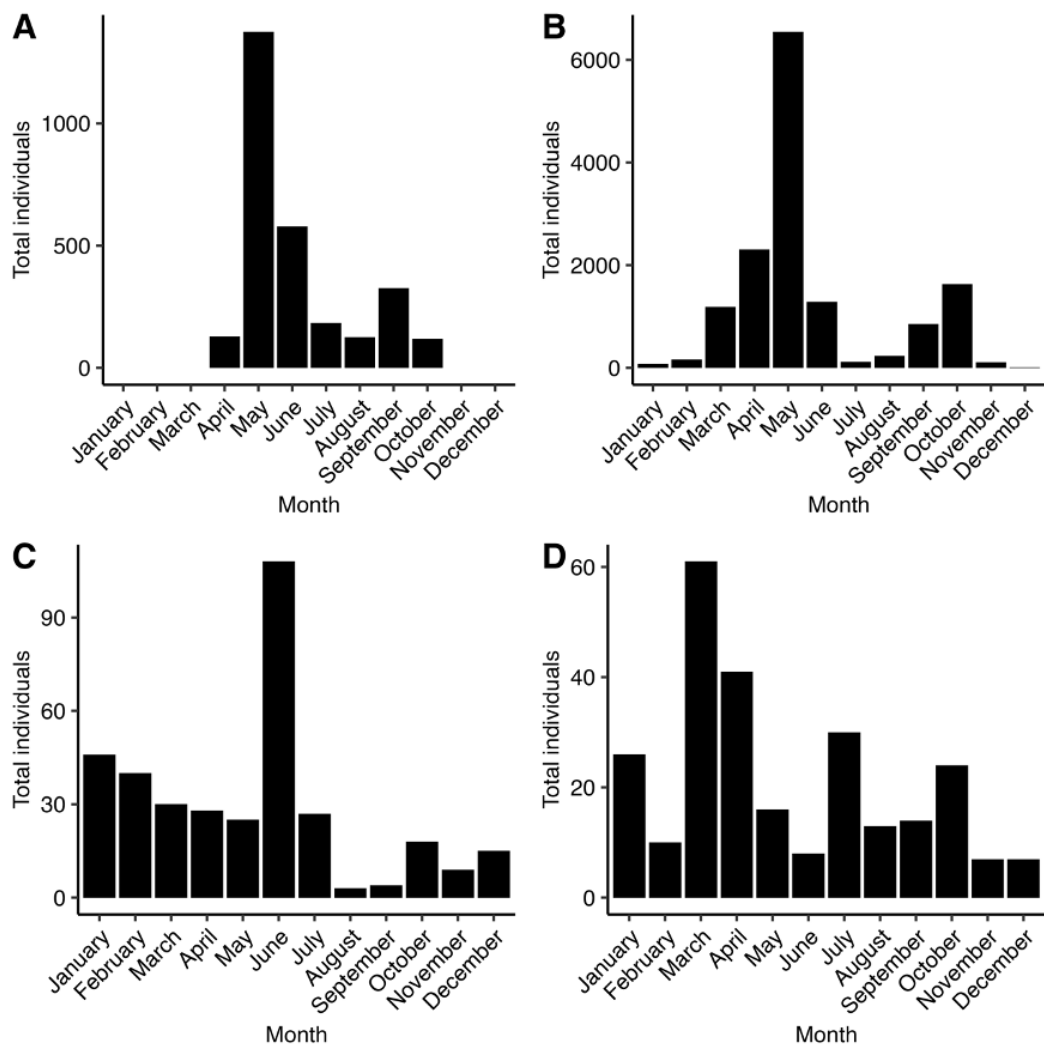


Figure 2. Total individual sighted during each month across the entire study period for the species: A) Scopoli's Shearwater, B) Yelkouan Shearwater, C) Northern Gannet and D) Sandwich Tern.

ed and the small number of individuals recorded did not allow for an analysis of group size between seasons. Presence was recorded from March to September, with a peak of 22 individuals in May, followed by July and August with 15 and 14 individuals respectively. The total ER for the species

across the study period was 0.046. The highest seasonal average ER was recorded in spring (0.072), followed by summer (0.066) and autumn (0.003); no individuals were sighted in winter. The ER did not differ significantly between seasons (Kruskal-Wallis test: $H(3) = 6.830$, $p = 0.078$).

Sulids

Northern Gannets

The Northern Gannet represents the third most frequently observed species with 512 individuals recorded, accounting for 2.8% of all seabirds sighted. Sightings of Northern Gannets were spread across the year with the highest number of sightings in summer, for a total of 177 individuals (34.6%) and peaking in June with 137 individuals (26.7%). This was followed by 142 individuals (27.7%) in winter, 100 individuals (19.5%) in spring and 93 individuals (18.2%) in autumn. No clear distribution in the monthly counts of individuals (Fig. 2C) seemed to emerge.

The ER for this species across the study period was 0.276. The highest seasonal ER was in winter (1.00) while the minimum was recorded in spring (0.198). The ER was 0.228 in summer and 0.212 in autumn. The ER did not differ significantly between seasons (Kruskal-Wallis test: $H(3) = 4.125$, $p = 0.248$), although winter presented a high variability (mean $ER \pm SD = 0.868 \pm 0.476$). The average group size was 1.2 ($\pm SD = 0.7$, min-max = 1-10) across the entire study period with no seasonal difference (Kruskal-Wallis test: $H(3) = 3.428$, $p = 0.334$). Single individuals made up the majority of sightings, 85.2% of groups.

Terns

Among Sterninae species, only the Sandwich Tern was sighted in larger numbers, with 257 individuals (1.4% of all individuals sighted) with an ER of 0.095

(Fig. 2D). This species had the highest seasonal ER in winter (0.318), followed by spring (0.133). The ER in autumn and summer were lower, 0.061 and 0.045 respectively. The ER did not differ significantly between seasons (Kruskal-Wallis test: $H(3) = 5.934$, $p = 0.115$), although winter presented a high variability (mean $ER \pm SD = 0.279 \pm 0.159$). The average group size was 1.8 ($\pm SD = 1.9$, min-max = 1-20) across the entire study period and presented significant seasonal differences (Kruskal-Wallis test: $H(3) = 14.674$, $p = 0.002$). Significant differences between winter and the other seasons were found (post-hoc Dunn test: Autumn: $Z = 2.110$, $p = 0.017$; Summer: $Z = 3.441$, $p < 0.001$; Spring: $Z = 3.160$, $p < 0.001$).

Fourteen individuals of Common Tern (*Sterna hirundo* (Linnaeus, 1758)) (ER = 0.004) and one of Gull-billed Tern (*Gelochelidon nilotica* (Gmelin, 1789)) (ER = 0.001) were recorded. For 13 individuals, the species could not be ascertained.

Skuas

Species of the family Stercorariidae were sighted 12 times. The Long-tailed Skua (*Stercorarius longicaudus* (Vieillot, 1819)), the Great Skua (*Stercorarius skua* (Brünnich, 1764)) and the Arctic Skua were recorded once - in August 2020 (Carta et al. 2021), June 2021 and April 2022, respectively - each with an ER of 0.001. Four Pomarine Skuas (*Stercorarius pomarinus* (Temminck, 1815)) were observed on two occasions, with a total ER of 0.001. In the remaining seven sight-

ings, species identification was not possible, and these individuals were classified as unidentified skuas.

Alcids

The only species of the Alcidae family recorded was the Atlantic Puffin with an ER of 0.003 across the entire study period. Single birds were sighted in July 2019 and August 2020, 2 individuals were sighted together in January 2022 and 2 together in March 2022.

DISCUSSION

Information on seabird presence and occurrence in the Ligurian Sea is limited and outdated. Atlases on birds wintering in the region rely on data collected from land during the 20th century (Spanò et al. 1998), whereas checklists only report species' occurrence and phenology over larger areas (Baghino et al. 2012). Moreover, there is a lack of studies specifically on the coastal distribution of seabirds in the Western Ligurian Sea. The current study is an attempt to address these gaps by characterising and describing the seabird species found in the coastal area of the Western Ligurian Sea. To our knowledge, the dataset presented in this paper is the largest yet analysed with 12 species considered for this marine area.

In terms of species occurrence, while spring had the highest ER, summer had the most species sighted. This can be explained by the increased surveying effort, which improved the likelihood of sight-

ings of rarer species of skuas and Common and Gull-billed Terns. The highest ER reported in spring, on the other hand, can be explained by the high primary productivity found in springtime (Estrada 1996; Bosc et al. 2004; Casella et al. 2014; Mayot et al. 2017) which can influence shearwaters distribution, the most frequently sighted species.

Overall, throughout the study period, the seabird community comprised several species observed year-round, and during all sampling periods, such as Northern Gannets, shearwaters and Sandwich Terns. In addition to these, other species were occasionally recorded, according to the migratory behaviour, contributing to the community diversity and stressing the ecological importance of the Western Ligurian Sea.

Procellariiformes

Shearwaters made up most sightings, with Yelkouan Shearwaters vastly outnumbering Scopoli's Shearwaters (5:1 ratio). This was expected as in the Western Mediterranean Basin major nesting colonies of both species of shearwaters can be found (Baccetti et al. 2009; Péron & Grémillet 2013). Shearwaters presented more numerous groups than other species, with significantly larger flocks recorded in spring. As shown for the Gulf of Lion – region close to the study area - bigger flocks have been linked to an enhanced productivity (Meier et al. 2015; Mayot et al. 2017) for both foraging Scopoli's Shearwater (Péron et al. 2018; Martín

et al. 2019) and for Yelkouan Shearwater feeding at low trophic levels (Bourgeois et al. 2011; Martín et al. 2019). The high primary productivity in the Ligurian basin consequently drives the presence of these species in the study area during spring (Mayot et al. 2017).

For shearwaters the ERs recorded well suit their known migratory behaviours with significant seasonal differences found in both species. Scopoli's Shearwaters were absent from the study area in winter. This result is in accordance with main research on its post-breeding migratory routes (Grémillet et al. 2015; Campioni et al. 2022; Muñoz Arroyo & Mateos-Rodríguez 2022), but it differs from what was previously reported in the Ligurian region (Baghino et al. 2012), therefore highlighting the need for further monitoring in this season. The large number of individuals in spring and early summer relates to the arrival of this species to main breeding sites on Italian and French coasts. From these colonies they depart for their foraging trips towards our study area (Péron & Grémillet 2013; Pollonara et al. 2015). The slight increase in numbers in autumn coincides with the pre-migratory movement, preceding the start of their migration outside of the Mediterranean Basin (Péron & Grémillet 2013; Grémillet et al. 2015).

Similarly to Scopoli's Shearwaters, Yelkouan Shearwaters increase in their numbers from March to May, likely in relation to foraging trips towards the Ligurian Sea (Pezzo et al. 2021). This increase leads to a significantly different seasonal

ER from both summer and winter. The low summer ER coincides with the inter-breeding migration to the Eastern Mediterranean Basin performed by part of the population (Militão et al. 2013; Raine et al. 2013). The slightly higher ER in autumn coincides with the return of breeding individuals to the French nesting colonies in preparation for the next breeding season (Brichetti & Fracasso 2003; Péron et al. 2013), while the number of individuals remains low also in winter, a period of low productivity of the Ligurian waters.

A good number of European Storm Petrels were recorded in this study. This species, normally found in more offshore and pelagic areas (Brichetti & Fracasso 2003), is in fact listed as an irregular migrant (Baghino et al. 2012) in the Ligurian region. The higher ERs during spring (0.069) and summer (0.063) corresponds to previous findings on the distribution of this species obtained through aerial surveys (Pettex et al. 2017) and observations in the Gulf of Lion (Rufay et al. 2014).

Sulids

Northern Gannet was the third species for individuals sighted. The few tracking studies performed in the Mediterranean (Kubetzki et al. 2009; Fort et al. 2012; Rodríguez et al. 2013), together with ringing activity, support the idea that the individuals found in the Western Basin come from breeding colonies in the British Isles (Spina & Volponi 2008). As supported by the Ligurian checklist (Baghino et al. 2012), this species appears to be a regular

migrant, both wintering and summering in our study area, with no significant seasonal differences in ERs. The highest ER was found in winter, similarly to other wintering areas in Western Iberian waters (Araújo et al. 2022) and in the Gulf of Lion (Rufray et al. 2014). Interestingly, more than a quarter of all individuals recorded were sighted in the single month of June. This finding is consistent with what has been described in the Gulf of Lion area, presenting a peak in numbers in the same month, although of lower magnitude (Rufray et al. 2014). Overall, this presence at the beginning of summer in the study area has not been investigated thus far, and hypotheses to explain this occurrence have not been put forward.

The presence of Northern Gannet year-round suggests the importance of the study area for foraging not only during winter, but also in summer for individuals not partaking in reproductive activities. This is linked to the presence in the area of waterfronts (Picco et al. 2010; Casella et al. 2014) that support an increased Chl-a, proxy of productivity, in turn linked to the foraging probability of this species (Grémillet et al. 2008; Sabarros et al. 2014; Scale et al. 2014).

Sandwich terns

Sandwich Tern was the fourth most abundant species recorded. It is a regular wintering migrant in the Ligurian region (Baghino et al. 2012), as confirmed also by our results. Regardless of its migratory and breeding habits on the Eastern coasts

of Italy (Brichetti 1980; Spina & Volponi 2008; Scarton et al. 2018; Valle & Scarton 2022), the species is present year-round in the study area (Fasola & Bogliani 1990). Spring and summer had the lowest ERs, aligning with its breeding season (Spina & Volponi 2008).

All other species

All the other species analysed in this study were spotted in smaller numbers. The Common and Gull-billed Tern, were sighted in summer and have been described as regular migrants in the region (Baghino et al. 2012). The sightings of skuas throughout the study period contribute significantly to the knowledge of the occurrence of these rare species in the area. This is particularly true for the Pomarine skua listed as Vagrant for the Ligurian region with only 6 individuals recorded until 2011 (Baghino et al. 2012), but registered, in this study alone, for a total of 4 individuals. Only 6 individuals of Atlantic Puffin were recorded, even though this species is described as a regular migrant (Baghino et al. 2012) with multiple sightings in Liguria (Carboneras 1988; Ballardini et al. 2005). The few sightings can be linked to a more offshore distribution or a higher use of the Gulf of Lion area (Rufray et al. 2014).

Methodological considerations

Opportunistic surveys of seabirds offer the chance to collect information on species that are otherwise difficult to study,

increasing our knowledge in their occurrences and behavioural patterns (Balance 2008; Viola et al. 2024).

In our study the opportunistic nature of the data collection enabled us to compile a large dataset on the occurrence of various seabird species in a coastal area. However, the lack of a standardised number of surveys per season, together with the need for favourable environmental conditions for comparable monitoring, led to a variation in surveying effort. This uneven effort likely contributed, at least partially, for the higher number of species recorded in summer. Although these differences did not hinder analyses of the most sighted species, they underscored the need for an increased monitoring effort during other seasons.

In order to avoid hindering the data collection on cetacean species, which was the main focus of these coastal surveys (Ascheri et al. 2022), a selection of the species to record was made. All landbirds sighted migrating in the area were omitted from data collection, as were seagull species, cormorants and shags. This allowed recording data only on species not easily sighted from land. For cormorants and shags, in particular, main monitoring studies are conducted on land, along the coast of their breeding areas. Similarly, counts of seagulls are highly efficient when performed at breeding colonies from land (Walsh et al. 1995). Moreover, for seagulls, the strong presence of Yellow-legged Gull as well as Black-headed Gull in our area of investigation, would have strongly impacted the data collec-

tion on other species both of cetaceans but also seabirds. This species selection, while preventing a complete description of the seabird community, allows us to provide important information on species less easily sighted from land, contributing to their study.

Conclusions

The findings of this study provide a valuable baseline for the seasonal occurrence of seabirds in this area, offer significant information about species presence, and underscore the potential ecological role of the Western Ligurian Sea for seabird populations. These results emphasise the crucial need to establish year-round, long-term monitoring programmes to gather essential information for the conservation of these species. This especially in light of the ongoing debate over the development of offshore wind farms in the Western Mediterranean Sea, which may cause significant impacts (Bray et al. 2016).

Future studies can assess the abundance and density of these species in the area, allowing for the revision of atlases of seabirds and helping to identify potential areas of conservation interest for the protection of the most vulnerable species. Moreover, long-term studies on seabird distribution in the area will help recognise possible spatial and temporal changes in occurrence in relation to environmental variables, therefore providing important information for their conservation.

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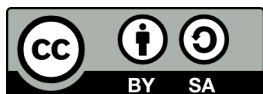
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Listening to climate change in my backyard: the frequency of overwintering Eurasian Blackcaps *Sylvia atricapilla* increased in a small town in Northern Italy, but not that of European Robins *Erithacus rubecula*

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Abstract

Climate change is reshaping biotic communities all over the world, and birds are often affected by climate variations, including outside the most investigated breeding season. Here, using an opportunistic but intensive data collection, I show how the frequency of overwintering Eurasian Blackcaps *Sylvia atricapilla* has increased in recent winters (since 2011-2012) in an area in northern Italy where it used to be very rare during the coldest months of the year. A linear model based on time progression explained more than half of the variation of the species' frequency. An alternative linear model based on the average daily temperature in the period December-February had a substantially similar (marginally better) performance, suggesting that such an increase could be driven by milder winter temperatures. A regular and abundant wintering species, the European Robin *Erithacus rubecula*, only showed fluctuations over the same period but not a temporal trend, nor a relation with average daily temperature. Given that the sampling effort was the same for the two species, finding a clear trend in Blackcaps but not in Robins pointed towards a real increase in the overwintering frequency of the former, rather than at sampling biases. This worked example also suggests that citizen science and opportunistically

collected data could be potentially used to assess the effects of climate change on fine-scale, local variations in bird distribution, especially if collected in areas or contexts that are regularly visited by observers. Similar considerations may apply to passive/automated recorders.

Keywords: migration, passerines, Robin, temperature, winter

INTRODUCTION

Climate change is reshaping biotic communities all over the world, and birds are often affected by climate variations (Bateman et al. 2016, Scridel et al. 2017), and by the consequences of climate modifications, from changes in habitat characteristics (Matthews et al. 2011) to variations in biotic interactions (Brambilla et al. 2020). While many studies focused on breeding bird species and assemblages, avian species and communities are affected by climate change also during the non-breeding season. The wintering season is receiving increasing attention, because of marked changes in distribution and/or abundance of wintering species related to the ongoing climate change; well-known examples involved waterbirds (Lehikoinen et al. 2013, Pavón-Jordán et al. 2015), but similar dynamics might apply to passerines (Brambilla et al. 2024) and raptors (Morganti et al. 2017).

With this short contribution, I explore whether the frequency of a common species in Northern Italy, the Eurasian Blackcap *Sylvia atricapilla*, has increased in recent winters, in an area where it used to be very rare during the coldest months of the year. In the Prealps of northern Italy, where this study took place, Blackcap is

a very common and abundant breeder, but typically a rare and localised wintering bird, mostly found during mild winters (e.g. Pedrini et al., 2005). Blackcap has been reported as a flexible species, able to adapt its migratory behaviour and strategies to changing climatic, available resources and environmental conditions (Berthold & Terrill 1988, Delmore et al. 2020, Plummer et al. 2015, Pulido & Berthold 2010, Van Doren et al. 2021). Therefore, it can be assumed that a possible increase in overwintering rate could be the result of climate change leading to more favourable, warmer winters; to test this, I also investigate the link between Blackcap frequency and average daily temperature during the winter. To exclude other possible confounding effects such as temporal increases in observation efforts, improved conditions for small wintering birds, increased food availability for insectivorous species, etc., I also evaluate the trend over the same period and in the same site of a species showing an opposite phenology and pattern of seasonal occurrence, the European Robin *Erithacus rubecula*. Indeed, the Robin is an abundant wintering species in the area, but a much rarer and localised breeder, especially in urban environments. Considering also Robins, surveyed

with the same method and timing of the target species, allows testing for the occurrence of possible biases due to potentially different sampling efforts along the study period. This approach could be considered similar to the target-group background one, adopted to correct for sampling biases in species distribution models (Phillips et al. 2009).

STUDY AREA AND METHODS

The study took place in Cantù (Como province, Lombardy region; approximate position 45°44'N 9°07'E), in northern Italy, within the Prealps just north of the Po plain. The site at which all observations had been collected is located in the western part of the town, at an elevation of c. 360 m asl, and is characterised by residential buildings, frequently surrounded by small gardens and roads. I recorded all the observations of Blackcap and Robin I made at home (mostly vocal contacts), for 13 consecutive winters (1st December – end of February, from 2011–2012 to 2023–2024). No time was exclusively devoted to data collection; rather, I recorded all the contacts I obtained with the target species during standard behaviour at or around home. Given that most observations consisted of single individuals for Blackcap (377 obs. of 385 individuals), I considered the number of sightings rather than the number of individuals. For Robin (819 observations of 1058 individuals) also the overall number of individuals was analysed. The sampling effort was the same for both species, which were

always recorded when heard or observed. The surveyed area was not explicitly defined, but considering the location of recorded individuals can be approximated to a radius of 150 m from home (i.e., 7 ha) for both species.

I downloaded from the ARPA (Agenzia Regionale per la Protezione dell'Ambiente) website (<https://www.arpalombardia.it/temi-ambientali/meteo-e-clima/form-richiesta-dati/>) the average daily temperature recorded at a meteorological station (Cantù Asnago) located very close to the study site. Temperature records included missing values for only three days during the period, and the latter were omitted from the computation. Winters were temporally ordered from 1 to 13, thus indicating time progression. The number of observations per each species per winter was modelled as a function of i) the winter progressive number as a continuous predictor, to test for a linear variation in the number of observations during the study period, and ii) the average daily winter temperature as a continuous predictor to test for a linear effect of temperature. For these analyses, a negative binomial one was selected to account for overdispersion in the number of observations of both species. Each model was subject to assumptions testing, using 500 simulated residual distributions. I evaluated the uniformity of residuals, the possible occurrence of outliers, the simulated vs. observed dispersion, the occurrence of zero-inflation and the distribution of residuals' quantiles. All tests led to non-significant outcomes and hence both models were considered as fully valid. Akaike's informa-

tion criterion corrected for a small sample size was computed for alternative models (winter progression vs. average daily temperature) to evaluate which option (temporal increase or temperature effect) was more supported. The winter progressive number and the average daily temperature were strongly and significantly correlated (Pearson's $r = 0.60$, $p=0.031$), indicating a progressive increase in winter temperature (with an impressive change from a minimum of 1.33 °C in 2011-2012, to a maximum of 4.44 °C in 2023-2024), and thus their effects were separately modelled. Models' R^2 was calculated using the 'r.squaredLR' command in MuMIn. Data were analysed in R, using the packages MuMIn (Barton 2020), and MASS (Ripley 2011) and model results and residual fits were graphically displayed with visreg (Breheny & Burchett 2018) and tested with performance (Lüdecke et al. 2020) and DHARMA (Hartig 2020) packages. Data are publicly available (Brambilla 2025).

RESULTS

The number of observations of both species showed some fluctuations during the study period, but, while for the Robin no significant trend was detected, for Blackcap there was a clear increase (Table 1).

The numbers of observations of the two species were not correlated ($r = 0.066$, $p = 0.829$). The progressive number of winter and the average daily winter temperature had no effect on the negative binomial regression modelling the number of wintering or the overall number of individuals

Table 1. Number of observations recorded for the two target species during the study period between December and February

Winter	Blackcap <i>Sylvia atricapilla</i>	Robin <i>Erithacus rubecula</i>
2011-2012	4	52
2012-2013	1	85
2013-2014	8	46
2014-2015	5	86
2015-2016	6	46
2016-2017	4	52
2017-2018	3	33
2018-2019	3	84
2019-2020	7	62
2020-2021	19	115
2021-2022	11	66
2022-2023	23	41
2023-2024	14	51
overall	108	819

for Robin (all β values very close to zero; all $P > 0.5$, for three out of four models >0.9). However, both predictors had a strong influence on Blackcap observations (for the progressive number of winter: $\beta \pm SE: 0.15 \pm 0.04$, AICc 77.60, Fig. 1; for average daily winter temperature: $\beta \pm SE: 0.61 \pm 0.16$, AICc 77.26, Fig. 2). The two Blackcap models, therefore, were similarly supported, as indicated by the very small difference in their AICc values, and they also had a nearly identical and high R^2 ($R^2 = 0.56$ for the model based on time progression; $R^2 = 0.57$ for the model based on temperature).

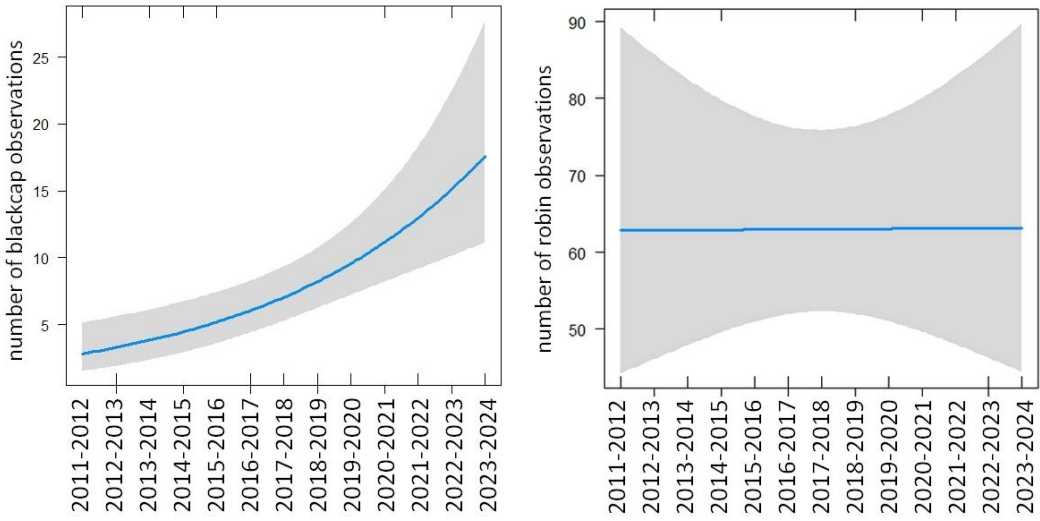


Figure 1. Modelled number of Blackcap and Robin observations per winter (December-February) during the period considered in the study.

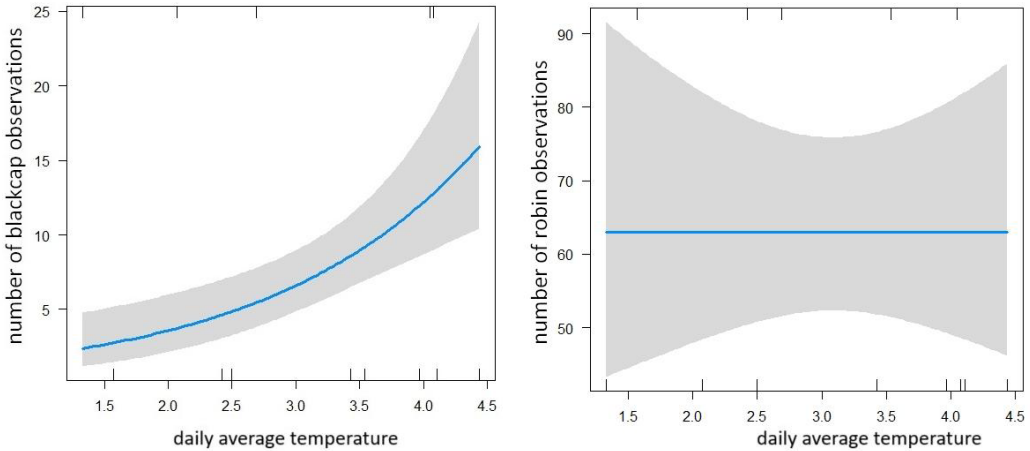


Figure 2. Modelled number of Blackcap and Robin observations per winter (December-February) in relation to average daily temperature recorded over the same period at a closely located meteorological station.

DISCUSSION

Climate change has pervasive effects on biodiversity and ecosystems world-wide. Birds are frequently used as model

taxa to investigate its effects on species and communities (Pearce-Higgins et al. 2015). Even if most studies, especially in Italy, have been focussing on breeding

period and distribution (e.g., Brambilla et al., 2022; Chamberlain et al., 2013; Scridel et al., 2017), climate change has already resulted in southern Europe in an increasing number of overwintering species and individuals belonging to taxa usually migrating over longer distances (Morganti & Pulido 2012), and in an increasing latitude of wintering assemblages of many species (La Sorte & Thompson III 2007). Wintering at higher latitudes, i.e. closer to breeding grounds, may provide advantages in terms of reduced energy consumption and risks along the migration routes, as well as earlier occupation of breeding areas with consequent better tracking of phenological advance due to climate change and reduced mismatch with spring phenology (Ambrosini et al. 2019, Koleček et al. 2020, Newton 2008).

Here, I provide a simple example of such dynamics on a common species, frequently found in urban areas, displaying flexible and complex migration strategies. Blackcaps are known to adapt their migratory behaviour as a response to climate change (Morganti & Pulido 2012, Pulido & Berthold 2010). The increase in the frequency of observations of overwintering Blackcaps within an area traditionally not occupied or seldom used by wintering individuals of the species highlighted such dynamics at a local scale. The marginally stronger effect of average daily winter temperature on the observation frequency confirmed that the increase in the species' occurrence rates can be due to climate change and, in particular, to milder winters.

The data used here to assess the changes in the frequency of winter observations of two model species had been collected through intensive but opportunistic efforts carried out at a single site. The paired surveys helped disentangle real trends from possible variations in the sampling efforts. Comparing the patterns shown by different species surveyed through the same methods might provide an easy-to-implement way to test for the reliability of temporal trends, similar to what is done to evaluate spatial patterns when dealing with species distribution (Phillips et al. 2009). This worked example, therefore, suggests that opportunistically collected data, citizen science data, or even data collected using passive automated recorders, could be potentially used to assess the effects of climate change on fine-scaled, local variations in bird distribution. Areas or contexts that are regularly visited (e.g., for job reasons, while commuting to the workplace, etc.) by observers might provide useful settings to collect data that over the years might provide useful information about phenological or distributional changes linked to climate and other environmental changes.

Conflict of interest

The author declares he has no conflict of interest.

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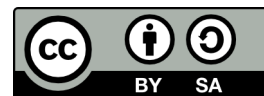
Data availability

All data used in this work are available on the UNIMI Dataverse repository at https://doi.org/10.13130/RD_UNIMI/EKJ3HG.

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Long-term citizen science program of the first arrival of Barn Swallows *Hirundo rustica* in Italy: a preliminary study on how the climate affects spring migration across the Mediterranean

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ABSTRACT

This study aims to present and analyze the spring migration of Barn Swallow *Hirundo rustica* data collected by a network of Italian birdwatchers in collaboration with a Research Institute in the framework of a citizen science project. More than 500 observations of the first sightings of Barn Swallow's arrival in Italy were collected from 2004 to 2019 throughout the country. Percentile indices were calculated for each year and four regional subdivisions of the Italian territory: Northern, Central, Southern Italy, and the main islands (Sicily and Sardinia). Our analysis showed that the first spring sightings were significantly advanced (from 1 to 1.2 days/year) during the study period. Our data also describe the progression of migration across Italy with first arrivals documented in the main island and progressing from South to North of Italy first in Sicily and Sardinia, then along the Tyrrhenian and Adriatic coasts and from there to the major mountain chains (Apennines and Alps). Analysis of climate data (February temperature) of Europe and Africa showed a recurrent pattern of years of late arrivals linked to a negative temperature anomaly over the Mediterranean and North Africa and years of early arrival with a positive temperature anomaly in the same area. First sightings were significantly correlated with December, winter and January-to-March average



temperatures at a stopover site in North Africa. Our study demonstrates that analyses based on a large environmental dataset can investigate complex phenomena such as bird migration and that a high volume of data combined with statistical indices may mitigate the limitations linked to a citizen science approach.

Keywords: Bird migration, Barn swallow, NAO, Climate, Citizen science

INTRODUCTION

Understanding the great phenomena of nature has always been a challenge for humankind. Bird migration, in particular, is a complex phenomenon, that has been widely studied (Alestorm 2011, Bertold 2001) using various models and methods, including some citizen science data. However, there are some concerns about obtaining large-scale unbiased data, since non-ornithologists should be educated and recruited to collect standardized records. This is feasible if the study involves a well-known species that is easy to identify. The Barn Swallow *Hirundo rustica* has been selected (Sparks & Braslavská 2001, Sparks & Tryjanowski 2007) since it is a common and easily detectable bird especially while in active flight and foraging.

The Barn Swallow is a small passerine undertaking a long migration between Europe and Africa. Each year migrants embark on a journey estimated to be at least 3000 km long between the two continents (Turner 2006). Along the route that passes through Italy, the Barn Swallows encounter important geographical barriers including the Sahara Desert and the Mediterranean Sea. Some tracked birds have been reported to regularly cross the equatorial rain forest to

reach South Africa and return (Klvaňa et al. 2017, Liechti et al. 2014, Pancerasa et al. 2022). In Europe, Barn Swallow spring migration begins as early as February though its timing varies from year to year sometimes by several weeks. Traditionally, people associate the arrival of the first Barn Swallow with the onset of warmer spring temperatures, but factors determining the timing of Barn Swallow migration are debated and not yet properly quantified. Changes in temperature, food supply and day length have been hypothesized to influence trans-Saharan migrants (Berthold 1996, Berthold 2001, Gordo et al. 2005, Møller et al. 2010, Rubolini et al. 2002). The timing of migration is influenced by the photoperiod (Berthold 1996) as arrival time is highly synchronized to ensure successful pairing and reproduction (Coppack & Both 2002). Variations in Barn Swallow arrival to the breeding grounds in Europe appear to be linked either with meteorological conditions at their destination (Pancerasa et al. 2018) or to environmental changes both in stopover and wintering areas (Balbotin et al. 2009, Sicurella et al. 2016). However, weather conditions that trigger early- or late spring arrivals at breeding sites in Northern Europe may differ from those

experienced by birds actively migrating, particularly when crossing major barriers such as the Mediterranean Sea and the Sahara Desert (Saino et al. 2004). It remains unclear whether warmer springs accelerate the migration process due to improved travelling conditions en route, or if large-scale meteorological variations and climatic changes across the continent play a role. This question is challenging to address as it requires significant resources (in time and costs) to monitor such large-scale phenomena both spatially and temporally. Tools like geolocators (Alex et al. 2013, Pancera et al. 2022) which track the migration routes of single individuals or radar systems which identify migration patterns of large numbers of birds (Kranstauber et al. 2020, Nilsson et al. 2018) may help to describe the temporal and spatial variation of bird migration. However, these tools do not provide detailed information on biological parameters, such as fitness, that may affect migration timing and routes (Ambrosini et al. 2014, Pancera et al. 2022). Direct observation and ringing remain the most used monitoring methods. Ringing schemes (e.g. EURING databank, <http://www.euring.org>) use capture and recapture methods to track individuals' locations and migration timing along their migratory routes or during their stay in the wintering and breeding grounds. The high cost of monitoring bird migration can be mitigated by long-term citizen science programs involving large numbers of volunteers, guided by experts, who can cover extensive areas

such as an entire nation, over multiple migratory seasons for several years (Newson et al. 2016). When properly designed, these programs not only enhance scientific knowledge but also build participants' scientific skills and environmental awareness (Roche et al. 2020). In this study, we report the experience of a citizen science project conducted in Italy and the findings of a 16-year study (2004-2019) led by non-scientist members from the birding association EBN Italia. The Barn Swallow was selected as a target species for two reasons: first, the arrival of this species has always been associated with the beginning of spring in the boreal hemisphere; second, it is a species easy to identify, not secretive in behaviour and not easily confused with others. Birdwatchers in collaboration with the National Research Council of Italy (CNR) were asked to report the first spring sighting of a Barn Swallow and data were analyzed to further address whether there is any trend in spring arrival timing on Italian coasts and if this change might be affected by climate changes.

METHODS

This citizen science study is based on the first sighting of Barn Swallows collected over the Italian territory (from 35° 29'N to 47° 5'N latitude and 6°37'E and 18°31'E longitude) from 2004 to 2019. These data were found as part of the citizen science project "GILIA – Signs of Spring" that was set up by the CNR and aimed to involve all stakeholders who

carry out recreational or professional activities in the environmental sector in this campaign: e.g. voluntary and cultural associations, administrators and operators of parks and protected areas and university researchers.

Phenology data

Data collection began in 2004 in the framework of GILIA, a collaboration between EBN Italia and the former Institute of Biometeorology, now the Institute of BioEconomy of the National Research Council (IBE-CNR) aimed to map the timing of the first Barn Swallow's arrival across Italian provinces and to investigate its relationship with climate change. Over the years, EBN Italia members and volunteers have contributed to citizen-science research (Di Febbraro 2023), concerning also the Common Crane *Grus grus* migration routes (Mingozzi et al. 2013), Short-toed Snake-eagle *Circaetus gallicus* autumn circuitous pattern migration (Ruggieri et al. 2007) and other local bird research initiatives.

EBN birdwatchers were asked to report any initial sighting of Barn Swallows in spring, including time and location, by email to the association's mailing list. From 2007 to 2013 IBE developed a dedicated webpage for easy collection of geo-located data. Observers recorded data by selecting the exact position on a map and filling out a form with the relevant information: timing, number of individuals, and weather conditions. Emailed data were processed and collected in a geo-

database. Between 2014 and 2019 additional georeferenced data were also gathered from platforms managed by birdwatchers and ornithologists: Ornitho.it (www.ornitho.it) and Ubird (<https://ubird.ebnitalia.it>). From this extensive database, containing more than 24.000 observations, the authors extracted the earliest record of a Barn Swallow for each of Italy's 106 provinces. This filtering process prevented multiple and duplicate counts from nearby locations, reports from different observers on the same day, or repeated sightings of the same individual at the same site. The refined dataset included 576 records for further analysis.

The timing of each observation was recorded as the Julian day of the year (doy), for example, January 1st is doy 1, February 28th is doy 59 and so on. Studies using the first arrival dates can sometimes overestimate changes in phenology, while the use of median and percentile observation dates within the same year allows a more detailed understanding of shifts in spring migration timing (Maggini et al., 2020). Therefore, to minimize the impact of outliers, we calculated the following indicators: 25th percentile (P25), median (P50) and 75th percentile (P75) of the first arrival dates per province in each year.

Climate data

The analysis of phenology in relation to climate was conducted by using large-scale climate indices and monthly temperature data. We selected the North Atlantic Oscillation (NAO) as a major climate

index. The NAO index is calculated as the difference of the surface sea-level pressure between the Azores High and the Subpolar Low (Hurrell 1995). Positive and negative phases of NAO are associated with large-scale weather conditions over the North Atlantic that result in different patterns of temperatures and precipitations over North America and Europe. Previous studies have already detected a correlation between the NAO index and spring migration timing of some bird species (Hüppop & Hüppop 2003, Rubolini et al. 2007). Monthly NAO data were obtained from the Climate Prediction Center of the National Oceanic and Atmospheric Administration (CPC-NOAA). To assess temperature patterns across Europe and Africa during years of late and early arrivals we used monthly temperature data retrieved from the ERA5 re-analyses dataset (Hendricks et al. 2010) provided by the European Centre for Medium-Range Weather Forecasts (ECMWF) with a spatial resolution of 30 km x 30 km. For each grid cell and each study year, the February temperature anomaly was calculated as the difference between each year and the average monthly temperature in 1980-2010. Maps showing anomalies for three late-arrival years and three early-arrival years were presented and discussed.

Statistical analyses

Observations were tested for potential weekend biases using the Mann Whitney's and Pearson's chi-squared test for binomial variables and no signi-

ficant bias was found regarding weekdays and weekends. The 25th percentile (P25), median (P50) and 75th percentile (P75) of the sightings were calculated on the complete dataset (ITA), as well as separately on four Italian geographical subsets (regions) based on latitude: Northern Italy (NI, latitude higher than 44°N), Central Italy (CI, latitude between 41.5 °N and 44°N), Southern Italy (SI, latitude lower than 41.5°N), and the main Islands of Sardinia and Sicily (ISL). Since Barn Swallows may be also a resident species in Central and Southern Italy, a few observations recorded before February 1st were excluded from the analysis.

Then, temporal trends in annual P25, P50 and P75 values were examined using regression analyses. Differences among years were assessed by one-way analysis of variance (ANOVA), followed by Tukey's HSD test with a significance level set to $p < 0.05$. Regional differences in P25 values among regions (NI, CI, SI and ISL) were also tested by ANOVAs followed by Tukey's HSD tests.

Regression analysis was also used to investigate the relationship between first sightings, as the dependent variable, and year and region (four-level factor) as independent variables. The reference value for the factor region was CI.

To map the temporal progression of bird migration, we calculated the anomaly of each observation date relative to the average date in the same year. Then, the 25th percentile (P25), median (P50) and 75th percentile (P75) of all anomalies were mapped to illustrate the geo-

graphical distribution of early and late observations.

We also investigated the relationship between P25, P50, and P75 metrics and both the average monthly and winter air temperatures in a region of Northern Africa (Long: 1.5°E – 11°E, Lat: 35°N – 38°N) that is considered one of the major stopover sites of Barn Swallows migrating through Italy and the Mediterranean Sea (Ambrosini et al. 2011, Sicurella et al. 2016).

The average air temperature for December, January, February and March, and the average winter air temperature (DJF) and the average January to March air temperature (JFM) at a height of 2 m were calculated from the period 2003 to 2019 using ERA 5 re-analysis. Relationships between P25, P50 and P75 and monthly NAO and the other climate variables were assessed by Pearson correlation analyses. Maps of the Pearson correlations between P25 sightings and temperature variables in the previously selected African region were also presented.

RESULTS

A total of 576 sightings of the first arrival of Barn Swallows in spring were used in this study (Tab. 1). The average date for the first spring sightings of a Barn Swallow in Italy was March 6th (day 65); the earliest sighting occurred on February 4th, 2017 (day 35) in SI (specifically in Lecce and Caserta), while the latest was on April 12th, 2009 (day 102) in CI (Arezzo). The

number of observations collected over the whole studied period ranged from 25 to 7 in NI, CI, and SI and from 8 to 2 in ISL (Tab. 1). Over the studied period, the number of observations (nrec) in NI ($t = -1.14$, $df = 14$, $P < 0.01$) and CI ($t = -0.5$, $df = 14$, $p < 0.01$) significantly decreased. No significant trend was assessed for SI ($t = -0.07$, $df = 14$, $p = 0.62$) and ISL ($t = +0.1$, $df = 14$, $p = 0.29$).

Differences among years were significant according to ANOVA analysis ($F = 22.1$, $df = 15,560$, $p < 0.001$). The first arrival was significantly late in 2005 (mean = 77 day, CI = 64-87 day), in 2008 (mean = 72 day, CI = 57-87 day) and in 2009 (mean = 71 day, CI = 61-96 day), and significantly advanced in 2017 (mean = 54 day, CI = 39-73 day), 2016 (mean = 57 day, CI = 47-67 day) and 2019 (mean = 58 day, CI = 43-73 day) (Fig. 1). The largest significant difference in P25 first sightings was found between 2012 and 2019 ($|t| \geq 2.235$, $df = 63$, $p \leq 0.029$), while the lowest not significant was found between 2010 and 2017 ($t \leq 0.542$, $df = 64$, $p \geq 0.059$).

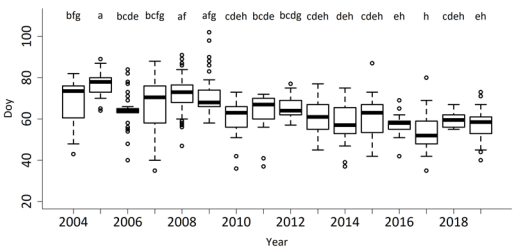


Figure 1. Box and whisker plot of first sightings of Barn Swallows in Italy each year. A significant difference between years was tested by conducting a one-way ANOVA followed by a Tukey HSD test. Different letters indicate significant differences ($p < 0.05$) between groups.

Table 1. Percentage and number of annual observations of the first sighting of Barn Swallows in North (NI), Central (CI) and South Italy (SI) and Italian Islands (ISL). Annual mean, confidence interval, median, 1st and 3rd quartile (Q.) of day (day of the year) of observations collected in Italy

Year	N. Rec	NI	CI	SI	ISL	Mean doy (conf. int.)	1 st Q. (doy)	Me-dian (doy)	3 rd Q. (doy)
2004	48	52% (25)	31% (15)	10% (5)	6% (3)	69 (48-82)	61	74	76
2005	45	56% (25)	27% (12)	11% (5)	7% (3)	77 (64-87)	73	78	80
2006	33	36% (12)	36% (12)	12% (4)	15% (5)	64 (46-82)	63	64	65
2007	28	43% (12)	29% (8)	14% (4)	14% (4)	67 (38-81)	58	71	76
2008	79	49% (39)	25% (20)	16% (13)	9% (7)	72 (57-87)	68	73	77
2009	53	45% (24)	28% (15)	15% (8)	11% (6)	71 (61-96)	66	68	74
2010	41	44% (18)	24% (10)	22% (9)	10% (4)	61 (42-71)	56	63	66
2011	28	29% (8)	39% (11)	25% (7)	7% (2)	64 (40-71)	60	67	70
2012	31	45% (14)	26% (8)	23% (7)	6% (2)	65 (57-76)	62	64	69
2013	25	44% (11)	28% (7)	12% (3)	16% (4)	61 (46-72)	55	61	67
2014	27	41% (11)	26% (7)	15% (4)	19% (5)	58 (38-74)	53	57	66
2015	28	32% (9)	18% (5)	29% (8)	21% (6)	61 (44-78)	54	63	67
2016	25	52% (13)	32% (8)	8% (2)	8% (2)	57 (47-67)	55	58	59
2017	25	28% (7)	36% (9)	20% (5)	16% (4)	54 (39-73)	48	52	59
2018	26	27% (7)	27% (7)	23% (6)	23% (6)	59 (55-67)	56	60	62
2019	34	32% (11)	26% (9)	18% (6)	24% (8)	58 (43-73)	53	59	61
Total	576	43% (248)	28% (161)	17% (98)	12% (69)	65 (42-87)	58	65	73

The trend for the first spring sightings showed a significant advancement for P25 (1.02 ± 0.24 SE day/year, $t = -4.334$ df = 14, $p < 0.001$, $R^2 = 0.57$), P50 (1.24 ± 0.20 SE days/year, $t = -6.071$ df = 14, $p < 0.001$, $R^2 = 0.72$) and P75 (1.15 ± 0.20 SE days/year, $t = -5.648$, df = 14, $p < 0.001$, $R^2 = 0.69$) across the studied period (Fig. 2).

Observations are spread throughout Italy with some hotspots in NI, the Liguri-

an and Tyrrhenian Sea, the southern Adriatic Sea and Sicily (Fig. 3a). Early sightings (below P25) and late sightings (over P75) are shown in Fig. 3b and 3d respectively while sightings between P25 and P75 in Fig. 3c. The distribution of Barn Swallow first sightings indicates that the first migrants are generally seen both on the main islands, Sicily and Sardinia (ISL) and along the Tyrrhenian coast as in

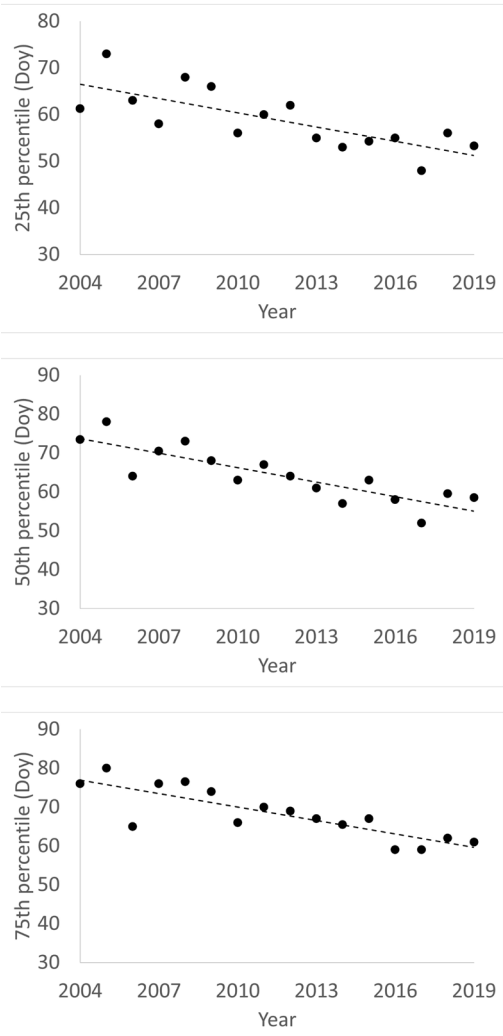


Figure 2. Temporal trend (year) of 25th percentile, 50th percentile and 75th percentile of first sightings (doy) of barn swallows in Italy. The dashed line represents the trend interpolated by the regression analysis.

Latium, Liguria and Tuscany (Fig. 3b). Late observations are mainly concentrated in the mountain regions of the Alps and Apennines (Fig. 3d).

ANOVA test on first sightings across the four different geographical areas was significant ($F = 16.19$, $df = 3,572$, $p < 0.001$, Fig. 4) and indicated that the first Barn Swallows reached the isles earlier than other parts of Italy.

Multiple regression analysis by year and region (Tab. 2 and Fig. 5) supports the hypothesis that Barn Swallows arrive first in ISL, then, after 5 days, in CI and SI, and finally, after 7 days, in NI.

In the year of latest arrival (2005) we report a large negative temperature anomaly present over the Mediterranean Sea, Italy and North Africa from Mauritania to western Libya with a similar pattern, though weaker, also present in 2009 (Fig. 6). The year with the second latest arrival (2008) does not show such pattern even though a negative anomaly is present over Libya.

In contrast, the year of the earliest arrival (2016) showed a large positive temperature anomaly over the Mediterranean Sea with a similar pattern, though of weaker intensity, evident both in 2017 and 2019 (Fig. 6).

No significant correlation was found between percentiles of first sightings and winter and monthly NAO indices (Tab. 3). Increasing average temperatures in the selected region of North Africa (Sicurella et al., 2016) significantly anticipated the 25th percentile of first sightings: December temperatures (Pearson's $r = -0.537$, $df = 14$, $p = 0.032$), winter (DJF) temperatures ($r = -0.577$, $df = 14$, $p = 0.019$) and JFM temperatures ($r = -0.530$, $df = 14$, $p = 0.035$). No other significant relationships

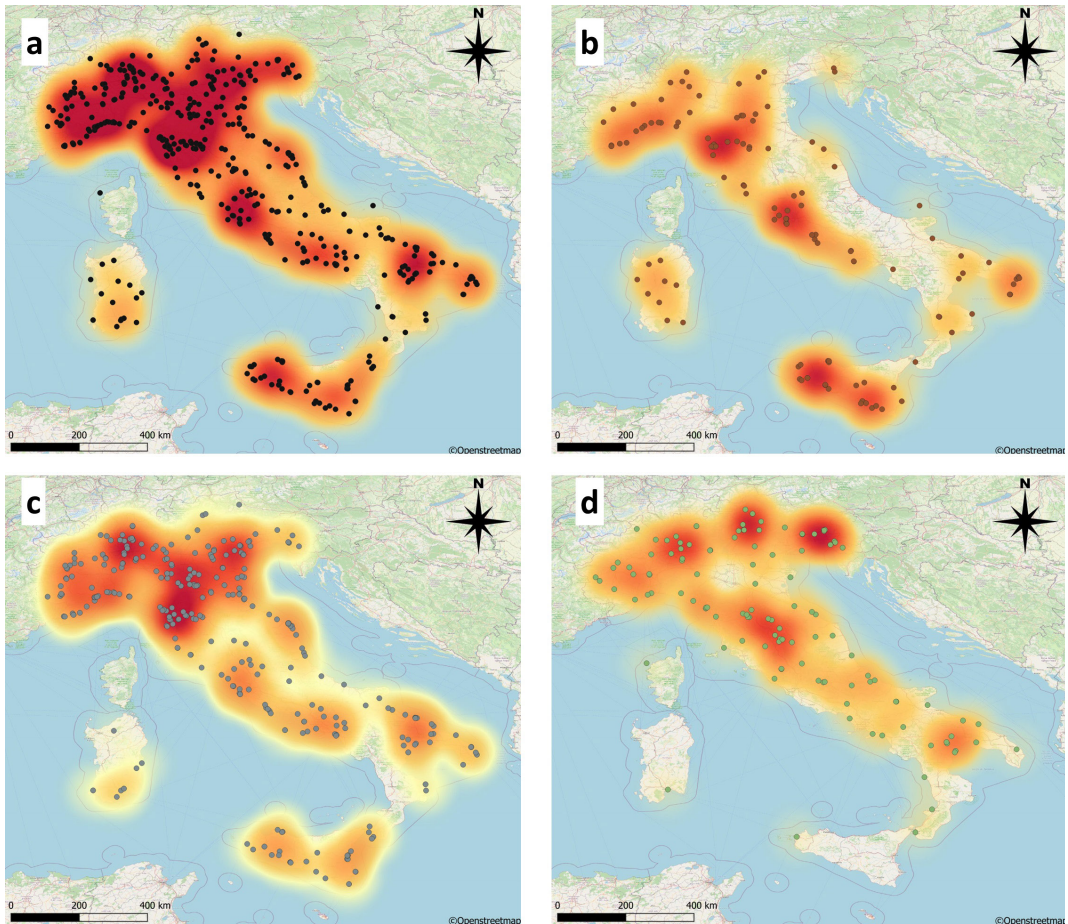


Figure 3. Geographical distribution and concentration of observations of first sightings of barn swallows in Italy for the whole dataset (a), for observation date lower than the 25th percentile (b), between the 25th and 75th percentile (c) and higher than the 75th percentile (d). Concentration is represented in graduated colours with increasing values from white to red.

between percentiles of first sightings and temperature indices were found (Tab. 3). The maps of correlation (Fig. 7) show that P25 sightings are also negatively affected by temperatures in the Western part of the selected area in December (Fig. 7a), while later in the season, in February and March, they are more negatively affected by tem-

peratures in the North-Eastern part (Fig. 7c and 7d). This is also confirmed by correlation with the three-month average temperatures: in winter, migration is advanced with increasing temperatures in the whole area (Fig. 7e), while in late winter and early spring, it advances with increasing temperatures along the coast (Fig. 7f).

Table 2. Regression analysis of first sightings of Barn Swallows as dependent variables and year and region as independent variables. Reference value for the factor variable region was CI (Central Italy) and the other factors were Northern Italy (NI), Southern Italy (SI) and main Islands (ISL). Residuals df are 571

Effect	Coef	SE	t	P
Intercept	2232.205	166.378	13.416	< 0.001
year	−1.078	0.083	−13.025	< 0.001
region ISL	−5.124	1.273	−4.024	< 0.001
region NI	2.063	0.901	2.291	0.022
region SI	0.470	1.148	0.409	0.682

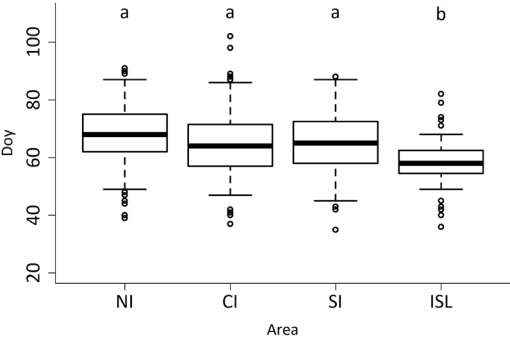


Figure 4. Box and whisker plot of first arrival anomaly per area for the whole study period: Northern Italy (NI), Central Italy (CI), Southern Italy (SI) and main islands (ISL). A significant difference between regions was investigated by conducting a one-way ANOVA followed by Tukey HSD tests. Different letters indicate significant differences ($p < 0.05$) between groups.

DISCUSSION

This study presents 16 years of observations of the first Barn Swallow in spring in Italy. This data was collected through a citizen science project initiated by the CNR to engage all stakeholders involved

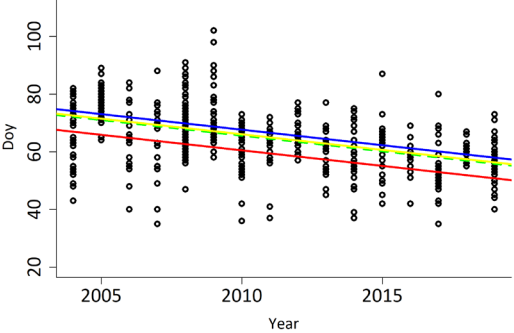


Figure 5. Scatterplot of the day of the year (doy) of barn swallow sightings collected from 2004 to 2019. Regional trend of barn swallow arrival interpolated by the regression analysis are represented with blue line (NI), green dashed line (CI), yellow line (SI) and red line (ISL).

in recreational or professional activities within the environmental sector, including voluntary and cultural associations, park and protected area administrators and operators, as well as university researchers. However, almost all the data, apart from the first year of the project when also other stakeholders contributed, were provided by volunteers connect-

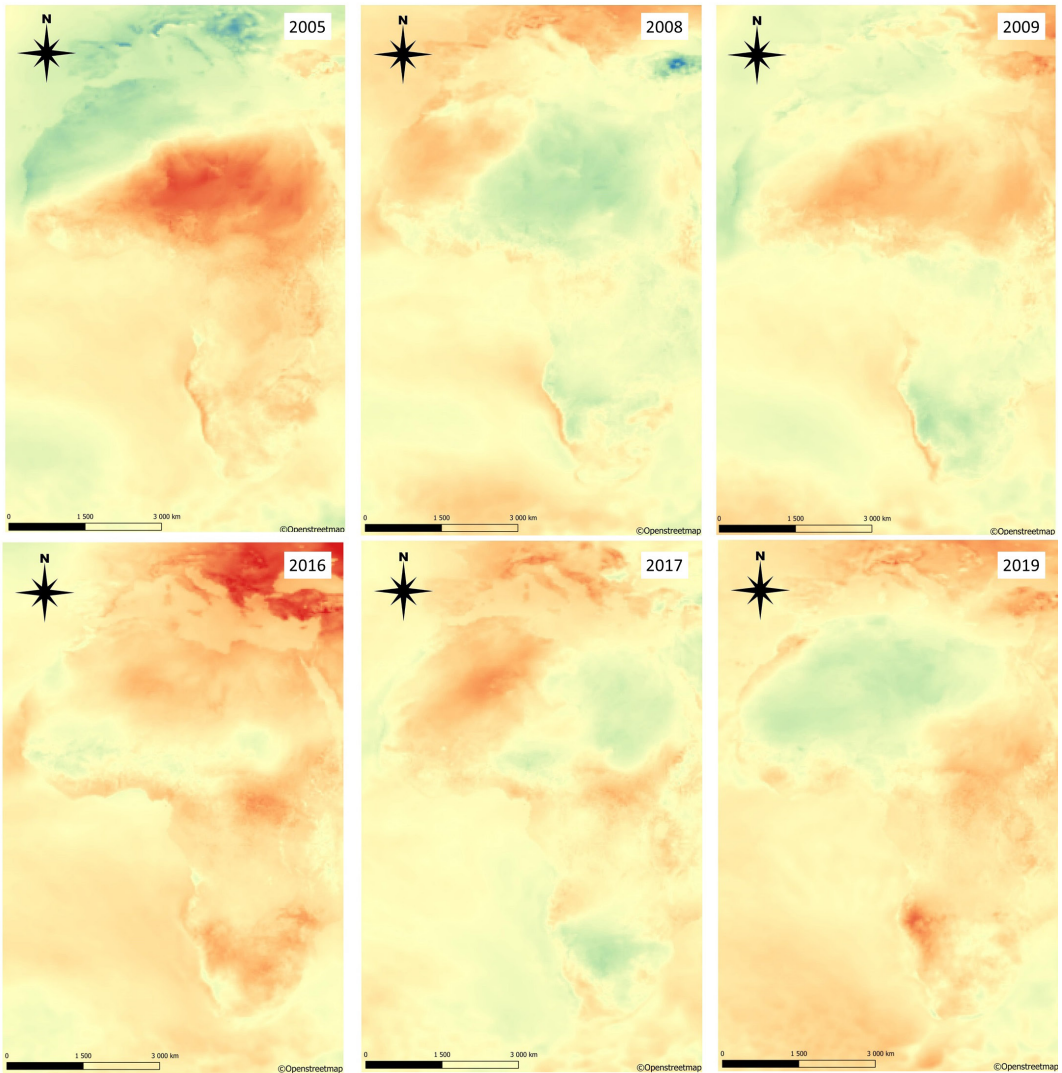


Figure 6. February temperature anomaly over Europe and Africa for the year of late arrival (2005, 2008 and 2009) and of early arrival (2016, 2017 and 2019).

ed to the EBN Italia network association. Participant involvement is always a recurring issue in citizen science as highlighted by other studies (Dickinson et al. 2012). For citizen science projects to be effective, participants must have a strong

interest in the project's theme and be willing to dedicate their time to specific activities. In this case, involvement was facilitated by the fact that the participants were already members of a community aligned with the environmental focus of

Table 3. Pearson correlation (r) between 25th percentile (P25), 50th percentile (P50) and 75th percentile (P75) of first sightings of Barn swallow as dependent variables and monthly (Dec, Jan, Feb, Mar) and seasonal (DJF, JFM) average North Atlantic Oscillation (NAO and temperature (TEMP) as independent variables. Significant correlations at $p < 0.05$ are indicated by*. Degrees of freedom are 14 in all cases

	P25	P50	P75
Dec NAO	−0.054	−0.067	−0.045
Jan NAO	0.191	0.027	−0.006
Feb NAO	−0.254	−0.362	−0.344
Mar NAO	−0.35	−0.171	−0.083
DJF NAO	−0.059	−0.16	−0.153
JFM NAO	−0.236	−0.255	−0.21
Dec T	−0.537*	−0.410	−0.423
Jan T	−0.322	−0.182	−0.169
Feb T	−0.474	−0.265	−0.239
Mar T	−0.183	−0.258	−0.329
DJF T	−0.577*	−0.358	−0.342
JFM T	−0.530*	−0.344	−0.341

the study. They contributed to the project’s objectives simply by performing the required observations as part of their regular hobbies. This approach enabled the collection of a significant number of observations within Italy, a country that lacks a consolidated tradition of engaging citizens in nature observations as seen in other countries (e.g. UK, Germany, USA).

According to our data, the interannual variability of the first sighting of Barn Swallow spring migration in Italy was very high. For instance, P25 was advanced by 25 days in 2017 (doy: 48) compared to 2005 (doy: 73). Our models explained between 57% (for P25) and 72% (for P75) variability, showing a significant trend

from 1 (P25) to 1.2 days/year (P50) of first Barn Swallow arrivals (Fig. 2). This temporal shift is consistent with other studies that found an advancement in Barn Swallow spring migration. Most studies found a lower advancement of the spring migration of this species between 0.1 to 0.3 days/year (Cohen et al. 2018, Lehtikoinen et al. 2019, Romano et al. 2022, Usui et al. 2017), while others found a higher significant advancement of the first arrival dates on small islands of the Tyrrhenian Sea (1.7 day/year) from the wintering grounds in tropical Africa (Maggini et al. 2020) and of the arrival date (1.3 days/year) in Badajoz, Spain (Balbontin et al. 2009). However, we acknowledge some

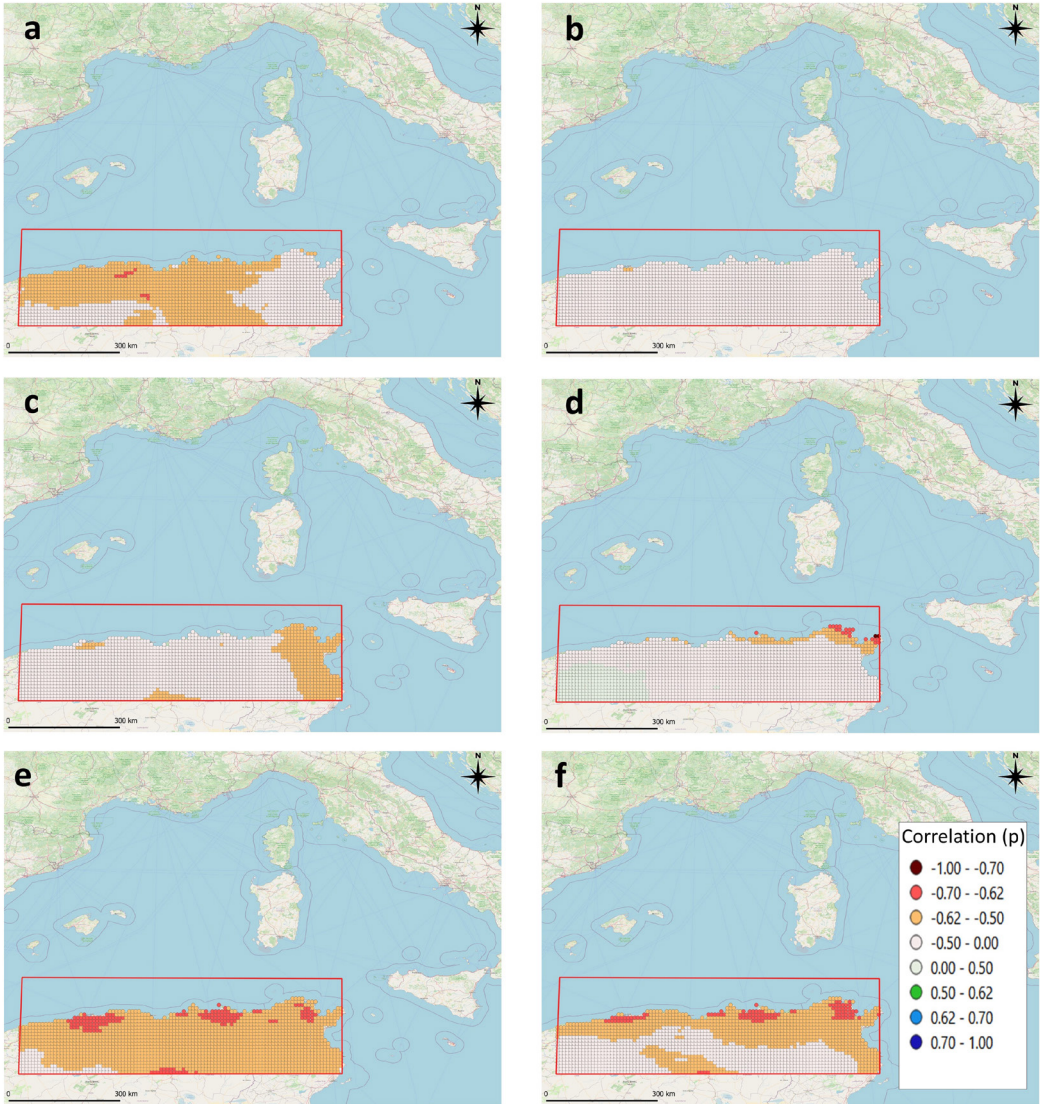


Figure 7. Pearson correlation between P25 sightings of Barn Swallows and December temperatures (a), January temperatures (b), February temperatures (c), March temperatures (d), winter temperatures (e) and January to March temperatures (f) calculated on the ERA 5 reanalysis dataset on an area of Northern Africa (Long: 1.5° E – 11° E, Lat: 35° N – 38° N). Colours represent significance level at $p < 0.05$ (orange), $p < 0.01$ (red) and $p < 0.001$ (dark red).

limitations of our dataset, particularly the relatively limited length of our data series (16 years) which may have introduced some bias. This is particularly true as later arrivals were concentrated at the beginning of the series and early arrivals towards its end. Our findings should therefore be validated by analysing longer data series.

We also compared our findings on the first spring arrival of Barn Swallows on Italian coasts — the first step of their journey to Europe from Africa — as soon as they crossed the Mediterranean Sea. This is of particular interest as the progression of migration was not hampered or altered by atmospheric conditions over the European mainland. We found that the first Barn Swallows reach Sicily and Sardinia earlier compared to other parts of Italy (Fig. 4). Subsequently, the migration in Italy follows a clear SW-NE trajectory (Fig. 3). This is consistent with previous findings of a direct journey across the Mediterranean Sea from wintering grounds with no stopovers in Northern Africa (Rubolini et al. 2007) indicating that some routes involve necessarily a continuous non-stop flight over the sea without resting (Pilastro & Magnani 1997). Progression towards NE in Italy is hampered by crossing mountain ranges (i.e. the Apennines) and the Alpine chain is reached considerably later (9 to 10 days later) (Fig. 4). Moreover, regression analysis performed between sightings and year and region suggested a significantly different arrival time of Barn Swallow in ISL: 5 days earlier than CI and SI and 7 days earlier in NI (Tab. 3, Fig. 5).

It should be noted that our results might be affected by the odd geographical distribution of our observations throughout the years. Indeed, the percentage of observations collected in SI and ISL increased during the study period and the higher rate of observations collected in the South of Italy where Barn Swallows arrive earlier might have contributed to the pronounced trend.

We did not find any strong correlation with NAO, a large-scale climate index. The NAO index has been shown by Vähätalo et al. (2004) to affect the arrival in Finland of some migrant bird species, though not Barn Swallows, and of 23 out of 24 migratory bird species in Helgoland, Germany, (Hüppop & Hüppop 2002) where Barn Swallow was not tested. At the Ottenby Bird Observatory in Sweden, early arrivals of 16 out of 19 long-distance migrants — but not Barn Swallows — correlate with the NAO index (Sternvander et al. 2005). These differences may reflect the effect of the NAO index along an East-West gradient (Hüppop & Hüppop 2003, Sternvander et al. 2005), as the NAO effect is more pronounced for migrants following western routes. The number of studies that have investigated the effect of NAO on bird behavior on the one side and temperature and precipitation regime on the other (Gentilucci et al., 2023) along such an important migratory route is still scarce. This work thus adds further evidence to the studies that did not find any influence of NAO on bird migration through the Central Mediterranean Basin (Rubolini et al., 2007).

Both 2005 and 2016 were marked by significant and opposite temperature

anomalies over the Mediterranean Sea and North Africa in February: a negative anomaly in 2005 and a positive anomaly in 2016. This is confirmed by the significant correlation between P25 and December, winter and average January to March (JFM) temperatures over a stopover site in North Africa that suggests that marked temperature anomalies in late winter might affect Barn Swallow migration timing (Fig. 6 and 7). Consequently, the relationships between climate conditions and other environmental variables at wintering and stopover sites warrant further investigation.

The influence of climate on the timing of bird migration is still debated in literature, particularly in Europe. For instance, Barn Swallow's arrival and migration progression in Britain has been demonstrated to be influenced by temperatures along the route in continental Europe and in Britain (Huin & Sparks 1998). Other studies indicated that temperatures in NW Africa and SW Iberia affect the arrival dates of 5 different migrant species in Spain, including the Barn Swallow, suggesting that favourable weather conditions could facilitate faster migration (Gordo & Sanz 2005, 2008).

The main limitation of our study is the observation protocol which relied on the voluntary efforts of amateurs motivated by contributing to scientific research. Early sightings (P25) in the Southern part of the Tyrrhenian coast (Campania and Calabria) are less frequent, possibly due to the limited number of observations in these areas which may not be sufficient to accurately capture the timing of Barn

Swallow's arrival. This approach does not always ensure a homogeneous and consistent coverage of observations across spatial and temporal scales. However, we sought to limit this aspect by working on aggregated data. We used the P25 statistical index calculated across all observations to assess temporal differences between years and trends, and we used arrival date anomalies to describe the progression of migration across Italy. In studies of this kind, there can be also some concerns about the observer's ability to correctly identify the bird species: we mitigated this by focusing on a well-known and easily recognizable species, especially for skilled and experienced birdwatchers. In several cases, observations were supported by photos that allowed data verification.

The influence of climate change on bird migration is a very interesting and fascinating area of study. However, monitoring such a large-scale phenomenon is challenging and entails high fieldwork costs to collect the necessary amount of data. In addition, climate or environmental indicators made available by earth monitoring systems are still underused in this type of study. Citizen science projects have emerged as an efficient way to collect such data, involving a large number of participants who contribute their observations. This approach is particularly valuable when the events span over a broad geographical area, as is the case for bird migration. Volunteers and skilled participants in these projects not only collected field data but also received scientific feedback address-

ing fundamental questions and tested the initial hypothesis: Do barn Swallows progressively advance spring migration along Italian coasts? Is this phenomenon correlated to climatic changes or weather anomalies? The answer remains complex, as environmental factors, which can be summarized by different climatic indices (Alerstarm 2011, Berthold 2001, Coppack & Both 2002), are involved in this extensive process, alongside biological and genetic influences (Møller et al. 2004, 2010) which must be understood, to predict Barn Swallow migration patterns.

Conflict of interest

The authors declare they have no conflicts of interest

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Data availability

Data are available in the Electronic Supplementary Materials of this paper.

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Temporal and site-specific variations in two bird assemblages: insights from anthropized landscapes in the Isthmus of Tehuantepec, Mexico

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ABSTRACT

The increasing prevalence of anthropized landscapes, often characterized by extensive agricultural practices and artificial infrastructure developments (e.g. wind farms), can lead to complex ecological scenarios where the functional roles of species within their communities are altered. This study aims to compare bird populations at two anthropized sites (Stipa and Sureste, Mexico) over a four-year period. Given their proximity (< 5 km) and the shared characteristic of being located within wind farm areas on agricultural ground, similarities in bird species composition were expected. During the study, 88,765 birds of 178 species were recorded. The results revealed comparable species richness

at both sites, with 137 species observed at Stipa and 135 at Sureste. Differences in assemblage composition were significant between sites and seasons (fall vs. summer, fall vs. spring), but not between years. The dissimilarity between the two sites seems to be mainly influenced by the presence of waterbirds associated with an irrigation canal at Stipa and raptors associated with open areas at Sureste, likely a favourable habitat to maximize hunting success. The stable species assemblage structure observed over the study years suggests constant resource availability resulting from habitat homogenization driven by expanded sorghum cultivation displacing other crops. Conversely, variations in bird composition between seasons were influenced by migratory patterns, particularly among raptors, which became more abundant over the study years. This study supports the idea that artificial water supplies can favour the presence of bird species with an affinity for aquatic habitats in anthropized habitats, such as at Stipa. This highlights the importance of designing, regulating and well-managing artificial resources in anthropized landscapes, as these can contribute to habitat restoration, increase taxonomic diversity, and help achieve long-term conservation goals.

Keywords: wind turbines, agriculture, irrigation canal, Isthmus of Tehuantepec, aquatic birds

INTRODUCTION

Anthropic perturbations such as habitat loss, resource overexploitation, and pollution, have caused detrimental effects on biodiversity (Singh et al. 2021). These disturbances are generally categorized into three types: i) direct human impacts; ii) biotic pressure (e.g. invasive species); and iii) environmental changes (e.g., abiotic conditions and habitat loss; Mouillot et al. 2013). Specifically, among the environmental changes, habitat loss is known for having negative impacts on local bird assemblages in which declining specialist species are often replaced by generalist species thus leading to the homogenization of the communities (Ibarra & Martin 2015, Callaghan et al. 2019).

Birds are highly sensitive to habitat changes, making them excellent indicators of ecosystem health (Fraixedas et al. 2020). Their presence and diversity provide crucial insights into the overall condition and sustainability of natural environments (Fraixedas et al. 2020, Chowfin & Leslie 2021). Numerous studies have demonstrated that while disturbances can sometimes increase total bird abundance (Stouffer et al. 2006, McWethy et al. 2010, Battisti et al. 2016), they often result in altered assemblage composition, with declines in species diversity (Proppe et al. 2013, Bregman et al. 2014, Rigal et al. 2023). This is particularly relevant in Mexico, where the growing prevalence of anthropized landscapes, characterized by extensive agriculture and artifi-

cial infrastructure, can lead to complex ecological scenarios that alter species' functional roles within their communities (Villegas-Patraca et al. 2012, Smith et al. 2015). While anthropogenic activities can introduce new habitat components that sometimes increase biodiversity (intermediate disturbance hypothesis; Connell 1979), they may also facilitate the dominance of human-associated birds, which can out-compete native species (Samia et al. 2015, Almeida et al. 2020, Hendershot et al. 2020, Lindenmayer et al. 2023). As a result, species richness values may remain stable despite disturbances, masking underlying effects on taxonomic, genetic, and functional diversity (Mouillot et al. 2013, Liang et al. 2019). Understanding how do bird species respond to these environmental disturbances is thus a key issue for the management and conservation of their habitats.

Bird assemblages can vary across time (within and between years), making consistent habitat management in anthropized landscapes a challenging task (Villegas-Patraca et al. 2012, Farfán et al. 2017). Nevertheless, most studies focus only on specific periods of the birds' annual cycle, namely during migration or the breeding season (Villegas-Patraca et al. 2014, Cabrera-Cruz et al. 2017). Therefore, a comprehensive understanding of the impacts on community assemblage, along with consideration of temporal variability,

is essential for assessing the overall effects of human disturbance.

This study aims to quantify differences in bird assemblages between two wind farm sites located in the Isthmus of Tehuantepec, a key area for wind energy development in Mexico (Solórzano-Tello & Portador-García 2016, Zárate-Toledo & Fraga 2016). Over a four-year period, we assessed seasonal and annual variations in birds' presence and community composition in agricultural landscapes. Given the close proximity of the sites (< 5 km) and their shared agricultural surroundings, we expected both to exhibit similar bird species assemblages, primarily composed of generalist species associated with crop environments. However, our research could not directly evaluate the impact of wind farms on avian assemblages due to the absence of control data from wind farm-free areas. Nonetheless, by examining bird communities within these sites, we provided valuable insights into the avian species inhabiting disturbed environments, thus, contributing to a better understanding of changes in bird assemblages within anthropized landscapes.

MATERIALS AND METHODS

Study area and data collection

A total of 768 diurnal sampling sessions from 8:00 AM to 12:00 PM were conducted over a four-year period (from summer 2018 to spring 2022) to count bird species and estimate richness and abundance.

These sampling sessions were conducted by the same person and were evenly distributed across seasons (24 transects in winter, spring, summer and fall) and years (96 transects). Each sampling session consisted of six one-kilometer-long transects, each with a width of 50 meters, and a duration of 90 minutes per transect. Bird species were recorded using both auditory methods, by identifying bird calls, and visual observations of individuals. Observations were conducted using Celestron UpClose G2 10×50 binoculars to ensure accurate identification and minimize errors in species detection.

The Bii Nee Stipa Wind Farm (hereafter Stipa) and Project 40 CE Sureste I, Phase II (hereafter, Sureste) are located in southeastern Oaxaca, within the Isthmus

of Tehuantepec region, Mexico, and are 4.5 km apart (edge to edge; Fig. 1). The Stipa wind farm is located at an altitude of 40 m a.s.l. and has 37 wind turbines distributed over an area of 413.56 ha (1 turbine/11.17 ha). The land use is primarily agricultural (crops) interspersed with small patches of plant species characteristics of the deciduous forest, mainly from the Fabaceae family. The northern boundary of Stipa is delimited by an irrigation canal and deciduous forest, while the southern boundary is surrounded by other wind farms. The Sureste wind farm is located at an altitude of 50–70 m a.s.l. and comprises 34 wind turbines distributed over an area of 894.50 ha (1 turbine/26.3 ha). Its land use is primarily agricultural (crops), which de-

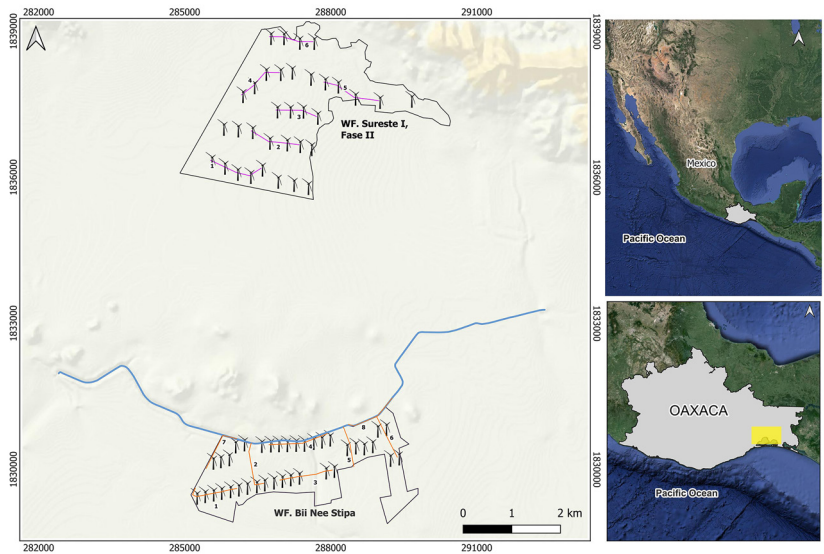


Figure 1. Distribution of bird monitoring transects in the Stipa (yellow lines) and Sureste (purple lines) wind farms. The blue line represents the irrigation canal, and the wind turbine icon represents the location of the wind turbines present at both sites.

pendes on the rainy season. The site is limited to the west by thorn forest and to the north by a mountainous strip of deciduous forest, and by two urban areas, La Cueva and La Mata.

STATISTICAL ANALYSIS

Bird assemblage structure analysis

The bird community assemblage was characterized by the number of species (species richness; *S*) and the total of individuals (abundance; *N*) and was further assessed using Bray-Curtis similarity and multivariate ordination (Clarke et al. 2014; Brabataetal.2019). Multivariate non-metric multidimensional scaling ordination (nMDS) was used to compare bird assemblages (individual species abundance) between the two wind farm sites (Stipa and Sureste). The Hotelling's T^2 permutation test was applied to identify significant differences in bird assemblages between the two sites (Willems et al. 2002). A two-way nested analysis of similarity (ANOSIM) was used to test for differences in the bird assemblages among the four years (season within years) and to test for differences among the four seasons (months within season) of the year. The ANOSIM analysis generates a probability value *P* and a statistic *R*, which takes a value of -1 when all elements within a group are less similar to each other than to elements in other groups, and of 1 when all elements within a group are more similar to each other than to elements in other groups. When the value of *R* is close to 0 , the similarities of elements between and within groups are on average equal (Clarke

& Warwick 2001). Pairwise ANOSIM comparisons of sample groups was applied to identify which group (i.e., Wind Farm/Year/Season) was significantly different (Clarke et al. 2014).

Similarity percentage analysis (SIMPER) was performed to determine the average similarity and dissimilarity among the wind farms (Sureste and Stipa), years, and seasons. The variability among samples (bird censuses) among the wind farms, years, and seasons of the study was compared with the index of multivariate dispersion (MVDISP) routine. For all multivariate analysis, data were fourth root transformed to reduce the influence of highly abundant taxa (Clarke et al. 2014) and calculated in R using the Vegan package (Oksanen et al. 2022).

To assess the association of bird species to each wind farm in each year and season, indicator value analysis (IndVal) was applied using the R package *indicspecies* (Dufrêne & Legendre 1997). The IndVal index is the result of the specificity 'A' (predictive value of the species as indicator of the site group) and fidelity 'B' (probability of finding the species in sites belonging to the site group; De Cáceres 2019). IndVal provides a quantitative measure of how strongly a species is associated with a particular site or period of time, helping to identify which species may serve as indicators of ecological conditions or habitat types. A higher IndVal value indicates stronger association, highlighting key species that may reflect environmental changes or habitat quality (Dufrêne & Legendre 1997).

Taxonomic structure analysis

In order to describe differences in taxonomic structure among the wind farms of the study (Sureste and Stipa), the index of Average Taxonomic Distinctness (AvTD; $\Delta+$) was applied using the software PRIMER 7 (Clarke et al. 2014). The AvTD ($\Delta+$) measures the expected taxonomic distance of the assemblage for a given number of species for a standard Linnean classification (Clarke & Warwick 1999). The hierarchical classification of the recorded bird's species (from species to order level; AOU 1998; Chesser et al. 2024) was used to calculate the values of AvTD ($\Delta+$) and results visualized using a Funnel plot. The results were displayed in a Funnel Plot of $\Delta+$ against m (number of species), allowing simultaneous comparison of distinctness values of each wind farm with the expected 95% probability limits.

RESULTS

Bird assemblage structure

Over the study period, a total of 88,765 individual birds from 178 species grouped in 50 families belonging to 21 orders were recorded (ESM 1). Ninety-four species (52.8 %) were identified at both wind farm sites; the species richness was comparable at both sites, with 137 species recorded in Stipa, including 43 exclusive species (those recorded only in one site), and 135 species recorded in Sureste, with 41 species being exclusive to that location. However, despite the comparable species richness, the total mean

abundance of birds was 33.3 % higher at Sureste compared to Stipa (ESM 1).

The nMDS clearly separated the observed birds by wind farm site (Fig. 2a), with a dissimilarity of 68 % (Table 1). Furthermore, there were significant differences observed in the bird assemblage composition between Sureste and Stipa ($T^2 = 3.21$ df = 589, $P < 0.001$; Fig. 2a).

In the Stipa wind farm, a higher abundance of species from the families Icteridae, Columbidae, Tyrannidae, Passerellidae, Cuculidae, Ardeidae, Psittacidae, Anatidae, Mimidae and Threskiornithidae was recorded. Moreover, Stipa presented the highest number of indicator species, mainly those associated with aquatic environments such as *Charadrius vociferus*, *Aramus guarauna*, *Ardea alba*, *Butorides virescens*, *Dendrocygna autumnalis*, *Eudocimus albus*, *Spatula discors*, *Egretta thula* and *Mycteria americana* (Table 2). In contrast, at Sureste wind farm site, a higher abundance of species of the families Columbidae, Icteridae, Passerellidae, Cardinalidae, Tyrannidae, Psittacidae, Cuculidae, Laridae, Corvidae and Polioptilidae were observed (ESM 1). Here the indicator species were insectivorous, granivorous and raptor species including *Morococcyx erythropygus*, *Icterus pus-tulatus*, *Peucaea sumichrasti*, *Myiarchus cinerascens*, *Circus hudsonius*, *Falco sparverius*, *Falco femoralis*, *Falco columbarius* (Table 2).

The year 2021/2022 exhibited the highest richness and abundance compared to the others, with 135 species and 30,238 individuals recorded. In contrast,

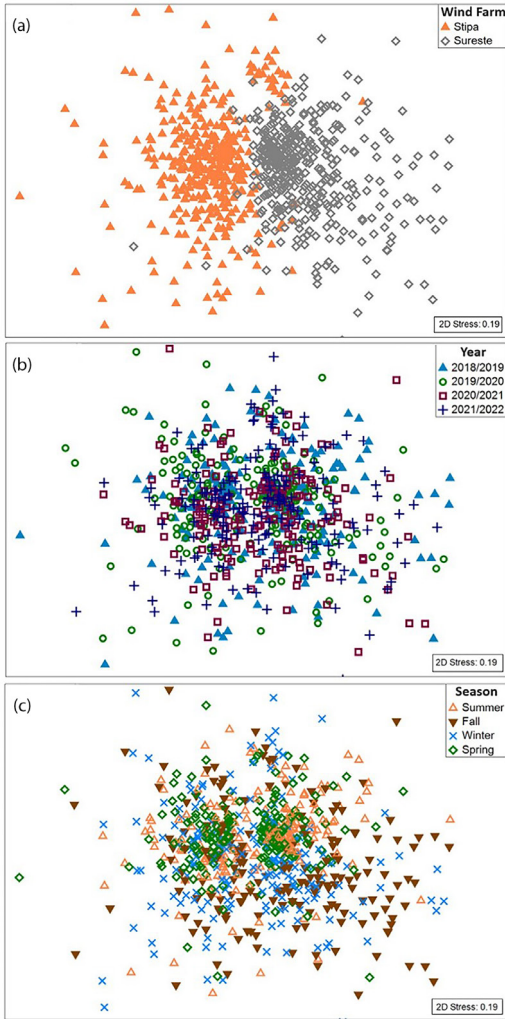


Figure 2. Non-metric multidimensional scaling (nMDS) plots based on species abundances obtained from 768 diurnal sampling sessions illustrating differences across: a) wind farms; b) years, and c) seasons. The nMDS represents sample similarities in a reduced-dimensional space, with points closer together indicating more similar species compositions. The degree of correspondence between the distances among points is quantified by a stress value (0.0: perfect, 0.1: excellent, 0.2: good, and 0.3: poor).

the lowest richness value was obtained for 2019/2020, while the lowest abundance occurred in 2018/2019. Nevertheless, the differences in the bird assemblage among years were not significant (ANOSIM, $R = -0.027$, $P = 0.262$; Fig. 2b).

With respect to the seasons, the highest number of species was observed during autumn and summer, with 135 and 131 species, respectively. Conversely, winter and spring recorded the lowest richness values with 118 and 116 species, respectively. Regarding the abundance of individuals, the largest count was in spring with 30,394 individuals, while the lowest counts were recorded in winter (17,780 individuals) and summer (17,125 individuals). Furthermore, differences in bird assemblage between seasons were only significant between fall and spring (ANOSIM, $R = 0.237$, $P = 0.014$, Fig. 2c), and between fall and summer (ANOSIM, $r = 0.171$, $P = 0.037$; Fig. 2c).

Taxonomic structure

The Sureste Wind Farm site exhibited the lowest value of recorded species and the lowest values of AvTD ($\Delta+$) compared to Stipa, indicating a narrower range of taxonomic groups (Fig. 3). In contrast, the high value of $\Delta+$ index at Stipa indicates that the species are unevenly distributed along the phylogenetic tree, suggesting that there is a large taxonomic distance between them. Concerning temporal patterns, both the spring season and the year 2019/2020 recorded the fewest number of bird species. However, despite the low-

Table 1. Similarity percentage analysis (SIMPER) and multivariate dispersion (MVDISP) values within and between the factors (Wind Farms, Years, Seasons) of the study. Higher values of dissimilarity indicate lower similarity between samples. Higher values of multivariate dispersion indicate more variability among bird samples within each factor

Factor	Average Similarity	Multivariate Dispersion	Stipa Sureste	Average dissimilarity							
				2018/2019	2019/2020	2020/2021	2021/2022	Winter	Spring	Summer	Fall
Wind Farm											
Stipa	37.02	1.066	-	68	-	-	-	-	-	-	-
Sureste	41.54	0.933	68	-	-	-	-	-	-	-	-
Year											
2018/2019	39.13	0.997	-	-	62.67	62.05	64.28	-	-	-	-
2019/2020	37.36	1.033	-	62.67	-	62.17	64.25	-	-	-	-
2020/2021	39.84	0.931	-	62.05	62.17	-	63.12	-	-	-	-
2021/2022	36.48	1.041	-	64.28	64.25	63.12	-	-	-	-	-
Season											
Winter	36.73	1.07	-	-	-	-	-	61.60	64.45	67.10	
Spring	43.68	0.769	-	-	-	-	-	61.60	-	60.31	65.91
Summer	38.44	0.966	-	-	-	-	-	64.45	60.31	-	67.56
Fall	33.85	1.204	-	-	-	-	-	67.10	65.91	67.56	-

Table 2. Indicator species analysis (IndVal) comparing Wind Farms, Years, and Seasons of the study. The IndVal index combines specificity (A) and fidelity (B) to assess a species' association with a site group, indicating its value as a habitat indicator. Higher values denote stronger associations. Only species with significant values ($p < 0.05$) are listed

Factor	Sample Group	Species	Specificity A	Fidelity B	IndVal Stat*	P value
Wind Farm	Stipa	<i>Tyrannus melancholicus</i>	0.85914	0.75521	0.806	0.0001
		<i>Charadrius vociferus</i>	0.97804	0.43750	0.654	0.0001
		<i>Aramus guarauna</i>	1.00000	0.38021	0.617	0.0001
		<i>Campylorhynchus humilis</i>	1.00000	0.38021	0.617	0.0001
		<i>Myiozetetes similis</i>	0.96377	0.39323	0.616	0.0001
		<i>Ardea alba</i>	0.87633	0.35938	0.561	0.0001
		<i>Sturnella magna</i>	1.00000	0.29948	0.547	0.0001
		<i>Leptotila verreauxi</i>	0.84477	0.32552	0.524	0.0001
		<i>Butorides virescens</i>	1.00000	0.24219	0.492	0.0001
		<i>Turdus grayi</i>	0.98611	0.23958	0.486	0.0001
		<i>Coragyps atratus</i>	0.80000	0.29427	0.485	0.0001
		<i>Dendrocygna autumnalis</i>	0.98845	0.20052	0.445	0.0001
		<i>Eudocimus albus</i>	0.94626	0.19271	0.427	0.0001
		<i>Agelaius phoeniceus</i>	1.00000	0.18229	0.427	0.0001
		<i>Spatula discors</i>	1.00000	0.17969	0.424	0.0001
		<i>Dives dives</i>	0.79386	0.21354	0.412	0.0001
		<i>Nannopterum brasilianum</i>	1.00000	0.16146	0.402	0.0001
		<i>Rostrhamus sociabilis</i>	1.00000	0.16146	0.402	0.0001
		<i>Zenaida macroura</i>	0.75090	0.21354	0.400	0.0001
		<i>Rupornis magnirostris</i>	0.77465	0.20052	0.394	0.0001
		<i>Icterus spurius</i>	0.83051	0.18229	0.389	0.0001
		<i>Cassidix melanicterus</i>	1.00000	0.15104	0.389	0.0001
		<i>Jacana spinosa</i>	1.00000	0.15104	0.389	0.0001
		<i>Egretta thula</i>	0.99259	0.14844	0.384	0.0001
		<i>Chondestes grammacus</i>	0.85714	0.15885	0.369	0.0001

(Continues)

Table 2. (Continued)

Factor	Sample Group	Species	Specificity A	Fidelity B	IndVal Stat*	P value
		<i>Chordeiles minor</i>	0.97849	0.09375	0.303	0.0001
		<i>Actitis macularius</i>	1.00000	0.08333	0.289	0.0001
		<i>Tachybaptus dominicus</i>	1.00000	0.08333	0.289	0.0001
		<i>Ardea herodias</i>	0.96875	0.07292	0.266	0.0001
		<i>Tachycineta albilinea</i>	0.97947	0.07031	0.262	0.0001
		<i>Euphonia affinis</i>	0.97436	0.06510	0.252	0.0001
		<i>Mycteria americana</i>	0.98462	0.04167	0.203	0.0002
		<i>Heliomaster constantii</i>	1.00000	0.02865	0.169	0.0008
		<i>Sporophila minuta</i>	1.00000	0.02865	0.169	0.0011
		<i>Turdus rufopalliatu</i>	1.00000	0.02865	0.169	0.0017
		<i>Glaucidium brasilianum</i>	0.83333	0.03385	0.168	0.0073
		<i>Megaceryle alcyon</i>	1.00000	0.02604	0.161	0.0022
		<i>Tachycineta thalassina</i>	1.00000	0.02344	0.153	0.0046
	Sureste	<i>Morococcyx erythropygus</i>	0.77485	0.50521	0.626	0.0001
		<i>Icterus pustulatus</i>	0.91040	0.41146	0.612	0.0001
		<i>Peucaea sumichrasti</i>	0.98734	0.29688	0.541	0.0001
		<i>Falco sparverius</i>	0.83673	0.29948	0.501	0.0001
		<i>Geococcyx velox</i>	0.97059	0.20573	0.447	0.0001
		<i>Myiarchus cinerascens</i>	0.92647	0.15625	0.380	0.0001
		<i>Geranoaetus albicaudatus</i>	0.98718	0.13542	0.366	0.0001
		<i>Circus hudsonius</i>	0.83607	0.12500	0.323	0.0001
		<i>Streptopelia decaocto</i>	1.00000	0.08073	0.284	0.0001
		<i>Molothrus ater</i>	0.97288	0.08073	0.280	0.0001
		<i>Polioptila caerulea</i>	1.00000	0.07812	0.280	0.0001
		<i>Mimus polyglottos</i>	0.73810	0.09635	0.267	0.0015
		<i>Spiza americana</i>	0.93831	0.07552	0.266	0.0006
		<i>Archilochus colubris</i>	0.85057	0.08073	0.262	0.0002

(Continues)

Table 2. (Continued)

Factor	Sample Group	Species	Specificity A	Fidelity B	IndVal Stat [†]	P value
		<i>Myiarchus nuttingi</i>	0.88889	0.07292	0.255	0.0002
		<i>Passerina caerulea</i>	0.98361	0.04688	0.215	0.0001
		<i>Cardellina pusilla</i>	1.00000	0.04427	0.210	0.0002
		<i>Tityra semifasciata</i>	1.00000	0.02865	0.169	0.0011
		<i>Columbina talpacoti</i>	1.00000	0.02604	0.161	0.0019
		<i>Myiarchus tyrannulus</i>	0.90000	0.02865	0.161	0.0052
		<i>Fregata magnificens</i>	0.84615	0.02604	0.148	0.0300
		<i>Falco femoralis</i>	1.00000	0.01823	0.135	0.0143
		<i>Vireo gilvus</i>	0.93333	0.01823	0.130	0.0310
		<i>Empidonax minimus</i>	1.00000	0.01562	0.125	0.0311
		<i>Falco columbarius</i>	1.00000	0.01562	0.125	0.0294
Season	Summer	<i>Volatinia jacarina</i>	0.63636	0.03646	0.152	0.021
	Fall	<i>Tyrannus forficatus</i>	0.91429	0.57812	0.727	0.001
		<i>Archilochus colubris</i>	0.80460	0.14583	0.343	0.001
		<i>Polioptila caerulea</i>	0.61905	0.10938	0.260	0.001
		<i>Tityra semifasciata</i>	1.00000	0.05729	0.239	0.001
		<i>Falco femoralis</i>	1.00000	0.03646	0.191	0.002
		<i>Falco columbarius</i>	1.00000	0.03125	0.177	0.002
		<i>Accipiter cooperii</i>	1.00000	0.02083	0.144	0.022
		<i>Buteo platypterus</i>	0.93333	0.02083	0.139	0.037
	Winter	<i>Spatula discors</i>	0.6891	0.2031	0.374	0.001
	Spring	<i>Dendrocygna autumnalis</i>	0.68360	0.23438	0.400	0.001
		<i>Momotus mexicanus</i>	0.72549	0.12500	0.301	0.001
		<i>Chordeiles minor</i>	0.68817	0.11979	0.287	0.001
		<i>Coccyzus minor</i>	0.64286	0.03646	0.153	0.049
Year	2019/2020	<i>Vireo gilvus</i>	0.93333	0.03646	0.184	0.002
	2020/2021	<i>Ammodramus savannarum</i>	0.60976	0.05729	0.187	0.032

(Continues)

Table 2. (Continued)

Factor	Sample Group	Species	Specificity A	Fidelity B	IndVal Stat*	P value
	2021/2022	<i>Polioptila caerulea</i>	0.84524	0.11458	0.311	0.001
		<i>Cardellina pusilla</i>	0.85294	0.07292	0.249	0.001
		<i>Tityra semifasciata</i>	1.00000	0.05729	0.239	0.001
		<i>Coccyzus minor</i>	0.85714	0.05208	0.211	0.001
		<i>Falco femoralis</i>	1.00000	0.03646	0.191	0.001
		<i>Columbina talpacoti</i>	0.73333	0.03646	0.164	0.008
		<i>Falco columbarius</i>	0.88889	0.02604	0.152	0.011
		<i>Falco peregrinus</i>	1.00000	0.02083	0.144	0.020

*The species are listed in descending order based on the IndVal Stat value

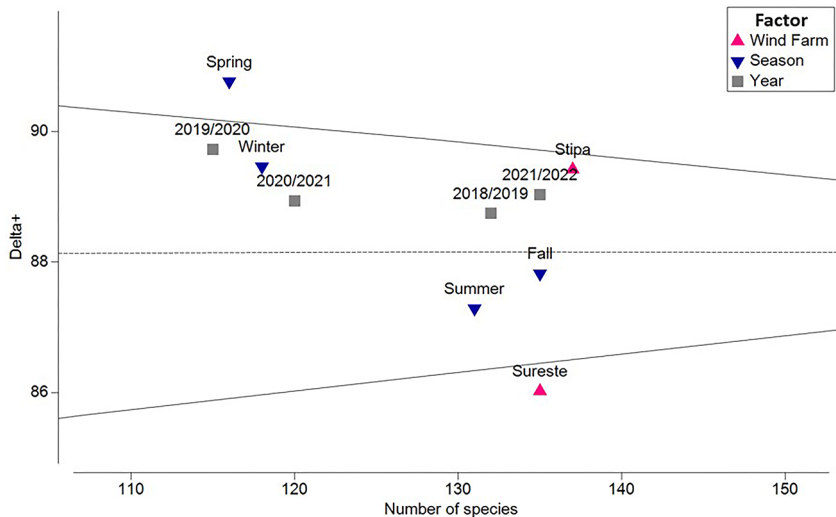


Figure 3. Average Taxonomic Distinctness ($\Delta+$) calculated for bird species across Wind Farms, Years and Seasons. The results were presented in a Funnel Plot, with $\Delta+$ plotted against m (the number of species), allowing for the comparison of distinctness values across wind farms, seasons and years. The solid lines indicate the 95% confidence interval, while the dashed line represents the expected mean.

er species richness, these periods also exhibited the highest values of taxonomic diversity, suggesting that the recorded species belonged to more distantly related taxonomic groups (Fig. 3).

DISCUSSION

Bird species are generally believed to exhibit lower overall species richness within anthropogenic environments such

as wind farms (Fernández-Bellon et al. 2019, Rehling et al. 2023). However, our study presents a different point of view. Although we could not directly assess the impact of wind farms on bird assemblages due to the lack of control areas, our findings indicate high richness and abundance of birds in anthropized landscape with wind farms. This was an unexpected result, particularly because other areas in the region, such as the Important Bird Conservation Area of the Isthmus of Tehuantepec, have recorded up to 172 bird species (Berlanga et al. 2008). Notably, our study sites accounted for approximately 53% of the total bird species (N= 335) present in the entire Isthmus of Tehuantepec region (Herrera-Alsina et al. 2013).

The use of wind farms by birds can be influenced by several variables related to human activities and the associated infrastructures, such as turbines, irrigation systems, heavy machinery, and rural roads (Villegas-Patraca et al. 2012, Rahman et al. 2022). In our study, the bird assemblages in the agricultural landscapes surrounding the wind farms exhibited a consistent pattern, being dominated by generalist species (González-Salazar et al. 2014). This pattern aligns with broader trends in agricultural settings, where intensified farming practices and the reduction of natural landscape elements drive habitat homogenization favouring a limited range of dominant species (Hendershot et al. 2020, Turkovska et al. 2021).

In this study, the most abundant species in both wind farm areas are synan-

thropic species (e.g., *Quiscalus mexicanus*, *Zenaida asiatica*, *Pitangus sulphuratus*, *Peucaea ruficauda*) that benefit from human settlements and structures associated with agricultural fields where they find food and nesting sites (Olvera-Vital et al. 2020, Gómez-Moreno et al. 2023). Conversely, endemic species such as *Peucaea sumichrasti*, *Ortalis poliocephala* and *Trogon citreolus* are more vulnerable to land-use changes, experiencing reductions in population densities (McAndrews et al. 2008, Monroy-Ojeda et al. 2018). Therefore, anthropic activities such as agriculture and urbanization, have not only altered the composition of species within ecosystems but may have also led to the establishment of novel communities at both study sites (Andrade et al. 2021). For example, changing species abundance and relative frequencies thereby resulting in uni-variate diversity metrics.

The species composition observed between the two wind farms showed significant differences, with waterfowl (e.g., *Nannopterum brasilianum*, *Tachybaptus dominicus*, *S. discors*), shorebirds (e.g., *Hesperoburhinus bistratus*, *C. vociferus* and *Actitis macularius*) and riparian birds (e.g., *A. guarauna*, *E. albus* and *Rostrhamus sociabilis*) contributing to increase the taxonomic diversity. Such diversity was largely influenced by the presence of an irrigation canal within the Stipa area. This result emphasizes the significant role of local water bodies in structuring the habitat composition and subsequently the bird community assemblage. Furthermore, it has been documented that small

irrigation canals can act either as partial replacements for lost natural habitats or as biodiversity hotspots in agricultural landscapes (Rohwer et al. 2015, Giralt et al. 2021). However, the irrigation canal at Stipa Wind Farm is privately owned by farmers and is managed primarily to improve crop yields and meet irrigation needs rather than for conservation purposes. Therefore, conservation strategies should point to addressing the needs of both, agricultural activities and bird communities conservation in order to achieve mutually beneficial outcomes with implication to reducing conflicts between stakeholders (Decker et al. 2012).

Additionally, water bodies in croplands can serve as refuges for insects and invertebrates, which in turn, attract farmland birds (Bretagnolle et al. 2019, Pustkowiak et al. 2021) such as *Sturnella magna*, *Agelaius phoeniceus*, *Campylorhynchus humilis*, *Turdus rufopalliatu*s, *Tachycineta thalassina* that were present at Stipa contributing to increase the diversity of bird assemblage at the site. Moreover, vegetation along irrigation canals is known to enhance habitat heterogeneity in croplands, providing favorable foraging and nesting conditions for bird species such as *I. pustulatus*, *P. sulphuratus* and *R. sociabilis* (Schaldach et al. 1997, Berlanga et al. 2008). This body of evidence underscores the importance of preserving water supply systems in anthropized landscapes to support bird assemblages, as species diversity may also be influenced by feeding strategies (Mariano-Neto & Santos 2023), habitat use (De Bonilla et al. 2012) and

the spatial characteristics of the vegetation surrounding water bodies (Almeida et al. 2020). However, further research is needed to determine whether the presence of artificial water systems near wind farms increases the risk of turbine collisions for species with aquatic affinities (May et al. 2021, Reid et al. 2023).

The differences in seasonal bird assemblages arise from the geographical location of both wind farms within the Isthmus of Tehuantepec, a vital stopover site and on the migratory route of several Nearctic-neotropical migratory birds in spring and fall months, with peak migration commonly observed in mid-October (Cabrera-Cruz & Villegas-Patraca 2016, Cabrera-Cruz et al. 2017b). Previous studies (Villegas-Patraca et al. 2012, Villegas-Patraca et al. 2014, Cabrera-Cruz & Villegas-Patraca 2016) have proposed that raptors migrating through the southern Isthmus of Tehuantepec have adapted their flight patterns to avoid wind farms. Conversely, our field observations provided contrasting evidence indicating that during fall, raptor species (e.g., *F. femoralis*, *F. columbarius*, *F. peregrinus*, *F. sparverius*, *C. hudsonius*, *Coragyps atratus*, *Caracara plancus*) use areas in close proximity to wind turbines for foraging. Raptors often favour open areas that facilitate hunting, enabling them to locate prey from the air and increase capture success (Negro & Galván 2018). The Sureste Wind Farm site, with is twice the size of Stipa, provides favourable conditions (i.e., open space) for species from the families Accipitridae (e.g., *G. albicau-*

datus, *C. hudsonius*, *Buteo platypterus*) and Falconidae (e.g., *F. sparverius*, *F. femoralis*) to maximize hunting success for birds and small mammals (Rojas & Stappung 2004, González-Salazar et al. 2014). Raptors are known to select habitats based on patterns of landscape composition and configuration (Mirski et al. 2024), which strongly correlate with prey abundance and diversity (Väli et al. 2023).

Agricultural activity remains constant throughout the year at both wind farms. However, Stipa is characterized by irrigated agriculture, while farming at Sureste relies on the rainy season (INECOL 2012). In recent years, both sites have experienced a significant expansion of sorghum cultivation, replacing crops such as peanuts, beans, corn, and chili (INECOL 2012, Santini et al. 2022). This shift has led to significant habitat homogenization, potentially promoting resource stability and therefore explaining the limited variation in the most abundant bird species observed over time.

Our findings show that a wide variety of bird species utilize wind farm sites across different seasons, with the bird assemblages being influenced by the surrounding habitat. This highlights the importance of carefully designing, regulating and managing artificial structures, such as wind farms and irrigation canals, in anthropized landscapes. When managed effectively, such resources may have the potential to increase species diversity and contribute to achieving long-term species conservation goals. In addition, the high number of birds observed near

the wind farms underscores the need to conduct future monitoring studies with control areas, which could provide valuable insights into the implications of these artificial habitats on bird assemblages and collisions.

Data Availability Statement

Data used for this research are available inside the paper and in the supplementary files attached.

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Nest composition of Blue Tits (*Cyanistes caeruleus*) along an urban gradient

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Abstract

Nests are structures that protect eggs and nestlings from the external environment while also serving various other functions in avian life histories. Nest-building behaviour varies between species and habitats, and recent work has highlighted that in areas with high human activity and low availability of natural nest material, birds may use anthropogenic material to construct nests. However, we know relatively little about how nest composition is affected by human presence along urban gradients. Here we examined how nest composition differed between urban and forest populations of Blue Tits *Cyanistes caeruleus*, and the impact that variation in nest composition had on reproductive success (clutch size, hatching and fledging success). We found a statistically significant decrease in the weight of moss and grass and an increase in anthropogenic materials in urban compared to forest nests. Nests initiated earlier in the urban environment showed a higher weight of anthropogenic materials. The weight of moss and grass was positively related to fledging success. Our results suggest that the use of anthropogenic material by urban birds might be a maladaptation, and/or that urban birds are constrained in the amount of moss and grass they can find during nest building. Future studies should aim to quantify the availability of material within the environment to test these non-mutually exclusive hypotheses.

Keywords: Blue Tit, anthropogenic nest materials, nesting behaviour, avian breeding



INTRODUCTION

The process of urbanization can have various impacts on ecosystems, such as the construction of artificial and impermeable structures, the elimination of natural vegetation (Ruas et al., 2022; Yan et al., 2019), the introduction of pollutants, including light and chemicals (Dominoni et al., 2013), and increased levels of human disturbance (Sol et al., 2013). This is followed by changes in ecological factors such as predation pressure (Eötvös et al., 2018), food availability (Marzluff, 2001) and temperature (due to the urban heat island effect) (Puppim de Oliveira et al., 2014). Whether a species can thrive in an urban environment depends on how it is affected by the changes brought about by its new habitat. Some animals can take advantage of the opportunities presented by urban environments and can survive or even thrive in cities. Some animals may not be able to tolerate the urban environment and may experience a population decline or avoid urban habitats (Kark et al., 2007; González-Lagos & Quesada, 2017; Corsini et al., 2021). Other animals can take advantage of the opportunities presented by urban environments and can survive or even thrive in them. However, to adjust to life in the city, changes in behaviour, physiology or genetic sequence may be required (Johnson & Munshi-South, 2017; Marzluff, 2001).

As nest building is a major part of an animal's life history, studies have suggested that nest composition may be affected by urbanisation (Reynolds et al., 2019).

These changes can involve using less natural materials, altering the structure of the nest, and/or incorporating man-made materials (Antczak et al., 2010; Jagiello et al., 2019; Votier et al., 2011). Anthropogenic nest material refers to items not naturally found in nature but created by human actions. Materials such as plastic, string, and coir are examples of human-derived (anthropogenic) nest materials (Briggs et al., 2023). Incorporating anthropogenic nest materials has a positive correlation with the human footprint index (Jagiello et al., 2019). In urban environments, the availability of natural nest materials is often reduced, leading birds to use anthropogenic nest materials as a replacement (Wang et al., 2009). Birds residing in urban environments may incorporate more anthropogenic nest materials into their nests than birds residing in non-urban environments (Jagiello et al., 2019). This raises the question of why birds use anthropogenic materials and how it affects their life histories.

Jagiello et al. (2022) suggested three major hypotheses that explain anthropogenic material use in bird nests. Firstly, the availability hypothesis states that when the availability of anthropogenic materials is higher than natural materials, there will be increased use of the former. However, there is mixed evidence for this hypothesis. For example, a study that looked at the preference for nest material in Pied Flycatchers, *Ficedula hypoleuca*, found that when given a choice, the birds preferred natural material over anthropogenic nest materials (Briggs et

al., 2023). Secondly, the age hypothesis proposes that the age of parent birds and their experience are connected to the use of anthropogenic material, where older and experienced birds use it as an extended sexual signal (Jagiello et al., 2022; Sergio et al., 2011). A study in Black Kites, *Milvus migrans*, showed that older birds incorporated more plastic material in their nests up to the age of 10-12 years, their prime reproductive age, and they reduced or even stopped using plastic after this age. This suggests that the use of plastic in this species might be used as a signal of sexual quality (Sergio et al., 2011). Finally, the functional hypothesis states that the functional advantage of anthropogenic materials leads to their use in nests (Sergio et al., 2011; Suárez-Rodríguez et al., 2013). Several advantages have been reported with the use of human-derived materials in bird nests. Plastic strings can play a role in enhancing the nest structure, which is a key factor in safeguarding the eggs and fledglings from harsh weather elements like the wind (Reviewed by Deeming, 2023). Manipulating human-derived materials, such as synthetic threads, during nest building could be easier and could lead to lower energy expenditure than manipulating natural alternatives (Esquivel et al., 2020). Cigarette butts are found to have a repelling effect on ectoparasites compared to natural nest materials, which could decrease the number of ectoparasites found in city bird nests if cigarette butts are included in nest construction (Suárez-Rodríguez et al., 2013).

There are also several potential negative impacts of anthropogenic nest materials. Modifications of nests might alter their structural and functional properties, including integrity, camouflage and thermoregulation (Mainwaring et al., 2014; Lopes et al., 2020). Suárez-Rodríguez et al. (2013) investigated the effects of the presence of cigarette butts in nests and the effects on breeding success. They found that even though cigarette butts have ectoparasite-repellent effects, the number of cigarette butts in the nest was positively associated with the level of female genotoxic damage in House Finches, *Haemorrhous mexicanus*, during breeding. The study also found that the negative effects of cigarette butts on the breeding success of urban birds outweigh any potential benefits from ectoparasite repulsion (Hanmer et al., 2017; Suárez-Rodríguez et al., 2013). Plastic waste can also cause chemical harm through the release of toxins, leachates, and non-degraded persistent organic pollutants, which can enter food webs via a process known as trophic transfer (Teuten et al., 2009). The inclusion of plastic in nests can lead to the entanglement of chicks, as reported in a study on Northern Gannets, *Morus bassanus* (Votier et al., 2011). In American Crows, *Corvus brachyrhynchos*, breeding success was lower in nests with higher amounts of plastic. A major reason for the reduction in breeding success was the entanglement of the chicks and they identified this as a major threat (Townsend & Barker, 2014). A similar case of strangling was reported in Great Grey

Shrikes, *Lanius excubitor*, and it is suggested that both adults and the chicks are prone to strangling (Antczak et al., 2010). Camouflage is an important nest characteristic to prevent nest predation, which is a major cause of nest failure (Corrales-Moya et al., 2023). Antczak et al. (2010) noted that, in Great Gray Shrikes, nests containing plastic string were more easily detected by predators. In a study on Clay-coloured Thrush, *Turdus grayi*, the proportion of the outer layer of the nest covered by anthropogenic nest materials was negatively correlated with the nest's daily survival rate, indicating that the more exposed anthropogenic nest materials, the higher the chance of it being predated (Corrales-Moya et al., 2023). The findings revealed that variations in the nest dimensions did not affect predation events, while the only factor that had an effect was exposed anthropogenic nest materials. Plastic is considered a thermal insulator; higher incubation temperatures and increased heart rates were observed in nests with higher plastic content (Veríssimo et al., 2024). Such effects may cause heat stress, especially in hotter regions.

Although several studies have looked into the effect of anthropogenic materials on breeding success, most of these have focused on marine habitats and seabirds, and only a few have focused on passerines (Jagiello et al., 2019). A study on Blue Tits, *Cyanistes caeruleus*, and Great Tits, *Parus major*, found that the presence of anthropogenic materials was negatively correlated to breeding success in Blue Tits

but not in Great Tits (Jagiello et al., 2022). Increase in the use of anthropogenic materials has been seen over a two-year comparison study that included Great Tits and Blue Tits (Girão et al., 2024). Green nest materials, such as aromatic plants in nests, help reduce ectoparasites and help strengthen nestlings' immune systems (Gwinner & Berger, 2005; Tomás et al., 2012). Feathers in nests are associated with increased thermal regulation and resistance against microbial and ectoparasite infections (Järvinen & Brommer, 2020). Hence, the use of anthropogenic materials instead of feathers might have implications for reproduction and fitness. On these accounts, Jagiello et al. (2022) suggested that the chicks from feather-rich nests have a higher chance of recruitment to the breeding population. Animal hair and wool also serve a similar purpose to feathers in providing insulation, which reduces energetic cost for parents (Harničárová & Adamík, 2016; Surgey et al., 2012).

In the current study, we aim to investigate 1) the effect of urbanization on nest composition and 2) the relationship between habitat, nest composition and breeding success. To this end we collected nests and breeding data from Blue Tits breeding at nine sites between the city centre of Glasgow and a forest approximately 35 miles away in the Loch Lomond and Trossachs National Park, UK. We predicted a higher quantity of anthropogenic materials in the urban nests. Specifically, we predicted that nests with higher amounts of anthro-

pogenic material would produce fewer nestlings than nests with higher natural material content.

MATERIALS AND METHODS

Study species and monitoring of breeding success

The Blue Tit is a small passerine widely distributed in Europe and Western Asia. They are cavity nesters and are usually found in deciduous to mixed woodlands and urban parks, and gardens. They usually have a life span of three years and start reproducing at the age of one year (Stenning, 2018). In Scotland, Blue Tits begin building nests in late-march to early-april, and the breeding season lasts until late-June. Nest building is primarily carried out by females, which uses multiple materials such as moss, feathers, and animal hair (Britt & Deeming, 2011). Clutch size ranges between 4 to 14 eggs, where one egg is laid per day (Perrins, 1990). In Scotland, Blue Tits only lay one clutch. The incubation time ranges between 10 days and three weeks (Gibb., 1950). Once the chicks are hatched, provisioning is shared by both parents, and fledging happens around 15-20 days post-hatching (Fargallo & Johnston, 1997).

The study was carried out along an urban-rural gradient in Scotland, using nine sites spanning a 56km transect from the city centre of Glasgow (55.8668° N, 4.2500° W) to the woods around The Scottish Centre for Ecology and the Natural

Environment (SCENE) on the east banks of Loch Lomond (56°7'44"N 4°36'46"W). Over the past few decades, approximately 500 Schwegler Woodcrete nest boxes with a 32mm entrance diameter have been placed along this gradient and monitored. For the current study, nest boxes were monitored across all sites from April 1st to June 15th, 2023. Starting from April 1st, all the boxes were checked once a week to assess the progress of the nest building and incubation. The first egg date was recorded as the day of the year when the first egg was laid. When nests were expected to hatch, we started to check the active nest every other day until chicks were found. Once the chicks had fledged, the data for breeding success was collected by counting the number of unhatched eggs and dead chicks. The nests (n=64; rural=33, urban=31) were collected in plastic zip-lock bags for dissection and analysis.

Nest collection and dissection

A total of 64 nests were analysed (rural = 33, urban = 31). Once the nests were collected, they were frozen for at least 12 hours to reduce the activity of arthropods, and they were kept frozen until the time of dissection. Before dissection, the nests were dried in a heat chamber at a temperature of 50 degrees Celsius for at least 12 hours to prevent moisture in the nests. Once dried, the nests were dissected, and the material assigned to a category and measured to an accuracy of 0.001 g. The nest materials were grouped

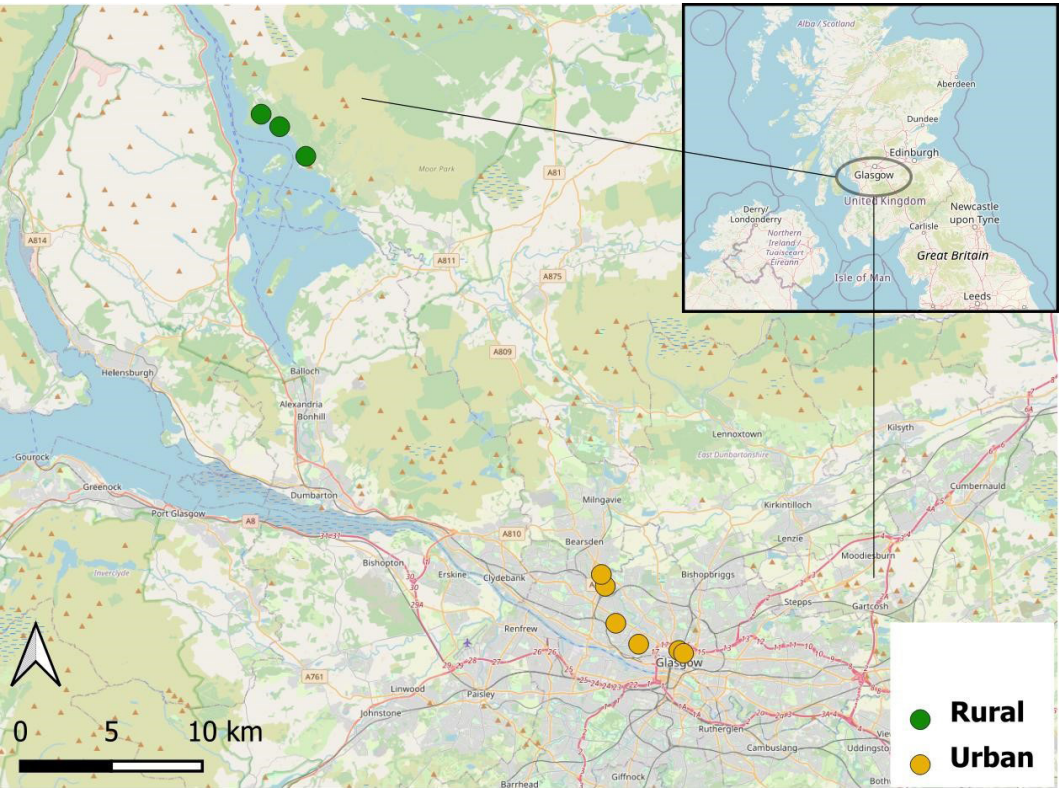


Figure 1. Map of study sites. The points represent different sites where nests were collected, with rural sites shown in green and urban sites in yellow. From six urban sites and three rural sites, a total of 64 nests (rural = 33, urban = 31) were collected. A detailed table and interactive map of the sites can be found in the supplementary materials.

into four categories: 1) moss and grass, 2) feathers, 3) wool and hair, and 4) anthropogenic material; together, they will be referred to as nest materials from now on (an image of each class can be found in Supplementary Fig. 1). The materials are intertwined intricately in the nests, and maximum effort was taken to separate them into each category.



Figure 2. Images of nests with anthropogenic materials. The nest on the left has a cup built largely from man-made fibers and the one on the right has fibers of multiple colors.

Environmental variables

Habitat was defined as a categorical variable with two levels (urban and rural) to represent the habitat in which the nests were collected. We also extracted the impervious surface area around a 100 m radius (IS100 from now on). The IS100 value represents the percentage of impervious surface area within a 100 m radius centred on each nestbox. This measure was calculated from Copernicus Land Monitoring Service, 2018, which captures the extent of non-permeable surfaces such as roads, buildings, and other urban infrastructure (*Copernicus Land Monitoring Service*, 2018; Jagiello et al., 2022).

Statistical analysis

The statistical analysis was performed using R version 4.3.3 (R Core Team, 2024). The analysis was conducted in two parts, corresponding to changes in nest materials and their effects on breeding success. In both parts, model selection was carried out via Akaike Information Criterion (AIC), and Interaction terms were removed if not statistically significant and if their removal improved model fit. The sJPlot package (version 2.8.16; Lüdecke, 2024) was utilised to visualize model predictions.

Nest Materials: To assess environmental effects on nest composition, we used Linear Mixed-Effects Models (LMMs) with each nest material type as the response variable and site as a random variable. Two sets of models were run for each nest

material type, with the following fixed effects: 1) habitat (categorical: urban or rural), first egg date (continuous) and their interaction; 2) IS100, first egg date and their interaction. We did so because habitat was collinear with impervious surface area, but we still wanted to distinguish between the effect of habitat *per se* versus the effect of a specific environmental variable that might better function as a proxy of human activity and, thereby, the use of anthropogenic materials in nests.

Breeding Success: We considered the effect of urbanisation on clutch size, hatching success (calculated as the number of hatched eggs divided by clutch size) and fledging success (calculated as the number of fledglings divided by the number of hatched eggs). Clutch size was modelled with a Poisson GLMM, while hatching and fledging success were modelled as proportions of clutch size with binomial GLMMs with logit link functions. This was to account for the effect of clutch size on the success parameters. In all models, nest material type (weight of each material in grams) and first egg date were included as fixed effects, and site as a random effect.

RESULTS

Nest materials

Our analysis revealed no statistically significant effect of habitat (as a categorical variable, urban *versus* rural) or first egg-laying date on variation in the weight

of nest material categories (Supplementary Tab. S3.1 to S3.6). The interaction between habitat and first egg date showed a marginally statistically significant variation in anthropogenic material per nest, indicative of a negative effect of first egg laying date on the weight of anthropogenic material per nest for the urban environment (estimate = -0.05, $P = 0.03$). Egg-laying dates did not appear to be correlated with variation in anthropogenic materials in rural nests (Fig. 4, Tab. 1).

We then assessed the effect of urbanisation as a continuous variable (i.e., the amount of impervious surface within a 100 m radius around each nest location) rather than as a dichotomous variable (habitat) on the mass of each nest material type. In all models, the interaction between the first egg-laying date and impervious surface area in 100 m was not statistically significant and hence, interaction terms were removed (Supplementary Tab. S4.1- S4.5). The first egg date was

Table 1- Output of linear mixed effect model used to assess the effect of habitat and first egg laying date on the weight of anthropogenic materials, with site added as a random effect.

Characteristic	Estimate ¹	SE ²	95% CI ²	p-value
Intercept	-0.06	4.88	-9.9, 9.7	>0.9
First Egg Date	0.00	0.041	-0.08, 0.08	>0.9
Habitat				
Rural	—	—	—	
Urban	12	6.13	-0.41, 24	0.058
First Egg Date* Habitat				
First Egg Date * Urban	-0.09	0.052	-0.20, 0.01	0.077

¹* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$

²SE = Standard Error, CI = Confidence Interval

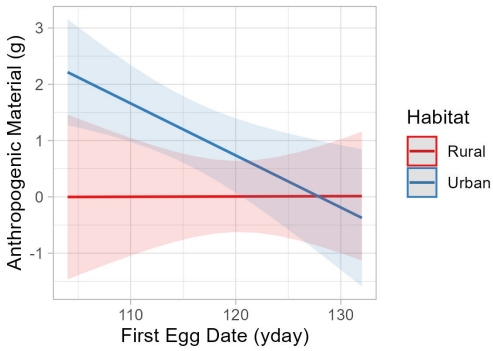


Figure 3. Predictions of a model explaining variation in anthropogenic nest material as a function of habitat and first egg date (y-day- count of days after January 1). The solid lines represent fitted linear regression, and the shaded area represents 95% confidence intervals.

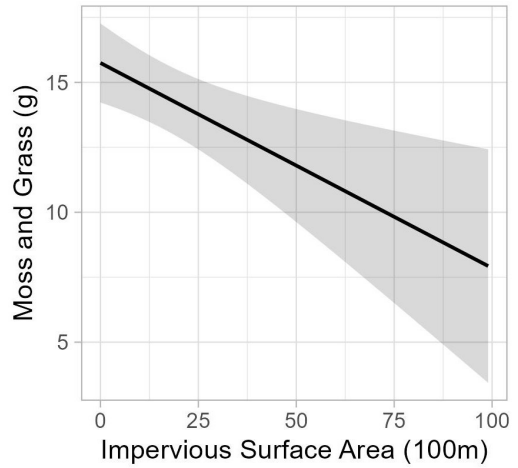


Figure 4. The predictive graph of the change in the weight of moss and grass with an increase in impervious surface area in a 100m radius, the solid line represents fitted linear regression, and the shaded area represents 95% confidence intervals. There is a statistically significant reduction in the weight of moss and grass with the increase in the amount of impervious surface area.

negatively correlated with the weight of anthropogenic materials (estimate = -0.42, $P < 0.01$; Tab. 2). In the case of moss and grass, IS100 showed a statistically significant negative trend with the increase in IS100 (estimate = -2.00, $P < 0.01$; Fig. 5, Tab. 3).

The total nest weight across habitats ranged from 7.5 g to 37.0 g, with a mean of 20.0 g (SD = 6.0). In rural habitats, the total weight had a mean of 18.0 g (SD = 5.0), while urban nests were heavier on average, with a mean of 22.0 g (SD = 7.0). Urban nests also showed greater variability in total weight, with heavier nests driving both the mean and median higher.

Anthropogenic material was present in 45.5% of rural nests and in 90.3% of urban nests, with an overall presence in 71.9% of nests across both habitats (Fig. 3). The weight of anthropogenic material ranged from 0 g to 7.9 g, with a mean of 0.5 g (SD = 1.3). It was nearly absent from rural nests, which had a mean of 0.0 g (SD = 0.1), whereas urban nests contained a mean of 0.9 g (SD = 1.7). The weight of moss and grass ranged from 4.8 g to 29.0 g, with an overall mean of 14.4 g (SD = 5.1). Rural nests had a higher mean moss and grass weight of 15.4 g (SD = 5.1), compared to 13.3 g (SD = 4.9) in urban nests. Feather weight was lower in rural nests,

Table 2- Output of linear mixed effect model used to assess the effect of impervious surface area within 100 m (IS100) and first egg laying date on the weight of anthropogenic materials, with site added as a random effect.

Characteristic	Estimate ¹	SE ²	95% CI ²	p-value
Intercept	0.59	0.245	-0.02, 1.2	0.056
First Egg Date	-0.42*	0.160	-0.74, -0.09	0.012
IS100	0.20	0.201	-0.23, 0.63	0.3

¹*p<0.05; **p<0.01; ***p<0.001

²SE = Standard Error, CI = Confidence Interval

Table 3- Output of linear mixed effect model used to assess the effect of impervious surface area 100m and the first egg laying date on the weight of moss and grass, with site added as a random effect.

Characteristic	Estimate ¹	SE ²	95% CI ²	p-value
Intercept	14***	0.635	13, 16	<0.001
First Egg Date	-0.38	0.668	-1.7, 0.95	0.6
IS100	-2.0**	0.668	-3.4, -0.69	0.004

¹*p<0.05; **p<0.01; ***p<0.001

²SE = Standard Error, CI = Confidence Interval

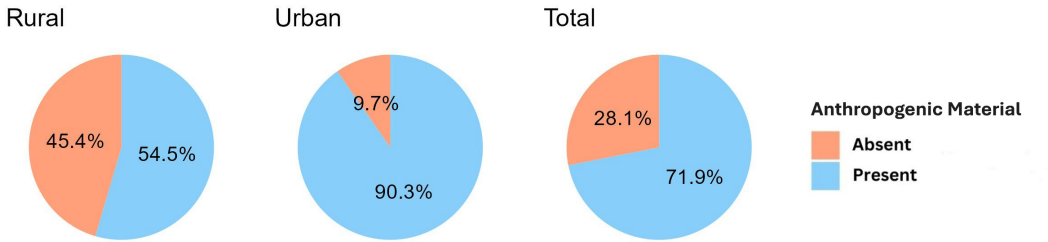


Figure 5. Pie charts illustrating the presence of anthropogenic materials in nests and the number of nests containing anthropogenic materials are presented. There was anthropogenic material in half of the rural nests, while 90.32% of urban nests had anthropogenic materials in them. In total, three-quarters of the nests had anthropogenic materials.

with a mean of 0.9 g (SD = 1.2), than in urban nests, which had a mean of 1.2 g (SD = 1.2). Lastly, wool and hair weights ranged from 0 g to 11.4 g, with a mean of 2.3 g (SD = 2.7). Rural nests had a mean of 1.3 g (SD = 1.8), while urban nests had more wool and hair, with a mean of 3.4 g (SD = 3.1) (Supplementary Tab S2).

Breeding success

The models with nest materials and first egg date showed no statistically significant results for clutch size and hatching success (Supplementary Tab. S5.1 and S5.2). However, for fledging success, the model selection indicated that the best model was the one with only moss and grass. In this model, the weight of moss and grass showed a positive effect on fledging success with a marginally statistically significant p-value (estimate = 0.27, $P = 0.06$), Fig. 6; Tab. 4).

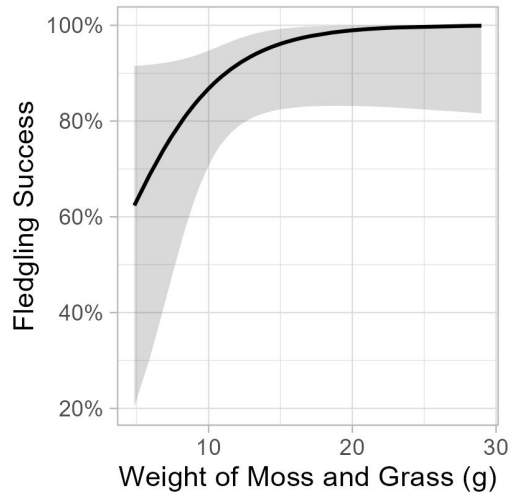


Figure 6. Predictive graphs on fledging success and the variation in the weight of moss and grass. The solid line represents fitted logistic regression, and the shaded area represents 95% confidence intervals. Fledging success increases with an increase in the weight of moss and grass

Table 4. Output of generalised linear mixed effect model (logit link) assessing the effects of moss and grass weight and first egg date on fledging success (proportion of fledglings per clutch), with site included as a random effect.

Characteristic	log(OR) ^{1,2}	SE ²	95% CI ²	p-value
Intercept	-8.2	9.35	-26, 10	0.4
Moss and grass	0.27	0.147	-0.02, 0.55	0.069
First Egg Date	0.06	0.077	-0.09, 0.21	0.4

¹*p<0.05; **p<0.01; ***p<0.001

²OR = Odds Ratio, SE = Standard Error, CI = Confidence Interval

DISCUSSION

This study provides evidence that urbanization influences nest material selection in blue tits and this might be marginally affecting fledging success. Also, egg-laying dates affect the amount of anthropogenic materials in the nests. We found that the urban nests had high variability in total nest weight and contained more anthropogenic materials. Considering the various nest materials, moss and grass were the only materials that showed a statistically significant reduction with an increase in impervious surface area. Total weight and wool, and hair also showed a reduction with the amount of impervious surface, but this result was not statistically significant. The weight of moss and grass was a marginal predictor of fledging success: nests that contained more moss and grass fledged more young. Conversely, anthropogenic materials were not as-

sociated with breeding parameters. This underlines the importance of natural materials especially “moss and grass” for reproductive fitness in Blue Tits.

Preferential selection of materials in urban and rural habitats?

The weight of anthropogenic materials in urban nests was higher than their weight in rural nests, while reproductive success and clutch size are known to be lower in urban compared to rural nests. Despite these trends, we did not find any statistical evidence for an association between anthropogenic materials and reproductive success. Also, it is to be noted that 72% of all the nests had anthropogenic material in them. We have noted that in urban nests, anthropogenic materials and wool/hair materials were mostly used to provide structural support instead of grass, which was more common in the rural nests (J.

Roy pers. obs.). The reduced availability of grass in the urban environment might be the reason for birds to use anthropogenic materials in their nests, or, following the availability hypothesis, anthropogenic materials may be more available in the urban environment than natural materials. The selective picking of nesting material was demonstrated by Briggs et al. (2023). While our study showed a reduction of moss and grass and an increased use of anthropogenic materials with increasing urbanization, it needs to be confirmed whether these patterns are a result of materials being actively selected by birds in urban areas or the result of lower availability of these materials. Thus, quantifying the availability of different types of materials will be crucial in future studies. This is particularly important when considering that the weight of anthropogenic materials was shown to increase the number of unhatched eggs in previous studies (Jagiello et al., 2022; Reynolds et al., 2019). In the review Reynolds et al. (2019) suggested city and site specific differences in nesting behaviours. Moreover, the changes we have observed may also be due to differences in the availability of materials within and between sites. Within sites, micro-habitat differences surrounding each nesting location might lead to differential selection of nest materials. Suárez-Rodríguez et al. (2013) reported cigarette butts used in Blue Tit nests as an insect repellent, but no nests in our sites had cigarette butts in them, which could be a city specific difference.

Anthropogenic materials as an extended sexual phenotype

Several theories have attempted to explain the reasons why birds incorporate anthropogenic materials in their nests, one of which is the sexual selection theory. When provided with natural materials, Black-Faced Spoonbills, *Platalea minor*, showed a preference for natural materials over anthropogenic nest materials (Lee et al., 2015). Surgey et al. (2012) suggest that the selection of wool-like artificial material is opportunistic. However, in our study, the three rural sites were oak woodlands with ample amounts of natural materials, and anthropogenic materials were scarce and mostly made up of trash from occasional tourists (J. Roy pers. obs.). Despite the lower availability of anthropogenic material, 54% of rural nests had anthropogenic materials in them. The presence of anthropogenic materials in the rural nests, despite natural materials being readily available, may suggest preferential selection towards anthropogenic material in rural habitats, as observed by Briggs et al. (2023). As previous studies have suggested, birds tend to use anthropogenic materials as an extended sexual phenotype (Jagiello et al., 2022). In the case of rural habitats, the anthropogenic materials were mostly used along with feathers as lining, which might play a decorative role in the nests, while in urban habitats, it was mostly added into the structural parts of the nests instead of grass (J. Roy pers. obs.). It can also be noted that the weight of an-

thropogenic materials was considerably lower in rural nests compared to urban nests. Thus, selective preference of anthropogenic materials in rural nests could point to this behaviour as an extended sexual phenotype, as suggested by Jagiello et al. (2022), while in urban nests might support the functional hypothesis.

Effects of parental phenotype on the selection of nest materials

Anthropogenic material was present in 90% of urban nests, whereas the weight of anthropogenic material in rural nests was nearly zero. The reason urban birds use anthropogenic material in their nests cannot be determined without quantifying the availability of natural nesting material in urban habitats. Although there was a marked increase in the amount of anthropogenic material in urban nests, breeding success was mostly driven by the weight of the moss and grass. Mainwaring & Hartley (2008) showed a reduction in cup lining with the progress of the breeding season, which shows a similar trend to the current observation in anthropogenic materials, which might be used as a cup lining. Earlier lay dates, larger and heavier nests, higher amounts of feathers, and the addition of aromatic plants are considered to correlate positively with parental traits such as age and experience (Mainwaring et al., 2008; Tomás et al., 2013; Williams et al., 2024). These act as sexual signals to elicit increased allocation by males, which is shown to improve breeding success (Tomás et al., 2013). In

the urban habitat, nests built earlier in the breeding season had a statistically significantly higher weight of anthropogenic material, while in the rural habitat, the weight of anthropogenic materials remained low throughout. Since anthropogenic materials are higher in earlier urban nests, it is worth noting that early breeding parents might be selecting these materials as an extended sexual phenotype or using them as a substitute for natural materials due to availability or preference (Deeming, 2023; Jagiello et al., 2022).

Limitations and future directions

In this study, we cannot conclude whether urban and rural birds selected natural vs anthropogenic material actively, either for structural or sexual selection benefits, or due to differential availability of materials in urban and rural habitats. To distinguish between these different hypotheses, future studies could focus on quantifying the availability of each material in the micro-habitat surrounding and relate this to the proportion of each material included in the nest construction. Moreover, performing experiments to manipulate the presence and location of anthropogenic materials in the nest might shed light on whether their use may act as an extended sexual phenotype.

DATA AVAILABILITY STATEMENT

The dataset supporting this study, Data for Nest Composition of Blue Tits (*Cyanistes caeruleus*) along an Urban Gradient, is

available in Dataverse UNIMI at https://doi.org/10.13130/RD_UNIMI/DUNY3S, under the CC-BY 4.0 license.

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Author contributions

Joseph Roy: conceptualization, methodology, formal analysis, original draft preparation, review & editing. **Claire J. Branston:** data curation, writing – review & editing; **Pablo Capilla-Lasheras:** data curation, writing - review & editing; **Paul J. Baker:** data curation. **Davide M Dominoni:** conceptualization, methodology, original draft preparation, writing - review & editing, supervision.

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Results of the pilot survey on the Lanner Falcon (*Falco biarmicus feldeggii*) in Thessaly Prefecture, Greece.

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Abstract

Lanner Falcon (*Falco biarmicus feldeggii*) is classified as endangered in Greece. Its breeding population is considered stable, with a patchy distribution on the mainland and the islands. Thessaly is considered one of the species' strongholds due to its arid climate, connecting the subpopulations of western and northern Greece to those in the south. This is the first dedicated pilot survey for the species in Greece. Historical and citizen-science data were compiled, and the prefecture was divided into seven sectors. Favourable areas were classified based on the abundance of past and recent observations, as well as the species' probability of presence. A total of 6,052 km was covered, with 107 field days and 480 monitoring hours invested from viewpoints during the breeding season. The species was recorded fifteen times, and eight territories were verified. Based on historical data, in four of the seven sectors, the species shows 59% decline. No fledglings or reproductive activity were recorded during 2024.

Keywords: Bird of prey, Endangered species, breeding season, monitoring efforts, territory verification, population decline, conservation

INTRODUCTION

The Lanner Falcon (*Falco biarmicus feldeggii*) is among the least-studied falcons in Greece, and its detailed population and distribution are still unknown in the country (Leonardi 2001; Alivizatos et al. 2021). The species has an extensive yet fragmented distribution, occurring across all thirteen Greek prefectures (Fig. 1A). Previous estimates of its population in Greece came from surveys of Important Bird Areas (IBAs) and Special Protected Areas (SPAs; Fig. 1B). The overall distribution includes 30 SPAs with one-third of the population living in medium-sized or large islands (10 SPAs), while the rest is on the mainland (Fig. 1B; Dimalexis et al. 2009). Ranging from 40 to 55 pairs in these assessments, this falcon was considered stable or locally declining (excluding potential pairs outside SPAs; Alivizatos et al. 2021).

Lanner Falcons in Greece can be found from sea level up to 2,300 m. Most territories are at moderate altitudes between 500 and 1000 m. In Crete, they are usually seen in rocky slopes between 400 and 1600 m. Nests have been found twice overlooking pine forests (Handrinos & Akriotis 1997) and one in a corvid nest on a plain (authors own data). In Thessaly, they were recorded near Lake Karla (Magnesia and Larissa) with one juvenile and two adults observed in 2022-2023 (authors own data). These observations, along with observations by citizen science network were the incentive of the current pilot survey in the Prefecture of Thessaly, Greece.

At the national level, the species is classified as “Endangered” (BirdLife International 1999; 2024). Its main threats include habitat loss, large photovoltaic parks, wildfires, flooding, poisoning from agrochemicals, and competition with the Peregrine Falcon (*Falco peregrinus*) (Birdlife International 1999). Other risks, such as egg collection and/or illegal shooting, are also possible (BirdLife International 1999; 2024). A major threat is also natural afforestation caused by land abandonment (e.g., the decline of traditional animal husbandry) which reduces the required open hunting grounds essential for the species (Alivizatos et al. 2021).

This is the first focused survey to document the species’ presence in the country. The goal is for the data acquired to serve as a basis for future studies on breeding parameters, habitat preferences, timing of reproduction, and population growth, comparable to other areas occupied by the subspecies *feldeggii* in the Mediterranean basin (Sarà 2014, Amato et al. 2014, 2021, Mascara & Nardo 2018, Sarà et al. 2022, Leonardi et al. 2024).

MATERIALS AND METHODS

Study area

The core study area was the Thessaly Plain in the Thessaly Prefecture, covering 14,036.64 km² (Fig. 1C, D). It lies in the central and eastern parts of the prefecture and is surrounded by Olympus

Mountain to the northeast, Ossa Mountain Mayrovouni and Pelion Mountains to the east, Othrys Mountain to the south, Chasia and Kamvounia Mountains to the northwest and Koziakas Mountain to the west (Fig. 1D).

The mountains have canyons and rocky foothills, while the plain is marked by low, rocky hills with scattered across the grasslands. Grasslands are the main natural vegetation in both lowlands and hilly areas, along with scrublands and open forests. Agriculture mainly consists of non-irrigated cereal and cotton crops (Galanaki et al. 2017). The Prefecture experiences hot, dry summers with temperatures exceeding 35°C, typical of a Mediterranean Xeric type, and mild, more wet winters, especially in higher areas, characteristic of a Subhumid Mediterranean climate (Rivas-Martínez 1996). The climate ranges from Mesomediterranean in the lowlands to cooler, wetter conditions in the Supramediterranean mountains (Tselepidakis & Theoharatos 1989).

Located in the northwest part of the Thessaly plain, near the town of Kalambaka, the Meteora rock formation consists of towering sandstone pillars. Recognized as a UNESCO World Heritage site, it includes the SPA GR1440005 (Mount Antichasia and Meteora), an area that has historically hosted at least four pairs of Lanner Falcons. Half of the mainland Greek population is found in Central Greece (East of Pindos Mt, within 10 SPAs) in the Prefecture of Thessaly, making this area a potential stronghold area for the species (Fig. 1C).

Compilation of historical and recent data

Data for the species were compiled from the following sources: a) previously published ornithological assessments of IBA/SPA monitoring from 2001, 2009, 2016 and 2024; b) Greek and international literature research through scientific databases such as PubMed and Google scholar; c) data extracted from e-Bird, iNaturalist observation platforms; d) private reports from ornithological field trips; e) contributions from foreign ornithologists and the authors; and f) photographs of the species shared in Greek wildlife/bird photography Facebook management. Data were assessed for quality. Data from e-Bird and iNaturalist was included only if the report was accompanied by pictures of the species or detailed description. Historical nesting territory information was considered the most valuable, followed by observations of adult birds (pair or singles) during the breeding season (February-May), which were seen as potential territory-holders. Juvenile observations in May-June indicated breeding success and an active territory. Observations of juvenile in July-August and adults from July to January were excluded, as they likely indicated juvenile dispersal or adult winter movement.

Field survey methodology

Thessaly was divided into seven sample areas (Fig. 1D). Candidate areas were classified as high priority, medium pri-

ority, low priority, and uncharted/possible, based on historical data, recent observations (within the last 5 years), and habitat evaluation. In total, 13 high-priority, 8 medium-priority, 7 low-priority, and 17 uncharted/possible areas were identified. Researchers used fixed viewpoints in each area to observe suitable nesting cliffs from both distant and up close. Viewpoints were set up in corridors linking foraging and nesting habitats to improve encounter chances. Due to the extended habitat and limited time, the survey focused on high-priority areas, mainly in the east, northeast, northwest and north sectors. Only the northern part of the southern sector was surveyed, while the western and southwest sectors were not visited.

Fieldwork was conducted from March to July 2024 using binoculars (10x45), field scopes (25 – 65x) and DSLR cameras. Earlier start of fieldwork (e.g. January-February) was not possible due to lack of funding. The procedure followed the Lanner Falcon's breeding phenology in Sicily and southern Italy (Amato et al. 2021). Sites were visited 2-8 times, and each session lasted at least 4 hours, with extension if the species was observed. Cliffs were checked for nests, and photos of both active, inactive and possible nests were taken from distance. Local residents, such as hunters and shepherds, were discretely interviewed about raptors when

crossed paths with the field researchers. Territories were defined within an 8 km radius. Over 6,052 km were covered in the selected sectors. Five full-day expeditions (4 days each) took place from March to early July, covering the northwest (2), northeast (2), and parts of the north and south sectors. Tab 1 provides a detailed summary of the fieldwork effort carried out in Thessaly during 2024, including the number of fieldwork days, cumulative monitoring hours, and visits to areas of varying conservation priority.

RESULTS

Historical population and distribution of the Lanner Falcon in Greece and Thessaly

The population size and distribution of the Lanner Falcon in Greece remains unclear. Cross-verification of historical records, citizen-science data, and authors' historical data, suggest a cautious estimate of 60-80 historical territories. In Thessaly Prefecture, there may have been historically 17-22 territories, distributed as follows: 4 in the southern sector, 1-2 in the western sector, 4-6 in the northwest sector, 2 in the northern sector, 5 in the northeast sector, and 4 in the eastern sector (Fig. 1D).

Table 1. Summary of fieldwork effort, monitoring hours, and site visit priorities by month in Thessaly during 2024.

Month	Fieldwork Days	Monitoring Hours	High-Priority Area Visits (all months)	Medium-Priority Area Visits (all months)	Low/Possible-Priority Area Visits (all months)
March	15	50	-	-	-
April	24	135	-	-	-
May	13	68	-	-	-
June	25	178	92	10	10
July	15	45	-	-	-
Total	107	480	92	10	10

Survey results

The Lanner Falcon was recorded 15 times: 12 times in high-priority areas and 3 times in uncharted areas in the southern sector. There were also 3 unverified sightings. Based on these, we confirmed 8 territories (3 in the northeast, 2 in the northwest, 2 in the east, and 1 in the south), with two more (1 in the south and 1 in the northwest) likely (Fig. 1D). Of the 10 territories, 8 were in high-priority areas with historical presence of the species, while two might be newly discovered areas.

Most observations (6) involved male adults mobbing other species (*Corvus corone* and *Falco tinnunculus*) or hunting and eating. In one case, a pair was seen, and in another, a female. In five cases, the sex was not identified. No juvenile birds or reproductive activity were recorded. The species was photographed three times. Three suspected nesting locations were found in cliffs where birds were roosting, and two abandoned historical

nests have been located. In other areas, no nests were found due to abundance of suitable cliffs, some with limited visibility.

DISCUSSION

Thessaly population estimation/trend

This pilot survey confirmed the presence of the species in Thessaly, mainly within historical territories. The southern, south-western and the western sectors were not surveyed meticulously, and therefore were excluded from the calculations. In the other sectors, the northwest shows a 50-66% decline (2 territories), the north a 100% decline (zero territories), the northeast a 40% decline (3 territories), and the east shows a 50% decline (2 territories). The average decline across the four sectors is calculated to 59% (17 historical vs 7 current; Fig. 1D).

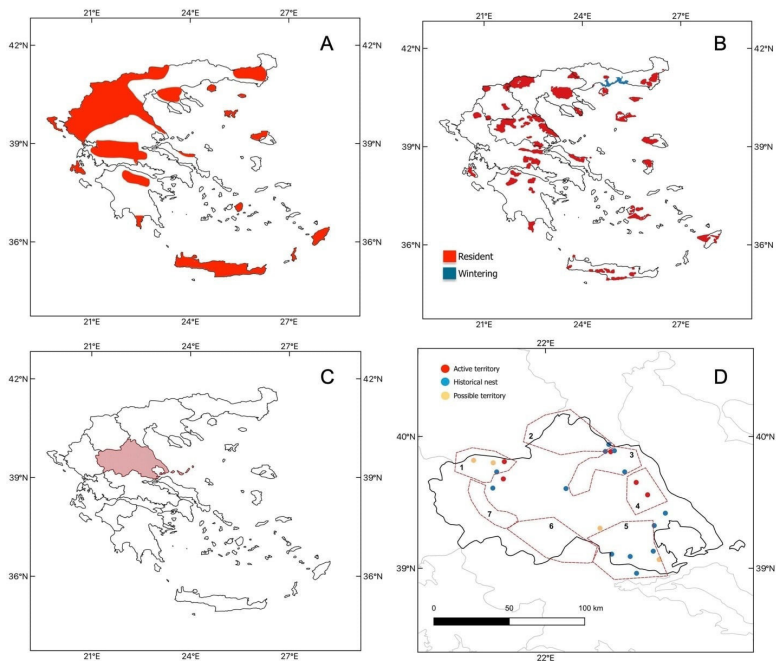


Figure 1. A - Lanner Falcon distribution in Greece (Alivizatos et al. 2021), B - Lanner Falcon in Greek Special Protection Areas (SPAs), C - Thessaly Prefecture, D - The seven research sectors of Thessaly Prefecture and historical, current and possible Lanner Falcon territories in Thessaly a – Sectors 1 = North West, 2 = North, 3 = Northeast, 4 = East, 5 = South, 6 = Southwest, 7 = West.

Reproductive performance/dynamics

It was even more concerning that no breeding behaviour or juvenile Lanner Falcons were observed in 2024. In 2022-2023, however, at least one juvenile was photographed in the east sector of Thessaly, indicating an active territory. Unfortunately, other territories were not regularly monitored before this pilot survey. During the current survey, a pair was seen only once in suitable cliffs in June, and no copulation was observed. The low number of pairs detected during this pi-

lot study may have been influenced by specific constraints, even with the time invested. For instance, the allocation and less conspicuous nature of vocal activity during courtship behaviour could have hindered the detection of occupied territories (Leonardi et al. 2013). In addition, population fragmentation and the low number of active pairs mean that unpaired individuals (floaters) are not closely involved in maintaining a suitable territory (Leonardi et al. 2025). The absence of juvenile bird observations could be attributed to a decline in productivity,

consistent with the recent trends seen in Italian populations (Amato et al. 2021; Sarà et al. 2022). February rainfall was the main environmental factor affecting Lanner Falcon breeding (Amato et al. 2021; Sarà et al. 2022). While moderate rain encouraged breeding, heavy rainfall delayed egg-laying, leading to nest failures and fewer fledglings (Amato et al. 2021; Sarà et al. 2022). Human-induced pressures, alongside climate change, further intensify the negative impacts and must be taken into account (Leonardi 2001; Sarà et al. 2022).

Threats and future research and conservation actions

Various threats have been recognized as direct or indirect risk factors impacting the viability of the *feldeggii* subspecies of the Lanner Falcon population in Europe (Leonardi 2001; Gustin et al. 2002; Andreotti & Leonardi 2007). Among the various threats, one of the most pervasive is land abandonment, combined with the gradual discontinuation of traditional agricultural practices, particularly in arable lowland areas (Sarà 2014). The impact on the Lanner Falcon can occur on multiple levels, affecting not only the composition and abundance of its preferred prey in foraging areas, but also the suitability of its nesting territories (Sarà 2014). Habitat degradation, driven by the abandonment of traditional land uses, is currently occurring in the north, northwest, and northeast sectors, making negative impacts on this falcon a likely outcome (Kairis et

al. 2022; Bouillet 2024). Preliminary observations indicate that competition with the Peregrine Falcon does not represent a significant threat, a finding consistent with existing quantitative studies (Amato et al. 2014; Sarà et al. 2016). No direct illegal persecution was detected or suspected through the fieldwork or interviews. Disturbance caused by climbers, hikers or tourists was observed in the northwest sector (Meteora area). Expansion and establishment of medium-sized photovoltaic parks has been observed across all Thessaly and close to some Lanner Falcon territories. Their possible impact needs further investigation.

Future efforts in the Prefecture should focus on finding new territories in the south, southwest, and west sectors. Surveys should start in February, when nuptial flights occur. The main priority is to monitor the eight existing territories in the northwest, northeast, and east sectors, assess breeding activity, and check productivity and fledgling numbers. Satellite telemetry, following the established protocols for the species, can offer valuable insights into various aspects of their behaviour (Stephenson 2001; Sarà et al. 2019). For adults, it aids in understanding foraging habits, nest locations, dispersal patterns, and habitat use (Stephenson 2001). For juveniles, it plays a crucial role in monitoring survival rates and tracking dispersal from the natal site (Sarà et al. 2019). Pellet analysis and nest camera (if applicable) could provide information on diet, prey selection, breeding performance and reproductive behaviour,

allowing comparisons with the Italian population (Grenci & Di Vittorio 2004). Finally, dissemination the results with local authorities (Forestry Department, NECCA - Natural Environment & Climate Change Agency and Administration) would help secure funding for actions to boost the population and reduce further decline in the Prefecture.

Acknowledgements

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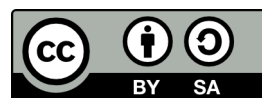
Competing interests

The authors have no competing interests to declare that are relevant to the content of this article

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First breeding of lesser kestrel *Falco naumanni* in Campania

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Abstract

The Lesser Kestrel (*Falco naumanni*) is a small falcon whose Italian breeding range is currently expanding. Summer records from Campania have been considered to refer to wandering individuals from breeding colonies in nearby Puglia and Basilicata. This short communication describes the first documented breeding record in Campania, from a farmland area on the coastal plain of Caserta province. The pair nested successfully with at least one fledged juvenile; the date of fledging, at the end of July, is about one month later than typical fledging dates elsewhere in Italy.

Keywords: lesser kestrel, nesting, breeding, rural areas

The Lesser Kestrel (*Falco naumanni*) is a long-distance migrant that winters in sub-Saharan Africa and breeds in southern Europe and Central Asia (Christakis et al. 2023). It suffered a dramatic population decline in the second half of the twentieth century (Donazar et al 1993) with an estimated population loss of 95% in Europe (Tella & Forero 2000). Starting in

the 1990s, European populations began to bounce back (Christakis et al. 2023). In Europe, the Lesser Kestrel has a predominantly Mediterranean distribution concentrated in Spain, Italy, and Greece. Historically, breeding sites in Italy were limited to Basilicata, Apulia, Sicily and Sardinia (Mascara e Sarà 2006). In recent years, its breeding range has expanded,

likely due to climate change (Morganti et al. 2017). The main breeding colony in Latium, in Tarquinia (VT), is expanding, as is the breeding population in the Po Plain, where Lesser Kestrels have been breeding in Emilia-Romagna for over twenty years (Roscelli & Ravasini 2009), and has recently expanded into Lombardy. Outside of its historical breeding range, the species has also recently nested in Calabria, northern Apulia, and Molise (La Gioia et al. 2017). Nearer to our study site – about 120 km to the northwest – in 2020 a pair nested successfully in southern Latium, in the municipality of Sezze in Latina province (Di Lieto 2021). In 2021, two pairs that had formed in the same site abandoned their nesting attempt, and more recently, in 2023 and 2024, the species was entirely absent from this site (Di Lieto, pers. com.).

The status of the Lesser Kestrel in Campania is somewhat uncertain due to identification difficulties and the risk of confusion with the much more abundant Common Kestrel (*Falco tinnunculus*). Scebba (1993) listed it as an uncommon but regular migrant in both spring and fall, with most records from the coast and islands. More recently, Fraissinet et al. (2015) broadly agreed with this assessment, listing it as rare but regular in April-May and July-September, with most records from coastal areas; inland records in summer are presumed to refer to wandering individuals from nearby regions, as evidence of nesting in Campania is lacking. Our own observations suggest that while the Lesser Kestrel's status as a fall migrant in the region remains cloud-

ed by identification issues and a lack of documentation, it is indeed quite regular in spring, when it often associates with flocks of migrating Red-footed Falcons (*Falco vespertinus*).

This brief article details our observation pertaining to the first known instance of successful breeding of Lesser Kestrel in Campania. Our observations took place between May and July 2024 at a site between the municipalities of Castel Volturno, Cancellorosso e Arnone and Villa Literno in Caserta province. This is a predominantly agricultural area, with crops including tomatoes and other vegetables, corn, and grasses used for fodder and hay, in addition to fields left fallow.

A distinctive element of the landscape is the presence of numerous abandoned farmhouses built in the 1920s and 1930s by the Opera Nazionale Combattenti, a charitable organization that assisted World War I veterans. These are in various states of disrepair, often with collapsed walls and overtaken by vegetation, usually fig trees. These abandoned farmhouses function as tiny ecological islands, providing breeding habitat for Eurasian Tree Sparrow (*Passer montanus*), Italian Sparrow (*Passer italiae*), Eurasian Hoopoe (*Upupa epops*), European Roller (*Coracias garrulus*), Common Kestrel, and Little Owl (*Athene Noctua*).

Most human disturbance consists of agricultural activities, which are often carried out adjacent to these abandoned farmhouses. Finally, nest robbery is a major problem, particularly for European Roller nestlings. In the

recent past, this was identified as a leading cause of the low reproductive success of Common Buzzards (*Buteo buteo*) and Common Kestrels (Cairone 1982). Finally, photographers getting too close to local nests of Eurasian Hoopoes and European Rollers have also caused problems. For these reasons, while conducting our observations we tried to avoid attracting the attention of potentially dangerous individuals.

The first observation of the Lesser Kestrel pair dates back to the afternoon of May 9, when an unidentified female kestrel was seen flushing from the nest site, while a male Lesser Kestrel remained perched atop the abandoned farmhouse. The next sighting was on the afternoon of May 22, when both birds were perched on the farmhouse walls (the roof had previously collapsed). Mating was observed on this occasion, with the male flying off a few minutes thereafter. Subsequent to this observation,

we attempted to monitor the nest site as regularly as possible: our observations are detailed in Figure 1, with the date and duration (in minutes) indicated. From May 22nd, the site has been monitored on average every 2.5 days, with a standard deviation of 1.9 days.

During our monitoring efforts, we also explored nearby areas to ascertain whether any of the other abandoned farmhouses in the vicinity were also occupied by Lesser Kestrels, without finding any. The pair of Lesser Kestrels we monitored thus appears to be the only one in the area; within a radius of 2 km of their nest site, at least two pairs of Common Kestrel, three pairs of Little Owl, and 3–4 pairs of European Roller also nested.

According to Assandri et al. (2023), Lesser Kestrels generally hunt within a radius of 4.6 km of their nest site, which area we were only able to explore in two directions. Nevertheless, we never managed to

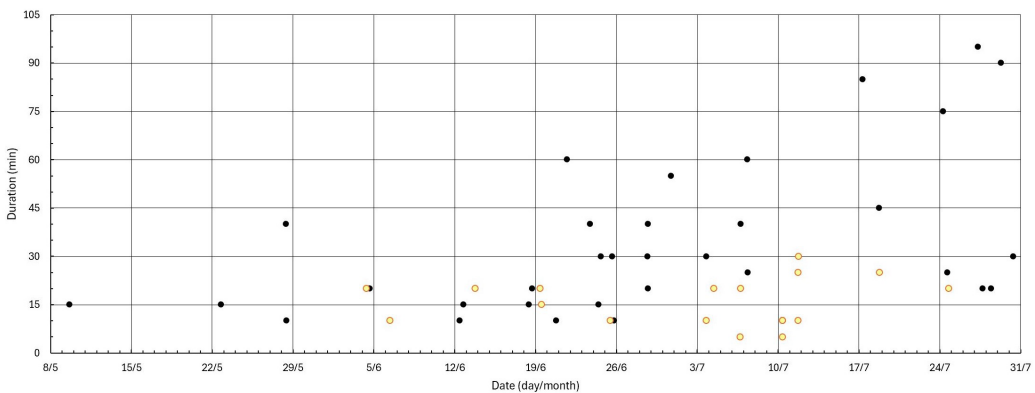


Figure 1. Seasonal distribution of field sampling events and their duration. Black filled dots indicate instances when Lesser kestrels were observed, while yellow empty dots depict instances when Lesser kestrels were not found.

find hunting Lesser Kestrels at any significant distance from the nest site. In the immediate vicinity of the nest site, the Lesser Kestrels hunted over an area comprising a large fallow field, a field planted with cantaloupes, one planted with tomatoes, and a corn field with rapidly growing stalks in June. While we cannot attribute any statistical significance to our observations, they seem to align with the findings of Berlusconi et al. (2022): Lesser Kestrels preferred to hunt over fallow fields rather than irrigated corn fields, where the local female Common Kestrel, on the other hand, frequently hunted. Finally, most of the prey items we saw were orthopterans, as evidenced by Christakis et al. (2023).

We can break our observations down into several periods characterized by the patterns of activity of the Lesser Kestrel pair, which at times caused uncertainty over how the nesting attempt was proceeding:

- a. Until around June 20, the Lesser Kestrels were difficult to observe. Even when we managed to find them, they were generally in view for no more than a few minutes, always one individual at a time, and with only very brief stops made at the abandoned farmhouse. To us, this suggested that the pair was incubating eggs. Unfortunately, the putative nest was not visible from outside, and the Lesser Kestrels flew into the farmhouse from above, through the collapsed roof.
- b. Starting on June 21, we noted a significant increase in activity, with numerous instances of the birds – especially the male – bringing prey to the nest. On June 21 we observed the male arrive with prey three times over the course of 40 minutes. Before flying into the farmhouse, it would stop on the outer walls to remove the wings from its orthopteran prey. This suggested that the eggs had hatched; as mating was observed on May 22, this was compatible with the four-week incubation period typical of the species. This activity pattern continued for about a week.
- c. From June 28 to early July, we noted a reduction in the frequency of prey being brought to the nest, while the female started spending significant amounts of time (several tens of minutes) atop the farmhouse at sunset.
- d. We witnessed a different behavior on July 6 and 7. The Lesser Kestrels never perched on the farmhouse; instead, on a very few occasions they went in and out at such speed that it was impossible to determine whether they were carrying prey. We never saw the two individuals together at the farmhouse, which seemed to be devoid of either the male or the female for significant amounts of time.
- e. On July 10 and 11 we failed to detect any Lesser Kestrels, and the nest site appeared to have been abandoned. A female Common Kestrel was briefly seen on the farmhouse on July 10, while at least one Little Owl seemed to be permanently present during this period.

- f. Between July 17 and 24 the male was once again seen several times, but we never saw the female. The male brought a great many prey items inside the farmhouse, which were able to identify on those occasions when it perched on the walls first: nearly all the identifiable prey were mole crickets.
- g. Finally, on July 27 we once again saw the female on the farmhouse, along with the male hunting nearby. Soon thereafter, a nearly fully-fledged juvenile hopped up onto the roof (Fig. 2). On July 29 we observed the fledged juvenile for the first time, initially as it took a brief flight over the farmhouse

itself, and later as it flew with more confidence and for longer distances in the general vicinity.

The first nesting record of Lesser Kestrel in Campania fits within a broader pattern of range expansion in this species in Italy (Morganti 2022). In fact, there are striking parallels between the areas recently colonized by the Lesser Kestrel in Italy – especially the Po Plain and Latina province – and our study site. All are in areas dominated by intensive agroecosystems that have created a steppe-like landscape. In both the Po Plain and in Caserta province, these ecosystems are mostly dedicated



Figure 2. Lesser kestrel female with her juvenile on July 27th.

to the production of world-renowned cheeses, Parmigiano-Reggiano in the former case and buffalo's milk mozzarella in the latter. Much as in the Po Plain, there are opportunities to use the Lesser Kestrel and other charismatic birds that have benefited from agricultural practices associated with the production of buffalo's milk mozzarella – European Roller in particular – to serve as flagship species for potential market-based conservation solutions (Assandri et al 2023).

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Successful rearing of a young Egyptian Vulture *Neophron percnopterus* by a single male after the death of his mate

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Abstract

The Egyptian Vulture *Neophron percnopterus* is critically endangered in Italy, with only 11–14 pairs censused in recent years, most of them in Sicily. Urgent conservation actions are therefore needed to prevent any mortality and increase the productivity of each pair. Here we present a case of supplementary feeding carried out in Sicily to sustain a breeding adult male Egyptian Vulture that lost his mate after hatching on May 19, 2023. The single male took advantage of the supplementary feeding right from the beginning and raised a chick until it fledged on July 26. He also formed a pair with a new adult female that was attracted by the food we provided. The new female showed aggressive behaviour towards the young immediately after fledging. However, five days after fledgling, the young was observed flying alongside the adults, suggesting that the breeding was successful.



Keywords: birds of prey conservation, illegal killing, pair formation, parental care, Sicily, supplementary feeding

INTRODUCTION

The Egyptian Vulture *Neophron percnopterus* is a migratory Old World vulture whose breeding range extends from north-western Africa and Portugal in the west to Central Asia and India in the east (Botha et al. 2017), and whose wintering areas are mainly located in the Sahel zone, East Africa, Arabian Peninsula and the Indian subcontinent (Botha et al. 2017, Buechley et al. 2021, Burnside et al 2023). Because of the rapid population decline in many parts of its range, the species is listed as globally endangered by the IUCN, with an overall population estimated between 12,400 and 36,000 mature individuals (BirdLife International 2025). The European population, totalling 3,000–4,500 breeding pairs, has declined by at least 10% over the last three generations (BirdLife International 2025).

The leading causes of this steady decline are human-related: poisoning (including lead-poisoning), electrocution, collision with overhead wires and wind turbines, poaching, disturbance and habitat changes (Donázar et al. 2002, Sarà & Di Vittorio 2003, Iñigo et al. 2008, Zuberogoitia et al. 2008, Hernández & Margalida 2009, Angelov et al. 2013, Grubač et al. 2014, Şen et al. 2017, Parvanov et al. 2018, Oppel et al. 2021, Ceccolini et al. 2023).

In Europe, the main strongholds of the species occur in the western Medi-

terranean (Portugal, Spain and France) whereas only small populations survive in the Balkans and Italy (EBCC 2022). In the latter country, the Egyptian Vulture was widely distributed on the mainland and in Sicily until the middle of the last century (Andreotti & Leonardi, 2009), but its breeding range and population are currently extremely reduced. In the 2019–2023 breeding seasons only 11–14 pairs have been recorded, 8–9 of which in Sicily, 2–4 in Southern Italy and 1 in Sardinia (Ceccolini et al. 2023, De Rosa et al. 2024, M Di Vittorio & WWF Italia raptors project pers. com.).

To counteract this situation, several conservation projects have been launched over the last two decades (see, for instance, LIFE Rupis in the Iberian Peninsula, LIFE Egyptian Vulture in Italy and the Canary Islands, Return of the *Neophron* and Egyptian Vulture New LIFE in the Balkans). In addition to the actions carried out to tackle threats menacing this species, the release of captive-bred individuals has been undertaken in Israel, Italy and Bulgaria (Arkumarev et al. 2020, Efrat et al. 2022, Ceccolini et al. 2023). Restocking has proved to be an effective measure to sustain small populations, but very expensive (Ferrer et al. 2018); furthermore, the low productivity of captive pairs in several cases hindered large-scale releasing programmes (Ceccolini & Cenerini 2023). Consequently, any action aimed at preventing adult and juvenile

mortality or supporting the breeding success of wild pairs, such as the insulation of electric power lines or the activation of supplementary feeding stations, becomes even more relevant to ensure the positive outcomes of the restocking efforts.

Here we present a case of supplementary feeding carried out to sustain a breeding adult male Egyptian Vulture that lost his mate after hatching (see Fig. 1 for the events timeline), with the aim of sharing our experience with other people working for the conservation of this species elsewhere.

CASE DESCRIPTION

On May 19, 2023, an adult Egyptian Vulture was found dead in western Sicily, close to a breeding site monitored in the framework of the WWF Italia raptors project (Fig. 1). The autopsy carried out on May 21 revealed that it was a female shot by a poacher.

The project staff immediately began an intensive survey to ascertain whether the dead individual was one of the partners

of the territorial pair monitored up to that point.

By May 21, it was clear that only one adult was visiting the nest and therefore that the shot individual was the breeding female from this nest. Furthermore, its behaviour suggested that in the nest cavity, not easily visible because very deep, there was at least one chick. Supplementary feeding was immediately provided on a ledge at the base of the rocky wall about 200 meters from the nest. This decision was taken to maximize the chances that the single male could raise the offspring, managing to find enough food without leaving the nest unattended. About an hour after the first supply of food, the male took a few pieces of meat and immediately brought them to the nest.

Since then, the nest has been regularly monitored for the following 70 days, during which supplementary feeding was provided 26 times by the volunteers of the Gruppo Tutela Rapaci, with the financial support of Stiftung pro Artenvielfalt, EBN Italia, LIPU and LIFE project Egyptian vulture. Initially, the food was supplied

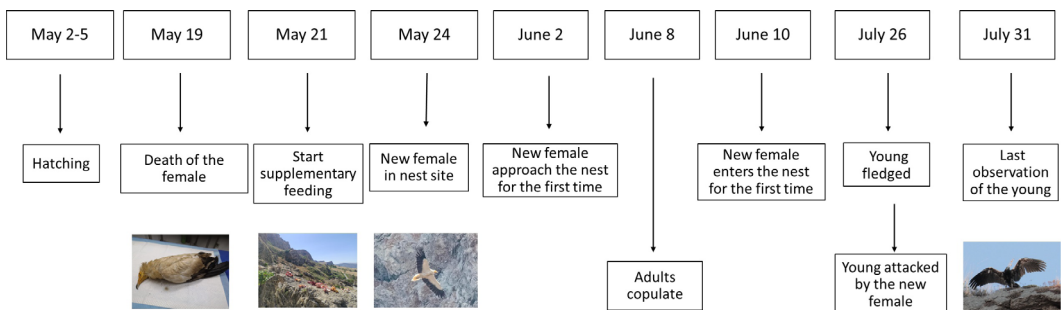


Figure 1. Timeline with the most important events recorded from hatching to the abandonment of the breeding territory.

daily in small quantities, then, as the breeding season progressed, the frequency decreased, and quantities increased (max interval: four days in the fledging period). Overall, around 350 kilograms of food were provided (daily min: 5 kg, daily max: 35 kg), mainly chickens, rabbits, eggs and slaughter waste purchased from local butchers.

On May 22 and 23, the site was visited by two other adult Egyptian Vultures, one of which began to eat the food supplied to support the single male. It cannot be ruled out that the two new adults were members of other nesting couples, as there were other breeding pairs in the surroundings—the closest of which was only 10 km away.

On the morning of May 24, an “intruder”, easily recognizable by its plumage and already observed the day before, was attacked by the local male as soon as it approached the food. The mobbing behaviour continued for approximately ten minutes. However, after about one hour, both individuals were seen feeding together and the local male started bringing pieces of meat to the nest to feed the offspring. In the following days, the pattern described above was repeated. The intruder constantly visited the site and the male allowed it to feed but not to approach the nest (Fig. 2).

On June 2, the two adults were observed for the first time resting together on a ledge not far from the nest. On the morning of the next day, they were observed flying close each other and moving away towards the nearby valley. After about half an hour they returned



Figure 2. Active nest defence by the male on May 26 (Coco M.).

and perched together on the nesting cliff. However, when the new adult tried to approach the nest, it was immediately attacked by the local male and moved away from the site. On the same day, shortly after noon, the local male returned to the nest with food supplied by us and during the feeding of the offspring it was possible to ascertain the presence of a single chick, whose age was estimated at 25–30 days based on the plumage.

On June 4, the new adult was observed near the nest offering a piece of meat to the male, that seemed to accept it. In the following days, the two vultures fed together on the food provided to support the breeding and often moved away together. The local male showed no further aggressive behaviour towards the other adult.

On June 8, the two adults copulated, and it became clear that the new individual was a female that had therefore replaced the dead mate.

On June 10, the female visited the nest for the first time, without any aggressive reaction from the male. However, the female did not approach the chick that, at the sight of the female, moved away to the innermost part of the nest.

On June 13, the two adults left the breeding site and returned at around 7:00 pm, the female carrying the hind end of a rabbit in her beak. When they landed close to the nest, the male took possession of the rabbit, then both vultures entered the nest. The female, however, flew away almost immediately and the chick was fed by the male.

In the following days the two adults always remained together, and several times entered the nest together. However, no interactions were observed between the female and the chick, that was only fed by the male. Furthermore, sometimes the female was observed entering the nest and feeding inside it, but without ever offering food to the chick, that at that moment appeared very developed, completely feathered and capable of feeding itself with the food brought only by the male.

The young continued to be supplied with food by the male and began to spend a lot of time outside the nest, until it fledged on July 26. About two hours after fledging, the young, perched on a rock not far from the nest, was attacked by the female, who grabbed it with her

claws and threw it to the ground, while the male was absent. After the attack, the juvenile was seen missing at least two secondary feathers from the left wing.

On July 27, the three birds were seen perched together on the nesting cliff (Fig. 3).

On July 31, the young was observed flying alongside the adults near the nesting site.

On August 2, the two adults were observed in flight and subsequently perching inside a cavity in the nesting cliff, but the juvenile was not observed. No Egyptian Vulture was spotted in the following two surveys on August 3 and 18.

Supplementary feeding was regularly utilised by both adults throughout the period, but as the chick grew up, the food we provided contributed to a lesser extent to its diet, most likely because the male was able to leave the nest unattended to look for prey in his hunting territory.

In the following 2024 breeding season, the same nest cavity was occupied on March 14 by a pair that successfully raised two chicks. It was not possible to ascertain if the two adults were the same observed in 2023.

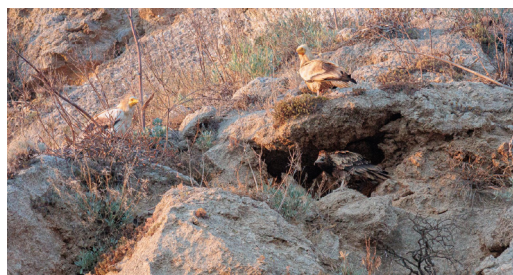


Figure 2. The two adults and the young perched together on July 27 (Coco M.).

CONCLUSIONS

The recovery of an adult Egyptian Vulture shot dead in May confirms that illegal killing still represents one of the major threats to birds of prey in Italy.

The prompt supply of supplementary food, immediately utilised by the male, supported him in raising the chick until fledging. This highlights the importance of the feeding stations as a conservation tool for this endangered species.

The sudden turnover of the female suggests the presence of a number of floaters, a positive sign of the local population viability. Sicily therefore proves to be crucial for the conservation of this species in Italy.

The chick was fed only by the male, while the new female never provided food or any parental care, even after the pair formed. The female's poor propensity to take care of the offspring is consistent with what reported by Ceccolini & Cenerini (2023) regarding the reproduction of the Egyptian Vulture in captivity. They noted, in fact, that a single female does not incubate the eggs but eats them within one day the removal of the mate from the aviary, whereas a single male usually incubates the eggs and often rears the chicks successfully.

The time of fledging was in line with what is normally observed in Sicily, as well as the time in which the adult birds leave the nesting site.

The female showed aggressive behaviour towards the young soon after fledging, probably because she did not recognise the

young as her offspring and considered it an intruder. Although aggressiveness of adults towards the offspring has been observed in other species of birds of prey at the end of the post-fledging period (see, e.g. Newton 1979, Alonso et al. 1987), this behaviour is unusual in the Egyptian Vulture, because territorial adults are tolerant towards newly fledged juveniles (Ceballos & Donazar 1990, Cortone & Mordente 1997, Corsange et al. 2005).

Our observations do not allow to exclude that the female continued to be aggressive after we stopped detecting the birds near the nest, to the point of preventing the young from accessing parental care and supplementary feeding. However, the fact that five days after fledgling the young was observed in flight together with the adults suggests that the breeding was successful. Indeed, observations carried out in the post-fledging period (Donazar & Ceballos 1990) and the experience gained with first-calendar-year captive-bred individuals released by the hacking method (Ceccolini et al. 2023) revealed that Egyptian Vultures can start migrating very soon, without any support by adults and independently of them after a short dependence period, even nine days after fledging, or six days after the release in the wild.

In summary, this case demonstrates that a single adult can successfully raise a chick if supported by supplementary feeding, but also that the aggressiveness of a new partner towards the offspring could potentially compromise the breeding outcome. Therefore, in similar

circumstances, the option of reallocating the chicks to captive breeding and/or restocking programmes should be considered on a case-by-case basis.

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Birds-of-paradise (Paradisaeidae) research: analysing research trends from 1862 to 2023

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Abstract

The Birds-of-Paradise (BoPs), celebrated for their exquisite plumage and significant historical allure, have faced threats from deforestation and hunting, necessitating ongoing conservation efforts. This study employs bibliometric analysis to examine the scientific literature on BoPs from 1862 to 2023, focusing on publication trends, influential countries, institutions, authors, and funding sources. By employing the Scopus database and VOSviewer for data visualisation, we have successfully identified a total of 255 publications, which include articles, reviews, and a variety of document types. Overall, the species of the genus *Paradisaea* are the most discussed. From a total of 44 species, only one species of BoPs is highlighted among all the papers examined using VOSviewer: *Lophorina superba* (n=14). This suggests that many other BoPs species have not received sufficient research attention. The analysis reveals a gradual increase in research interest since the 1970s, with the United States, Australia, and the United Kingdom leading in publication output. The study also maps the evolution of research topics, showing shifts from biogeography and species classification to phylogenetics and sexual selection. This comprehensive overview underscores the global research efforts and evolving focus areas, aiming to enhance awareness and guide future studies in BoPs conservation.

Keywords: Birds-of-Paradise, Paradisaeidae, Bibliometry, VOSviewer, Scopus database

INTRODUCTION

The fame of the Birds-of-Paradise (BoPs) was greatly influenced by the writings of the father of biogeography, Alfred R. Wallace, in “The Malay Archipelago: The Land of the Orangutan, and the Bird of Paradise. A Narrative of Travel, with Studies of Man and Nature” (Wallace 1869) who made them a symbol of beauty and fashion. BoPs have faced various threats of extinction due to increased demand and hunting (van Solinge 2008). According to Wallace’s travel records, some species of these birds were still very easy to find in the mid-19th century (van Solinge 2008). However, over time, they have become threatened again due to the large-scale deforestation in Indonesia (as one of the habitats for BoPs) that occurred from the 1970s until the end of the 19th century due to export-oriented log production and global demands (Tsujino et al. 2016).

Birds-of-Paradise have long been famous and attract attention due to the unique and extravagantly coloured plumage of the adult males (Diamond 1986). BoPs are birds that can only be found in Australasia (Gill et al. 2021), intended as the geographical area that includes Australia, eastern Indonesia, and nearby islands in the tropical southwestern Pacific (Gibson 2009). According to Tsujino et al. (2016) the areas in Indonesia that are the native habitats of these birds have suffered significant damage. Therefore, studies on population ecology and conservation efforts are needed to foster the preservation of these birds. One way to support conservation activities is by providing clear descriptions of their

condition and the extent to which these birds have been explored and studied. With all this, it is hoped that researchers will realise that these birds have not been studied in depth and have been studied quite disproportionately among all bird families, especially for its small number of species.

Bibliometrics (Pritchard 1969) is a discipline that involves methods for analysing and studying the progress and evolution of scientific literature (Hood & Wilson 2001). Bibliometrics is also often used for trend analysis of a topic in a region or around the world, for example, analysis of biodiversity identification through DNA barcoding research in Indonesia (Priyono et al. 2023). Systematic bibliometric reviews about BoPs have been previously realised (e.g. Heads 2001a; Heads 2002) but these are not so recent. Bibliometric studies related to the class Aves or the field of ornithology span a diverse range of topics and journal types, including those with dedicated ‘Reviews’ sections (Bautista & Pantoja 2000; Bibby 2003; Hood & Wilson 2001). But these generally focus on birds in relation to environmental or other subjects, such as metals accumulation, breeding, seed distribution, or even tourism (e.g. Çelik 2023; Celik et al. 2021; Mohammadi et al. 2024; Sarà 2023). Much rarer are the documents approaching a specific taxonomical group with a bibliometric approach, such as “Bibliometric Penguins Argentina” by Menéndez-Blázquez (2020). On the other hand, some discuss birds in a very wide perspective, for example with the subject of *Ornithology* by Bautista & Pantoja (2000).

This bibliometric study is focused on evaluating and providing comprehensive data related to BoPs, aiming to identify potential gaps in existing research. This study also aims to provide visual data on developing and mapping researchers' interests worldwide based on the number of documents each year. Additionally, it looks at which characteristics of documents are most frequently cited. The research topics that emerged and were discussed will be highlighted, as well as how the data has developed. The progress of research topics is also expected to be mapped out. Supporting data such as countries, authors, affiliations, and sponsors that focus on this topic will also be highlighted. It is hoped that this will attract the attention and interest of researchers to contribute to the conservation of BoPs.

MATERIALS AND METHODS

The Scopus database was used to collect documents in terms of BoPs published in 1862-2023, using "Bird-of-Paradise" AND NOT "sterna, strelitzia, steganura, vidua" as keywords on the search column (Article title, Abstract and Keywords). These publications were categorised into ten types: articles, reviews, book chapters, letters, notes, conference papers, short surveys, errata, books and editorials. All of the data and related documents were collected and extracted in June 2024 and then analysed using VosViewer (van Eck & Waltman 2010). Among all extracted terms, 45 meet the threshold. The top 10 most productive (assessed by

the total percentage of documents) and influential countries/affiliations/authors in terms of BoPs research, the highest cited articles, subject area of research, and funding sponsor of documents source will also be displayed. As additional data, we also attempted to compare the number of publications by the most contributing authors on Google Scholar. Bibliometric analysis is a study approach focused on identifying current research topics (Duan et al. 2020) of various disciplines in a specific area (Md Khudzari et al. 2018). The literature from the Scopus database will be analysed mathematically and statistically (Zou et al. 2018), to create and view bibliometric maps based on the following criteria: title, year, country, affiliation, author, keywords, and study area. This visualization can help to understand and summarize the development of a topic that is often discussed in a field of science, thereby encouraging researchers to advance this field of science.

RESULTS

Overall, we collected a total of 255 publications belonging to BoPs and spanning from 1862 to 2023. Most publications are in the form of articles (73.2%), followed by reviews (8.3%) and book chapters and letters (4.7%). Meanwhile, other publication types only contributed less than 4% each to the total publications.

The distribution of documents published annually regarding BoPs throughout the world can be seen in Fig. 1. Overall, the yearly increase of documents

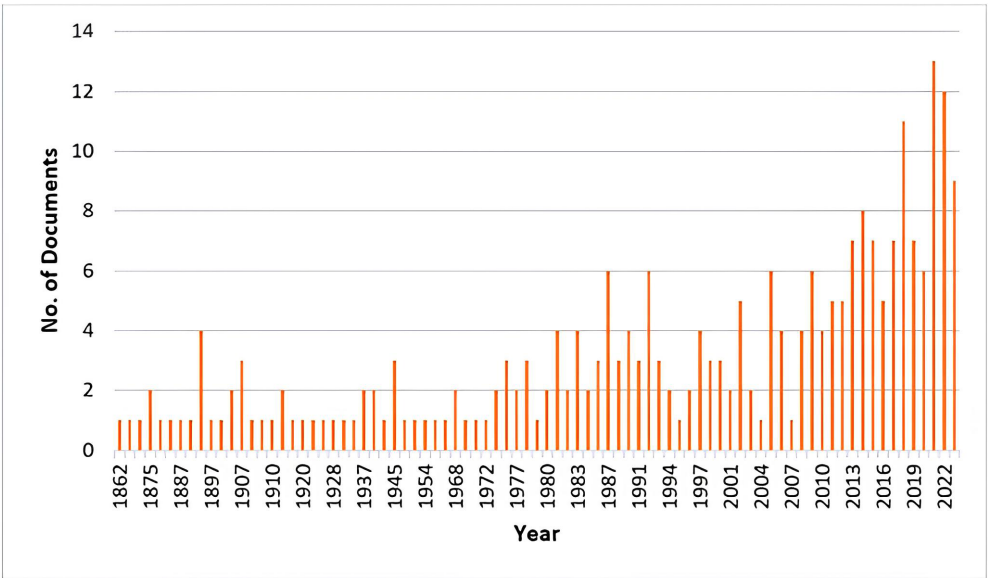


Figure 1. Annual publications of BoPs research, 1862-2023. A total of 255 documents were retrieved from the Scopus database. The productivity in BOP research has gradually increased since the 1970s and the highest number of documents was published in 2021.

started to rise abruptly around the 1970s. The overall publication record was produced by authors belonging to 36 different countries. The top 10 most productive countries can be seen in Supplementary Table 1, which illustrates the proportionate contribution number of total documents on a worldwide scale. Publications share by country ranging from 28.0% to 1.97% of the top 10. The United States led this list with 71 publications and also had the largest number of citations, ($n = 1,471$).

Research related to BoPs is mostly concentrated in the Americas (United States and Brazil), Oceania (Australia and Papua New Guinea), Europe (United Kingdom, Germany, Netherlands, Sweden, and Denmark), and Asia (Indonesia). The statistical

results of the main source countries for BoPs research also show that 7 out of the top 10 most productive affiliations are from the United States (Cornell University, Harvard University, Cornell Lab of Ornithology, Yale University, American Museum of Natural History, Smithsonian Institution, David Geffen School of Medicine at UCLA). The remaining 3 are from Europe, one of which holds the rank 1 position among the top 10 most productive affiliations, Naturhistoriska riksmuseet (Sweden, with a total of 9 publications).

Scientific publications on BoPs were derived from 159 affiliations in total (in three cases we could not properly assign an affiliation to an author). The ‘top 10’ research affiliations in terms of the number of produced documents are listed in Sup-

plementary Table 2. This list is led by the Naturhistoriska Riskmuseet from Sweden, which led with nine publications. From the second to the seventh position in this list are all occupied by affiliates originating from the USA. Cornell University, Harvard University, and Cornell Lab of Ornithology are ex-quo in second place with six publications each. On the other hand, the American Museum of Natural History suc-

ceeded in becoming the affiliate with the highest total document citations among the 10 other affiliates, with a total of 261 citations.

Between 1862 and 2023, 159 authors contributed to the publications on the BoPs research field. The top 10 most productive and influential authors on BoPs are listed in Table. 1. The author with the most publications publishing documents

Table 1. The highest cited articles on BoPs research

Rank	Authors	Title	Article Type	Year	Journal Title	Number of Citations
1	Helm-Bychowski & Cracraft (Helm-Bychowski & Cracraft 1993)	Recovering phylogenetic signal from DNA sequences: Relationships within the corvine assemblage (class aves) as inferred from complete sequences of the mitochondrial DNA cytochrome-b gene	Article	1993	Molecular Biology and Evolution	179
2	Stavenga (Stavenga 2014)	Thin film and multilayer optics cause structural colors of many insects and birds	Conference Paper	2014	Materials Today: Proceedings	120
3	Wilts et al. (Wilts et al. 2014)	Sparkling feather reflections of a bird-of-paradise explained by finite-difference time-domain modeling	Article	2014	Proceedings of the National Academy of Sciences of the United States of America	98

(continued)

Table 1. The highest cited articles on BoPs research (continued)

Rank	Authors	Title	Article Type	Year	Journal Title	Number of Citations
4	Cracraft (Cracraft 1992)	The Species of The Birds-of-Paradise (Paradisaeidae): Applying the Phylogenetic Species Concept to A Complex Pattern of Diversification	Article	1992	Cladistics	90
5	Stavenga et al. (Stavenga et al. 2015)	The high refractive index of melanin in shiny occipital feathers of a bird of paradise	Article	2015	Light: Science and Applications	83
6	Peona et al. (Peona et al. 2021)	Identifying the causes and consequences of assembly gaps using a multiplatform genome assembly of a bird-of-paradise	Article	2021	Molecular Ecology Resources	72
7	Ligon et al. (Ligon et al. 2018)	Evolution of correlated complexity in the radically different courtship signals of birds-of-paradise	Article	2018	PLoS Biology	71
8	Irestedt et al. (Irestedt et al. 2009)	An unexpectedly long history of sexual selection in birds-of-paradise	Article	2009	BMC Evolutionary Biology	66
9	Pratt & Stiles (Pratt & Stiles 1983)	How long fruit-eating birds stay in the plants where they feed: implications for seed dispersal.	Article	1983	American Naturalist	58
10	Diamond (Diamond 1986)	Biology of birds of paradise and bow-erbirds	Article	1986	Annual review of ecology and systematics	53

on BoPs research is “Frith, Clifford Brodie” with 16 publications, followed by “Frith, Dawn Whyatt” and “Irestedt, Martin” both with nine publications and “Beehler, Bruce M.” and Scholes, Edwin A.” with six publications each. However, the author with the most total citations on his documents was “Cracraft, Joel L.”, even though he only had five publications. “Irestedt, Martin” ranked second with 251 total citations. Among these authors, 97 authors (61,0%) published one document, and 51 authors published two or three publications. In total, 11 authors (6,91%) published at least four publications. Overall, 255 documents have been published from 1862-2023, Supplementary Table 3 shows the top 10 highest-cited articles on BoPs-related research. As additional data that is more detailed, we tried to analyse the number of publications published by each author who contributed the most in different databases. There were 11 files for Frith, Clifford Brodie; three for Frith, Dawn Whyatt, nine for Irestedt, Martin, six for Beehler, Bruce M., nine for Scholes, Edwin A., and five for Cracraft, Joel L.

The published documents are also the result of funding by several sponsors. In the case of these BoPs, the top 10 most funding sponsors are listed in Supplementary Table. 4 Rank 1 is held by the National Science Foundation, a US government agency. Ranks 2 and 3 are held by institutions from Sweden, namely Vetenskapsrådet (a Sweden government agency) and Science for Life Laboratory (a non-governmental; Swedish national centre for large-scale research). Apart

from institutions from the United States and Sweden, Australia also contributed to one institution that made it to the top 10. This is the Australian Research Council, a government agency (ranking 6th).

The published documents in the BoPs research field are published in several journals or other publication sources. The document per year by the top 10 main source journals on the BoPs research field from the first document published in 1862 to 2023 is presented in Supplementary Fig. 1. Emu (Australia) is the journal that has published the most documents related to BoPs, followed by Ibis (UK) in rank 2 and Notes And Queries (UK) in rank 3. The ranks 4 to 10, in order, are Nature (UK), International Zoo Yearbook (UK), Proceedings of The Zoological Society of London (UK), Bulletin of The British Ornithologists’ Club (UK), Zoo Biology (USA), Zootaxa (New Zealand), and Plos One (USA).

Furthermore, the data in this study also discusses occurrence terms or keywords that are widely used in documents, as well as the coverage of the research area or research subject area. VOSviewer mapping of occurrence terms extracted from titles and abstracts in BoPs research articles by Scopus. A total of 1,139 terms from the 255 documents related to BoPs were analysed. From all the terms extracted, 5 prominent clusters were generated and are presented in 5 representative colors (Fig. 2a). The red cluster is the largest with the highest number of members with 15 items. Common words in this cluster are as follows:

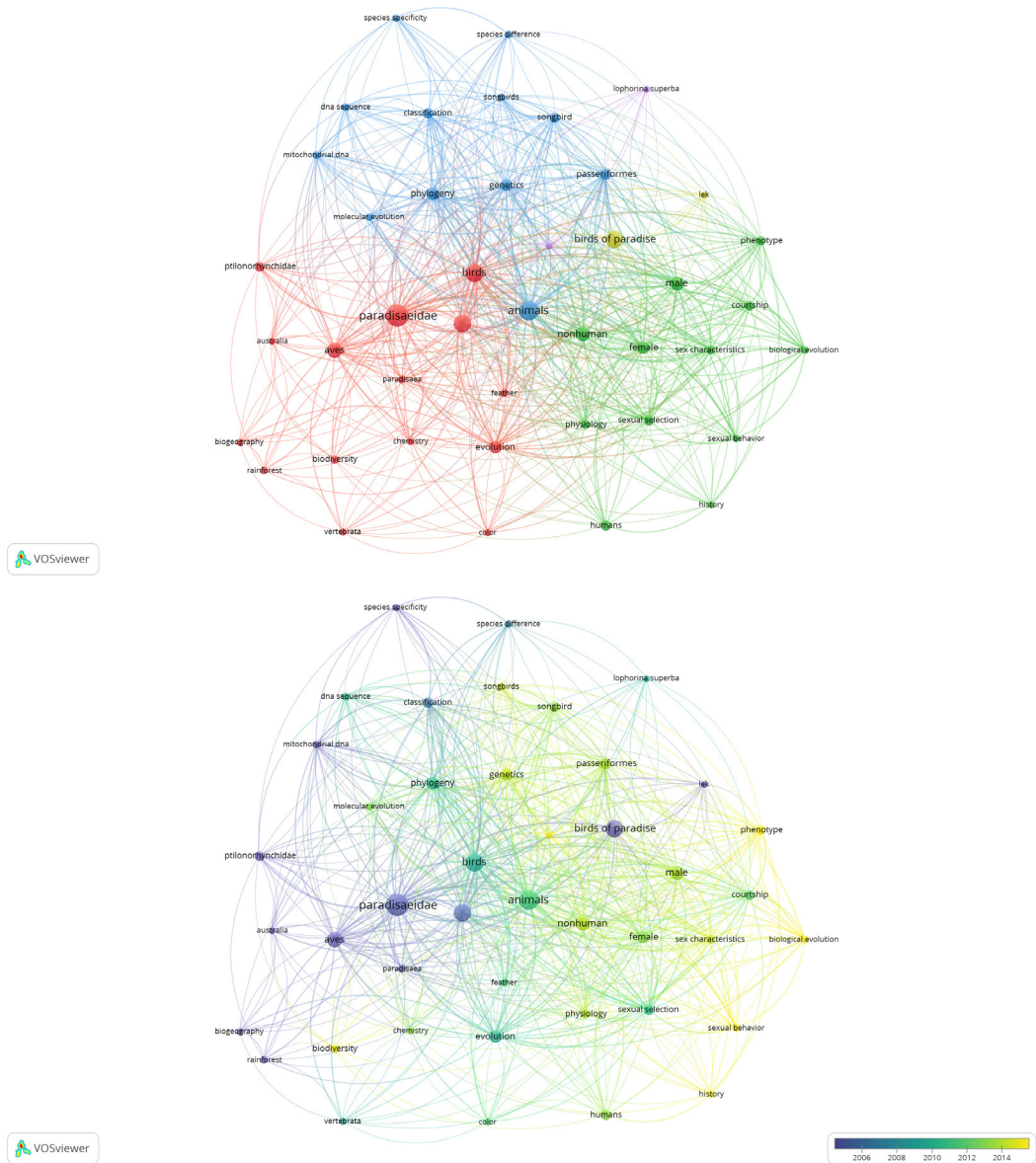


Figure 2. VOSviewer mapping of occurrence terms extracted from titles and abstracts in BoPs-related research articles. **(a)** network visualization, with 5 distinguished clusters: red, green, blue, yellow, and purple; **(b)** overlay visualization. The size of the circle indicates the proportion or frequency of occurrence of the term. the length of the link indicates the degree of relationship between terms and other terms.

evolution, Ptilonorhynchidae, biogeography and biodiversity. The green and blue clusters ranked second with 12 items for both. The green cluster focused on research related to sexuality, such as sexual selection and sexual behaviour. The blue cluster common keywords used were animals, phylogeny, Passeriformes, genetics, classification and molecular evolution. While the other 2 clusters are small clusters that only have 2 keywords. The yellow cluster focused on BoPs (Laska et al. 1992) in particular and lek (social mating system) (Beehler 1988). The keyword in the other smallest cluster (purple) is *Lophorina superba* (Beehler et al. 2012), a BoP species distributed across various mountainous areas, such as the Vogelkop and Arfak Mountains in West Papua, Indonesia, and areas around Tari in Hela Province, Papua New Guinea (Scholes & Laman 2018); and an animal experiment. Among all the documents analysed with VOSviewer, only one species of BoPs is highlighted, *Lophorina superba*. This indicates that many other species of BoPs have not been thoroughly studied.

An overview of the topics discussed and emerging each year is represented in Figure 2b. Categorization is depicted with a colour gradient from blue to yellow, which represents keywords that emerged in publications from the old to the latest year. The terms discussed at the beginning of the BoPs studies were Paradisaeidae, birds of paradise, Papua New Guinea, biogeography, mitochondrial DNA and species specificity. Meanwhile, the terms discussed in BoPs studies in recent years

are about biological evolution, sexual behaviour, phenotype and history. Data analysis shows that the most frequent terms are Papua New Guinea and male with, each appearing 17 times (2.15%).

DISCUSSION

Although the data in this study were solely obtained from the Scopus database, which may limit coverage of literature from other sources such as Web of Science or Google Scholar, the results still provide a comprehensive insight into the development of research in this field, offering a strong representation of research trends and patterns. By using Scopus, this study successfully identifies key trends, author contributions, and the most influential institutions, thus providing an informative and meaningful overview.

Since Wallace, A.R. re-popularized BoPs in his writing "Narrative of Search After Bird of Paradise" in 1862 (Wallace 1862), studies on the BoPs have been carried out for the past 162 years. More than 1.5 centuries is a relatively long period, but research progress related to the BoPs is still not extensive. However, this estimate could have been made longer, because based on Frith & Beehler's 1998 monograph, this bird was already known and popular in the 16th century. The phylogenetics of some BoPs members (as in the superclade *apoda-minor-raggiana*) is still not completely resolved and still requires several studies to prove the actual phylogenetics of the BoPs (Stelbrink et al. 2022).

The development of BoPs studies in terms of the number of documents since it was first discussed in 1862 has not experienced a constant increase until 2023 (Fig. 1). The publication time intervals between documents appear relatively far apart. The number of documents in the first 124 years was recorded at only 76 (from 1862 to 1986), with no more than 4 documents per year. There was indeed an increasing in the number of documents in the following years and 1992 (reaching 6 documents in one year), but the number then experienced a drastic decline until 2005. It was only in 2008 that researcher interest began to rise again (though still not constant), as indicated by the increasing number of documents related to BoPs until 2023. The highest number achieved was in 2021 with 13 publications. The oscillating interest in BoPs research could be attributed to fluctuations in funding priorities for biodiversity studies, advancements in research technologies, or geopolitical challenges affecting accessibility to study sites. Alternatively, it may reflect natural variations in researcher focus or global events influencing conservation awareness during specific periods.

In the history of BoPs research, the evolution of research topics has continuously changed and can be divided into three stages (Fig. 2b). First, from 1862 to 2008, the focus was on BoPs, the newest publication by Sanders (Sanders 2023). Then was about *Paradisaeidae* (Diamond 1986), Papua New Guinea (Alamgir et al. 2019; Marsden et al. 2006), classification (Anmarkrud & Lifjeld 2017), and species

specificity (Skoracki 2005). Second, from 2008 to 2012, the focus was on phylogeny (Cracraft 1992; Irestedt et al. 2017; Nunn & Cracraft 1996; Stelbrink et al. 2022), evolution (Ligon et al. 2018; McNab 2005), DNA sequencing (Peona et al. 2021), and sexual selection (Irestedt et al. 2009) (Wilts et al. 2014), including feather aspects (Burger et al. 1993; Van Den Bergh et al. 2013) and colours (Arnold & Houck 2006). Third, from 2012 to the present, the focus is on Passeriformes (Johansson et al. 2011), genetics (Prost et al. 2019; Xu et al. 2020), sex characteristics (Miles & Fuxjager 2018), biological evolution (Eliason 2018), sexual behaviour (Wang et al. 2013), and history (Chapman 2015).

VosViewer highlights terms or nodes based on their frequency and co-occurrence strength in the dataset being analysed. In this case, the presence of certain species that are the most highlighted suggests that this species is particularly prominent in the literature due to its high citation frequency or its frequent association with key research topics in the field. This may also indicate a disproportionate focus on research on BoPs species.

If classified based on the species recognition of the BoPs in each of the previous three periods, then it could be described as follows: At the beginning of his period of discovery, the introduction of all species in the family BoPs that were known at that time was massively carried out in documents published by the researchers. The species described by Wallace (Wallace 1862) is *Paradisaea apoda*, and it tells a lot about the genus. He also

mentioned several other species names of the BoPs: *P. regia*, *papuana*, *magnifica*, *superba*, *rubra*; *Astrapia nigra*; *Epimachus magnus*; *Seleudicis alba*; *Lophorina superba*; *Parotia sexsetacea*; *Paradigalla carunculate*; *Diphyllodes wilsoni*; *Cicinnurus regius*, and *Semioptera* genus. He then described *Seleudicis alba* specifically in his second document (Wallace 1870). Some traces of new species growth in the BoPs family like Sclater added *Drepanornis albertisi* to the new species (Sclater 1873). Meyer also added a new species, *Diphyllodes guilhelmi* (Meyer 1875).

At this first to second stage (1862-2012), a lot of research was done on the genus *Paradisaea* in general and specifically on the species *P. raggiana*, *P. rubra*, and *P. minor*; species of the genus *Cicinnurus* are also mentioned several times. While the third stage (2012-present) deals with several species, most species discussed also come from the genus *Paradisaea*, as well as some articles dealing with *Lophorina superba* specifically.

Several researchers focus on various topics related to BoPs. For example, studies addressing phylogenetic relationships were conducted by Nunn & Cracraft (1996) and Irestedt et al. (2009). So far, the most comprehensive discussion on phylogeny at the species level has been conducted by Irestedt, M. Discussions on BoPs have also gained attention as these birds are prime examples of sexual selection and geographical speciation (Stelbrink et al. 2022). Some researchers and highly cited publications focusing on this include Ligon et al. (2018), and Irestedt

et al. (2009). Additionally, discussions on biogeography, terrane tectonics in New Guinea, and ecology related to BoPs distribution patterns have been extensively conducted by Heads in the Journal of Biogeography (Heads 2001a, 2002), Biogeography of Australasia (Heads 2011), and the Journal of Zoology (Heads 2001b). Quite an interesting discussion regarding the physical basis of structural coloration in this group has also been discussed (see Wilts et al. 2014).

The total number of published documents is also viewed from the geographic origin of the countries. The United States is the country with the most publications, with a total of 71 documents (28.0%). This is followed by Australia with a total of 44 documents (17.3%) and the United Kingdom with a total of 24 documents (9.45%). However, the researchers of these countries also collaborate to research this topic. Among these top three ranked countries, only Australia is home to the BoPs species. Essentially, BoPs are found in three countries: Australia, Indonesia, and Papua New Guinea. Two of these countries are still in the top 10 most productive countries, ranking 7th for Papua New Guinea (3.54%) and 9th for Indonesia (2.36%). BoPs are not taxon with a rich species diversity (Stelbrink et al. 2022); they only have 16 genera with 44 species. Nonetheless, 90% of them are endemic to Papua New Guinea, and the surrounding islands (Frith & Beehler 1998).

The statement that research related to BoPs is mostly concentrated in the

Americas can be understood from a historical and research resource distribution perspective. European countries and the United States, as former colonial powers, have large natural history museums with extensive collections of BoPs specimens, obtained during the colonial-era explorations in the Australasian region. These museums, such as the American Museum of Natural History, have become research hubs because they house critical collections for studies on the morphology, evolution, and diversity of BoPs. Furthermore, the advanced research facilities and funding available in these countries enable researchers to analyze specimens using cutting-edge technologies, even though BoPs are not native to the Americas or Europe. Therefore, while the natural habitat of BoPs is in Australasia, the focus of research often shifts to countries with greater access to scientific resources.

The analysis of the source countries of the top 10 authors who publish the most documents on BoPs research indicates that researchers from Australia have a greater interest in BoPs research. This is likely because Australia is also one of the regions where BoPs originate, giving researchers in this area easier access and more opportunities to study BoPs. Besides, the most cited publication among the top three authors is: "Archbold's bowerbird *Archboldia papuensis* (Ptilonorhynchidae) uses plumes from king of saxony bird of paradise *Pteridophora alberti* (Paradisaeidae) as bower decoration," a collaborative work by "Frith, C.B." and "Frith, D.W." published in the journal *Emu*

in 1990 with a total of 17 citations (Frith & Frith 1990). Although this paper does not discuss BoPs directly, this paper has used data from BoPs species which shows that BoPs is also included in the discussion. On the other hand, the paper that discusses BoPs directly by "Irestedt, M." received the highest number of citations for his collaborative article titled "Identifying the causes and consequences of assembly gaps using a multiplatform genome assembly of a bird-of-paradise", with a total of 72 citations (Peona et al. 2021). Additionally, based on data from Scopus, it is known that "Frith, D.W." has always collaborated with "Frith, C.B." in all of their publications (a total of 9 documents from 1981 to 1998).

The number of documents published by researchers, affiliations, and certain countries is certainly influenced to some extent by the availability or absence of sponsors funding research on this topic. This is evidenced by the analysis of the top 10 funding sponsors for BoPs research found that the institutions providing the most funding came from three countries: the United States, Sweden, and Australia. In addition to being ranked 2nd in countries with the most published documents and also being the country of origin for the most productive and influential authors, Australia also has one institution in the top 10, the Australia Research Council. Similarly, Sweden, as the country ranked 1st in most productive affiliations in terms of BoP research, also has 3 out of the 10 most funding sponsors, namely Vetenskapsrådet (ranked 2nd),

Science for Life Laboratory (ranked 3rd), and Knut och Alice Wallenbergs Stiftelse. From this statement, it can be concluded that the support of countries and funding from government or non-government institutions greatly influences researchers' interests. Thus, indirectly, countries also play a role in supporting the conservation of BoPs by helping to provide research funding.

The highest coverage area for research subjects on BoPs comes from Agricultural and Biological Sciences. This data is certainly influenced by the subject area of the source type of these documents. Looking at the total documents per year of the top 10 main source journals (Supplementary Fig. 1), ranks 1 and 2 are Emu and Ibis, both of which are journals with subject areas in Agricultural and Biological Sciences. Therefore, it is not surprising that this research subject area is the most indexed by Scopus.

Discussions about BoPs in other subject areas were also found in this analysis. For instance, the discussion on BoPs conservation is addressed by van Solinge (van Solinge 2008) in his writing titled *"The Land of the Orangutan and the Bird of Paradise Under Threat."* He juxtaposes the Orangutan and the Bird of Paradise in the same discussion because both are native species from the same nation. Additionally, mining and oil palm are the two main causes of tropical deforestation that affect them both. In his writing, he narrates the journey of the Bird of Paradise's fame starting from Wallace (Wallace 1862, 1869) until it faced the threat

of extinction, and then it can be said to have been saved due to the conservation movement for this bird. However, documents discussing the conservation of this bird are still not widely found. This is certainly not surprising, because more targeted work on ecological surveys of BoPs would be important, because this data alone is still very lacking.

Another equally interesting subject is the evidence we found of the fame and beauty of BoPs in the field of fashion. Abrego (2012) has written a document from a film festival event in New York, with the theme *"New York with Birds of Paradise: A Major Extravaganza in Costume Spectacle, Dance, and Diabolical Glamour."* Abrego also states that the BoPs managed to showcase an unusual interconnectedness in filmmaking. Designers use the beauty of this bird as inspiration in creating fashion and costumes in film and television. The fashion world also "seen" BoPs as one of the world's jewels that can create unlimited imagination.

If we analyse further, each of these top 10 publication sources has a different time range or publication year scale. Emu, ranked 1st, started publishing one document in 1901, but Emu began publishing numerous documents in the period from 1975 to the early 2000s. Additionally, Ibis, ranked 2nd, published many journals in 1897 but stopped in 1929. Ibis published one document in 1970 and 1988, and the last document in 2006. Another example is the Proceedings of The Zoological Society of London. Although ranked 6th, this journal has been active and first

published a document related to BoPs in the early days of research on these birds in 1862. This journal only published one journal each year, last publishing a document related to BoPs in 1938, and has not been seen again until 2023.

If we explore the last 20 years, the journals or publication sources that started to discuss BoPs are the last four ranks of the top 10. These three journals are Bulletin of the British Ornithologists' Club, Zoo Biology, Zootaxa, and PLOS One. Narrowing it down to the last three years, the most active journals are Zoo Biology and Bulletin of the British Ornithologists' Club, which recently published documents related to BoPs in 2023. From these results, it can be predicted that the journals or publication sources that will actively publish documents related to BoPs in the coming years are these four journals (ranks 6 to 10).

Ultimately, the most popular topics related to BoPs can also be seen in the top 10 most cited articles. The most cited discussions are about the genome, sexual selection, phylogenetics and evolution (Cracraft 1992; Helm-Bychowski & Cracraft 1993; Irestedt et al. 2009; Ligon et al. 2018; Peona et al. 2021); feathers (Stavenga 2014; Stavenga et al. 2015; Wilts et al. 2014); and their ecology (Pratt & Stiles 1983; Diamond 1986). This article also highlights that many research gaps have not been deeply studied regarding BoPs, including genomic aspects, evolution, and conservation strategies. Research shows that despite attention to BoPs for more than 1.5 centuries, the

development of research related to these birds is not very extensive. This indicates that many aspects have not been deeply explored regarding birds-of-paradise.

The study indicates that to date, although quite a lot of work has been done on BoPs genomics over the last 15 years including whole genomes, there is still no available complete genome of this bird group published in documents or Genbank. This shows a gap in the genomic understanding of BoPs, which is an important area for understanding their evolution and genetic diversity. This study also identifies research gaps related to BoPs, specifically concerning distinguishing characteristics from morphological or genomic data that differentiate subspecies of *Paradisaea minor*. Additionally, there is a lack of research on the conservation of this bird species. This article hopes that the understanding and descriptions provided will offer information on knowledge gaps about BoPs and will attract researchers to participate in uncovering these gaps. The goal is to raise awareness and guide future studies in the conservation of BoPs.

We can concentrate on the most crucial strategies or initiatives to protect this species first if we are aware of the current status of its family. For instance, doing equal study on all members of this family and concentrating more on ecological surveys. Furthermore, it is strongly advised to conduct research that aims to provide complete genomes from members of this family. Bibliometric surveys of BoPs literature can produce real action

in conservation efforts, including through improving habitat protection policies and data-based conservation management. For example, by understanding critical habitat areas that are often identified in the literature, conservationists can propose the establishment of protected areas or expanding areas that are already protected. In addition, bibliometrics can show the specific types of threats (such as hunting or deforestation) that are most discussed in research, so that governments or NGOs can plan direct actions, such as anti-poaching patrols and reforestation programs.

On the other hand, the results of this survey can also be used to identify key institutions or research groups that are active in the study of BoPs. With the collaboration between researchers and conservation institutions, it is hoped that sustainable conservation programs can emerge, such as long-term population monitoring programs, training local communities in ecosystem management, and public education campaigns that focus on the ecological value of BoPs. These real actions become more focused and evidence-based, thus strengthening the chances of success of BoPs conservation efforts.

In summary, the discussion of the results of data analysis regarding BoPs sourced from the Scopus database provides an overview of the development of BoPs studies that have been carried out throughout the world. Apart from that, it also provides an understanding of the extent to which this BoPs topic has been discussed. Studies in the fields of biological

evolution, history and sexual behaviour will probably be discussed a lot in the future. The hope is that this understanding and description can provide information about the gaps in BoPs knowledge. Apart from that, it is also hoped that it will provide ideas for hot topics to be discussed. Thus, it will attract the interest of researchers to participate in uncovering gaps in BoPs knowledge. In the end, all the knowledge gained will help preserve the BoPs, because all this information will be useful in developing BoPs conservation policies.

Electronic Supplementary Material are available on the website

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search questions); FS (conduct data analysis, data visualization), WAP (conduct data analysis and design the methodology), NIS (conduct data analysis, formulate research question).

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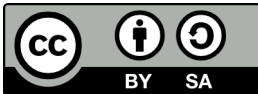
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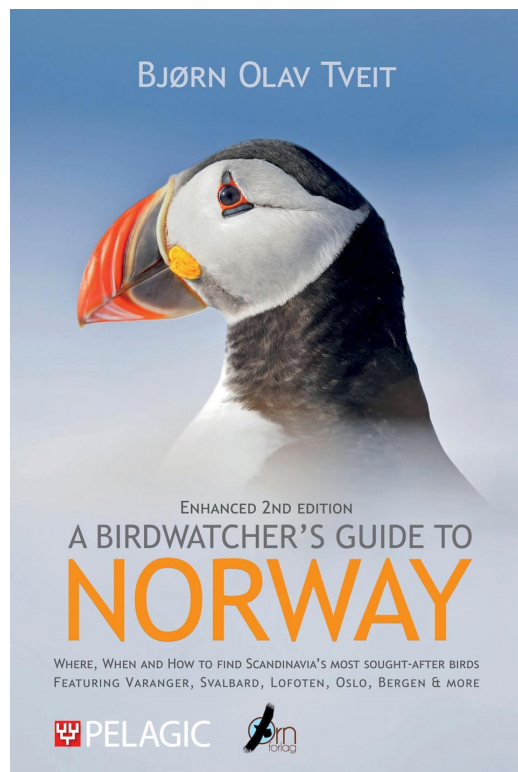
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A GUIDE TO BIRDWATCHING IN NORWAY



Tveit B.O. 2024. A Birdwatcher's Guide to Norway. Where, When and How to find Scandinavia's most sought-after birds. 2nd ed. Ørn Forlag & Pelagic Publishing. 460 pp., many color photos and maps.

Norway is located on the Scandinavian peninsula with a population of only 5.5 million as 2024 and a total area of 385,207 square kilometers. Its fjords spread over much of the coastline are famous. Bjørn Olav Tveit is a well-known birdwatcher, who has explored all the best birding sites of Norway. In 2024 BirdLife Norway granted him a honorary award for his many years of commitment to birdwatching, organizational involvement and bird conservation. As the author wrote in his first preface 'Every respectable nation should have at least one birdwatching site guide'. Thirteen years have passed since the first English edition of this book was published; now the second edition has been edited. Norway, due to its location far north in Europe, has a number of species that are difficult to see further south. The country is considered a very safe area because of low crime rates and no really poisonous or otherwise dangerous animals, except for Polar bears on Svalbard islands.

This book describes in detail the best sites for finding the most sought-after birds. More than 530 species of wild birds have been recorded in Norway, of which 220 breed regularly and about 100 are considered regular visitors either as migrants or winter visitors. The book is di-

vided into eight areas, easily recognizable by a small map at the top right of each odd-numbered page, where the area of the region in question within the borders of Norway is reproduced in red. A total of 151 birdwatching sites are described in detail, two of which on Svalbard islands.

All of Norway is dotted with birdwatching spots, watchtowers and comfortable wooden birdhouses; so birdwatching is greatly facilitated and provides numerous opportunities to observe interesting species. Some Norwegian environments are very well organized for visiting; for example in the Fokstumyra marsh during the breeding season traffic is only permitted along the easy-to-walk boardwalks. Many visitors from abroad use the main international airport Gardermoen as their gateway to the country. The airport hotels are also regular venues for business conferences, and many people may therefore have a few hours at their disposal near the airport to see birds. Gardermoen is particularly popular in terms of birds that even the resident birdwatchers regularly make the trip up there.

Here are reported some considerations on environments and species that may be useful for the reader. Forests occupy a wide surface in Norway; among the birds the Black woodpecker *Dryocopus martius* is the most important provider of natural large cavities in the Scandinavian forests. It uses the hole only the year it makes it, leaving it for the breeding of owls and many other secondary users (e.g., many species of tits) in subsequent seasons. Differently from the previous bird, the

White-backed woodpecker *Dendrocopos leucotos* is an endangered species that has almost completely disappeared from many parts of Norway. The Pine grosbeak *Pinicola enucleator*, a large member of the finch family and the only species of the genus, lives with eight subspecies in coniferous woods with a rich juniper undergrowth across the northern part of the north hemisphere, and is a sparse breeder in the Pasvik valley (north Norway). The Nightjar *Caprimulgus europaeus*, like the Woodlark *Lullula arborea*, is usually found in association with dry, open pine forests; it has the strongest population in the south-eastern parts of Norway. The ornithologist notoriously uses his hearing as well as his sight to a great extent; Nightjars are seldom seen, and their presence is usually noticed by the buzzing song performed in quiet early summer nights.

Willow ptarmigan *Lagopus lagopus variegata* is considered the only endemic taxon in Norway, that is the only bird that is not found in any other country. It differs from other Ptarmigans in that it does not turn completely white in winter; however, the taxonomy of Ptarmigans is confused, just because of the changes in plumage several times a year and the different colors and pattern of the summer plumage. Therefore the species should deserve a more in-depth taxonomic study.

Northern European countries have not always protected their species, especially birds of prey. In old times White-tailed eagles *Haliaeetus albicilla* were hunted by trappers; they sat in a hiding place

where a lamb carcass had been deposited. When the eagle landed, the trapper grabbed hold of the eagle's feet. In 1968 the eagle was protected and this tradition ended. Presently it has become common in eastern Finnmark (north Norway). Today the population of another raptor, the Gyrfalcon *Falco rusticolus*, is greatly reduced, not only for the human nest depredation but also for the collision with reindeer fences, a growing problem difficult to solve.

Norway is a country rich in water; streams and rivers flow through many areas of the country and as a result, bird species related to these environments live at ease. The Dipper *Cinclus cinclus* was named Norway's national bird in 1963; it thrives in waterways in most of the country, and it will survive as long as it has access to open, flowing water.

Also wetland environments are widespread in Norway and provide excellent opportunities to observe birds rare in Europe. Pectoral sandpiper *Calidris melanotos* breeds in North America and Siberia, and is one of the most regular of the rare shorebirds in Norway. Knot has one of the most important staging grounds in Norway; many individuals are color ringed for research purposes and many birdwatchers go in search of these birds to read their rings and communicate their position to researchers. Black-tailed godwit has in Norway two subspecies, the southern *limosa* breeds on Joeren, while the northern *islandica* in north Norway. Interestingly, this subspecies winters hundreds of kilometers from the nesting site

and the two sexes migrate separately. Sabine's gull *Xema sabini* is an arctic species that can be observed in the Varangerfjord (north Norway). Another interesting bird is the Arctic tern *Sterna paradisaea*, the world's longest-travelling migrant; it breeds along most of the Norwegian coasts and in Svalbard, and every year its migration journey covers thousands of kilometers to reach the wintering areas in the Antarctic seas. The Arctic skua *Stercorarius parasiticus* has one of the largest and densest colonies in Norway at Slettnes headland.

King eider *Somateria spectabilis* has its most important wintering area in Europe along the coast of Finnmark (north Norway), particularly in the Varangerfjord. Even the beautiful Steller's eider *Polysticta stelleri* has the most important wintering area in Europe in eastern Finnmark; however, the numbers have decreased noticeably in recent years. In several places along the Varangerfjord also the Shore lark *Eremophila alpestris* nests right down to the sea-level; elsewhere in Norway it is a distinctly mountain bird associated with dry tundra, often occurring side-by-side with the Dotterel *Charadrius morinellus*.

Storm petrels *Hydrobates pelagicus* spend their lives on the open sea and only come ashore during the breeding season under the cover of darkness. Interestingly, because of the midnight sun in the north of the country, this seabird postpones nesting until the nights are dark and it can crawl into the nest holes without risking attacks from gulls and other predators. It would be interesting

to know whether this is a genetically fixed adaptation.

A chapter is dedicated to two sites on Svalbard islands, where the birdwatcher can truly observe numerous Nordic species. But beware: an encounter with the Polar bear is possible. A final chapter is devoted to 155 'Selected Species'; the biology of each is briefly outlined and information is provided on the best opportunities to encounter them in Norway.

The book is excellently illustrated with beautiful bird photos and maps of all the sites the birdwatcher can visit. If you are an ornithologist or a birdwatcher and you decide to visit Norway, pack this book, it will be very useful!

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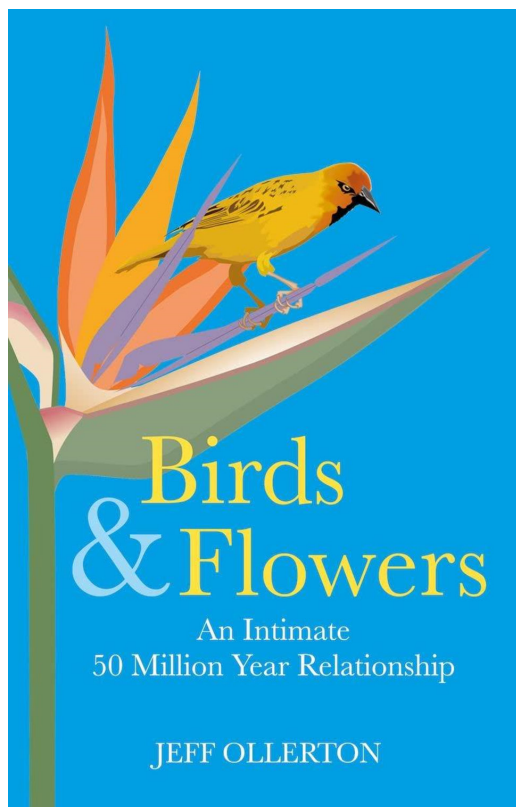
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AN INTERESTING SYNTHESIS ON THE EVOLUTION OF PLANT POLLINATION BY BIRDS



Ollerton J. 2024. Birds & Flowers. An Intimate 50 Million Year Relationship. Pelagic Publishing, London. 312 pp., 28 color plates.

Jeff Ollerton is an expert in the field of biodiversity; he has worked extensively on the pollination of plants, in particular by birds, and has already published two books, *Plant-Pollinator Interactions: from specialization to generalization* (2006, N.M. Waser ed.) and *Pollinators & Pollination: Nature and Society* (2021, Pelagic publ.), other than many scientific papers on this subject. Writing *Birds and flowers*, the purpose of Ollerton is treating two aspects of the natural world with which people are most familiar, bringing together the global diversity of these two distinct, but often interdependent, groups of animals and plants.

The book is structured according to three main themes, the evolution and subsequent diversification of the relationships between flowers and birds, the present knowledge (and also unknown) on the ecology and interactions between birds and flowers, and finally the relationships between birds, flowers and humans.

Following Ollerton, in the Jurassic period, perhaps 170 million years ago, a group of dinosaurs evolved a set of novel traits that allowed them to exploit a semi-arboreal lifestyle that included the ability to glide between trees. The evolution of

wings, provided with feathers, resulted in more or less 11,000 species that some scientists now recognize as the only living dinosaurs, the birds. Also, in the Jurassic, 145 million years ago or possibly much earlier a distinct group of seed plants (angiosperms) appeared; it had an incomparable ability to evolve into '*endless forms most beautiful and most wonderful*', Ollerton's citing a Charles Darwin's phrase. These flowering plants continued to diversify during the Cretaceous and overcame the mass extinction event about 66 million years ago that interested all of the dinosaurs, but not the birds and other groups of plants and animals.

Known pollinators per excellence are insects, reliable flower visitors whose life histories are linked to flowers which provide them with sugary nectar rich in minerals, amino acids and organic compounds. However, no animal could subsist for its entire life on just nectar, it is impossible to build bones and muscles from such a limited diet; even insects like some butterflies, which appear to survive only on nectar, obtain most of their food from the plant materials that they consume as caterpillars, and as adults will often suck inorganic nutrients from dung, urine and mud.

Ollerton highlights that also most birds shifted between feeding on different types of food, insectivory possible was at the origin of behaviors which gave rise to the exploitation of flowers by birds. Nevertheless, birds, compared to insects are much less numerous; for example, in comparison to the c. 360 species of hum-

mingbirds (Trochilidae), there are at least 2,000 neotropical hoverflies (Diptera Syrphidae) and 5,000 bees (Hymenoptera Apoidea)! The flowering plants are about 30 times more diverse than the birds.

Likely, more than 50 million years ago, insectivore birds visiting flowers to prey upon insect, began to change behavior and evolved into bird pollination. According to the present assessment of current knowledge, of 253 recognized taxonomic families of birds, 74 (29.2%) include birds that visit flowers and are known or presumed pollinators. Even if we accept that the this percentage is twice that number, the scale of bird diversity is very small compared to insects, which are counted in the millions of species. The world holds 300,000 (possibly 400,000) species of angiosperms, but a significant fraction has co-opted birds to move their pollen around, as either their sole pollinators or in concert with other animals such as insects, bats or lizards. However, there are wide geographical differences; for example in the Americas, there are plant families with a high proportion of species (whole genera), that are hummingbird-pollinated, including groups with thousands of species, such as the families of Acanthaceae, Asteraceae, Bromeliaceae, Cactaceae, Gesneriaceae, and many more. As Ollerton writes, avian pollination is widespread, ecologically important over much of the world, and has evolved many times in different groups of plants. He also proposes to keep the use of '*ornithophily*' to simply refer to '*bird pollination*'. Bird pollination is very rare on Euro-

pean continent, and this is considered a real puzzle, there is no easy answer. Very few European birds are plant pollinators; *Anagyris foetida* (Fabaceae) is bird-pollinated, the first that has been demonstrated for any native European plant. In addition, the author records that the Canary Island chiffchaff *Phylloscopus canariensis* is presently considered an excellent pollinator of at least three plant species; this could be an insular specialization. However, there have been many previously published observations, over the last 100 years, showing that small passerines in Europe probe flowers for nectar. It is also not uncommon for migrant warblers to arrive in their north European lands loaded with amounts of southern European pollen on their faces (*pollen horns*) and bodies.

Ollerton shows the copious nectar spilling from the center of the flower, below the orange petals, and allows to taste its sweet promise of a reward for services rendered, explaining where the stigma is located, a sharp point standing out from the bloom, waiting for pollen to arrive. Pollen may be dry and dusty or wet and sticky, it varies hugely in shape, and in size from microscopic to individual grains that can be seen without the aid of magnification. Also, cohesive masses of pollen known as '*pollinia*' have evolved independently in two plant families (Orchidaceae and Asclepiadaceae); units comprising the pollinia, together with accessory structures for attachment to the pollinator, may remain onto the bird's tongue. They are able to do this because

the tips of the tongue are finely frayed and narrow enough to act as points of attachment for the pollinaria. They need a lot of energy, and, according to Ollerton, 'nectar can provide a very quick boost, much like a glass of lemonade after a period of hard graft in the garden. Nectar contains more than carbohydrates, however, and it cannot be emphasized enough just how complex it is both as a substance and as a tool in a plant's strategy for reproduction'.

Other than a reproductive function, pollen of some flowers is a reward for those pollinators that can digest its protein-rich contents. In addition, in bird-pollinated flowers, pollen often remains on the feathers of the bird visitor, captured by the barbs and barbules. Even though feathers would seem to be possible evolutionary choice for where to place pollen, really there are many alternative flower strategies in which beaks, feet or even tongues are involved.

Flowers are very variable and diverse; some are long and tubular in form, and bright red, fitting the expectations of the hummingbird '*pollination syndrome*', others are funnel- or bowl-shaped, and variously white, yellow, orange or pink. Flowers that are bird-pollinated, such as the fuchsias (Onagraceae), kniphofias (Liliaceae) from South Africa and New Zealand, are larger, more robust, and more brightly colored, and unscented. The penstemons (Pentaginaceae) include 270-300 species, most bee-pollinated, but perhaps 39 (13-14%) are pollinated by hummingbirds. Red flowers are less

conspicuous to bees, but they certainly are not invisible to them, and these insects will find and keep visiting them if they offer appropriate rewards. Birds, which have a tetrachromatic vision, are equally capable of detecting flowers of any color and searching for the flowers that are most rewarding in a community. Vision is not the only sense at play for avian flower visitors, however, and in some respects smell is a more puzzling aspect of bird pollination.

Following Ollerton, when viewed phylogenetically, it seems clear that some degree of hummingbird pollination had evolved from exclusive bee pollination on a minimum of 13, and possibly as many as 25, occasions during the past history of this group of plants. These switches from bee to bird pollination correlate with changes in the flowers; for example, bee-pollinated flowers tend to be purple, bluish or yellow in color, whereas penstemon flowers that use birds are usually red, orange, magenta or rose-colored to human eyes. The bees exploit the flower in two ways: by making holes at the base into which they can insert their tongues, or by crawling past the dangling sexual parts of the flower and entering from the front. The latter technique may occasionally result in pollination, but really the flowers have evolved to be effectively serviced by hovering buzzers rather than crawling bumblebees. The Bird of Paradise (*Strelitzia*) employs a sophisticated mechanism which, in its native Southern Africa, ensures seed set via its main pollinators, perching birds such as the Cape

weaver *Ploceus capensis*.

Concerning the nectar, in addition to water, most abundant chemicals are energy-rich sugars, such as hexose sugars (six carbon atoms), glucose and fructose (monosaccharide sugars), and sucrose (disaccharide sugar formed from a combination of glucose and fructose molecules). Hummingbirds are completely dependent on nectar to provide energy, but not for essential amino acids and minerals, so all species include insects, spiders and other arthropods in their diet.

According to Ollerton, there is a clear difference between specialists and generalists pollinating birds; generalists are typically characterized by beaks and tongues that are well adapted to consuming nectar from flowers, specialists often have narrow and pointed beaks, ideal for probing within the deepest of flowers, and the tongues may be highly fringed, to act as a mop, or partially tubular, to pump up the bird's fluid diet. From the physiologist point of view, there are specialized enzymes for breaking down sugars; this is undoubtedly an evolutionary adaptation. Concerning adaptations, the nectar of tree tobacco (*Solanaceae*) contains nicotine and the chemically similar anabasine, both powerful insecticides. The capacity of sunbirds (*Nectariniidae*) to deal with nicotine and anabasine seems to be mediated by the bacteria in their guts; the same is almost certainly true of hummingbirds, highlighting the importance of microbes in the ecology and evolution of bird-flower relationships. Interestingly, the Palestine sunbird *Cinnyris osea*, which

pollinates the plant in the eastern Mediterranean, have a limited capacity to cope with these toxins, and in the absence of alternative nectar sources, it may remember the location of plants that produce lower amounts of these alkaloids and visits their flowers preferentially.

This fascinating book concludes with interesting ecological considerations on the consequences of interactions between different species not only from different families, but from different kingdoms. As the ecologist Dan Janzen put it in 1974, ‘what escapes the eye is a much more insidious kind of extinction: the extinction of ecological interactions’. What happens when one of the partners is lost from a community? What if a bird loses an important nectar source or a plant loses its bird pollinator? When a bird becomes extinct, also specialized bacteria, fungi and parasites with which it is associated end up the same way. Species do not occur in isolation, and the biodiversity of species interactions is fundamental to the ecology of the planet.

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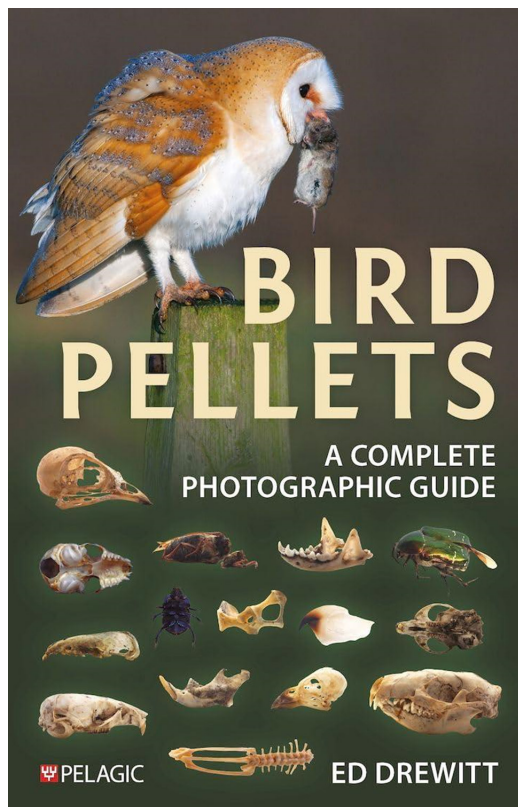
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A NEW AND COMPREHENSIVE GUIDE TO THE IDENTIFICATION OF PREY REMAINS IN RAPTOR PELLETS



Drewitt E. 2024. Bird Pellets. A complete photographic guide. Pelagic Publ., London. 250 pp., 685 color photos of mammal and bird skulls, and prey.

Bird pellets are the undigested remains of food that form together into a ball and are regurgitated by birds. They are generally associated with nocturnal and diurnal birds of prey, but in reality there are numerous species of birds that regurgitate pellets, like corvids, waders, bee-eaters and many others. Ed Drewitt is a naturalist with a high interest in the birds' diet; his interests appeared since he was seven years old and was collecting pellets, skulls and feathers. Those who have studied raptor pellets have undoubtedly consulted Yalden's excellent guides from the 1970s, where many mammal bone remains were drawn. Drewitt's book goes much further than previous guides and illustrated articles, thanks to the author's long experience and the present availability of digital photographs that make it much quicker to assemble the images.

Dissecting bird pellets and identifying their contents may be an useful tool for understanding what birds are feeding, but it is necessary to follow a method and be rigorous in recognizing prey. The book of Drewitt explains what pellets are and how they are formed; it also gives methodological instructions on how to dissect them and analyze the contents, so as to

get a clear picture of the diet of many birds from the golden eagle to the dipper.

The analysis of pellets is incomparably an excellent method of introducing school and university students to the world of nature. When these classroom exercises are carried out, one almost always discovers the hidden interest of a few students who would like to pursue these studies on their own.

On the first pages, the author explains the difference between pellets and faeces, also with the help of numerous photos. He then explains where pellets can be found, how to store them, and how dissection and identification are carried out. The special feature of this book is the quantity of photos of pellets of numerous bird species, how to recognize and compare them. Traditional studies of pellets mostly concern birds of prey, but this guide also covers the analysis of pellets of many other birds, such as corvids, gulls, terns, herons, cormorants, kingfishers, bee-eaters, waders, dippers, shrikes and even robins and blackbirds. A good half of the book is dedicated to prey, through a meticulous presentation of the bone parts that can be found inside the pellets, how to recognize the different species of small mammals (but also larger mammals, like rabbits, weasels and hedgehogs) by the shape of their incisors and molars, and other bone parts. In addition, and this is a truly original part, there are numerous photos of reptile (snakes and lizards) and amphibian (frogs, newts and toads) bone remains. A final chapter is devoted to invertebrates and a sequence of some 40

bird skulls. The seven pages of references contain the entire bibliography cited in the text.

The book largely lives up to the expectations derived from its title; this is a beautiful and comprehensive photographic guide to bird pellets and their prey, which the author has extensively summarized. A must-have in the library of anyone studying bird diets.

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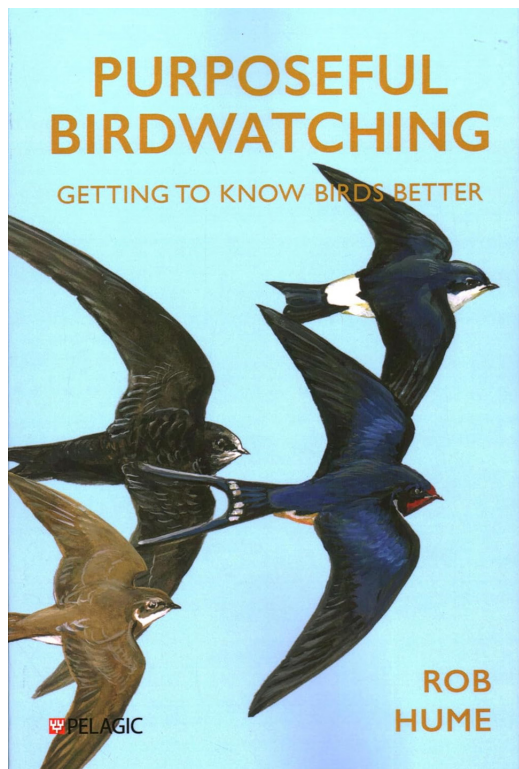
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A FINE ACCOUNT OF THE THRILL OF BIRDWATCHING



Hume R. 2024. Purposeful Birdwatching. Getting to know birds better. Pelagic Publishing, London. 290 pp., many b/w sketches by the author.

In the international ornithological panorama Rob Hume has the distinction of having published a considerable number of guides on bird identification and can be regarded as one of the leaders in committed and scientifically recognized birdwatching. Between 1989 and 2009 he was editor of *Birds*, the journal of the Royal Society of Protection of Birds, he was member and also chairman of the British Birds Rarities Committee, and member of the editorial board of the scientific journal *British Birds*. He has led wildlife holidays in various European countries, Israel and Africa and has birdwatched widely in Europe, India, Sri Lanka, Australia, the Caribbean and North America. His ability to make improvised sketches of birds and the habitats in which they live is widely known and is perhaps the distinguishing feature of his guides and articles. These sketches in some cases have toured the world, as, for example, those of the immature and adult roseate tern

This book is in a way a kind of autobiography, in which the author recounts his most significant observations, the emotions he felt the first time he observed certain bird species and the places where he went birdwatching, observing sometimes very unexpected species. It is pos-

sible to understand the differences between the original text and the text from the author's notes, because they have different characters. Reading this text is very instructive, not so much to learn how to distinguish related species in the wild (for this there are already excellent guides, even by Rob Hume himself), but to understand how serious and profitable birdwatching should be done, what the ethics and philosophy of this activity that involves thousands of people worldwide are.

'*Anything can happen*' he writes about his observation in a October day of a Cory's shearwater sitting on a shingle shore in bright sunshine, the first and for many years the only inland record in Britain. Very interesting is what he writes about royal and lesser crested terns: '*if at first you don't succeed*' mantra applies to them. Nevertheless, he reports his notes from Gambia, where he observed lesser crested, royal, sandwich and caspian terns; the notes suggest that lesser crested would be smaller-bodied than sandwich head-on, but bulkier and deeper-bodied in a side view, broader-winged and with a fractionally deeper and longer bill. Once again the notes taken during field observations and sketches come in handy for correct identification.

Another his interesting observation reported in the notes of the book occurred in Ireland, where Hume found a flock of small waders; one of them resulted to be a Baird's sandpiper, a pretty good American rarity, but another one was a white-rumped sandpiper, another accidental

American wader. The sketch of the two birds shows this excellent find and the small differences between them. Roosts of corvids are unusual, but the author records thousands of rooks and jackdaws, the total was in excess of 5,000, probably 6,000, predominantly jackdaws. The spectacle continued for a couple of years but has since dwindled; the periodic behavior of these birds to aggregate and form conspicuous flocks in roosts in some parts of the world remains unexplained.

Towards the end of the book, the author highlights the importance of consulting skins preserved in museums, where an ornithologist or simple birdwatcher can compare his own drawings, sketches and notes with the actual plumage of the preserved specimens.

Hume highlights also that an important aspect that should not be underestimated by the birdwatcher is the song of the birds; it is essential to recognize not only the songs but also the simple calls in order to understand whether you are looking at a common and widespread species or an exceptional visitor. The considerations on the last pages are somewhat sad in a way: 'Going through my old notebooks brings back so very many memories and experiences, some of which simply reinforce what we have lost'. And also: 'It always seems a great pity to me that [Black Grouses] are just thought of as game birds and hardly get the credit they deserve as wild beautiful, evocative birds on the hills, with their brilliant calls'. Even in the UK, the problem of hunting and all that goes with it (such as birds bred and

released as put and take game) is struggling to be resolved in a world with fewer and fewer birds for a variety of causes; however, hunting adds to these causes and can be the straw that breaks the camel's back.

This book was written by someone who has had a passion for ornithology since childhood, and on every page it shows this man's enormous passion for birdwatching, ornithology, and bird identification in the field. Reading it is a great pleasure for anyone with the same passion.

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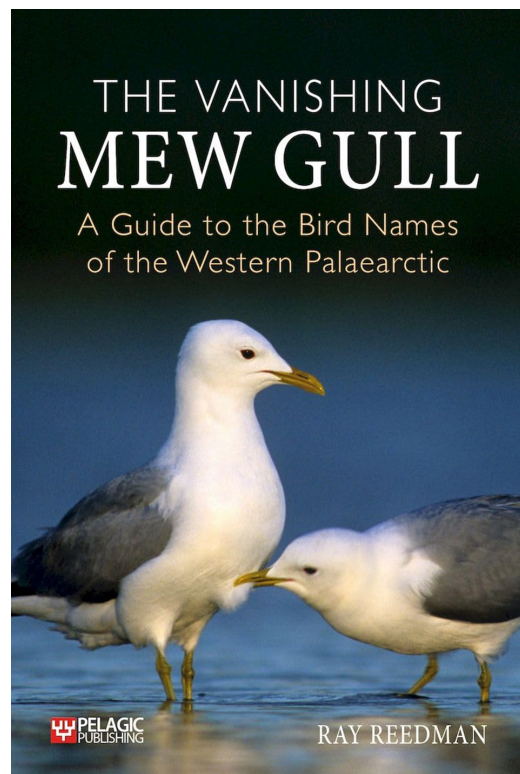
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RECENT NAME CHANGES IN ORNITHOLOGICAL TAXONOMY



Reedman R. 2024. The Vanishing Mew Gull: A Guide to the Bird Names of the Western Palearctic. Pelagic Publishing, London. 378 pp.

The title of this book symbolizes the many changes in the names of Palearctic birds of recent years. The action of splitting former subspecies raising them to full species has been more and more frequent. Why ‘*vanishing Mew gull*’? Two subspecies were historically recognized for *Larus canus*, the American one was named Mew gull, while the European one Common gull; with the definitive split of the two subspecies by International Ornithological Congress (IOC) the Mew gull *Larus brachyrhynchus* received the vernacular name of Short-billed gull. Mew gull name now is vanishing!

Regrettably, it has not yet been possible to arrive at a list of birds agreed upon by all countries, for various reasons there are still many differences between the HBW-BirdLife Checklist (2018) and the IOC World Bird List (2020). The most obvious differences are in the treatment of the genera of Laridae (e.g., *Croicocephalus* instead of *Larus*) and some Sylviidae traditionally included in the genus *Sylvia*, presently treated as *Curruca*. In addition, the sequence of bird lists changed following the recent genetic acquisition of affinities between different families.

Ray Reedman is an erudite ornithologist, very passionate about the Latin,

Greek and Central European etymological origins of both English vernacular and scientific names. In 2016 he had already addressed this issue in his book 'Lapwings, Loons and Loosy Jacks. The how and why of bird names', published by the same editor (see the review in Avocetta, 2016, 40: 97-99). In the present book Reedman follows the version 13.2 of the IOC World Bird List (available at <https://www.world-birdnames.org>), which, as above recorded, is different from the HBW-BirdLife Checklist, adopted by CISO (see Baccetti, Fracasso & COI, 2021. Avocetta, 45: 21-82). On the whole, the author reports entry information of about 1,100 scientific and vernacular bird names, other than some data on the distribution of cited taxa.

Of each species, the author mentions the current English and scientific name, the present distribution and, in the case of occasional species, the known records in Britain; he then explains the origin of the English name, often consisting of two words and not infrequently dedicated to a personage (providing an explanation), after which he moves on to the etymological explanation of the Latin name and often provides some additional notes that may prove useful. There are some very interesting etymologies; for example Vega Gull *Larus vegae* derives from an odd chain that has a bird at the end. It has its roots to Cape Vega in northern Siberia, but the cape itself was named after the Norwegian ship that made the first trip through the N-E Passage in 1878-1879, and the ship in turn was named after the

brightest star in the constellation Lyra. The ultimate root of that name lies in an Arabic word that was translated into Latin as the 'falling vulture'. Or the example of the Tristan Albatross, which is named after Tristan da Cunha, a group of islands in the South Atlantic where the bird breeds, but Tristan is named after the Portuguese explorer who gave his name to the main island in 1506. Some species have remained with different English names, one international, the other British [one example for all: Common Murre (international) and Common Guillemot (British) for *Uria aalge*].

I have some doubts about the use of *pygmaeus* (correct in Latin), when originally described as *pygmeus* (wrong in Latin). With respect to 'correct original spelling' and the cases in which such original spelling may be amended the rules governing are articles 32.3, 32.5 of the ICZN. However, if the subsequent spelling is in prevalent use, then the subsequent spelling must be retained (whether unjustified emendation, see art. 33.2.3.1, or incorrect subsequent spelling, see art. 33.3.1). In the cases of *Calidris pygmaea* and *Microcarbo pygmaeus* it seems that they are not in prevalent use; thus the correct names should be *Calidris pygmea* and *Microcarbo pygmeus*. Besides, *Nannopterum* is neuter, thus *Nannopterum auritum*; *Butorides* is masculine, thus *Butorides striatus*. Francesco Cetti was a professor of Mathematics and naturalistic Sciences in the late 1770 in the newly established University of Sassari (Sardinia) and in 1776 he published 'Gli Uccelli di

Sardegna' (Birds of Sardinia); his observations on the Cetti's warbler were carried out in Sardinia, not in Sicily.

I must point out that the author does not always take into account the officially recognized Palaearctic subspecies; however, he writes at pag. 320 "This area has not been treated exhaustively in the species entries, though some more obvious cases, such as the Mew Gull of the title, is considered". Nevertheless, I would cite just two examples of subspecies that deserve to be studied in depth, the Long-tailed tit *Aegithalos caudatus* and the European Storm Petrel *Hydrobates pelagicus*. Many subspecies have been recognized of the former bird, some of which have a clear geographic isolated distribution. The latter is known to have clearly separated populations in the Atlantic (subspecies *pelagicus*) and the Mediterranean (subspecies *melitensis*), so much so that they now even have different English names: Atlantic Storm Petrel and Mediterranean Storm Petrel. It is, however, very likely that the two subspecies will soon be separated as full species.

Apart from these minor inconsistencies, I believe that this book will remain for many years the must-have reference for anyone wanting to know the etymology of English and Latin bird terms. This book really does contain a wealth of information on the origin of bird names, and objectively Reedman has surpassed himself by writing the last word on the subject, at least for the species known from the Western Palaearctic.

At the end of the book Reedman reports that the American Ornithological Society in November 2023 announced the intention to remove all eponyms (names of people recorded in the bird-names) from the vernacular names of American birds because some of those commemorated were linked historically to aspects of slavery and colonialism. Of course such decision will open a debate; most vernacular bird-names dedicated to people have reason to exist, but to purge a few undeserved eponyms there is no point in erasing hundreds of years of ornithological history. I hope for a serene reconsideration of this hasty and above all ahistorical decision.

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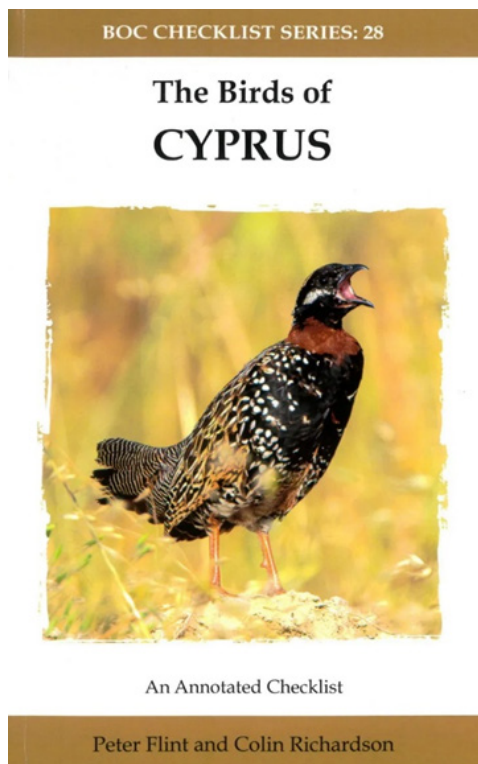
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MUCH MORE THAN A CHECKLIST: AN INTRODUCTION TO THE BIRDS AND NATURE OF CYPRUS



Flint P. & Richardson C., 2024. The Birds of Cyprus. An annotated Checklist. BOC Checklist Series: 28. British Ornithologists' Club. Tring, UK, 492 pp.

The Birds of Cyprus is the 28th volume of a renowned series of checklists dating back to 1976. Checklists are invaluable tools for ornithological research as they allow organising and synthesising observations under the supervision of experienced researchers. They allow monitoring populations and highlighting variations that may indicate environmental change; they facilitate research and conservation and, last but not least, they share information in a synthetic and standardized way. Not surprisingly, Avocetta regularly publishes the checklist of Italian birds redacted by the Italian Ornithological Commission (COI) and the Italian Centre for Ornithological Studies (CISO). Authored by Peter Flint and Colin Richardson, this third edition of the checklist of the birds of Cyprus is published by the British Ornithologists' Club (BOC) and updates two earlier checklists compiled in 1983 and 1992, the latter published as the 6th volume of the same series by the British Ornithologists' Union (BOU).

The series aims to document the status of birds in various regions of the world. Each volume contains a systematic list of the species recorded in that area accompanied by extensive notes on the status, movements, records and other relevant

information specific to the area. Of particular interest for Italian readers is the only volume in the series dedicated to Italy, the 11th volume titled “The Birds of Sicily”, edited by Carmela Iapichino and Bruno Massa, former Editor-in-Chief of *Avocetta*.

The *Birds of Cyprus* includes about 60 pages of introduction providing detailed information on the history of ornithology in Cyprus, the geology, climate, vegetation and environment of the island, its biogeographical location and the migratory movements that interest it. This extensive introduction gives a great overview of Cyprus’ nature and its recent changes, which is particularly relevant for putting the information on the single species into a broader context. In this part, I found a discussion on the species/area relationship and the equilibrium theory particularly interesting. It shows, for example, that Cyprus avifauna includes fewer species than expected given the island’s area compared to the other major Mediterranean islands, which the authors relate to the greater aridity and geographical isolation of Cyprus.

Appendices at the end of the book provide condensed information on biometric measures of birds trapped for ringing in Cyprus and sites of ornithological interest. Birders will find the information in this book invaluable to find the correct time and location to maximise chances of finding a target species.

To produce this list, the authors not only reviewed publications of the islands’ past and present bird societies and searched

ring encounters and citizen science databases like eBird, but also included results from tracking data, which revealed fascinating insights into bird origins and destinations. This book summarizes tons of literature (including the often difficult grey one) and is extremely relevant to anyone interested in the birds of Cyprus and the wider Middle East.

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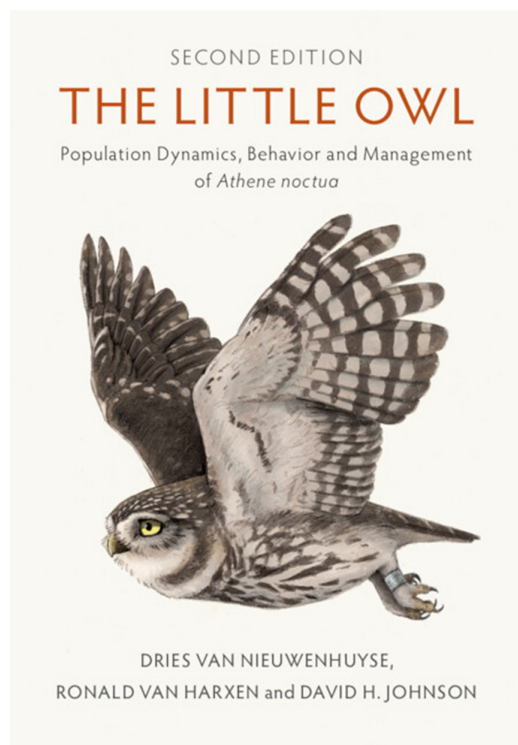
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ALL YOU NEED TO KNOW ON A SPECIES THAT INSPIRED MYTHS AND LEGENDS: ECOLOGY, BEHAVIOUR, EVOLUTION, CONSERVATION AND CURIOSITIES ON THE LITTLE OWL



Van Nieuwehuyse D., van Harxen R. and Johnson D.H., 2023. The Little Owl. Population Dynamics, Behavior and Management of *Athene noctua*. 2nd Ed. Cambridge University Press 616 pp.

Little Owls (*Athene noctua*) have inspired human folklore and myths for centuries, symbolizing knowledge, dread, wisdom, and witchcraft. Humans have shared a strong cultural relationships with this small, synanthropic species, which has benefitted from human alteration of the landscapes, at least until the mid-twentieth century, when drastic declines in many owl species caught the attention of ornithologists and conservation biologists.

This book synthesizes the vast body of literature on the Little Owl, exploring the history and traditions on this species, its genetics and evolution, habitat, distribution, population trends and regulation, and behaviour. The books end with two chapters dedicated to conservation and research priorities needed to address the significant gaps that still exist in our knowledge of the Little Owl.

Written in an extremely rigorous yet enjoyable language, the books stands out in the monographic literature on bird species for its completeness and detail. Certain sessions, such as those on population regulation, delve into broader ecological concepts, but always without losing the rigor or the focus on the Little Owl. These

sections, in my opinion, are joy to read. simply fantastic to read, at least in my personal opinion.

A large number of colour and gray-scale pictures, maps and graphs enriches the book, making it an indispensable resource for both professional and amateur ornithologists with an interest in this Little Owl (but, honestly, what ornithologist wouldn't be interested in this captivating species?).

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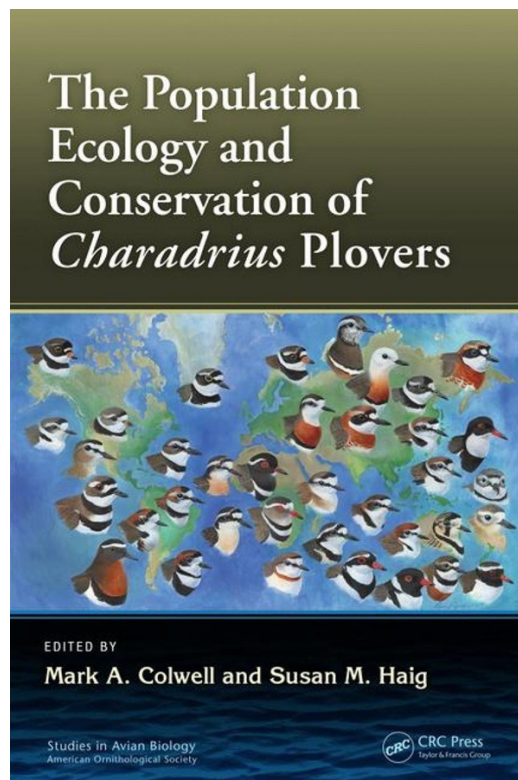
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COUNTING PLOVERS IS NOT ENOUGH: GET ACTIVE IN MONITORING TOO THREATS AND ACTIONS!



Mark A. Colwell and Susan M. Haig., 2020. The Population Ecology and Conservation of Charadrius Plovers. Edited by CRC Press – Taylor & Francis Group, New York, 342 pp

We all know the critical state of conservation in which the Italian Charadriids are, first and foremost the Kentish Plover. This last species, in particular, requires strategic to tactical actions at different scales, carried out both by expert researchers and by local groups, often socially and culturally heterogeneous: the latter strategic because they are functional to the protection of this species in the (beach) conservation front lines. It is time, therefore, that expert ornithologists train and support volunteers and collect data not only on demographic and ecological variables (i.e., density, status, phenologies of plovers), but also on all those related both to the human dimension and related conflicts (e.g., density of predators, dogs, people, entrapping litter; dynamics among social targets) and to the effectiveness of project management (how useful are the local solutions adopted?).

The text edited by Colwell and Haig is a handbook that every local conservation project group aimed at protecting plover nesting sites should study carefully. If the first chapters provide a bio-ecological framework of the Charadriid species worldwide, some of which are at the brink of extinction, chapters 6, 9 and 11 report a review of the many possible approach-

es and solutions to be implemented in the conservation ‘theaters’ where conflicts between these species and people occur: e.g., direct surveillance of nests; placement of cages, fences, panels, and anti-predator silhouettes; improvement of habitat suitability; communication with critical unaware social targets (such as dog owners, fishermen, and beachgoers who trample on dunes and nests); direct and indirect control of predators and many other solutions, even extremely creative. This review is accompanied by a rich bibliography that reports evidence on the effectiveness (or not) of each category of action. In particular, Table 6.1 (pages 129-131) should be the reminder for actions declined by each local group on plover nesting sites!

I think of the many debates on the conservation of the Kentish Plovers, also in Italian contexts: these meetings are useful but often too focused on the status and trends of the species and on conflicts of competence between institutions and associations (still human dimension!). Perhaps it is time to better use the scarce and precious time that remains to conserve this species by concretely adopting many of the actions suggested in this text. Many local groups already implement these actions: from this book they can acquire further opportunities to experiment and test with other techniques. Ultimately, the message suggested by these chapters is to act and then monitor in the broadest sense: not only the biological target (the Kentish Plover or other species in decline), but also the

threats (pressure indicators; how many dogs? How many people on the dunes? How many predators? How much beach litter trapping the beach?) and, finally, verify the effectiveness of the actions using specific indicators of response.

A final consideration: in the face of hundreds of international citations reported in the text, I found only (sic!) one reference to Italian authors. A stimulus to our ornithologists (especially those working in the conservation front lines) to publish more (and not only in local journals) the results of their monitoring, successes and (why not?) failures: Avocetta hosts a Conservation Evidence column and wait for evidence!

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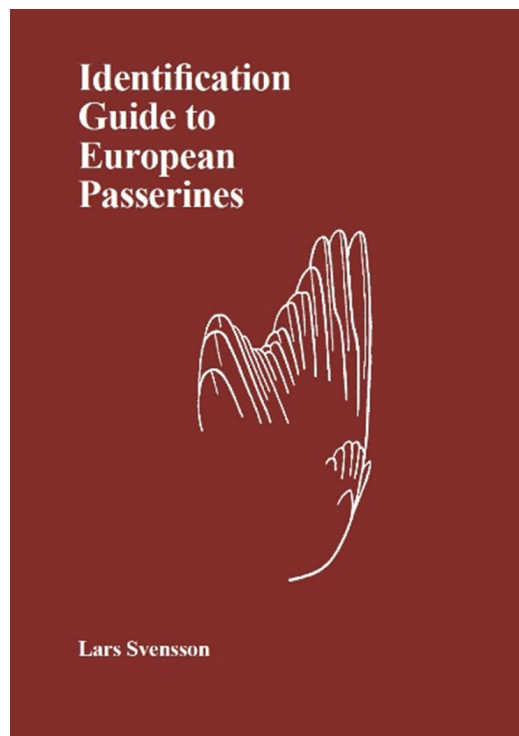
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THE “BURGUNDY ONE”: 5TH EDITION OF THE RINGER’S BIBLE



Svensson L., 2023. Identification Guide to European Passerines. Lullula Förlag, Stockholm. 448 pp.

There is a small green guide in the library of every bird ringer. Its cover is simple, the edges worn, the pages yellowed with time, inside strange abbreviations and black-and-white sketches. Opening it feels like entering a world closed off to most people. A world where birds are studied one feather at a time and the entire life of a migrant can be inferred from the moult of its plumage. This is the fourth edition, published in 1992, of a leading guide in the field of bird ringing, which first saw the light in 1970.

Today, more than 50 years after the first edition and over 30 years since the last, “Identification Guide of European Passerines” is back, with a burgundy cover and several new updates.

The structure of the species accounts remains unchanged, designed to provide a simple and quick guide for identifying a bird in hand. After a brief introduction to the species’ general characteristics, the description of any subspecies follows, along with concise information on moult, age, and sex. When necessary, the texts are accompanied by schematic drawings.

The accounts are preceded by a comprehensive introduction - a guide within the guide - to measurement techniques, ageing, and sexing.

However, the similarities with previous editions end here. The text has been thoroughly revised and significantly expanded following a monumental update effort, both in the field and in museums, with measurements taken from hundreds of additional specimens. The taxonomy has been radically overhauled to reflect the latest IOC updates. For species that undergo partial post-juvenile moult, a brief but essential description of its extent has been added. The number of species described has increased from 229 in the previous edition to 267, thanks to splits, as well as the addition of vagrants of Asian and, to a lesser extent, African origin.

This guide, stripped of any superfluous elements, gets straight to the point - a key strength when working in the field. While many other similar excellent identification guides have emerged since the last edition, some featuring stunning colour images, Lars Svensson's magnum opus remains an indispensable resource. With this new edition, it is poised to continue educating a new generation of bird ringers for years to come.

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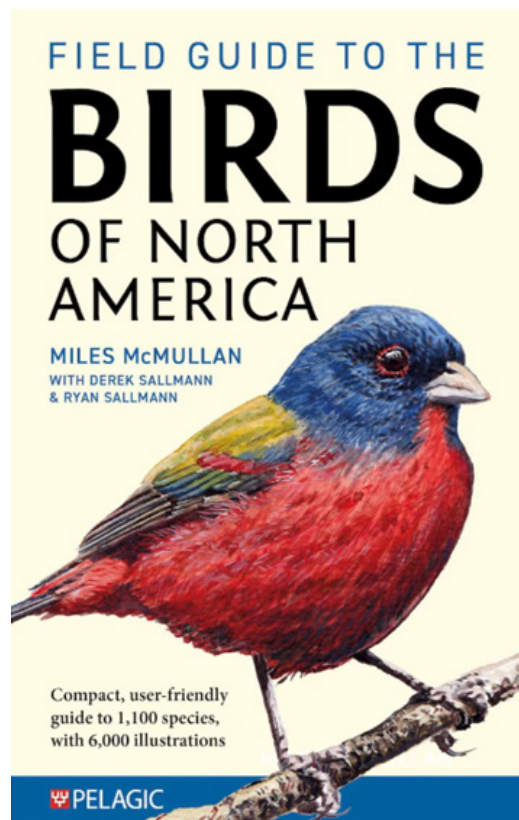
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A RELIABLE COMPANION FOR DISCOVERING NORTH AMERICAN BIRDS



McMullan M., Sallmann D. & Sallmann R., 2025. Field Guide to the Birds of North America. Pelagic Publishing, Exeter, UK, 360 pp

The book by Miles McMullan, with contributions from Derek and Ryan Sallmann, is a fresh and vibrant addition to the ever-growing library of ornithological field guides. Published by Pelagic in 2025, this guide manages to be both a comprehensive resource for birders and an approachable entry point for beginners, where the clarity of the book and the thoughtful design are key elements. Covering an impressive 1,100 species, the guide is compact and easy to carry in the field, an achievement in itself given the breadth of content. The organization is intuitive, with clear species accounts and logical groupings that make navigation through is an easy task even for novice users. The soft cover contributes to its portability in the field, making it easy to pack and handle, though it may slightly compromise durability over extended use or in harsh weather conditions. What truly distinguishes this guide are the illustrations. With over 6,000 detailed images, the visual element is exceptional. Each bird is shown in various postures and plumage phases, including juvenile and seasonal variations when relevant, making identification in the field much easier. The artwork is consistently high-quality, managing to combine scientific accuracy

with artistic clarity. Another standout feature is the inclusion of useful maps at the beginning of the book, depicting North America's biomes, precipitation patterns, and provincial boundaries. These provide valuable ecological and geographical context and help orient the reader before even getting into species-level details. The authors' experience in the field shines through in the concise yet informative descriptions. Each account includes key ID features, vocalizations, habitat preferences, and often, behavioural notes that enrich the species presentation. All this information is provided through an accessible language, never losing the reader in incomprehensible technical jargon. This field guide also stands out in its sensitivity to regional diversity. From arid deserts and boreal forests to coastal wetlands and mountain ranges, the authors ensure a fair representation of the vast geographic and ecological diversity of North American birds. In sum, the *Field Guide* is a reliable companion for any birdwatcher eager to explore and identify the rich avian life of North America. Whether you are scanning your backyard feeder or trekking through remote wilderness, this guide earns its place in your backpack.

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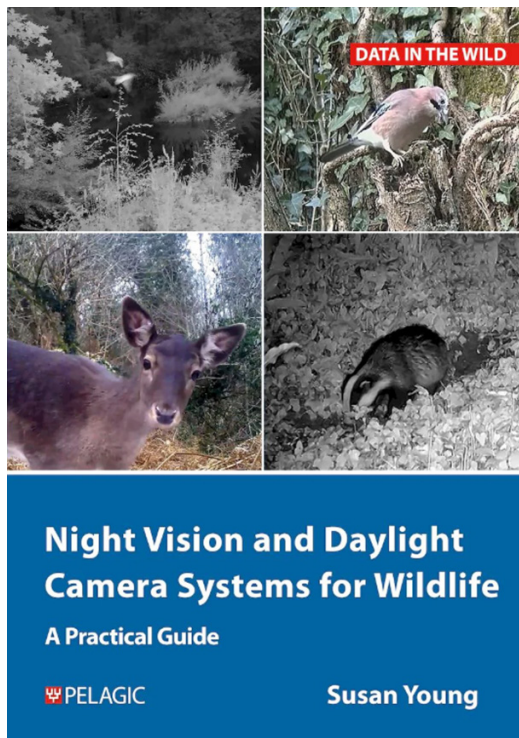
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A RESPECTFUL GAZE: UNCOVERING THE SECRETS OF WILDLIFE WITH REMOTE CAMERA SYSTEM



Susan Y., 2025. Night Vision and Daylight Camera System for Wildlife. Pelagic Publishing, Exeter, UK, 180 pp.

Observing wildlife through the lens of remote cameras has become an increasingly popular activity, both among researchers and nature enthusiasts. In addition to enabling non-invasive wildlife monitoring, these tools open a window into the secret lives of animals, fostering engagement and appreciation from the broader public. This growing accessibility to wildlife observation is reshaping how we connect with nature whether through citizen science projects, personal curiosity, or conservation work. In this context, this book arrives as a timely and practical guide to operate mostly in our gardens or woodland settings.

Comprising a total of 7 chapters, the book moves from general introductions to night vision and daylight imaging technologies, through technical considerations, to practical applications in the field. The final two chapters walk the reader through the process of assembling and deploying the camera system, including crucial considerations such as power supply, weatherproofing, and data storage, which are key aspects for ensuring successful filming in the field.

The species featured in the book range from well-known forest birds to badgers, foxes, small mammals, reptiles among

others, with the author proposing different camera system setups tailored to each condition and context. Young's writing is clear, concise, and rooted in hands-on experience. Her background in field research and photography is evident throughout the book, lending credibility and reliability to the guidance she offers.

The tone is accessible yet professional, making the book suitable for a broad range of readers. From wildlife biologists to early-career researchers to naturalists and nature enthusiasts with little technical experience in camera use. Young avoids unnecessary jargon and consistently frames her explanations in practical field scenarios accompanied by explanatory sketches. This makes the book not only a manual, but also a practical companion for solving challenges encountered during wildlife monitoring in remote and variable environments. As the author notes, the chapters follow a consistent structure, and this repetition allows readers to easily focus on specific sections of interest without needing to read the entire book from cover to cover.

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This column aims to collect a series of interesting observations, collected without time, space or species limitation, focusing on a limited series of category of interest.

In this volume of *Avocetta*, you will find news items about the following species: Greater Flamingo (*Phoenicopterus roseus*), Glossy Ibis (*Plegadis falcinellus*), Night Heron (*Nycticorax nycticorax*), Purple Heron (*Ardea purpurea*), Short-eared Owl (*Asio flammeus*), Griffon Vulture (*Gyps fulvus*), Three-toed Woodpecker (*Picoides tridactylus*), Yellow-billed Blue Magpie (*Urocissa flavirostris*), White-throated Dipper (*Cinclus cinclus*), and Common Stonechat (*Saxicola torquatus*).

Congratulations to all the dedicated observers whose contributions have enriched the content of this volume.

See more on Avocetta website: <https://riviste.unimi.it/index.php/avocetta/bird-news-column>

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1. GREATER FLAMINGO *PHOENICOP- TERUS ROSEUS*

Site location: Monte Catria, Frontone
(Pesaro-Urbino, Marche), Italy

Observers: Iacopo Burattini, Angelo Giuliani, Marco Pantalone (pantalone.marco@libero.it)

Date of observation: 14th-15th March 2025

Category: Species of unusual occurrence for a given area, Unusual rescue record

Number of individuals: 9

Status: Actively migrating / Dead

Notes of the observers: A flock of this species was hit by a storm during migration over the Apennines. The following day, the birds were found: seven had died after colliding with rocky walls at 1500 m a.s.l. The two survivors were recovered by the Marches Wildlife Rescue Center (CRAS) and later released at the Saline di Cervia (Ravenna, Italy).



Reason of interest: Uncommon causes of death. One of the two survivors had a metal and color ring (CZTS), applied when it was a flightless chick in 1997, in Bouches-du-Rhône (France).



2. GLOSSY IBIS *PLEGADIS FALCINELLUS*

Observers: Simone Ottorino Bai, Marco Pantalone (pantalone.marco@libero.it)

Category: Unusual number

Number of individuals: 49

Status: Actively migrating

Site location: Stagno Santa Rita and Lago Vicini, Fano (Pesaro-Urbino, Marche), Italy

Date of observation: 15th April 2025

Note of the observers: In the days preceding the observation, there had been heavy rainfall, which ended on the night of April 14. Some individuals had been present in the area for several days and remained there in the days that followed.

Reasons of interests: This was the highest number recorded in the Marche region, at least in the 21st century.

3. NIGHT HERON *NYCTICORAX NYCTICORAX*

Observers: Simona Corbellini, Marco Pantalone (pantalone.marco@libero.it)

Category: Unusual number

Number of individuals: 147

Status: Actively migrating

Site location: Stagno Santa Rita and Lago Vicini, Fano (Pesaro-Urbino, Marche), Italy

Date of observation: 15th April 2025

Notes of the observers: In the days preceding the observation, there had been heavy rainfall, which ended on the night of April 14. Some individuals had been present in the area for several days and remained there in the days that followed

Reasons for interest: This was the highest number recorded in the Marche region, at least in the 21st century.

4. PURPLE HERON *ARDEA PURPUREA*

Observers: Simone Ottorino Bai, Marco Pantalone (pantalone.marco@libero.it)

Category: Unusual number

Number of individuals: 27

Status: Actively migrating

Site location: Stagno Santa Rita and Lago Vicini, Fano (Pesaro-Urbino, Marche), Italy.

Date of observation: 15th April 2025

Notes of the observers: In the days preceding the observation, there had been heavy rainfall, which ended on the night of April 14. Some individuals had been present in the area for several days and remained there in the days that followed

Reasons for interest: This was the highest number recorded in the Marche region, at least in the 21st century.

5. SHORT-TOED OWL *ASIO FLAMMEUS*

Observers: Davide Aldi (davide.aldi@gmail.com), Davide Meggiorini

Category: Unusual rescue record

Number of individuals: 1

Status: Actively migrating

Site location: Mantova (Lombardia), Italy

Date of observation: 13th March 2025

Notes of the observers: An adult female found in the city center of Mantua died after rescue; toxicology confirmed brodi-

facoum poisoning, supporting the clinical and pathological suspicion of rodenticide exposure.

Reasons for interest: The Short-eared Owl, strictly protected, faces growing risk from rodenticide poisoning; 11 of 14 raptors submitted to CRAS tested positive, highlighting the urgent need for tighter regulations.



6. GRIFFON VULTURE *GYPS FULVUS*

Observers: Maurizio Saltarelli, Marco Pantalone (pantalone.marco@libero.it)

Category: Unusual number

Number of individuals: 24

Status: Actively migrating

Site location: Furlo gorges, Fermignano (Pesaro-Urbano, Marche), Italy

Date of observation: 25-26th April 2025

Notes of the observers: Birds, both adults and immatures, arrived above the gorge at 5 p.m. and perched on the pinnacles and highest rocks. The local pair of Golden Eagles *Aquila chrysaetos* did not show any aggressive behavior toward them. On the morning of 26 April, five individuals were still present.

Reason of interest: The highest number observed in the Northern Apennines.

**7. THREE-TOED WOODPECKER
*PICOIDES TRIDACTYLUS ALPINUS***

Observers: Pierandrea Bricchetti (pierbrichetti@gmail.com), Stefano Sandrini

Category: Unusual breeding location

Number of individuals: 2 adult birds and 2 juveniles

Status: Breeding

Site location: Pezzo di Ponte di Legno, upper Camonica Valley (Brescia, Lombardia), Italy

Date of observation: 29th September 2022, between late March and early July 2024 (active nest found on 17th June) and in May-June 2025

Notes of the observers: A pair successfully nested in a mature forest of *Picea abies* and *Larix decidua* at 1,730 m asl on

a steep slope with S-SW exposure with the presence of large clearings with many trees on the ground, caused by the passage of the “Vaia” storm at the end of October 2018. The nest-hole was excavated on a dead spruce (c. 15 cm in diameter at the height of the entrance) at c. 2.60 m above the ground, with SW exposure. Considering that the two young birds fledged on 29 June, the start of egg laying can be dated between May 20th and 27th. Breeding was successfully repeated in May-June 2025 in the same nest.

Reasons for interest: First certain case of nesting in the Province of Brescia and one of the rare cases recorded in Lombardy, confirming the south-west expansion of this woodpecker.



One of the two young birds one day before fledging

8. YELLOW-BILLED BLUE MAGPIE
UROCISSA FLAVIROSTRIS

Observer: Tiziano Londei (londei.tiziano@gmail.com), Giuliana Marzi

Category: Unusual behaviour

Number of individuals: 1

Status: Unknown

Site location: Dobato, Nepal (N 27.072°, E 88.005°)

Date of observation: 31st March 2025

Notes of the observers: This individual fed for about one minute on the nectar of the tree rhododendron *Rhododendron arboreum*, one second per flower, then showing a lot of pollen stuck to the feathers around its bill. It was part of up to six conspecifics used to congregate for human food scraps near a homestay close to an extensive oak and rhododendron forest.

Reason for interest: This is the first report of nectarivory for this omnivorous, though chiefly carnivorous, species, and the second for its genus (Chand et al. 2022. *Scientia Forestalis*, 50, e3783).



9. WHITE-THROATED DIPPER *CINCLUS CINCLUS*

Date of observation: 15th December 2024

Observers: Redaelli Giuseppe (giuseppe.redaellibw@gmail.com)

Notes of observers: An active nest was found, and two juveniles fledged between 26 and 28 December 2024.

Category: Unusual breeding for timing

Reason of interest: This represents an unusual breeding period for the species.

Number of individuals: 2 juveniles

Status: Chicks still unable to fly

Site location: Robbiate (Lecco, Lombardia), Italy; 195 m a.s.l.

10. COMMON STONECHAT *SAXICOLA TORQUATUS*

Site location: Saltpan of Trapani (Trapani, Sicily), Italy

Observers: Luigi Barraco, Salvatore Surdo (salvatore.surdo@unipa.it)

Date of observation: 20th January 2025

Category: Unusual chromatic aberration

Notes of the observers: an individual with a 'Dilution' colour aberration, caused by a defect in melanin deposition in the feathers.

Number of individuals: 1

Status: Foraging

Reasons for interest: colour aberration.



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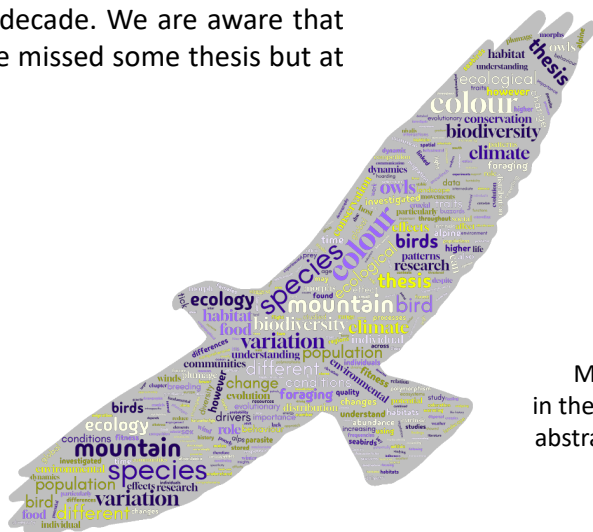
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PHD DISSERTATION REVIEW IN ORNITHOLOGY (FIFTH EDITION)

INTRODUCTORY NOTE

In this fifth review section we are presenting the abstracts of some of the PhD-Dissertations defended by Italian PhD students between 2019/2020 and 2023/2024 academic years. In line with the previous edition we are including in this collection also the Italian students who undertook an international PhD programme developing its thesis in Europe or in collaboration with foreign institutions. This was absolutely needed since the number of Italian students looking at PhD opportunities abroad has been growing over the last decade. We are aware that we could have missed some thesis but at

the same time we are confident that the review provides a comprehensive view of the research topics. The PhD-Dissertations are presented in alphabetical order by author's surname and, then, by year. We can appreciate that nowadays the students are highly motivated to publish their research producing a significant number of scientific articles. The Reference section below provides a comprehensive list of publications authored by the PhD students during their doctoral studies or shortly after.



Most frequently used words
in the reviewed PhD-Dissertation
abstracts. Figured made through
WordClouds.com

*THESIS 1***THE ROLE OF ECOLOGY IN THE EVOLUTION OF COLORATION IN OWLS****ARIANNA PASSAROTTO**

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ABSTRACT

Birds exhibit an extraordinary diversity in their colour patterns shaped by natural and sexual selection to fulfil communication, camouflage and/or protection functions. The factors promoting colour variation can be diverse and act differently on different traits and levels of organization. Therefore, to fully understand how ecology influences the evolution of colour diversity, it is necessary to consider holistic approaches combining multiple levels of study, including different traits and species with a wide range of ecological conditions. Owls display a remarkable diversity in colour patterns and morphology associated to a complex ecology, constituting an ideal system to understand the evolutionary causes of phenotypic variation. Using a multiple-scale approach, this thesis combined i) ecogeographical analyses at a world scale, ii) comparative analyses to control for the possible effects of common ancestry, and iii) field data of two species collected at the population

level, to assess the relative importance of a number of ecological and evolutionary factors in determining colour variation in owls. Particularly, I investigated i) large scale geographic variability of melanin-based colour patterns in relation to environmental gradients in the frame of classic ecogeographical rules; ii) interspecific variability in colour polymorphism in relation to key ecological drivers; iii) the evolution of interspecific iris colour in relation to activity rhythm; and iv) the potential of iris coloration as a quality indicator in parent-offspring communication and other social contexts in Little Owls (*Athene noctua*) and Eurasian Scops Owl (*Otus scops*). My thesis showed that environmental variation may act in several ways promoting the evolution of colour variation in owls at different spatial scales. Specifically, it provided strong support for the idea that detectability in different light conditions, determined by both differences in activity rhythm and vegetation cover, may be a key driver of inter- and intraspecific colour variation in different traits in owls. Plumage attributes (i.e. melanin-based coloration and colour polymorphism) and iris colour are adaptive traits likely maintained by the selective advantage of camouflage under different light regimes or in terms of physiological adaptation to climatic and/or environmental conditions via different mechanisms. Finally, this research gave a first glimpse at the role of iris colour in communication in owls, suggesting that iris yellowness may potentially play a signalling role in social contexts. Evidently,

further experimental work is needed to better understand causes promoting evolution of colour variation and disentangle the role of colour in signalling individual quality in owls.

THESIS 2

MIGRATION STRATEGIES AND CIR- CANNUAL PATTERNS OF HABITAT USE OF SNOWFINCHES (*MONTIFRINGILLA NIVALIS NIVALIS*) IN A PATCHY ALPINE LANDSCAPE

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ABSTRACT

Mountain regions are among the richest terrestrial ecosystems in terms of biodiversity and most threatened by anthropogenic modification and climate change. Species living in mountain regions are already responding through e.g. shifts in phenology or upslope migration. However, due to the complexity of species and community dynamics, the actual effects of climate change on mountain biodiversity are extremely difficult to predict. More-

over, the harshness of mountains hampers research activities, so we often lack knowledge of species ecology. In this thesis we studied the distribution range, the habitat specificity, the movement strategies and the group dynamics of one of the most emblematic alpine bird species, the snowfinch *Montifringilla nivalis nivalis*, focusing on the Western Europe populations. We introduced our study with an insight into the Holarctic mountain bird communities, their functional diversity and the functional uniqueness of their species, which resulted to be independent from the geographical distribution of mountain species. Moreover, it increases along the elevational gradient, following increasing specialization in high-elevation taxa adaptations. The current breeding distribution of the snowfinch is considerably greater than the potential distribution obtained by modelling breeding records with climatic, topographic and land-cover variables. Discrepancies are particularly evident in eastern Europe, where there is a lack of monitoring. Southern populations that live in lower elevation ranges, are more fragmented and isolated and could experience higher range contraction as a consequence of global warming. The species depends on high-elevation habitats throughout the year, although with a higher plasticity during winter, that allows it to cope with an unpredictable environment. Unpredictability of winter conditions at high elevations influences the snowfinch' movements as well. We found that the species undertakes wintering partial migration, connecting the

population of the Alps with those of the northern Iberian ranges, which could potentially reduce genetic drift, with important implications for the resilience and persistence of these populations. Yet, snowfinches seem to move when winter conditions in the Alps are harsher. Global warming might thus reduce migration propensity, with effects on population demography, structure and heterogeneity. Warmer conditions seem also to reduce the size and duration of flocks, potentially increasing the asynchrony with the peak of resource availability, with consequences on breeding performances. This doctoral thesis not only brings novel insights into the ecology of the snowfinch, but it also represents the starting point for future research on population connectivity and dynamics and on the species' responses to climate change.

THESIS 3

POLYMORPHIC COMMON BUZZARDS IN TIME AND SPACE

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Abstract

Visible phenotypic variations within a species, known as polymorphisms, are widespread in plants and animals. These traits, being heritable, provide excellent models for studying micro-evolutionary processes. Fitness, a key concept in evolutionary theory, measures an organism's contribution to the gene pool and helps biologists assess natural selection and microevolution. Morphs coexist at stable frequencies in nature, such as plumage polymorphism in 3.5% of bird species. However, the mechanisms behind the evolution and maintenance of such polymorphisms are often poorly understood. This thesis explores the evolutionary ecology of plumage colour variation in the Common buzzard (*Buteo buteo*). We quantified individual fitness in relation to plumage variation to understand the mechanisms maintaining intraspecific colour variation and its functions. Additionally, we analysed this polymorphism from both temporal and spatial perspectives. Initially, we described the type of polymorphism in buzzards, using pictures and pixel-based colour quantification. Our findings reveal continuous, unimodal variation ranging from very light to very dark individuals, rather than distinct categories. Morph types were stable throughout an individual's lifetime, despite minor darkening with age. Balancing selection likely maintains colour polymorphisms over evolutionary timescales. In buzzards, a proposed heterozygote advantage hypothesis suggested higher fitness in intermediate morphs compared to

light or dark homozygotes. Using social pedigrees of buzzards, we confirmed the high heritability of plumage colour but found no support for a simple Mendelian one-locus, two-allele inheritance model. Instead, plumage colour appears to be a quantitative polygenic trait. Analysing 20 years of reproductive data, we observed fitness differences among morphs, with intermediate morphs having the highest fitness. Assortative mating by morph was common, and such pairs had longer pair bonds and higher reproductive success. We also found an increase in intermediate morph frequencies over time. Finally, we studied the effect of plumage colour on dispersal behaviour using GPS-tracking data. Darker juveniles visited more areas during dispersal compared to lighter individuals, but colour did not affect other dispersal traits or habitat selection. For Common buzzards remarkably little is known about the geographical distribution of the morphs. Therefore, the “Buteo Morph” project was launched, where citizen scientists could enter their sightings and classify coloration in order to map morph distribution for the species on a large scale. Unpublished data show clinal variation in morph frequencies confirming anecdotal information about the presence of higher proportions of darker morphs in the south and increasing frequencies of lighter morphs in the north across their range in Europe.

THESIS 4

FOOD HOARDING OF AN AVIAN PREDATOR UNDER FOOD LIMITATION AND CLIMATE CHANGE

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Abstract

Hoarding behaviour (storing food for later use) has evolved to reduce the risk of starvation when resources are scarce. In this thesis, I studied the food-hoarding behaviour of Eurasian pygmy owls (*Glaucidium passerinum*) under spatio-temporally varying environmental conditions. I investigated differences between age and sex classes, the effect of intra-specific competition, predator responses to the abundance of the main prey, and the effect of climate on the behaviour. The data were collected starting in 2003 in western Finland, where the abundance of voles fluctuates in three-year population cycles. The number of stores per year and the biomass of prey items stored increased with vole abundance. Females and yearlings had larger and heavier stores than males and

adults, respectively. At times of low vole abundance, adult owls stored more small birds and fewer small mammals than yearlings. Females stored more small mammals than males, and showed a tendency to store fewer birds. The numbers of yearlings of both sexes and adult females increased with increasing vole abundance. Owls were less likely than expected to have a neighbour of the same class (sex or age) when the main prey was abundant, suggesting high sex- or age-specific competition. Food stores, however, were mostly larger when the nearest neighbour was of the same sex. In years of low vole abundance, increasing conspecific density reduced the total prey number stored by an owl, suggesting a high cost of competition. The thesis also reveals a strong effect of autumn and winter climate on food-hoarding pygmy owls and on the quality of the stored food. Pygmy owls may be partly able to adapt to climate change by delaying the initiation of food-hoarding. Numerous weather variables nonetheless affect their hoarding behaviour and the perishability of the cached food. Rotten food may be of poor quality and may be connected to a lower recapture probability. In female owls, rotted food hoards, often consumed, are linked with a lower future recapture probability, presumably indicating that they either die or emigrate permanently from the area. Detailed knowledge of age- and sex-related differences in hoarding behaviour under fluctuating abundances of the main prey can thus provide a fundamental tool to

better understand the dynamics of a predator population and its response to climate change.

THESIS 5

INTRINSIC AND EXTRINSIC DRIVERS OF FORAGING MOVEMENTS IN COLONIAL BIRDS

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Abstract

Foraging is a central trait in species' life history, being tightly linked to individual fitness and therefore to population processes. To be successful, individuals should forage in a way that minimise energy expenditure and maximise energy intake. However, this balance depends on a mixture of different elements of intrinsic and extrinsic nature that drive foraging choices of individuals. Intrinsic drivers are elements inextricably linked to an individual's characteristics or qualities that often are a function of age or sex (e.g., dimorphism, social dominance). Extrinsic drivers are elements linked to the surrounding environment that can be abi-

otic (e.g., landscape features, weather), or biotic (e.g., heterospecific/conspecific presence, resources distribution). In this thesis I used a combination of bio-logging technologies and statistical modeling techniques to investigate in detail the drivers of foraging movements in different colonial bird species. Specifically, I investigated intrinsic and extrinsic drivers on sea and land (Chapters I and II), the effects of competition (Chapter III), the role of weather (Chapter IV), how food resources can be found in the sea (Chapter V) and its consequences (Chapter VI). My results suggest that a complex interplay of intrinsic and extrinsic drivers shape spatio-temporal foraging decisions in wild bird species, and their combined effect can be sometimes difficult to disentangle. Wind conditions, rainfall, morphological differences linked to sex, inter- and intra-specific competition all affect how individuals optimize their search for food, via the adoption of different behavioural tactics. Moreover, the search for food is particularly challenging in the marine environment, which is extremely dynamic and three-dimensional. Here, individuals could use a combination of static and dynamic features to locate prey aggregations. However, such features also aggregate contaminants such as microplastic, enhancing the risk of ingestion. In conclusion, understanding the connection between individual qualities, foraging movements and external agents is particularly important given the predicted global changes for future years. Ultimately, behavioural flexibility in foraging could

be an important trait to successfully cope with such changes and could contribute to increasing the resilience of populations over time.

THESIS 6

INDIVIDUAL VARIATION IN AN ECTOPARASITE-HOST SYSTEM: LIFE HISTORY, FITNESS AND EVOLUTIONARY POTENTIAL

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Abstract

Parasites and hosts constitute dynamic interactions exerting reciprocal selective pressures. Host-parasite interactions are thus ideal systems for the study of ecological and coevolutionary processes. However, while the effects of parasites on hosts have been extensively investigated, host-induced parasite evolution and parasite life history have been mostly neglected. In particular, knowledge on the amount of among- and within-individual variation between parasite traits is mostly unknown despite its fundamental importance to understand parasite performance and evolution. In this dissertation,

I report four experimental studies investigating several aspects of parasite individual variation in a songbird-tick system, namely the bird-specialized tree-hole tick *Ixodes arboricola* and its main host, the great tit *Parus major*. First, I investigated behavioural preferences for tick attachment sites on the bird body. Experiments were carried out using three tick species differing in ecology and host specificity both with and without bird grooming restrictions. The experimental findings as well as literature evidence suggest that ticks prefer to attach to the host head and actively move to this area when given the possibility. I hypothesize that this pattern is consistent throughout ixodid ticks feeding on birds. Second, I report how fundamental life-history traits affect individual tick success at every life stage, and estimate their phenotypic and genetic correlation between and within stages as well as the trait evolutionary potential (through animal models). Specifically, I investigated the following life-history traits: feeding time, engorgement weight, moulting time, and number of hatched eggs. Additionally, I accounted for the effect of tick sex, maternal effect, host identity, fasting time and batch. Results suggest differences in tick individual quality, for which engorgement weight seems to be a good proxy. Third, I investigated variation and heritability of host quality from the parasite perspective. Here, I measured to what extent hosts can affect tick performance and life history of larvae and nymphs both on- and off-host. I show that host individual characteristics significantly

influenced larva and nymph attachment success. Additionally, hosts had a heritable effect on tick feeding time and, to a lower extent, on several other traits and success parameters. Lastly, I investigated whether *I. arboricola* males prefer to mate with heavier engorged females in order to obtain a higher fitness. Surprisingly, male mate choice experiments carried out in two different setups showed a lack of preference for heavier females. However, males seem to remember and avoid the mating partners they previously met.

THESIS 7

DYNAMIC SOARING IN THE WINDS OF CHANGE. THE EFFECTS OF WIND AND OCEANOGRAPHY ON THE POPULATION AND SPATIAL ECOLOGY OF SEABIRDS

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Abstract

Despite acting as central place foragers during breeding, most seabirds belonging

to the order Procellariiformes can perform foraging trips covering thousands of kilometres by extracting energy from the wind through a flight behaviour known as “dynamic soaring”. The overarching aim of my thesis is to understand the pathways through which wind and oceanographic processes affect the demography, foraging ecology and spatial distribution of procellariiform seabirds. Focussing on the black-browed albatross (*Thalassarche melanophris*), we investigate the environmental drivers of demography. By developing integrated population models on a demographic database spanning nearly two decades, we found that the population breeding parameters were negatively impacted by ocean warming and positively affected by stronger winds, presumably through bottom-up environmental processes modulating food availability and accessibility. The population was highly sensitive to the survival rate of sub-adults, which comprised approximately half of the total population size. Our demographic investigation also revealed that albatross chick mortality events, clustered at small scales in time and space, suggest the role of an unidentified infectious disease prevalent in the study population. We documented a “habitat-mediated” pathway linking environmental conditions to the breeding processes of social monogamous seabirds. We found a higher prevalence of divorce in resource-poor years characterised by warmer sea surface temperatures, highlighting the direct disruptive effects of ocean warming on the social monogamous bonds of albatrosses. Our work then

focussed on the role of winds in shaping the flight behaviour and the foraging ecology of the hypermobile Desertas petrel (*Pterodroma deserta*) and Bulwer’s petrel (*Bulweria bulwerii*). Desertas petrels used favourable winds to maximise their ground speed and distance covered throughout their round-trip foraging movements. Bulwer’s petrels, on the other hand, exploiting the stable North Atlantic trade winds, exhibited a striking selectivity for crosswinds. By engaging in crosswind zig-zag flight, they maximised both the distance travelled and the probability of detecting odour plumes along the round trip. Crucially, the movement patterns of these two species suggest that seabirds have a priori knowledge of the regional winds and can plan their round-trip with an expectation of predicted wind conditions and costs of flight. Collectively, the findings of my thesis highlight the sensitivity of seabirds to changes in oceanographic conditions and their reliance on winds. Given the accelerating pace of global change, monitoring the diagnostic responses of these “sentinels” of the global ocean is a conservation goal of utmost importance.

Thesis 8

INTERACTIONS BETWEEN ALPINE BIODIVERSITY, SNOW AND CLIMATE CHANGE

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Abstract

Mountain regions cover approximately a quarter of the Earth's surface, harbouring remarkable levels of biodiversity due to diverse habitats occurring along elevation gradients. These areas, exemplified by the Alps, are ideal for ecological research, offering different environmental conditions where to study animal communities. However, climate change and human activities threaten mountain ecosystems, making them among the most vulnerable worldwide. Despite their significance, mountain birds remain poorly studied due to logistical challenges in research. Focusing on European mountain bird assemblages, particularly in the Alps, this thesis examined various aspects of their ecology throughout the year. Starting from a comprehensive literature review, I identified the key drivers of population changes, highlighting direct threats such as mortality and habitat alteration as primary concerns, while the impacts of climate change were more difficult to detect, although increasing in time. Surprisingly, avalanches, despite their primary ecological role in mountain ecosystem dynamics, are poorly studied yet in this thesis I highlighted how they contribute positively to biodiversity by creating habitat mosaics that are suitable for a wide range of threatened species. In contrast,

artificial disturbances like ski pistes can have adverse effects, reducing bird abundance and diversity due to habitat alteration. Nevertheless, with proper management, I argued that ski pistes could serve as refuges for certain open habitat species, particularly against vegetation encroachment. Detailed species-specific studies on mountain birds are lacking and thus one emblematic species, the Northern Wheatear *Oenanthe oenanthe* served as an excellent study species and sentinel for climate change at high-elevations. Crucial habitat requirements during different life stages emphasized the importance of maintaining traditional grazing practices to counteract vegetation changes induced by climate change and land abandonment. At last, the post-breeding migration period emerged as critical for mountain birds, with high-elevation habitats serving as crucial stopover sites rich in trophic resources. Understanding these dynamics is vital for conservation efforts, necessitating further research into habitat interactions and interspecies relationships. By exploring bird assemblages across elevation gradients and seasons, this thesis enhanced the understanding of mountain ecosystems and shed light on previously unknown relationships between bird species and habitats. It underscores the need for comprehensive conservation strategies, stressing the importance of studying ecosystems beyond the breeding season and extending research efforts to other taxa. In conclusion, this research contributed to the broader understanding of mountain bio-

diversity and calls for a holistic approach to conservation, encompassing various habitats and seasons.

THESIS 9

ASSESSING THE IMPACT OF HABITAT AND LANDSCAPE HETEROGENEITY AND LAND-USE CHARACTERISTICS ON MOUNTAIN BIRD COMMUNITIES, AND THE EFFECTIVENESS OF BIRDS AS INDICATOR OF OVERALL BIODIVERSITY

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Abstract

Birds are a crucial component of Alpine biodiversity, however, there is a lack of studies on their ecology. The effectiveness of birds as indicators of biodiversity patterns has been demonstrated in many contexts, but mountain birds remain poorly studied as possible proxies for the diversity of other taxa. This gap

is exacerbated by the environment complexity, unique biodiversity, ecology, and the global changes affecting these regions. Many mountain birds inhabit heterogeneous habitats distributed across ecological gradients, posing challenges to comprehensive studies. Furthermore, the Alps are undergoing significant global changes impacting ecosystem functioning and ecological patterns. Understanding mountain bird ecology and their functions is crucial for effective conservation strategies. This thesis presents four studies analysing drivers affecting mountain bird communities, using diverse methodologies, examining functional and taxonomic indices, and exploring an entire ecological gradient or specific habitat types. The work investigates the effects of landscape composition, climate, and topography on bird communities across landscapes. It relies on data from South Tyrol and integrates different habitat, providing insights into Alpine ecological patterns. It highlights the crucial role of heterogeneity surrounding agricultural and urban/suburban landscapes, of natural/seminatural habitats, and of the continuity of forests. It utilizes remote sensing data to evaluate the impact of landscape heterogeneity and canopy height on bird communities in farmlands. This research highlights the importance of preserving landscape diversity to mitigate the effects of modern agriculture on bird biodiversity. The thesis assesses the role of different successional forest stages on the hazel grouse, a forest specialist species, in a Natura2000 area. The work highlights the

importance of understanding forest dynamics resulting from land-use changes and their implications for conservation. It addresses the impact of deadwood and tree-related microhabitats on bird and bat communities across forest types within South Tyrol. This work adopts a multi-taxon approach, emphasizing the complementary responses of different ecological indicators. It also assesses the potential of birds as reliable bioindicators for evaluating conservation measures and their ecological implications for Alpine biodiversity. Within this research I stress the significance of multi-taxon survey schemes to gain a comprehensive understanding of the whole biodiversity. In sum, this thesis contributes to the understanding of Alpine birds' ecology, their potential as ecological and taxa-based bioindicators, and the intricate relationship of ecological factors shaping their communities. It offers insights for the conservation of Alpine biodiversity and provides a foundation for future research and conservation efforts in the Alps and similar mountain regions.

THESIS 10

CARRY-OVER EFFECTS ACROSS LIFE STAGES IN RED KITES *MILVUS MILVUS*

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Abstract

Understanding behavioural differences among individuals and the mechanisms driving them is increasingly recognized as essential for explaining the demographic patterns of animal populations. Throughout life, external and internal conditions interact to shape distinct behavioural phenotypes, ultimately influencing individual fitness and population structure. However, studies that adopt such mechanistic, longitudinal perspectives remain scarce due to the difficulty of collecting detailed individual-level data. This thesis builds such a framework using an extensive GPS-tracking dataset of red kites (*Milvus milvus*) to explore how early-life conditions shape behavioural development, sociality, and survival across life stages. First, I examined the dynamics of sibling aggression during the nestling stage to understand how food availability and competition influence behavioural differentiation. Using a null-model approach, I found that red kite nestlings strategically adjust aggression according to daily fluctuations in food provisioning, and that these adjustments associate

with a skewed food allocation towards senior siblings when food is scarce, but allow for higher intake of youngest siblings, and thus catch-up growth, when conditions improve. These patterns suggest that food-driven aggression mediates both developmental trajectories and the formation of dominant–subordinate behavioural types. Next, I investigated how early-life nutritional conditions influence the emergence of social behaviour during dispersal. Combining a food supplementation experiment with social network and movement analyses, I found that last-hatched chicks—typically the least competitive—had the fewest social encounters after fledging. However, food supplementation reversed this pattern, leading to increased social interactions and spatial clustering in resource-rich areas. This demonstrates that early nutritional conditions can shape social and spatial phenotypes beyond independence, with implications for population structure. Further, I explored the drivers of variation in winter communal roosting behaviour, hypothesizing that these differences reflect cost–benefit trade-offs across life-history stages. Birds that joined communal roosts showed higher mobility and greater success in locating ephemeral food sources, suggesting enhanced foraging efficiency. Roost attendance declined with age and breeding onset, and was consistently lower in females, indicating that the benefits of communal behaviour vary with experience, sex, and reproductive status. Finally, I assessed the fitness consequences of early-life so-

cial phenotypes and found that high sociality was unexpectedly linked to lower survival, driven by increased mortality from collisions near roads. These findings reveal how anthropogenic environments can transform adaptive behaviours into ecological traps. Collectively, this work highlights the importance of integrating individual–environment interactions over time to understand how behavioural variation shapes population dynamics.

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