

IUCN-SSC Stork, Ibis and Spoonbill Specialist Group Special Publication 4

Proceedings of the International Northern Bald Ibis Symposium

Jerez de la Frontera, Andalusia, Spain 11th - 14th March 2025



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Editor's Letter

The International Northern Bald Ibis Symposium, which will take place in Jerez de la Frontera, Andalusia, Spain, from 11 to 14 March 2025, marks a significant milestone in the long and collaborative journey towards the recovery of the Northern Bald Ibis *Geronticus eremita*. The symposium will bring together a diverse body of work reflecting decades of dedication and international cooperation aimed at securing the future of one of the world's most emblematic bird species.

The Northern Bald Ibis is a symbol of both loss and resilience. Once widespread across Europe, North Africa and the Middle East, the species experienced a dramatic population decline due to human activities and environmental changes. Its near-extinction catalysed a global conservation response that continues to evolve today. The contributions compiled in this issue demonstrate how far this effort has progressed, from safeguarding the last remaining wild populations to re-establishing them across their historical range.

A central theme emerging from these proceedings is the integration of multiple conservation strategies. The long-term success of “*Proyecto Eremita*” in establishing a sedentary population in southern Spain, the restoration of lost behavioural traditions in Central Europe through human-led migration, and the efforts to establish populations along the Mediterranean coast of Africa all exemplify the importance of adaptive, science-based management in the recovery of the Northern Bald Ibis. These approaches are further strengthened by advances in tracking technologies, veterinary care, genetic management and threat mitigation, all of which are well represented in this Special Publication.

The IUCN SSC Stork, Ibis and Spoonbill Specialist Group is firmly committed to promoting the conservation of the Northern Bald Ibis and other species within its remit. This commitment is demonstrated through supporting international working groups, facilitating collaboration among experts and institutions, and leading initiatives across the entire species conservation cycle, from assessment and planning to implementation and monitoring. These efforts depend on the support of partner institutions and the broader IUCN network, whose financial and institutional backing is essential for sustained, coordinated long-term conservation action.

It is equally important to recognise that conservation is not solely a biological endeavour. Several contributions emphasise the vital importance of education, community engagement and interdisciplinary collaboration. The involvement of local stakeholders, students and citizen scientists emphasises a shift towards more inclusive conservation models that consider the social and cultural contexts of species recovery.

The symposium also provided an important platform for regional dialogue. Contributions from North Africa, the Middle East, and Europe emphasise the transboundary nature of conservation challenges and the necessity of coordinated international frameworks.

Despite the considerable progress documented here, significant challenges remain. Anthropogenic mortality, habitat pressures and the emerging impacts of climate change continue to threaten population viability. These proceedings highlight the need for



sustained monitoring, policy support, and innovative solutions. Notably, the lessons learned from the northern bald ibis are widely applicable, providing valuable insights into reintroduction biology and species recovery efforts worldwide.

I would like to express our sincere gratitude to all the contributors, reviewers and partners who made this publication possible. The collective expertise represented here demonstrates a genuine international dedication to conservation. I would also like to acknowledge the field teams, institutions and local communities whose daily efforts form the foundation of the achievements described within.

I hope that this Special Publication will not only document progress, but also inspire continued collaboration and action. The recovery of the Northern Bald Ibis is ongoing, and its future depends on our ability to adapt, innovate and collaborate across disciplines and borders.

Luis Santiago Cano Alonso

Chair, IUCN SSC Stork, Ibis and Spoonbill Specialist Group

Foreword

The International Northern Bald Ibis Symposium, held in Jerez de la Frontera, Spain, from 11–13 March 2025, brought together researchers, conservation practitioners, and institutional partners committed to the recovery of one of the world's most historically significant bird species. Hosted at the historic Alcázar of Jerez, whose Moorish architecture reflects the cultural landscape of the species' former range, the symposium welcomed 66 participants from 14 countries. During the meeting, 29 presentations and 9 posters were presented by scientists, conservation practitioners, zoo professionals, government representatives, and students, highlighting the growing international community dedicated to the conservation of this remarkable species.

The reintroduction of the Northern Bald Ibis *Geronticus eremita* has become a powerful example of how coordinated international efforts can reverse the decline of a species once lost from much of its historical range. The contributions collected in this volume reflect the wide range of work currently supporting its recovery and demonstrate that effective conservation depends on the integration of practical field measures, long-term management strategies, genetic management, and a strong scientific foundation.

Ex situ breeding programmes coordinated through the European Endangered Species Programme (EEP), including long-term studbook management and associated research, remain essential for maintaining a genetically viable assurance population and for providing individuals for reintroduction and research. Alongside these efforts, reintroduction projects, migration restoration, anti-poaching initiatives, veterinary monitoring, behavioural research, and technological innovations such as GPS tracking and remote sensing continue to advance both conservation practice and scientific understanding.

A central theme of the symposium was the importance of international cooperation. The recovery of the Northern Bald Ibis as a migratory species cannot be achieved through isolated national initiatives but requires coordinated collaboration across Europe, North Africa, and the Middle East. This network links governmental institutions, research centres, conservation organisations, zoological institutions, and local stakeholders.

This collaborative approach was further strengthened during the symposium through the establishment of a new partnership between the Andalusian Regional Government (Junta de Andalucía), representing the sedentary population of “*Proyecto Eremita*”, and Waldrapteam Conservation & Research, representing the European migratory population. The signing of a Memorandum of Understanding marks the beginning of a coordinated conservation initiative spanning six European countries and an area of approximately 600,000 km², connecting colonies and migration routes from the northern Alpine foothills to Tuscany and Andalusia, with additional colony development planned along the Mediterranean coast in Catalonia and Valencia.

Several contributions also highlight developments in regions historically central to the species' distribution. The paper from Morocco provides important insights into the status of the last wild population within the species' historical core range and its continued expansion from Souss-Massa National Park through habitat protection, monitoring, and adaptive management. The contribution from Turkey summarises the long-term



conservation work at the Birecik breeding station, where intensive management and scientific monitoring have prevented the extinction of the remaining population while exploring future conservation strategies. The paper from Algeria explores the historical occurrence of the Northern Bald Ibis and ongoing efforts to rediscover former breeding sites and assess the feasibility of future reintroduction through field research and community engagement.

On behalf of the organizers of the symposium, I would like to express my sincere gratitude to all contributors for sharing their work and expertise. I would also like to thank my co-organizers: Catherine King (Zoo de Lagos, EAZA), Juliane Pokorny (Alpenzoo Innsbruck, Northern Bald Ibis EEP Coordinator), Miguel Ángel Quevedo (Zoobotánico Jerez, Proyecto Eremita), and Barbara Steininger (Schönbrunn Zoo and Waldrappteam Conservation and Research, LIFE Northern Bald Ibis). The continued exchange of knowledge and experience across disciplines and countries will remain essential in our efforts to secure the long-term recovery of the Northern Bald Ibis.

Johannes Fritz

Leader, Waldrappteam Conservation & Research

Credits & Acknowledgements



**LIFE20 Northern Bald Ibis (LIFE20
NAT/AT/000049 – LIFE NBI)**



**EAZA Pelecaniformes, Ciconiiformes
and Phoenicopteriformes Taxon
Advisory Group**

PELECANIFORMES, CICONIIFORMES & PHOENICOPTERIFORMES
TAG



**European Association of Zoos and
Aquaria**



Proyecto Eremita



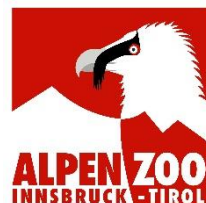
**Waldrappteam Conservation &
Research**



LIFE Programme (European Union)

Co-funded by
the European Union

Additional Partners:



Programme

TUESDAY

11.03.2025

17:00	Registration
18:30	Welcome & Icebreaker

WEDNESDAY

12.03.2025

09:00	Official welcome	
09:20–10:00	Miguel Angel Quevedo Jose Cabral	<i>Proyecto Eremita</i>
10:00–10:20	Luis Santiago Cano Alonzo	<i>Tracking Northern Bald Ibis in “Proyecto Eremita”: A Quick Overview</i>
10:20–10:40	María Jesús Fernández María Victoria Gutiérrez Ruíz Christian Ceballos Relinque Indhira Domínguez Márquez Claudia Pineda Peña Celia Tirado Oliva Érika Tirado Oliva	<i>Waldrappteam’s Northern Bald Ibis Field Data Collection in Andalusia: Towards a Connection Between Science and Education.</i>
10:40–10:50	Discussion of the previous presentations	
10:50–11:20	Coffee break	
11:20–11:40	Johannes Fritz	<i>Northern Bald Ibis in Europe: 20 Years of Conservation, Research, and Reintroduction Success</i>
11:40–12:00	Anne-Gabriela Schmalstieg	<i>Safeguarding the Northern Bald Ibis: Integrating Management Measures and GPS Tracking</i>
12:00–12:20	Laura Stefani	<i>Protecting Northern Bald Ibis from Illegal Hunting in Italy</i>
12:20–12:40	Bernhard Gönner	<i>Electrocution on Medium Voltage Power Poles: Threat to the Reintroduced Northern Bald Ibis Population and Measures Against It</i>
12:40–13:00	Barbara Steininger	<i>The Method of Human-Led Migration: A Unique Approach to Restore the Migratory Tradition of Birds Like the Northern Bald Ibis</i>
13:00 –13:10	Discussion of the previous presentations	
13:10–14:10	Lunch	
14:10–14:30	Didone Frigerio	<i>The Northern Bald Ibis as a Model for Behavioural & Conservation Studies at the Konrad Lorenz Research Center</i>

14:30–14:50	Sarah Wirtz	<i>Insights into the Northern Bald Ibis Genetics in European Zoo Populations, Recommendations for Captive Breeding and Reintroduction</i>
14:50–15:10	Sinah Drenske	<i>On the Road to Self-Sustainability: Population Viability of Reintroduced Northern Bald Ibises</i>
15:10–15:30	Alexandra Scope	<i>Veterinary Care of the European Migratory Northern Bald Ibis Population</i>
15:30–15:50	Helena Wehner	<i>Remote Sensing for Conservation of the Northern Bald Ibis – Ongoing Studies and Opportunities</i>
15:50–16:00	Discussion of the previous presentations	
16:00–16:30	Coffee break	
16:30–18:00	Poster presentations	
18:00	End of official agenda	

THURSDAY

13.03.2025

09:00–09:20	Melissa Lewis	<i>Species Action Planning and Implementation under the African-Eurasian Migratory Waterbird Agreement</i>
09:20–09:40	Chris Bowden	<i>Establishing the International Working Group, Its role & Outcomes for Conserving the NBI</i>
09:40–10:00	Amina Fellous Djardini	<i>The Bald Ibis in Algeria: Between the Past and the Future</i>
10:00–10:20	Latifa Sikli	<i>The National Action Plan for Conservation of the Northern Bald Ibis in Morocco</i>
10:20–10:40	Latifa Sikli	<i>The Wild Northern Bald Ibis: Expanding from Souss-Massa National Park to the World.</i>
10:40–11:00	Nurben Koptekin	<i>The Status of the Northern Bald Ibis in Turkey</i>
11:00–11:10	Discussion of the previous presentations	
11:10–11:40	Coffee break	
11:40–12:00	Jorge Orueta	<i>Northern Bald Ibis Conservation from SEO/BirdLife's Perspective and Experience</i>
12:00–12:20	Bernat Garrigós	<i>Proposal for the release of NBI in the region of Valencia (Comunidad Valenciana)</i>
12:20–12:40	Miguel Casares	<i>Proposal for the release of NBI in the region of Valencia (Comunidad Valenciana)</i>
12:40–13:00	Juliane Pokorny	<i>The Northern bald ibis EEP - an Overview and Current Data</i>
13:00–13:10	Discussion of the previous presentations	
13:10–14:00	Lunch	

14:10–14:30	Caterina Spiezio	<i>Individual and Social Behaviour of Juveniles and Adults of Northern bald ibis (Geronticus eremita): Ex-Situ Conservation for Reintroduction.</i>
14:30–14:50	Tatiana Beuchat	<i>20 Years of Support for Species Conservation</i>
14:50–15:10	Willam Costa	<i>An Introduction to the EAZA Conservation Translocation Working Group</i>
15:10–15:30	Thomas Grangeat	<i>Management of a Free Flying Group of 14 Bald Ibis</i>
15:30–15:40	Discussion of the previous presentations	
15:40–16:10	<i>Coffee break</i>	
16:10–16:30	Markus Unsöld	<i>Some New Historical Facts about the Northern Bald Ibis in Europe</i>
16:30–16:50	Carlos Castillo Gomez	<i>Can the Northern Bald Ibis Become a Rock Star? Should It?</i>
16:50–17:00	Discussion of the previous presentations	
19:30	<i>Collective dinner at a local restaurant</i>	

FRIDAY

14.03.2025

08:30 - 09:00	<i>Meeting and departure for excursion</i>
10:00 - 13:00	<i>Excursion to local NBI breeding sites</i>
13:00 - 14:00	<i>Lunch at a local restaurant</i>
14:00 - 15:00	<i>Excursion to local NBI breeding sites</i>
16:00	<i>Arrival back in Jerez - official end of Symposium</i>



Participants

Name	Institution Represented	Country represented
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Participants of the International NBI Symposium 2025. Photo: Stephanie Peters

Proceedings



Photo: Bernat Garrigós

Update of Proyecto Eremita

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Abstract

Proyecto Eremita started in 2004 as a joint project between Zoobotánico Jerez and the Regional Environment Ministry of the Andalusian Government. At present, the Andalusian population is considered sedentary and is composed of around 300 birds with 37 breeding pairs distributed over three breeding sites in the region of La Janda, Cádiz, southern Spain. For the last 20 years, 695 EEP birds from EAZA zoos have been released. During the first seven years, the primary release method used was hand-rearing by characterized foster parents dressed with an ibis-shaped helmet and black t-shirts to slightly distort the human figure. Once the initial hand-rearing group had settled in the wild-selected area, an average of 30 juvenile birds from EAZA zoos were released annually until 2024. These birds were kept in the aviary for an acclimatization period of 2 months before release. All birds are marked with a white or yellow metal and plastic ring. Some of them were fitted with GPS/GSM transmitters for geolocation tracking. Currently, this population seems to be stable and sedentary with annual breeding. The main mortality causes are electrocution (19.7%), traumatismos (19%), and predation (17.4%). At present, the population is under monitoring to assess whether it can be considered self-sustaining. In the last 20 years, another ongoing reintroduction program has been developed in Europe by the Waldrappteam under the LIFE-Northern Bald Ibis. In both projects, the final objective is to establish a viable and self-sustaining sedentary and migratory population, respectively, in their distribution area. Proyecto Eremita has collaborated since 2023 with the Waldrappteam-LIFE-NBI to consolidate a migratory route connecting both populations. This is a good example of how international conservation organizations, governments, the EEP, and EAZA zoos are working together to ensure the long-term survival of this endangered species in Europe.

Introduction

In 1989, the Northern Bald Ibis *Geronticus eremita*, classified as a critically endangered species, was facing a critical situation. The remaining migratory Eastern population in Turkey was declared extinct in the wild. That same year, the global population was reduced to a small colony located in Morocco, consisting of approximately 250 individuals and fewer than 50 breeding pairs. Due to the species' critical situation and high risk of extinction in the wild, international expert meetings were held to reverse the declining trend of the species. One of the first measures taken was to strengthen protection and implement conservation programs for the last wild population in Morocco. The implementation of these measures has led to the current Moroccan population of Northern Bald Ibis reaching approximately 750 individuals, of which around 120 are breeding pairs. In addition to this important in-situ conservation action for the last wild Northern Bald Ibises, efforts have been proposed to recover populations in parts of the species' historical range, such as Algeria and Syria, although these efforts have not yet been implemented. Only Turkey, in the Bireçik region, has maintained a growing population of Northern Bald Ibises in aviaries under semi-wild conditions.

The next conservation step for the species was to develop reintroduction programs in areas where it had previously gone extinct. In Europe, where the species became extinct in the 17th century, two reintroduction projects have been developed: one in Central Europe (Waldrappteam-LIFE NBI), aimed at establishing a migratory population, and another in southern Spain, in the province of Cádiz (Proyecto Eremita), with the goal of establishing a sedentary population. Both projects use captive-bred birds from the EEP programs of EAZA ZOOS.

Proyecto Eremita

This is a joint project between the Jerez Zoo and Botanical Garden (Zoobotánico Jerez) and the Regional Government of Andalusia, with the aim of establishing a stable, sedentary, and self-sustaining population in the La Janda region. It began in 2003 with field studies and awareness, sensitization, and education campaigns targeting local communities.

Over the 20 years of the project, two main phases can be identified: an experimental phase (2004–2013) focused on testing release methods, and a reintroduction phase starting in 2013, when the project was officially approved by the Spanish Ministry of the Environment.

Methods

Release area

The La Janda region, in the province of Cádiz, was selected as the release site due to its highly favourable ecological conditions for the species, a choice that has proven successful. A year-long field study was conducted in 2003 to assess several key factors, such as food availability, prey quantity and diversity, and potential risks including predators, electrocution, wind farms, illegal hunting, pesticide use, freshwater sources, rocky cliffs, and suitable structures for nesting. The extensive grasslands and traditional livestock farming, along with appropriate nesting areas, made La Janda a suitable habitat for the species. The next step was to select the location for building the acclimatization and release aviary. A military area was chosen, Sierra del Retín, which provided a degree of protection and was located directly opposite the Barbate cliffs.



Figure 1. Original aviary built at Retin area, with view of Barbate cliffs

At first, it seemed like the right place for the release aviary, although over time it became clear that it was not suitable due to pressure from natural predators, such as the European eagle owl. In 2018, a new acclimatization and release aviary was constructed on the property of Pierre Gay in San Ambrosio. This turned out to be a great success due to its location in a more human-influenced area, surrounded by grasslands suitable for the species, where some Northern Bald Ibises were already foraging. Over time, we've observed that the species appears undisturbed by human activity and, in fact, seems to seek out the added safety of these areas, avoiding natural predators.

Awareness and education campaigns

Before beginning the release of individuals in the La Janda region, awareness, sensitization and education programs about the species were developed. Meetings and talks were held with livestock farmers, agricultural workers, hunters, the local population, and schools to inform them about Proyecto Eremita and how a new bird species was going to become part of the regional fauna.



Figure 2. Educational campaign of Northern Bald Ibis conservation at Jerez zoo

Release Protocol

In the early years of the project, hand-rearing with characterized foster parents was used to establish the primary group in the region. The eggs from the Zoobotánico Jerez were artificially incubated in an incubator at 37.4° C temperature and 55% humidity with automatic turning. After a period of 27 to 28 days, the chicks hatched and were hand-raised by Proyecto Eremita staff. Foster parents, dressed in black shirts and wearing ibis-shaped helmets, hand-reared the chicks. This approach was designed to prevent or minimize human imprinting, ensuring the chicks remained focused on their species' natural behaviour. Once the chicks reached 30–40 days of age, they were transferred from Jerez Zoo to the release aviary in the Sierra del Retín, where they were placed on artificial ledges simulating nests. At approximately 47 to 50 days old, when the young birds reached the fledgling stage, they began to leap from the ledges to the ground, marking the start of their first flights within the aviary. Before being taken outdoors, all birds were marked with a metal ring bearing an official number and a plastic ring with an

alphanumeric code. It was then that they were allowed to leave the aviary and to begin exploring the surrounding area, guided by their characterized human foster parents. The use of insects such as mealworms, crickets, and grasshoppers were essential to stimulate foraging behaviour and strengthen the bond between the birds and their foster parents. Once the entire group of ibises was flying outdoors, their foraging distances with the foster parents gradually increased, reaching up to 3–4 km from the aviary. Every day, they were taken outside, where the characterized foster parents awaited them and stimulated them with calls, whistles, or clicking sounds they had been accustomed to since they were chicks. One way to confirm that the "ibis parent" disguise was effective was the fact that when the foster parents removed their black shirts and ibis-helmets, the birds would move away and not allow them to get close.



Figure 3. A group of hand-reared juveniles' birds foraging along with their human foster parents.

At the end of each day of ranging, foraging for food and water, and exploring new areas, always accompanied by their foster parents, the birds were safely returned and secured in the aviary for the night, where they remained until the following day. This outdoor exploration and training protocol was repeated daily until mid-August, after which the birds were kept in the aviary until November to prevent the possible phenomenon of "juvenile dispersal," in which some young birds fly off to explore new areas. During the first eight years (2004–2012), hand-rearing was used as the primary method to establish the initial group of birds at the release site, Sierra del Retín, which, as mentioned earlier, was not ideal due to high predator pressure in the area. This hand-rearing method was extremely costly in terms of finances, staff dedication, and effort. Therefore, we began exploring the integration of juveniles raised by their natural parents into the group of hand-reared birds as a second release strategy. These juvenile birds came from EAZA-accredited European zoos and were selected by the EEP coordinator. Upon arrival, the birds were ringed with both metal and plastic rings with alphanumeric codes, underwent veterinary checks, and were kept in the acclimatization aviary for about two months before final release. The release date was chosen based on factors such as weather forecasts and the presence of other ibises in the surrounding area. This second method showed promise, but once again, predator presence in the area negatively affected release outcomes. Due to the high concentration of predators, it was decided to change the release location to a more humanized and suitable area for the birds. The new acclimatization and release aviary was built in 2018 in an area known as San Ambrosio, on land owned by Pierre Gay, a friend, and the owner of the

Doué-la-Fontaine Zoo. This new area has proven to be one of the greatest successes of the Proyecto Eremita.

Veterinary Protocol

All birds used in this project come from the captive breeding programs of EAZA-accredited European zoos and therefore undergo prior health control at their origin zoo's veterinary service. Animal health regulations for zoos in Europe, include routine checks for certain avian diseases, such as avian influenza, Newcastle disease, West Nile virus, and psittacosis. These annual checks are designed to ensure the optimal health and well-being of the zoological collection. As a requirement, zoos of origin are asked not to send any individuals if they have detected avian tuberculosis in their Northern Bald Ibises or any other avian species within the past 10 years. Once the birds arrive at Zoobotánico Jerez, they are placed in quarantine in an isolation aviary, where faecal samples are taken to check for parasites and tests are performed for major avian diseases including avian influenza, Newcastle disease, and West Nile virus.

Monitoring the sedentary population

The already established population in the La Janda region requires routine tracking and monitoring. On one hand, there is a monitoring plan for the free-ranging birds, including the recovery of any sick or dead individuals by the environmental agents of the Junta de Andalucía. Injured or sick birds are taken to the Zoobotánico Jerez for veterinary treatment. Dead birds are sent to the Analysis and Diagnostic Centre of the Junta de Andalucía for post-mortem examination. The main mortality causes are electrocution (19.7%), traumatismos (19%) and predation (17.4%). Once a year, a coordinated census is carried out to estimate the number of birds in the wild. This is done by counting birds at known roosting sites and reading leg rings whenever possible. During the breeding season, nests are counted and breeding pairs identified. Once the chicks have reached an appropriate size and before they fledge, the annual ringing campaign is conducted. Team members ascend to the nests to tag the chicks with both metal and numbered plastic rings. Some chicks are also fitted with GPS transmitters, and biological samples such as blood are taken for sex determination and viral analysis, along with a veterinary check to ensure they are in good health.



Figure 4. Leg banding campaign at one of the breeding sites.

Results

After 20 years of work, releasing juvenile Northern Bald Ibises in the release area, the Janda region, Cádiz, a sedentary population of around 300 individuals has been established, including about 37 breeding pairs and 3 regular breeding sites where they nest every year. Results can be summarized as follows:

- We learned how to establish a stable, sedentary population at the release site.
- The release site must be carefully selected, considering both the advantages and limitations, to ensure the successful establishment of the Northern Bald Ibis population.
- To establish an initial group in the area, the use of hand-rearing techniques ensures social bonds between the reared individuals and their attachment to the first foraging area they use as their flying grounds, following the training protocol.
- Once the primary group is established and attached to the release area, the next step is to integrate newly reared juveniles from natural parents sourced from EEP/EAZA zoos.
- The EEP program through European EAZA zoos is the source of the juvenile birds used in the reintroduction programs.
- A motivated and dedicated team is necessary for the monitoring, tracking of the population, and conducting leg banding campaigns and annual censuses.
- Raising awareness among the local population, students, farmers, ranchers, and hunters about living with this new species has been key to its social acceptance.
- International exchange and cooperation in Northern Bald Ibis conservation.

Acknowledgements

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Tracking Northern Bald Ibis *Geronticus eremita* in Proyecto Eremita: A Quick Overview

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Abstract

The Northern Bald Ibis *Geronticus eremita* is one of Europe's rarest birds, with historic populations once spanning large parts of the Mediterranean. Centuries of hunting, habitat loss and environmental changes led to its disappearance from most of its former range. The Proyecto Eremita, launched in 2004 in Andalusia, southern Spain, has been working to re-establish a free-ranging population. Since the project began, 598 individuals have been released into the wild by 2023, with the goal of creating a self-sustaining population.

Background and Research Questions

From early on, researchers and conservationists raised crucial questions about the population's potential movements: Could this reintroduced group develop a migratory behaviour similar to historical populations? Would birds attempt to cross the Strait of Gibraltar into North Africa, potentially connecting with the Moroccan colonies? Was there a risk of genetic exchange with the Moroccan colonies?

These questions took centre stage after a 2017 short note in *Oryx Journal* highlighted the uncertainties around the Spanish population's dispersal tendencies (Muñoz and Ramírez 2017). Specifically, the authors asked whether birds would move south toward Morocco, whether they would return if they crossed, and whether they could reach existing colonies in Morocco. A year later, additional colleagues revisited the same questions, curious about any signs of migratory patterns developing.

Tracking Effort and Dataset Overview

To address these questions, a comprehensive GPS tracking program began in 2014. The Proyecto Eremita has used two types of transmitters of 23–35 g: OrniTrack-25 (Ornitela) solar-powered GPS/GSM tracker and Druid (DEBUT series prototypes, Devices of Biological Ubiquitous Telecommunication) by Interrex-Tracking.com, model LEGO 2G with raised solar panel. By 2023, 269 ibises had been tagged and monitored. The sample was slightly male-biased, with around 100 females and a single bird of undetermined sex. Importantly, this group included 124 wild-born birds, offering a valuable opportunity to compare behaviour between wild-born and captive-bred individuals.

The tracking period averaged just over one year per bird, though this varied due to mortality, loss of signals, or birds moving out of range. This variability made careful modelling necessary to avoid skewed interpretations based on individual tracking lengths.

Movement Patterns and Home Range Analysis

The tracked birds mostly stayed within a range of 60,000 km² in southern Spain (Figure 1), with their daily movements largely concentrated within a core area of about 8,000 km².

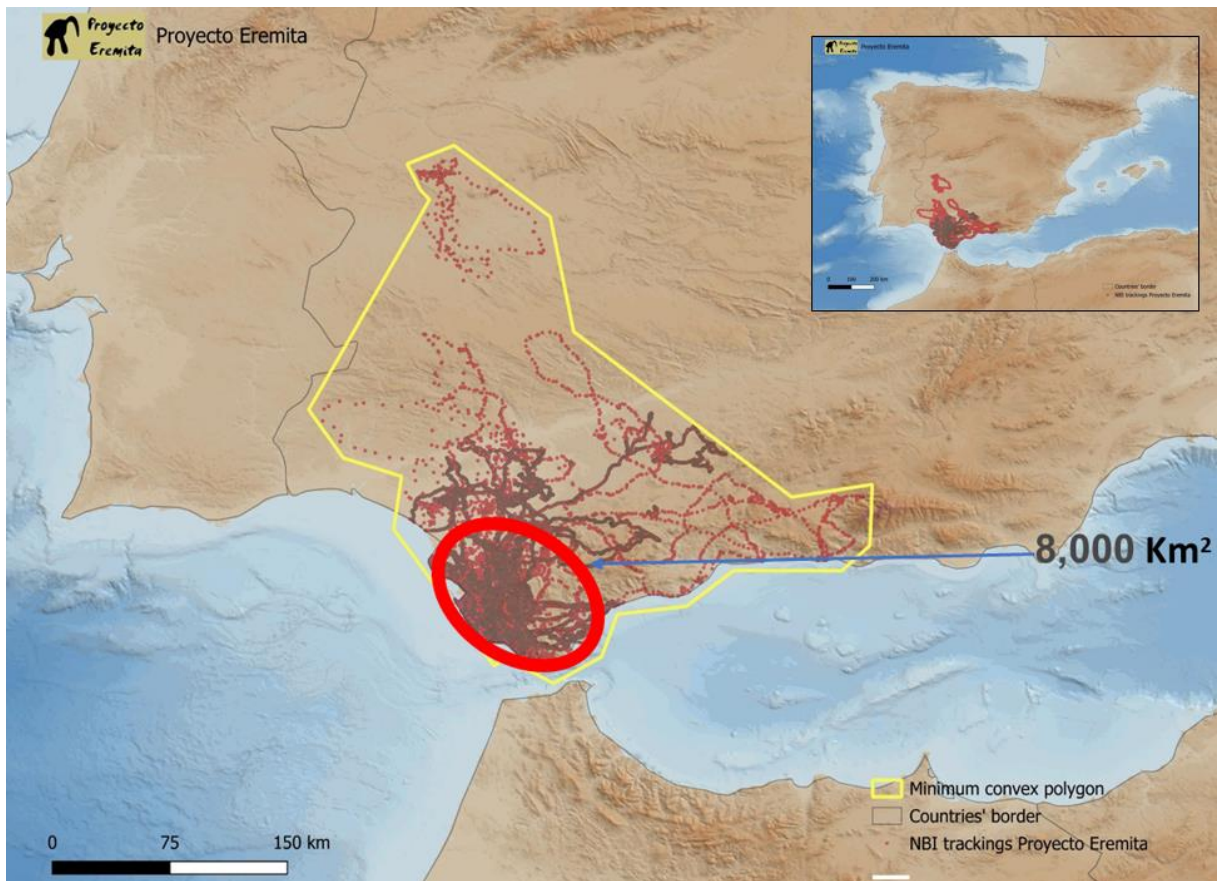


Figure 1. Movements of 269 Northern Bald Ibis between 2014 and 2023

Due to the different period of time for tracking among the birds, instead of producing a generalized home range for the population, we modelled individual home ranges while controlling for key variables such as age and origin (captive- or wild-born). They standardized their analysis based on 172 days of data, selected as the period during which most birds were monitored.

The results revealed significant differences in movement behaviour. Males exhibited larger home ranges than females, suggesting they move more widely—potentially linked to territorial behaviour or breeding-related activities. Perhaps even more intriguing was the difference between captive-bred and wild-born birds. Wild-born ibises had significantly larger home ranges, implying a stronger tendency or ability to explore their environment.

Why wild-born birds move more remains an open question. It could relate to their natural early-life experiences, better survival skills, or fewer behavioural limitations compared to their captive-bred counterparts. Further studies are needed to explore these hypotheses, but the

findings already highlight the importance of fostering wild-born individuals in reintroduction projects.

Southward Movement and Gibraltar Crossing

The core conservation question—whether these birds would migrate south—was explored through both the tracking data and the Spanish Migres program, which monitors bird migration across the Strait of Gibraltar.

Observations from Migres reported 61 ibises moving south toward the Strait. However, these sightings only confirmed the birds were heading in that direction, not that they completed the crossing. In fact, many were later seen turning back or were never seen again. Crucially, among the 269 GPS-tracked birds, not a single individual successfully crossed the Strait of Gibraltar.

There are scattered reports of ringed birds showing up in Morocco, confirming that crossing is technically possible. However, the consistent absence of crossings in GPS data suggests that, at least for now, regular migratory behaviour or long-distance dispersal toward North Africa is not occurring within this population.

The reasons remain speculative. The population may still be too small, or environmental and behavioural triggers for migration might be absent. It could also be a matter of generational change; as more wild-born birds mature, patterns might shift. Alternatively, habitat conditions or landscape barriers may discourage such long-range movements.

Mortality and Threat Assessment

The study also provided valuable data on mortality causes. Predation and what the researchers called “retropulsion”—possibly involving intraspecific aggression or behavioural stress—were significant factors. Drowning also accounted for some losses. Interestingly, the growing number of wind farms across Andalusia did not emerge as a major threat. Although soaring birds like ibises are vulnerable to turbine collisions, wind farms accounted for very few deaths in this dataset.

Preliminary Conclusions and Conservation Implications

Overall, the Andalusian population of Northern Bald Ibis appears largely sedentary, with home ranges expanding based on sex and origin but showing no strong migratory impulses toward Africa. This suggests that re-establishing a natural migratory link between Europe and Morocco is unlikely without active human intervention, such as managed migrations or translocations.

The behavioural differences between wild-born and captive-bred birds stand out as a critical insight. Wild-born individuals seem better adapted to broader ranging behaviours, raising important questions for reintroduction programs globally. Ensuring a high proportion of wild-born birds could enhance population resilience and natural movement potential.

This project’s findings will be published in *Oryx* in 2026 (Fernández-López *et al.* in press), with detailed modelling results and conservation recommendations. However, it is clear that further long-term monitoring is essential. Future generations may behave differently, and environmental changes could alter current patterns. Identifying key habitats, protecting movement corridors, and continuing to study mortality factors will be vital for ensuring the population’s long-term success.

Looking Ahead

The story of the Northern Bald Ibis in Spain is still evolving. For now, the birds seem to have adapted to their Andalusian landscapes, thriving in certain areas but not yet venturing into the kind of long-range migration that many hoped might develop. Whether this changes as the population grows or new environmental pressures emerge remains to be seen.

What's clear is that the data gathered over the last decade offers invaluable insights not just for ibises but for reintroduction projects worldwide. The balance between captive breeding and fostering wild-born behaviour, the need for robust movement and mortality data, and the ongoing evaluation of potential threats like wind farms—all these lessons will serve future conservation efforts.

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Post-Release Monitoring of juvenile Northern Bald Ibises in Andalusia: Linking Conservation and Secondary Education

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Abstract

This article derives from a joint presentation delivered at the I International Northern Bald Ibis Symposium and synthesizes the contributions of conservation practitioners and secondary school students involved in post-release monitoring of Human-Led Migration (HLM) Northern Bald Ibis *Geronticus eremita* in Andalusia, Spain. The monitoring framework builds upon the long-term conservation work of Waldrappteam, as well as Proyecto Eremita led by Zoobotánico Jerez, which established and consolidated the sedentary population in southern Spain. Between February 2023 and February 2024, systematic field monitoring was conducted in the province of Cádiz following the arrival of HLM cohorts from Central Europe. The initiative was integrated into the Research Baccalaureate programme ‘Investiga y Descubre’ at IES La Janda, allowing five students to participate in standardized habitat sampling, GPS-based tracking interpretation, and incident-response protocols. During the study period, approximately 300 sedentary ibises were recorded in the region, while 32 juveniles arrived from Germany under the 2023 HLM programme. Post-release integration with the resident population was seamless. This article presents the ecological context, monitoring framework, student research contributions, and educational implications of this collaborative model. The experience demonstrates how structured integration of formal secondary education into operational conservation projects can strengthen both scientific practice and environmental learning.

Introduction

This International Northern Bald Ibis Symposium brought together researchers, conservation practitioners, and educators working on the recovery of Northern Bald Ibis *Geronticus eremita*. The presentation summarized here was delivered jointly by a conservation volunteer affiliated with Waldrappteam and Sociedad Gaditana de Historia Natural (SGHN), a secondary school research coordinator, and five students participating in a Research Baccalaureate programme in Andalusia.

The session aimed to illustrate how post-release monitoring of Human-Led Migration (HLM) ibises in southern Spain became not only a conservation task but also an educational framework embedded within formal secondary education. This article restructures that joint intervention into a scientific narrative while preserving its integrated and collaborative character.

Conservation Context: HLM and the Cádiz Population

The Northern Bald Ibis is the focus of coordinated European reintroduction efforts. One of the most innovative strategies is Human-Led Migration (HLM), whereby trained human caretakers guide juvenile birds along migratory routes using microlight aircraft to establish learned migration traditions.

In 2023, 36 juvenile ibises departed from Germany under the HLM programme. Approximately three individuals were lost during migration. The remaining birds reached Andalusia and underwent acclimatization prior to release.

Simultaneously, the province of Cádiz supported an established sedentary population derived from earlier reintroduction efforts. By December 2023, approximately 300 individuals were recorded during census activities.

Post-release observations indicated seamless integration between HLM arrivals and the sedentary population. Birds shared feeding territories and roosting areas, primarily remaining near San Ambrosio during the initial months. In spring, some juveniles dispersed northward along established migratory corridors, in documented cases accompanied by locally born individuals, suggesting emerging inter-population connectivity.

Embedding Monitoring within a Secondary Research Programme

The educational dimension of this initiative was structured through the Research Baccalaureate programme at IES La Janda (Vejer de la Frontera), coordinated by María Victoria Gutiérrez Ruiz (PhD in Biological Sciences) within the regional ‘Investiga y Descubre’ framework. Five students participated throughout the 2023–2024 academic year, engaging in sustained research activities connected to post-release monitoring of Northern Bald Ibis in Cádiz.

Field integration and continuous mentoring were provided by María Jesús Fernández Vélez, who served as project tutor and field supervisor. In this role, she guided the five students during habitat sampling sessions, ensured methodological accuracy in data recording, supported interpretation of GPS tracking information, and acted as the operational link between the school-based research programme and conservation workflows implemented within Waldrappteam and Proyecto Eremita led by Zoobotánico Jerez.

This dual supervision structure — academic coordination at school level and field-based mentoring within the conservation project — allowed the five students to participate in authentic research processes while maintaining scientific consistency and integration with ongoing post-release monitoring.

Student Research Contributions within the Monitoring Framework

The following subsections synthesize the thematic contributions presented by the participating students at the International Northern Bald Ibis Symposium. Each subsection corresponds to an individual research focus developed within the broader post-release monitoring programme conducted between February 2023 and February 2024.

Population Adaptation and Cohort Integration (Indhira Domínguez Márquez)

Indhira Domínguez Márquez examined the ecological context of the Northern Bald Ibis in the province of Cádiz, focusing on the distinction between sedentary individuals established through earlier reintroduction efforts and migratory cohorts arriving under the Human-Led Migration (HLM) programme.

Her analysis addressed breeding colonies located at La Barca de Vejer, Torre de Castilnovo, and Finca Eremita de San Ambrosio, as well as post-breeding movements toward feeding areas in the La Janda region. During the study period, approximately 300 sedentary individuals were recorded in the region (December 2023 census). The 2023 HLM cohort, consisting of 35 juveniles departing from Germany (with three losses during migration), integrated seamlessly upon arrival.

Field observations documented shared feeding territories and roosting sites between sedentary and migratory birds. In spring, some juveniles dispersed northward along established migratory corridors, occasionally accompanied by locally born individuals. These observations suggest behavioural compatibility and potential inter-population connectivity.

Habitat Assessment and Field Data Collection (Érika Tirado Oliva)

Érika Tirado Oliva developed and implemented the field data collection protocol used to characterize recurrent foraging territories.

Between February 2023 and February 2024, habitat sampling was conducted approximately three times per month, resulting in an estimated 36 field campaigns. Sampling locations were identified using ibis density maps provided by Waldrappteam. At each selected site (typically four to five per campaign), up to five 1 m × 1 m quadrats were assessed where access conditions permitted.

Variables recorded included:

- Minimum and maximum vegetation height (mean calculated per quadrat),
- Soil moisture,
- Percentage cover of biological elements (e.g. dung, gastropods, fungi),
- Percentage cover of anthropogenic elements (e.g. litter, hunting cartridges),
- Soil type and land use,
- Terrain slope,
- Presence and behaviour of ibises and associated species.

Assuming up to 25 quadrats per campaign, the annual dataset likely exceeded 800 quadrat assessments. Students were responsible for measurement, recording, and preliminary interpretation under supervision, ensuring methodological consistency.



Figure 1. Secondary students from IES La Janda (Vejer de la Frontera, Cádiz) conducting field data collection. From left to right: Christian Ceballos, Érika Tirado and Celia Tirado

GPS-Based Monitoring and Spatial Analysis (Claudia Pineda Peña)

Claudia Pineda Peña focused on the integration of GPS-based tracking into the monitoring framework. Using the Animal Tracker platform, she analysed spatial data from tagged HLM and sedentary individuals to interpret movement patterns, feeding site selection, and roosting behaviour.

This technological component allowed students to connect field observations with real-time spatial information, strengthening understanding of post-release adaptation and migratory dynamics. GPS data also supported rapid identification of anomalous stationary signals potentially indicating injury or mortality.

The integration of tracking technology into the educational framework enhanced spatial literacy and data interpretation skills within a real conservation context.

Incident Management and Conservation Response Protocol (Celia Tirado Oliva)

Celia Tirado Oliva examined threats affecting Northern Bald Ibis in the La Janda region and described the structured incident-response protocol implemented locally.

Identified threats included predation by large raptors, collision with power lines and wind turbines, electrocution at electricity pylons, drowning in livestock water troughs, and road mortality. Among these, electrocution at poorly insulated power line supports represents the primary documented cause of mortality for ibises from both Waldrappteam HLM cohorts and the sedentary population established through LIFE Proyecto Eremita in the region.

Given the recurrence of electrocution incidents, mitigation efforts focus on the correction and insulation of hazardous pylons. These corrective actions include modification of support structures to prevent perching on conductive elements and installation of protective devices

designed to reduce electrical contact risk. Coordination with environmental authorities and energy infrastructure managers is essential in implementing these measures.

The incident-response protocol presented during the symposium involves:

1. Detection of anomalous GPS signals,
2. Field verification by authorized personnel,
3. Coordination with veterinary services when intervention is required,
4. Notification of environmental authorities in confirmed mortality cases,
5. Documentation of infrastructure-related hazards for mitigation follow-up.

Students were assigned responsibility for monitoring specific individuals, reinforcing continuity of observation and awareness of real conservation risks, particularly those associated with anthropogenic infrastructure.

Community Engagement and Inter-Population Connectivity (Christian Ceballos Relinque)

Christian Ceballos Relinque explored the social and ecological dimensions of the project. His contribution highlighted documented cases of mixed-group movements involving migratory (HLM) and locally born ibises, including dispersal events toward northern areas along the migratory corridor.

These observations illustrated the fluidity of interactions between cohorts and reinforced the concept of emerging connectivity between European reintroduction efforts.

Additionally, field sampling frequently required engagement with private landowners. Informal conversations during habitat assessments functioned as outreach opportunities, extending awareness of the species beyond academic and conservation circles.

The broader ‘Escuela de Ibis’ initiative further linked multiple educational centres, conservation organizations, and regional authorities, embedding the monitoring framework within a wider educational and community network.

Discussion

The joint symposium intervention illustrated how post-release monitoring of HLM ibises in Andalusia functions simultaneously as a conservation operation and an educational platform.

Ecologically, the integration of migratory and sedentary cohorts suggests compatibility between management strategies and potential long-term connectivity. Educationally, embedding secondary students within operational workflows provides authentic exposure to scientific methodology, spatial analysis, and conservation ethics.

Unlike simulated school projects, this framework situates students within real conservation processes, including data collection, technological monitoring, and incident response. The model demonstrates that structured collaboration between conservation practitioners and formal education institutions can be operationally viable.

Limitations include the absence of formal pre- and post-assessment of learning outcomes and the descriptive nature of habitat data analysis within this publication.

Conclusions

The experience presented at the I International Northern Bald Ibis Symposium demonstrates that conservation practice and formal secondary education can be structurally integrated rather than merely associated.

Waldrapteam's post-release monitoring in Andalusia provided a living research environment in which five secondary students participated in standardized habitat assessment, GPS-based tracking interpretation, and conservation response protocols over a one-year period.

This framework represents a replicable model for linking species recovery programmes with research-based education, strengthening both scientific monitoring and environmental literacy.

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Northern Bald Ibis in Europe: 20 Years of Conservation, Research, and Reintroduction

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Abstract

Over the past two decades, the reintroduction of the Northern Bald Ibis *Geronticus eremita* in Europe has evolved from an experimental conservation effort to a scientifically monitored success story. Building on the results of two LIFE-funded projects and various peer-reviewed studies, this manuscript synthesizes twenty years of progress in restoring a self-sustaining migratory population in Central Europe.

Combining human-led migration, intensive ecological monitoring, campaigns against the main mortality causes, and cross-border cooperation, the population now exceeds 250 wild individuals and exhibits high fecundity and migration fidelity. However, anthropogenic mortality and climate change pose ongoing challenges, prompting the creation of a new Andalusian migration corridor to mitigate the increasing difficulty of transalpine crossings.

This paper summarizes the methodological innovations, population outcomes, and lessons learned from one of Europe's most advanced avian reintroduction programs.

Introduction

The Northern Bald Ibis *Geronticus eremita* historically occupied extensive regions across Europe, the Middle East, and Africa (Fritz & Janák, 2022; Schenker, 1977; Schenker et al., 2024; Schenker & Serra, 2022). The European population became extinct by the early 17th century, primarily due to intense human persecution, as the species was highly valued as food. Climatic deterioration during the Little Ice Age likely exacerbated this decline (Fritz et al., 2019; Fritz & Janák, 2022).

Throughout the 20th century, most remaining colonies in the Middle East and North Africa also vanished (Schenker et al., 2020; Schenker & Serra, 2022). In addition to continued hunting pressure, these losses were driven by habitat degradation, pesticide use, and electrocution on unprotected medium-voltage power lines associated with expanding industrialization and electrification (Hirsch, 1980).

Given the rapid and dramatic contraction of its entire range, the species was classified as Critically Endangered on the IUCN Red List from 1980 onward. In 2018, following major international conservation achievements, its status was revised to Endangered.

Since 2002, a research and conservation project run by Waldrappteam Conservation & Research and partners has aimed to re-establish a self-sustaining migratory population with breeding sites in the Alpine foothills. This initiative marks the world's first reintroduction of a continentally extinct migratory bird species (Drenske et al., 2023; Fritz et al., 2017).

While early efforts focused on reintroducing migration behaviour through human-led flights, recent challenges have emerged due to climate change. Warmer and longer autumns have delayed migration, preventing an increasing number of birds from crossing the Alps to reach suitable wintering sites. These shifts necessitated emergency interventions and adaptive management, including the establishment of a new migration route to Andalusia, Spain (Fritz et al., 2024).

To prevent mortality north of the Alps, emergency translocations were repeatedly required, highlighting the need for a more sustainable climate-adaptive solution: the Andalusian migration corridor. This route also facilitated contact with the sedentary Proyecto Eremita population in Spain, creating an opportunity for inter-population connectivity and behavioural reinforcement.

In 2025, the first individuals trained along this new flyway – including the females Dr. Saurier and Espi – independently returned to breeding areas in Central Europe, confirming successful cultural transmission of the new migration tradition. These returns mark a major milestone in reversing a 400-year behavioural extinction event and demonstrate the species' remarkable navigational flexibility.

At the same time, illegal bird hunting in Italy remains a key threat, representing a disproportionately high proportion of mortality, particularly in Italy but also in Spain. A coordinated effort with legal authorities and environmental organizations has emerged to address structural deficiencies in wildlife crime enforcement and to oppose regulatory rollbacks that would jeopardize recovery.

Materials and Methods

Since 2014, the reintroduction efforts have been carried out within the framework of two consecutive LIFE projects. The first project (LIFE+12 BIO/AT/000143; 2014–2019), led by the association Förderverein Waldrappteam in collaboration with six international partners, enabled the establishment and expansion of the migratory population. Based on the successful implementation of the first project, the initiative was granted a second LIFE project (LIFE20 NAT/AT/000049; 2022–2029), currently implemented by ten partners under the leadership of Zoo Vienna. Waldrappteam Conservation & Research, a private conservation organization led by Johannes Fritz, is responsible for all human-led migrations, the overall population management, and the population's long-term monitoring. All interventions are conducted in accordance with the IUCN Guidelines for Reintroductions and Other Conservation Translocations (IUCN/SSC, 2013).

Human-led migration served as the primary method for establishing social traditions of migration among zoo-born juveniles. Chicks are raised using a socially involved hand-raising method in which two designated human foster parents maintain permanent and exclusive contact with the juveniles throughout the entire process of hand-raising, training, and human-led migration. No visual disguises are used, enabling the formation of a strong social bond. The birds are conditioned to respond to and follow a specific call of their foster parents, which is crucial for coordinated flight training and safe guidance during migration. After fledging, birds

were trained to follow microlight aircraft at 40–45 km/h. Each migration journey included several flight stages and stopovers (Fritz et al., 2017, 2024).

Since 2016, over 80% of birds have been equipped with solar-powered GPS transmitters using Teflon leg-loop harnesses (Mizrahy-Rewald et al., 2023). Data were uploaded to the Movebank platform for behavioural, spatial, and survival analysis, as well as published via the App Animal Tracker. Breeding success was recorded as mean fledglings per nest per year. Mortality was categorized by electrocution, collisions, hunting, or natural causes. Timing of autumn migration was determined annually for the Burghausen and Kuchl colonies (2011–2023). Statistical analyses were conducted using R 2023.12.1+402. Unless otherwise stated, values are given as mean ± standard deviation.

Results

Reproduction

Since 2012, four breeding colonies have been established in the wild: three north of the Alps (Burghausen, Bavaria; Kuchl, Salzburg; Überlingen, Baden-Württemberg) and one south of the Alps (Rosegg, Carinthia; Figure 1). All birds are migratory, and all reproductive birds so far winter in Italy (WWF Oasi Laguna di Orbetello). Since 2023, birds also winter in Spain, either in Andalusia or in Catalonia, but they are not yet sexually mature.

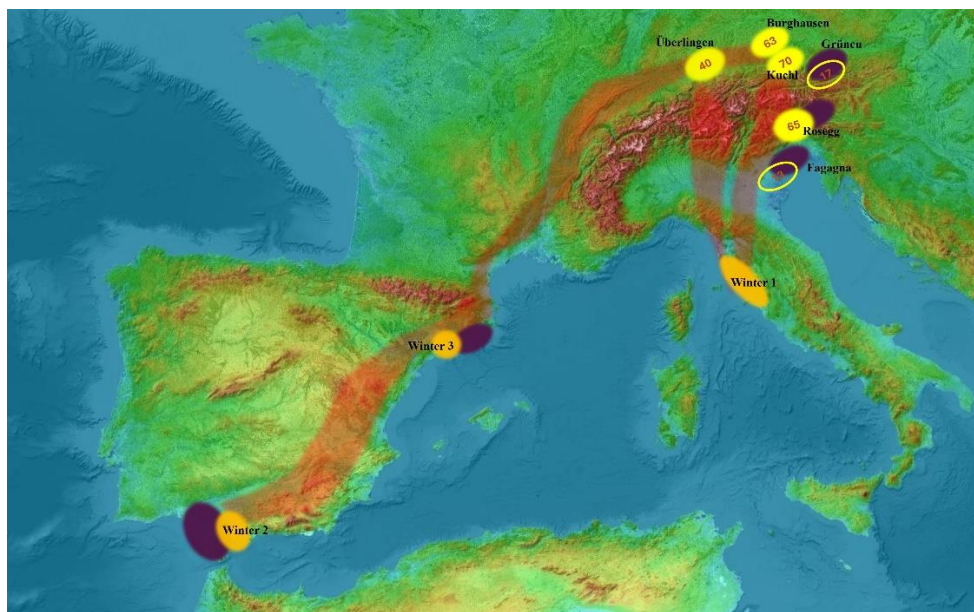


Figure 1. Territory of the European Northern Bald Ibis population. Yellow: established breeding sites (with colony sizes as of the end of 2024); orange: wintering sites; violet: sedentary breeding colonies; yellow circles: individuals recruited from the respective sedentary colonies into the migratory population; red routes: established migration corridors

Between 2012 and 2024, a total of 446 chicks hatched and 380 fledged in the wild, corresponding to a fledging rate of $85.9 \pm 4.5\%$. Across all colonies, breeding success—measured as mean fledglings per nest per year—has steadily increased over time ($R^2 = 0.74$, $p = 0.0039$; Figure 2). In Burghausen, the oldest colony with continuous reproduction since 2012, breeding success is 3.0 fledglings per nest in 2024.

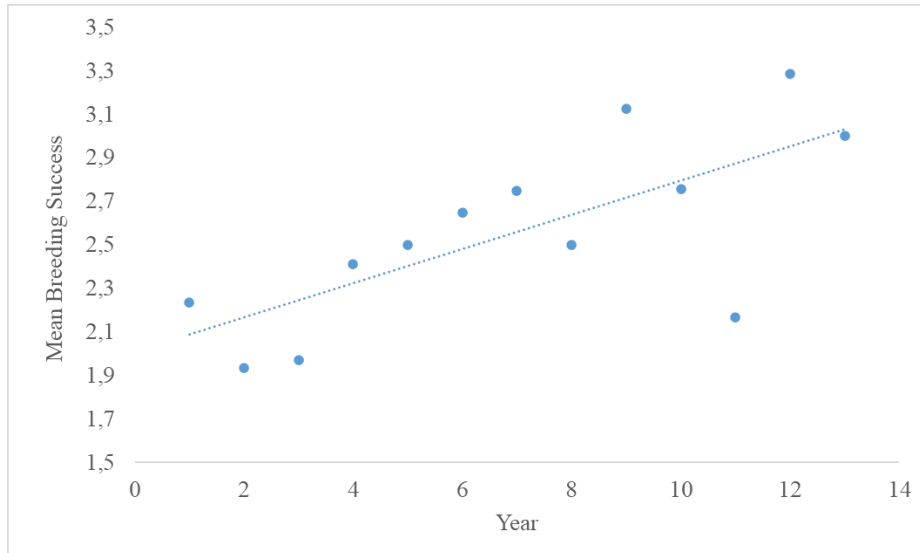


Figure 2. Breeding success in relation to colony age. Data include four established migratory breeding colonies. Breeding success increases significantly with colony age ($R^2 = 0.74$, $p = 0.0039$)

Extraterritorial Reproduction

In 2023, birds started to breed outside the four established breeding sites, in Italy and Switzerland (Figure 3).

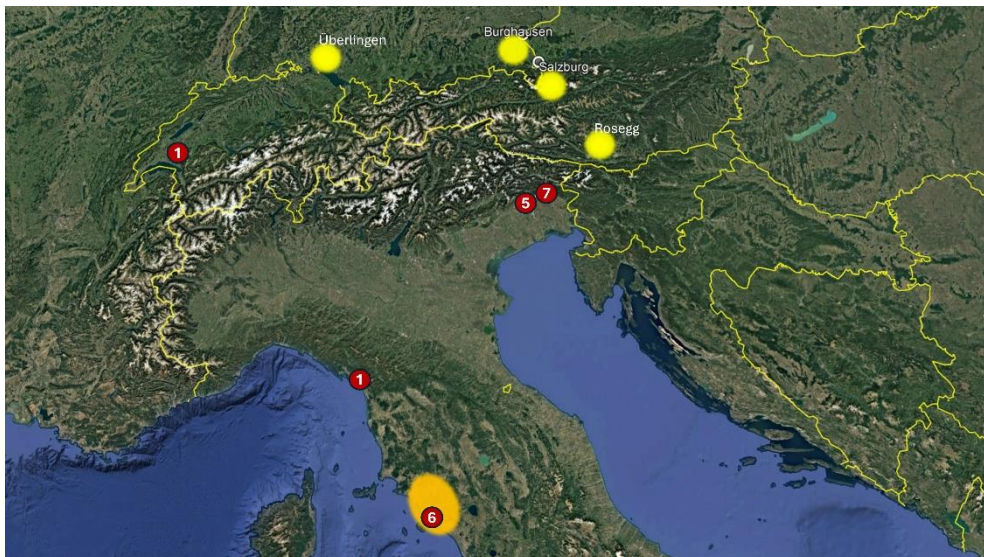


Figure 3. Extraterritorial breeding in Italy and Switzerland. Red: extraterritorial breeding sites (numbers indicate the number of nests at each site in 2025); yellow: established breeding colonies; orange: winterring site

In Italy, the number of nests increased sharply from 8 in 2023 to 21 in 2025, while breeding success remained rather low, with 0.25 fledglings per nest in 2023 and 0.95 fledglings per nest in 2025 (Table 1).

Table 1. Extraterritorial breeding in Italy, 2023–2025.

	2023	2024	2025
Nests	8	12	21
Fledglings	2	12	19
Mean breeding success	0,25	1	0,90

In Switzerland, a pair bred near Zurich Airport (Canton of Zurich) in 2023 and raised two chicks. Both adults died before the next breeding season, so no breeding occurred in 2024. In 2025, another pair bred in Canton Fribourg and successfully raised three chicks (Figure 3).

Migration Tradition to Tuscany

From 2004 to 2022, fifteen human-led migrations were conducted from breeding sites north of the Alps to Tuscany, with a total of 280 juveniles released at the wintering site (Figure 4). These migrations covered an average distance of 927 ± 215 km, consisting of 8.5 ± 4.7 flight stages over 25 ± 10 days.



Figure 4. Human-led migration flights from breeding sites north of the Alps to the wintering area in Tuscany, Italy (2004–2022)

In 2011, the first birds returned from Tuscany to the breeding site in Burghausen, Bavaria (Germany). In 2012, the first wild-fledged juveniles followed their conspecifics along the same route to Tuscany. This event marked the beginning of a stable migratory tradition, which has since been successfully passed on to the F3 generation.

Climate Change Effects on Migration Timing

Analysis of the autumn migration timing to Tuscany (2011–2023) revealed a statistically significant delay of over 30 days in the onset of migration ($R^2 = 0.576$, $p = 0.004$; Figure 5). This delay correlates with prolonged warm autumns that reduce thermal updraft availability, essential for transalpine flight. As a result, increasing numbers of birds remain north of the Alps, where survival through winter is unlikely (Fritz et al., 2024). Between 2017 and 2023, emergency translocations were conducted to transfer 270 stranded birds south of the Alps.

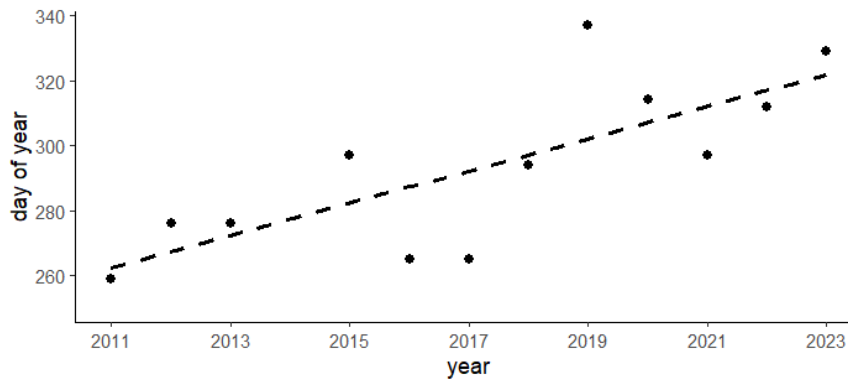


Figure 5. Onset of autumn migration in the Burghausen and Kuchl colonies. The trend toward progressively later departures is statistically significant ($R^2 = 0.576$, $p = 0.004$)

Migration Tradition to Spain

A migration route to Spain, which bypasses the Alps, is considered a mitigation measure against the observed effects of climate change. Beginning in 2023, human-led migrations were redirected toward Spain. That year, the migration started near the breeding colony in Überlingen at Lake Constance and ended in Andalusia, southern Spain, covering approximately 2,300 km in 19 flight stages over 43 days (Figure 6).

In 2024, a second migration to Andalusia began from a campsite in Bavaria, near the breeding colonies of Burghausen (Bavaria) and Kuchl (Salzburg, Austria), covering approximately 2,700 km in 19 flight stages over 51 days. Across both years, a total of 68 juveniles were released into the area of a sedentary colony established by Proyecto Eremita (Böhm et al., 2021; López & Quevedo, 2016).

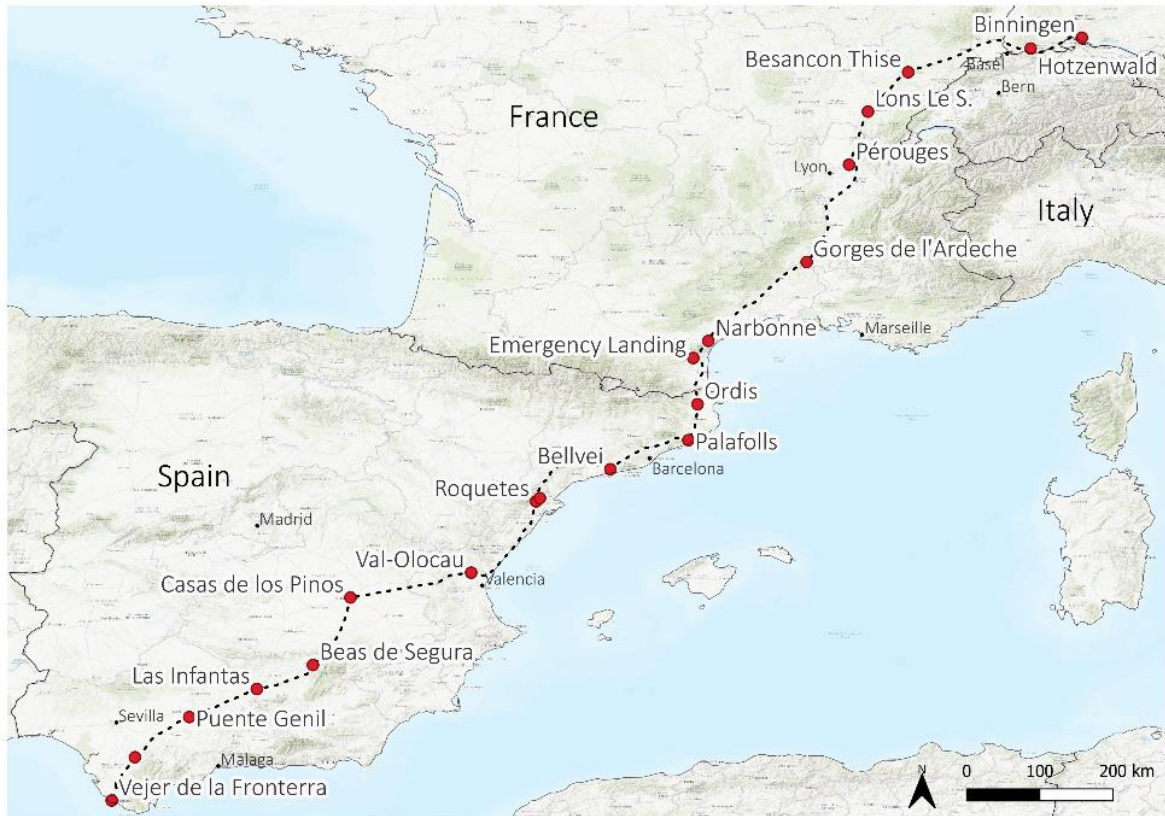


Figure 6. Route of the human-led migration in 2023 from Baden-Württemberg to Andalusia. The birds covered approximately 2,300 km in 19 flight stages over 43 days

In 2025, a third human-led migration toward Spain concluded in Catalonia, close to the French border. This migration was exceptional because the birds consistently refused to follow the microlight aircraft. On two stages, they initially accompanied the aircraft before turning back, and on all remaining stages, they stayed at the campsite. Consequently, the birds were transported by car in individual boxes for every stage. The 1,400 km route was completed in 10 stages over 39 days. The 29 birds will serve as part of the founders of a new colony in Catalonia. As in the Proyecto Eremita colony in Andalusia, this new colony will consist partly of sedentary birds that remain and breed on site, and partly of migratory individuals that migrate to the northern Alpine foothills for breeding.

Mortality and Threats

Each year, $46.8 \pm 8.4\%$ of the population present at the beginning of the year dies or disappears, resulting in a total loss of 607 birds between 2014 and 2024. In contrast, gains through reproduction, releases into the wild, and recruitment from semi-wild colonies added 838 juveniles during the same period. This corresponds to an overall ratio of 0.70 ± 0.21 losses per juvenile produced, released, or recruited.

For 56.0 % of these losses, the cause of death could be identified. Electrocution on medium-voltage power poles remains the leading cause of death. It accounted for 31.2 % of the losses, followed by injury (26.8 %), poaching (19.4 %), predation (12.1 %), and 10.6 % of the losses were caused by other reasons (Figure 7).

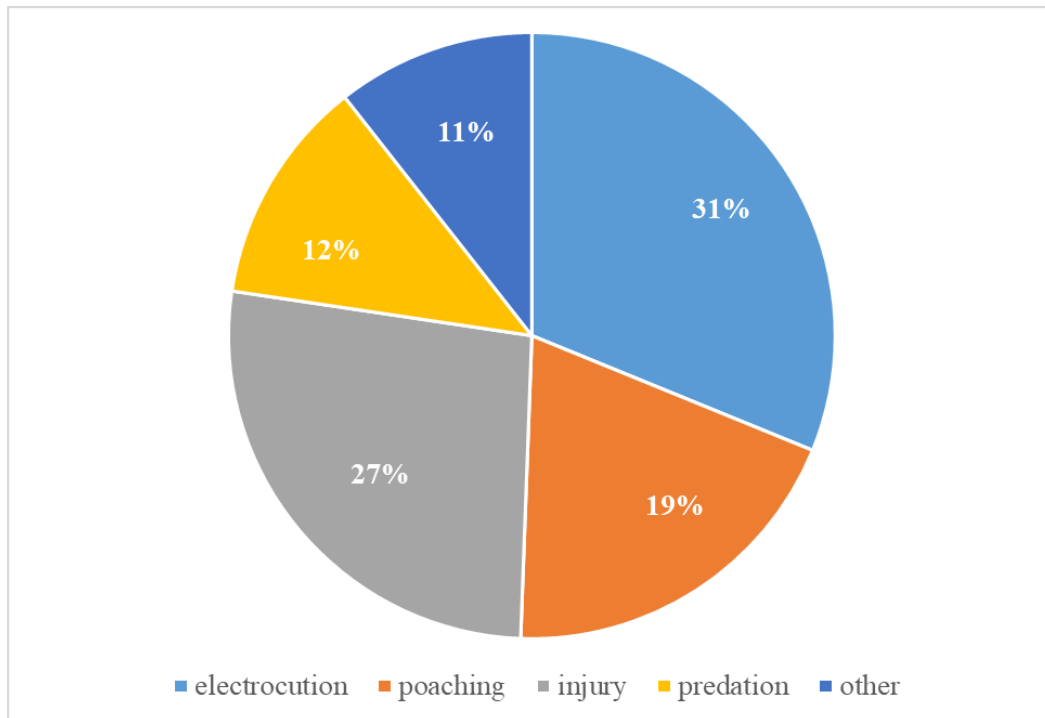


Figure 7. Mortality statistics of the European Northern Bald Ibis population, 2014–2024. Percentages refer to losses with an identified cause

Electrocution is the main mortality cause in all countries except Germany. There, legal regulation requires the network provider to retrofit medium-voltage power poles, which has a strong positive effect on the population. Even with considerable presence in southern Germany, only 6.2% of the confirmed electrocution cases occurred in Germany between 2014 and 2024 (Figure 8).

For poaching, the effect is opposite in Italy: 83.3% of the confirmed poaching cases occurred in this country (Figure 8). Poaching accounts for 29.7 % of all losses with known cause within Italy.



Figure 8. Proportion of mortality attributed to the two main causes across the European Northern Bald Ibis population range. Electrocution: comparison between Germany and the rest of the range; poaching: comparison between Italy and the rest of the range

Since 2016, most birds have been equipped with GPS tags, enabling comprehensive remote monitoring of mortality causes and the implementation of targeted countermeasures. Both main mortality causes show a decreasing trend, which is significant for electrocution ($R^2 = 0.46$, $p =$

0.036; Figure 9), whereas for poaching the decline is evident but does not reach statistical significance ($R^2 = 0.20$, $p = 0.227$; Figure 9).

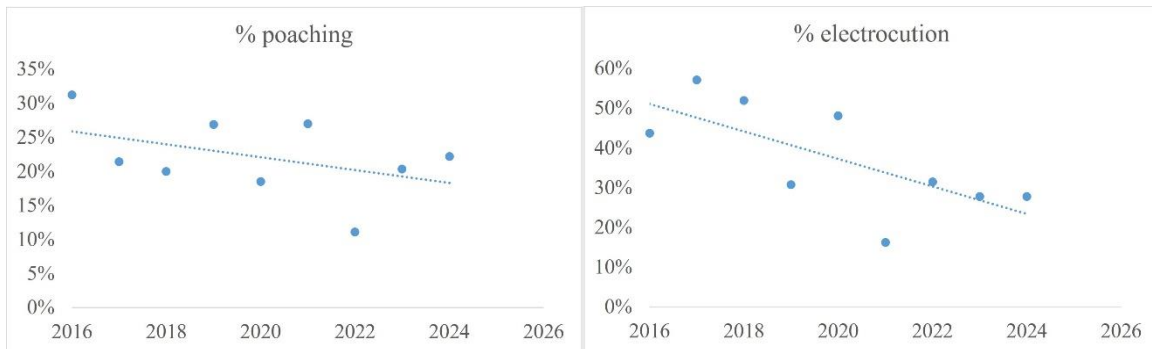


Figure 9. Proportion of the two main mortality causes relative to total losses in the European Northern Bald Ibis population during 2016–2024. Poaching shows an evident but non-significant decline ($R^2 = 0.20$, $p = 0.227$); electrocution shows a significant decline ($R^2 = 0.46$, $p = 0.036$)

Demography

By the end of 2024, the migratory release population comprised 280 individuals (Figure 10), consisting of 54% released (founder) birds and 46% wild-fledged individuals (F1–F3 generations). If population growth continues at the current rate, the Minimum Viable Population Size ($N = 314$; Drenske et al., 2023) is expected to be reached in 2026, and the minimum target population defined by the ongoing LIFE project ($N = 357$) is projected to be surpassed in 2027.

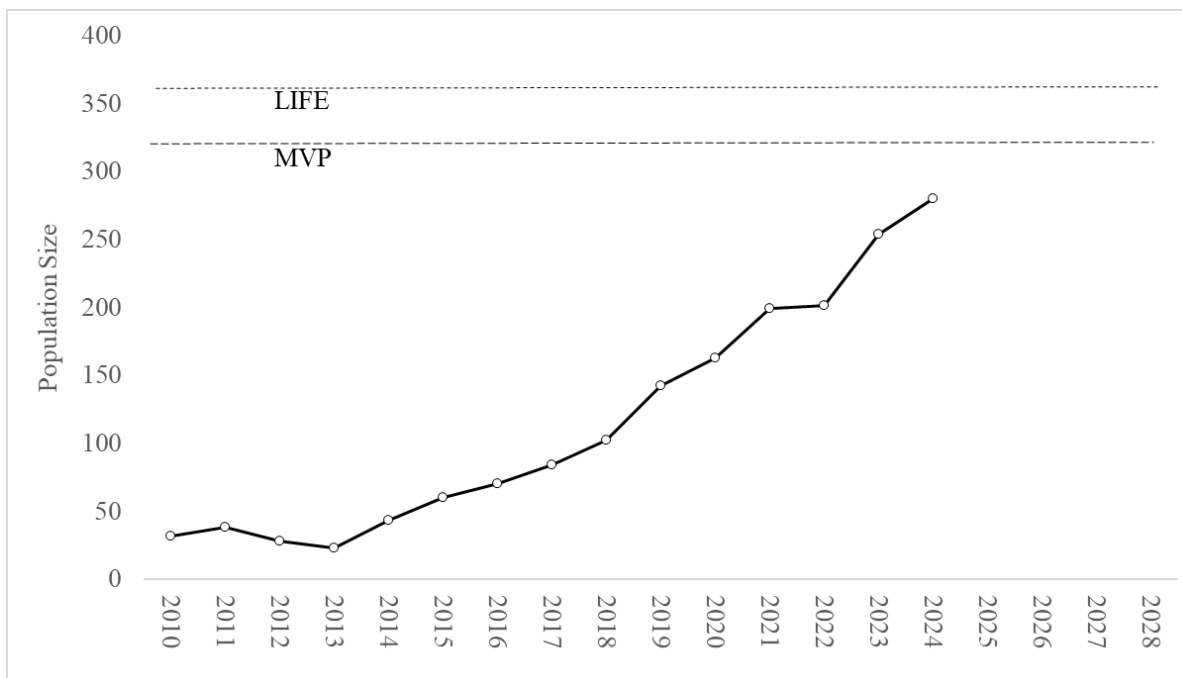


Figure 10. Population development of the European Northern Bald Ibis from 2010 to 2024. MVP: Minimum Population Size threshold ($N = 314$ individuals) according to Drenske et al. (2023); LIFE: target of the ongoing LIFE project ($N = 357$ individuals)

The population shows a balanced sex ratio of 51% males ($N = 125$) and 49% females ($N = 121$), with 34 individuals of undetermined sex. Eighty-five percent of the population ($N = 238$) belong

to the four established breeding colonies, while 4% ($N = 12$) hatched at other sites in Italy or Switzerland. An additional 11% ($N = 30$) are recruited juveniles originating from the sedentary semi-wild colonies in Upper Austria (Konrad Lorenz Research Station) and Friuli, Italy (Oasi Naturalistica dei Quadris, Fagagna).

Discussion

The results presented here demonstrate a substantial consolidation and diversification of the reintroduced migratory Northern Bald Ibis population in Europe. The establishment of four breeding colonies north and south of the Alps, together with the increasing occurrence of breeding outside established colonies in Italy and Switzerland, reflects a successful demographic expansion and growing ecological resilience.

The species shows remarkable adaptability in breeding behaviour, utilizing both natural cliffs and a wide range of anthropogenic structures such as towers, roofs, ledges, and window frames. It has even nested in pine trees, abandoned stork nests, and palm trunks. This behavioural flexibility likely facilitates colonization of new areas and supports continued population growth.

Reproductive performance in the reintroduced population is exceptionally high compared to both wild and captive reference groups. Published data for wild, sedentary, and zoo populations consistently report no more than 1.5 fledglings per nest, with the semi-wild colony in Rosegg being a notable exception (2.24 fledglings per nest; Drenske et al., 2023). In contrast, the high and steadily increasing breeding success across the migratory colonies highlights the outstanding quality and suitability of the selected breeding habitats. This interpretation is supported by remote sensing analyses (Wehner et al., 2022) showing an abundance of high-quality foraging areas along the northern Alpine foothills—habitats accessible only to migratory individuals. Consequently, maintaining migratory behaviour is essential for the long-term stability and self-sustainability of the European population (Fritz et al., 2024).

Current growth trends indicate that the minimum viable population threshold ($N = 314$) will be reached by 2026, and the LIFE project target ($N = 357$) by 2027. This trajectory underscores the demographic sustainability of the population under current management. Moreover, key behavioural traditions, especially migratory knowledge, have been successfully restored and transmitted across generations. The establishment of a stable migratory route to Tuscany, now maintained by the F3 generation, demonstrates the resilience of culturally inherited migration behaviour.

However, ongoing climate change is altering this dynamic. The autumn migration onset has been delayed by over 30 days due to prolonged warm periods and reduced late-autumn thermals in the Alps, causing an increasing number of birds to remain north of the Alps where mortality risk is high. To prevent losses, these birds are captured at winter onset, transported individually over the Alps, and released on the southern side—an effective but unsustainable emergency measure.

The successful completion of human-led migrations to Andalusia (2023–2024) and Catalonia (2025) aims at mitigating the observed climate change effects. It offers a viable alternative to the increasingly hazardous transalpine route. Independent returns from Andalusia in 2025 confirm early transmission of this new route. The resulting multi-corridor migration system represents a major step forward in climate-adaptive management and provides a model for future translocation programs under changing climate conditions.

The study by Drenske et al. (2023) on habitat quality, however, did not account for these recent climate-induced developments. It focused exclusively on the migratory population wintering in Tuscany and did not consider the emerging Spanish migration corridor or the growing influence of climate-related stressors. To address these limitations, a comprehensive follow-up study is planned to analyse the entire European Northern Bald Ibis population—encompassing migratory, sedentary, and mixed colonies—and to model population dynamics under different climate change scenarios.

Despite these advances, anthropogenic mortality remains a major limiting factor. Electrocutation continues to be the leading cause of death, though mitigation efforts in Germany demonstrate that technical retrofitting can drastically reduce this risk. Illegal hunting, particularly in Italy, persists as a critical threat, accounting for more than one-third of recorded deaths. Comprehensive monitoring, strengthened law enforcement, cross-border cooperation, and policy reform are essential to secure long-term population persistence.

The European Northern Bald Ibis program exemplifies how integrative conservation—combining behavioural training, technological monitoring, and adaptive management—can restore not only population numbers but also complex, culturally mediated life-history traits once extinct in the wild. Human-led migration, though resource-intensive, has proven effective in re-establishing lost migratory traditions. The integration of climate-adaptive management strategies, combined with sustained efforts to mitigate anthropogenic mortality, will ultimately determine the resilience and long-term success of this reintroduction program.

Acknowledgements

This work was supported by the European Union’s LIFE Programme (LIFE+12 BIO/AT/000143 and LIFE20 NAT/AT/000049). We thank all project partners, co-financers, field teams, foster parents, and volunteers whose dedication has enabled this long-term conservation success.

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Protecting the Northern Bald Ibis *Geronticus eremita* from Poaching in Italy

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Abstract

The illegal hunting of the Northern Bald Ibis *Geronticus eremita* represents one of the most significant challenges to the species' reintroduction efforts in Central Europe. Italy is the European country in which the majority of the reintroduced Northern Bald Ibis population spends most of its life. The birds are born at breeding sites in Austria and Germany — Überlingen, Burghausen, Kuchl, and Rosegg (Figure 1) — and migrate south to the WWF Oasis Laguna di Orbetello to spend the winter. Many individuals join their conspecifics during the autumn migration already in their first year of life, remaining at the wintering site or along the migration route until they reach sexual maturity and begin returning to their breeding grounds. Others, however, remain in Italy year-round. Together, these patterns result in a distribution range that encompasses almost all of northern and central Italy throughout the year.

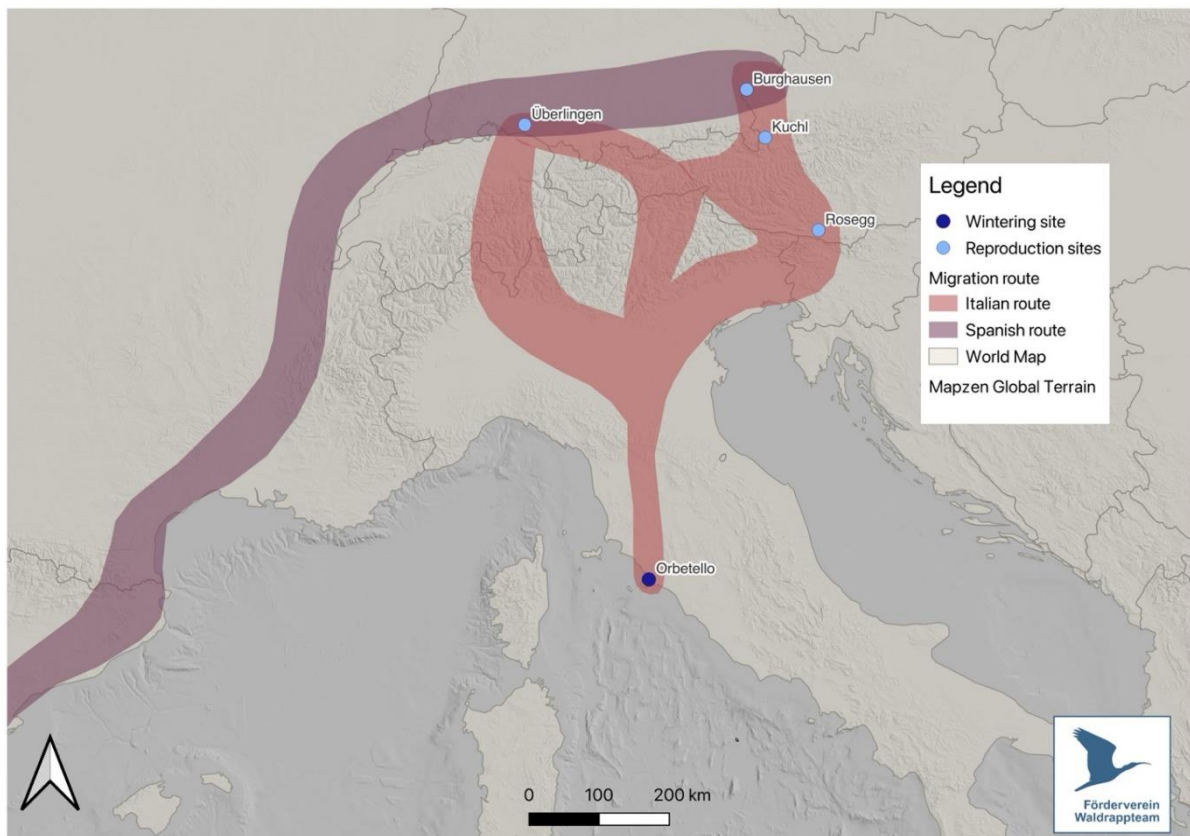


Figure 1. Breeding sites and migration routes of the European Northern Bald Ibis population

Introduction

According to BirdLife International's report *The Killing* (2015, reviewed 2016), Italy ranks as the Mediterranean's worst offender for wild bird killings among European states. Despite European Union action, beginning with a pilot procedure in 2013, and Italy's creation of a National Action Plan against poaching in 2017, widespread poaching persisted, leading to a formal infringement procedure in 2023 for failure to implement adequate protective measures against wild bird killings.

Methods

Monitoring and data collection on illegal killings of wild birds in Italy are largely absent: few species are monitored, and only in restricted areas and for limited periods, and the causes of death are often not determined. The Northern Bald Ibis Project represents a unique exception, as almost the entire population (> 90%) has been continuously and thoroughly monitored since 2016, producing unprecedentedly precise and reliable mortality data. Given this combination of consistent monitoring and broad geographical distribution across Italy, it is reasonable to assume that the mortality rates due to poaching recorded for this species reflect what occurs to other species present in the same areas, whether during migration or as year-round residents. However, since these species are not monitored, their losses remain invisible.

Results

The comprehensive analysis of these data reveals alarming trends: poaching is the main cause of death for the Northern Bald Ibis *Geronticus eremita* in Italy, as it accounts for 36% of all documented losses since 2016, as shown in Figure 2.

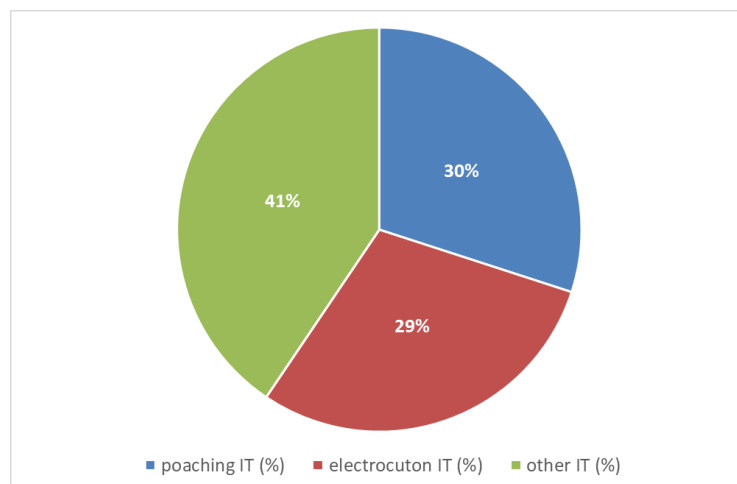


Figure 2. Main causes of death for the Northern Bald Ibis population in Italy (2016-2024). Poaching accounts for 30% and is therefore the main single cause of death.

Although, during our extensive anti-poaching campaign, we recorded a progressive reduction in documented poaching incidents, as illustrated in Figure 3, nearly 50% of mortality causes remain unverified, indicating that the true extent of poaching-related deaths is likely substantially higher than recorded.

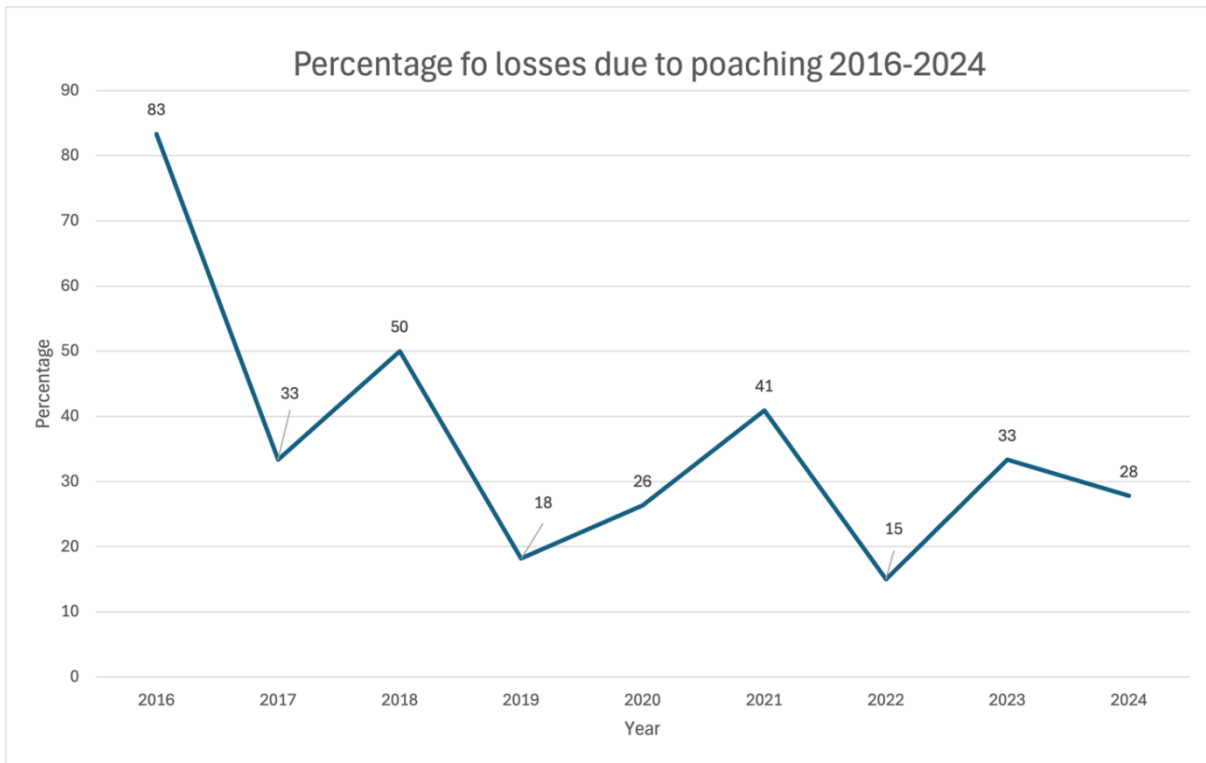


Figure 3. Trend of percentages of losses due to poaching in Italy from 2016 to 2024

Between 2006 and 2024, we recorded 70 confirmed poaching cases across Italy: 70% of these cases were confirmed through veterinary reports that identified gunshot pellets in the body, while the remaining 30% were verified using GPS data that clearly indicated illegal killings.

An alarming 90% of all documented cases occurred during the Italian hunting season, which spans from September to January. Geographically, poaching episodes show a clear concentration primarily along the Tyrrhenian coast and in Northeast Italy (Figure 4). These distribution patterns closely align with the areas identified as critical in Italy’s 2017 National Action Plan for traditionally intense hunting activity, confirming that our data, as a key resource of information, accurately reflect the broader landscape of wildlife crime.

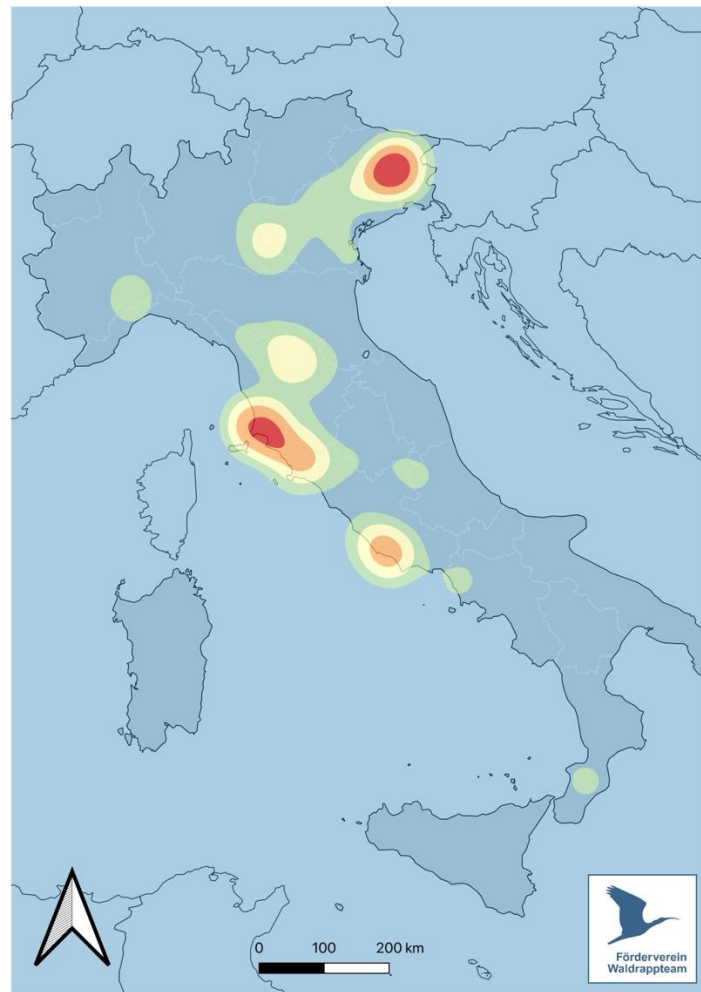


Figure 4. Geographical distribution of poaching cases in Italy, indicating a concentration along the Tyrrhenian coast and in Northeast Italy

To protect the Northern Bald Ibis from poaching in Italy, we implement an anti-poaching strategy that includes two types of measures: post-poaching actions, which focus on monitoring and tracking offences and taking legal action; and preventive actions, which are intended to support and complement post-poaching measures and ensure long-term and broad-spectrum protection, as they benefit many wild bird species in Italy. Specifically, these include public relations activities and political lobbying.

Our post-poaching protocol involves five interdependent steps following bird mortality:

1. Death detection through GPS monitoring
2. Police activation for body recovery
3. Transport to the nearest zooprophyllactic institute
4. Veterinary examination (X-ray and necropsy)
5. Submission of a legal complaint to the Public Prosecutor's Office

Despite this comprehensive approach, only one offender has been convicted in over 20 years, highlighting systemic challenges in wildlife crime prosecution.

The preventive measures focus on long-term benefits for wildlife through political lobbying and public sensitisation; an example is the following two recent initiatives, which have had a great impact on wildlife protection in recent years.

The first is an expert symposium titled *New Approaches and Technologies against Poaching*, which we organised in 2024 in collaboration with Parco Natura Viva in Verona, our project partner. This technical event identified critical weaknesses in Italy's regulatory framework and defined shared investigation best practices with innovative tools.

The symposium revealed that Italy's regulatory framework and supervision system have significant weaknesses, preventing effective wildlife protection and enabling wildlife crime. To overcome these structural limitations, two imperative solutions were identified.

The first is the implementation of adequate institutional and legal reforms to create stronger deterrents and raise costs for offenders, while the second focuses on defining shared investigation best practices with innovative tools, such as advanced GPS technology to pinpoint crime locations and times, addressing the key reason most wildlife crimes go unpunished; forensic veterinary medicine to analyse crime scenes and bodies through X-rays, necropsies, and ballistic examinations; and scientific quantification of environmental damage related to biodiversity crimes to prove the ecological impact and broader consequences of wildlife crime so as to strengthen complaints and elevate these offences from crimes considered minor to serious environmental violations.

A landmark conference was organised in 2025 in collaboration with LAV (Lega Anti-Vivisezione), Lipu (Lega Italiana Protezione Uccelli), and WWF Italy (World Wide Fund for Nature Italy) at the Italian Chamber of Deputies. This classical political lobbying event focused on the transposition of the new EU Directive on the protection of the environment through criminal law, with particular attention to poaching regulations. This represents a crucial opportunity for environmental organisations to influence the legislative framework and implement necessary institutional reforms by presenting our data on the severe situation of poaching in Italy. The output of the event will be a shared document that can guide the transposition of the Directive from a wildlife conservation perspective.

We are also developing a new project aimed at improving the prosecution of wildlife crimes using innovative techniques. This initiative stems from implementing best practices identified during the Verona symposium and includes cutting-edge technology for crime documentation, innovative methods for assessing environmental damage from biodiversity loss, and more effective prosecution frameworks and deterrents, which we intend to implement beyond Italy's borders.

Discussion

The Northern Bald Ibis project represents a unique conservation model due to several distinctive features that set it apart from other wildlife protection efforts. Our comprehensive monitoring of nearly the entire population over multiple years, combined with year-round observation capabilities, enables precise mortality documentation that would be impossible to achieve with other species. This exceptional data collection opportunity has allowed us to integrate effectively into broader wildlife crime prevention networks, providing valuable insights that extend beyond our target species. These characteristics make the Northern Bald Ibis a powerful symbol in the fight against illegal hunting and establish our responsibility to act for the benefit of all protected species threatened by wildlife crime.

Our integrated approach, combining post-poaching response protocols, preventive measures, technological innovation, and political advocacy, represents a comprehensive strategy for Northern Bald Ibis protection. The shift from awareness-raising to direct political engagement reflects our evolving understanding of conservation challenges and the need for systemic change in wildlife protection frameworks.

Through targeted lobbying, scientific conferences, and collaborative partnerships with authorities, including the Carabinieri, we aim to ensure biodiversity protection becomes a higher priority on the political agenda. Our initiatives have successfully integrated us into a broader network of conservation organisations dedicated to combating wildlife crime, positioning the Northern Bald Ibis as both a conservation success story and a powerful advocate for enhanced wildlife protection legislation.

Acknowledgements

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Electrocution on Medium-Voltage Power Lines as a Major Threat to the Reintroduced Northern Bald Ibis *Geronticus eremita*: Evidence, Impacts and Mitigation Measures

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Abstract

Electrocution on medium-voltage power lines is a leading cause of human-induced mortality for large birds globally and poses a critical threat to the ongoing reintroduction of the Northern Bald Ibis *Geronticus eremita* in central Europe. This paper analyses electrocution mortality in the reintroduced migratory population and describes mitigation measures implemented in the EU-funded ‘LIFE Northern Bald Ibis project’ (LIFE20 NAT/AT/000049 – LIFE NBI). Between 2014 and 2024, 103 electrocution deaths were recorded, accounting for 31.2% of all mortality events with a known cause. Most incidents occurred in Italy and Austria, where no mandatory bird-safe power pole legislation exists, in stark contrast to Germany, where such requirements have reduced electrocution rates substantially.

High-risk poles were identified by combining GPS-derived habitat-use data with structural risk assessments, focusing on poles bearing horizontal insulators and complex branching configurations. A five-step workflow guided the selection and retrofitting of 170 power poles across three Austrian federal states, exceeding the project target. Retrofitting methods included cover caps, insulation tubes, insulated cages and insulation tape. No electrocution incidents have been recorded at secured poles to date, though the full population-level impact of these measures requires further monitoring. The findings highlight that regulatory framework mandating bird-safe infrastructure represent the most effective and scalable solution, and we call for harmonised legislation across all range states of the Northern Bald Ibis.

Keywords: Northern Bald Ibis, *Geronticus eremita*, reintroduction, electrocution, anthropogenic mortality, conservation

Introduction

The Northern Bald Ibis *Geronticus eremita* is classified as Endangered on the IUCN Red List (IUCN 2026). Once distributed across North Africa, the Middle East, and southern and central Europe, it was extirpated from Europe about 400 years ago because of habitat loss, climate change, and direct persecution. A remaining wild colony with about 700 individuals persists at Souss-Massa National Park in Morocco (Böhm et al. 2021).

A project for the reintroduction of the Northern Bald Ibis in central Europe started in 2002 as a feasibility study. Through a process of human-led migration, hand-reared birds from zoo populations have been trained to follow ultralight aircraft from breeding sites in Austria and Germany to a wintering area in Tuscany, Italy, where they are released (Fritz et al. 2017). From

2014 until 2019, the reintroduction project was funded by the EU LIFE Programme (LIFE+12 BIO/AT/000143 – LIFE Northern Bald Ibis). Currently, a second LIFE project, ‘LIFE Northern Bald Ibis’ (‘LIFE NBI project’; 2022–2028; LIFE20 NAT/AT/000049 – LIFE NBI), coordinated by Tiergarten Schönbrunn (Zoo Vienna), is running and aims for the establishment of a self-sustaining migratory Northern Bald Ibis population in central Europe by the end of 2028. Despite steady population growth (over 300 individuals by the end of 2025), the long-term viability of the reintroduced population remains contingent on reducing human-caused mortality to levels that allow sustainable natural increase. Population viability analyses indicate that the population is not yet self-sustaining without active management interventions (Drenske et al. 2023).

Mortality caused by power line infrastructure — in particular electrocution on medium-voltage power poles — has been recognized as a major conservation problem for large birds globally (Bevanger 1994, 1998; Lehman et al. 2007). A landmark study analysing 1,704 mortality records from tracking studies across the African-Eurasian flyway and 45 tracked species found that, among human-induced deaths with a confirmed cause, electrocution was the most frequent, accounting for 40.5% of cases overall, rising to 47.2% in Europe (Serratos et al. 2024).

The physical mechanism by which birds are electrocuted is illustrated in Figure 1. Birds are fatally shocked when they simultaneously bridge two energized components, or a live conductor and an earthed pole component, completing a circuit through their body (Bevanger 1998; Durgapersad et al. 2025).

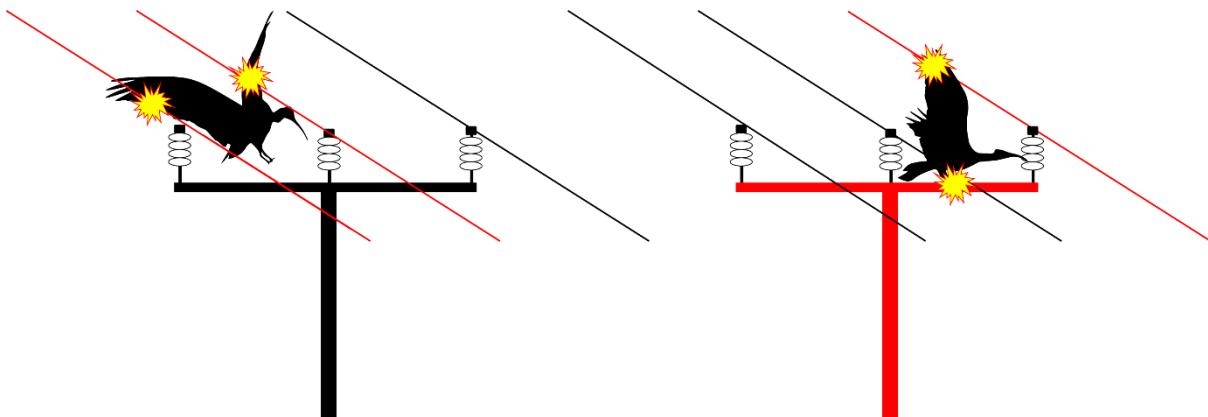


Figure 1. Mechanisms of bird electrocution on medium-voltage power lines. A bird creates a fatal short circuit either by simultaneously touching two live conductors (left panel) or by connecting a live conductor to an earthed pole structure (right panel). Graphic: M. Heiderer

The risk of electrocution is influenced by different factors. Large birds — like the Northern Bald Ibis — are more likely to connect electrical components with their wings, beaks, or feet. Another factor is the availability of alternative perches, such as trees, houses, or other structures. Studies showed that a high incidence of electrocution occurs in open habitats lacking natural perches (Lehman et al. 2007).

The reintroduced Northern Bald Ibis population frequently uses power poles as roosting places during day and night, as they provide attractive elevated perch sites in their open agricultural foraging habitat. Most electrocution events recorded in the Northern Bald Ibis population

happened on power poles bearing horizontal insulators and/or complex branching constructions (Figure 2). These designs include several areas for the birds to land and sit on, with small distances between energized and/or earthed components, and therefore pose a high risk for electrocution.



Figure 2a & b. Two high-risk medium-voltage power poles with horizontal insulators and complex constructions in Austria. Pictures: C. Esterer

Study Area

This study focuses on the reintroduced migratory Northern Bald Ibis population of central Europe, which breeds at four main colonies: Kuchl and Rosegg in Austria, and Burghausen and Überlingen in Germany. Birds migrate to a wintering area in Tuscany, Italy. Since 2023, a second migration route to another wintering area in Andalusia, Spain, has been established (Fritz et al. 2024).

Methods

Mortality Monitoring

Nearly all birds in the reintroduced population are identified by colour rings with numbers. About 80% of the population is also equipped with GPS/GSM transmitters that provide continuous location data. When a bird ceases to transmit, or when a stationary GPS fix is recorded, field teams investigate the last known location. Recovered carcasses are subjected to veterinary post-mortem examination, including external inspection for burn marks, feather singeing, and internal haemorrhage consistent with electric shock.

The mortality cause was classified as verified electrocution when post-mortem findings and/or the spatial context (carcass found beneath a power pole) provided unambiguous evidence. All mortality events are recorded in a database combining all information about individuals.

Power pole risk assessment and retrofitting

As part of the ‘LIFE NBI project’, starting in 2022, a concrete conservation action was planned to retrofit high-risk power poles in the surroundings of the Northern Bald Ibis breeding areas in Austria. These measures are the responsibility of the local electrical grid operators — Netz

Oberösterreich GmbH (for Upper Austria, area near the Burghausen breeding colony) and Kärnten Netz GmbH (for Carinthia, area near the Rosegg breeding colony) — and the regional government of Land Salzburg (for Salzburg, area near the Kuchl breeding colony), which are associated beneficiaries of the ‘LIFE NBI project’.

A five-step workflow was implemented to plan and implement the measures against electrocution. First, positioning data from the Northern Bald Ibis reintroduction project were analysed to determine the main habitats used by the birds. Data collected from 2013 to 2023 using various transmitters were used. The data were collected and analysed on the Movebank platform (www.movebank.org) by creating a density map.

Then, the high-risk power poles in these areas were identified using data from the grid operators and local inspections. Power poles were classified as high-risk if they displayed horizontal insulators and/or complex branching structures — configurations known to provide simultaneous access to live and grounded components for large-bodied birds. High-risk poles in areas of intensive habitat use were prioritised for retrofitting.

Based on these criteria and the available project budget, the power poles for retrofitting were selected in each area. In Upper Austria, 43 high-risk power poles were selected in the municipality of Hochburg-Ach, which serves as the main feeding area of the Burghausen colony, as GPS data show that about 70% of feeding activities take place in this area. In Salzburg, 68 high-risk power poles were identified along the river Salzach, from Salzburg City in the north to Golling in the south. This includes the area around the Kuchl breeding colony, as well as meadows around Salzburg airport and meadows in the ‘Leopoldskroner Moos’, which are primarily used in summer and autumn. In Carinthia, 71 high-risk power poles were selected in the primary area surrounding Tierpark Rosegg, where the Northern Bald Ibis aviary and breeding wall is located (Figure 3).

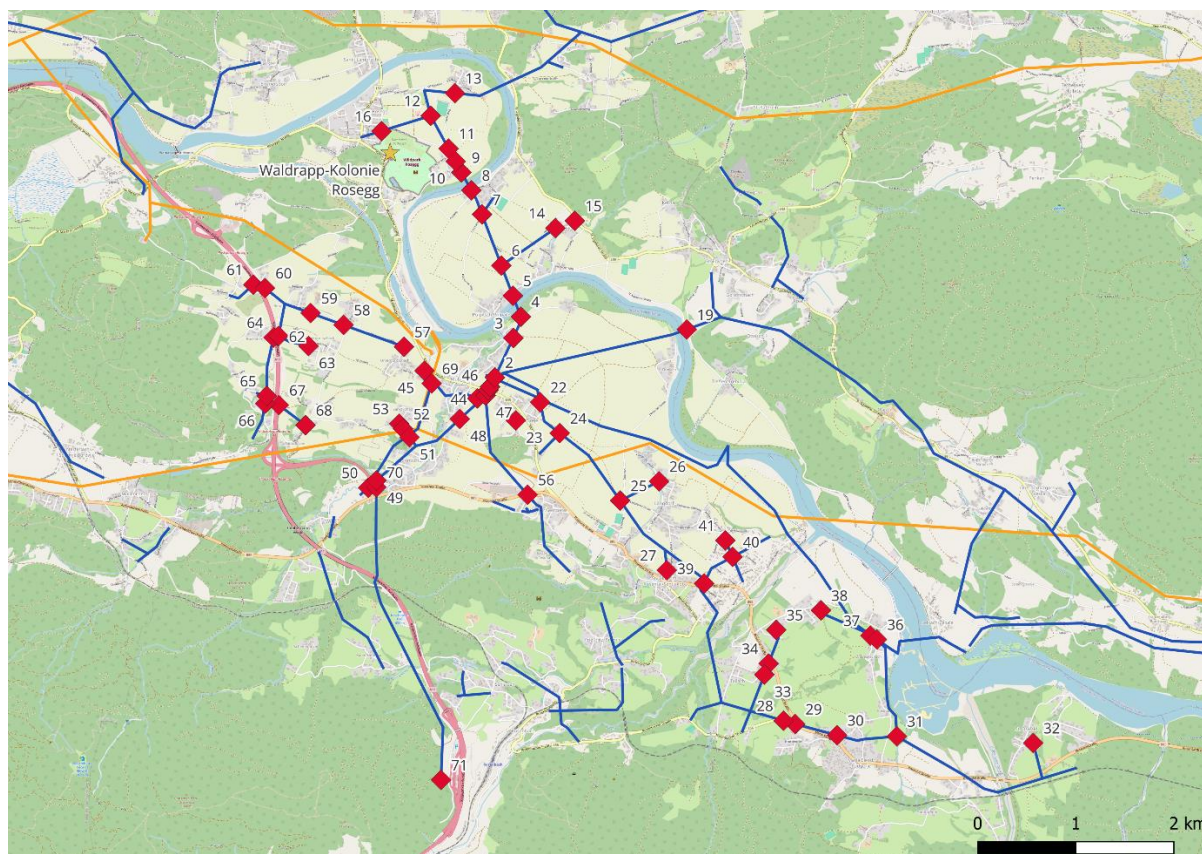


Figure 3. Overview of measures against electrocution in Carinthia. Red: targeted power poles (N = 71); blue lines: medium-voltage power lines in the project area; orange lines: high-voltage power lines in the project area

After selection, retrofitting of the power poles was carried out by the local grid operators. Cover caps, insulation tubes, insulated cages, and insulation tape were used to secure power poles (Figure 5). As the last step, the measures will be documented and evaluated to ensure their sustainable effect. GPS data will be used to assess continued use of retrofitted structures and to monitor any subsequent mortality events at secured power poles.

Results

Mortality by electrocution

Between 2014 and 2024, electrocution was the most frequent cause of death in the reintroduced Northern Bald Ibis population, responsible for 31.2% of all cases with known mortality cause (Figure 4). During this period, a total of 103 cases of electrocution were recorded. The majority (93 cases) could be verified using GPS data and/or evidence on the ground. In 39 cases, a veterinarian was able to examine the body and verify the cause of death.

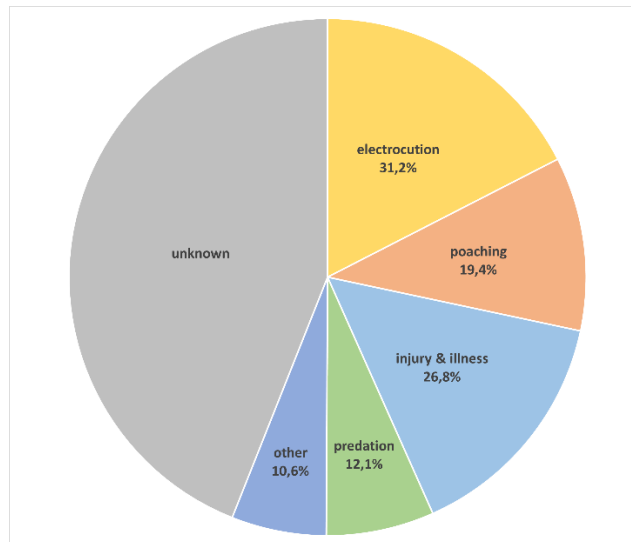


Figure 4. Causes of mortality (% of cases with known cause) in the reintroduced European Northern Bald Ibis population, 2014–2024 (N = 607 cases; 340 cases with known cause = 56.0%)

Electrocution mortality was uneven across countries. As the population mainly stayed in Germany, Austria, and Italy during the study period, the high number of cases in Italy (N = 54) and Austria (N = 33) was expected. In contrast, the frequency of electrocution in Germany was substantially lower (N = 7) because national legislation requires grid operators to secure all medium-voltage power poles against bird electrocution. Cases of electrocution were also recorded in Slovenia (N = 3), Switzerland (N = 2), Croatia (N = 2), France (N = 1), and Spain (N = 1).

Retrofitting measures

In Upper Austria, all 43 selected power poles were retrofitted by the end of 2024. The planned measures in Carinthia were carried out in 2024 and 2025, securing 71 power poles. In Salzburg, 56 power poles were retrofitted by the end of January 2026. Four more poles are planned for 2026, while measures on the remaining eight planned power poles will not be carried out due to budgetary constraints. Nevertheless, in the ‘LIFE NBI project’, 170 power poles have already been retrofitted across three Austrian federal states within the breeding range of the reintroduced Northern Bald Ibis population, with four more planned. This exceeds the goal of 160 secured power poles specified in the LIFE Grant Agreement.

As the retrofitting of power poles in the ‘LIFE NBI project’ was only recently completed, it is currently not possible to draw any conclusions about the effect of these measures on mortality in the Northern Bald Ibis population. Nevertheless, no incidents have occurred on the power poles since they were retrofitted.



Figure 5. (a, left) Retrofitted power pole in Upper Austria with cover caps (black), insulation tubes (red), and insulated cages (red); (b, right) Retrofitted power pole in Carinthia with insulation tape (red) wrapped around the power line and connection. Pictures: B. Gönner

Discussion

The data presented here confirm that electrocution on medium-voltage power poles is one of the most important identifiable causes of anthropogenic mortality in the European reintroduced Northern Bald Ibis population. With 103 confirmed deaths over eleven years and a large proportion of total mortality of unknown cause, the cumulative impact on a population of this size is severe. Population viability modelling by Drenske et al. (2023) demonstrated that the reintroduced Northern Bald Ibis population is not yet self-sustaining without active management, and that reducing anthropogenic mortality is among the most impactful interventions available to managers. Given that the reintroduced population consists of approximately 320 individuals, each confirmed electrocution death represents a measurable setback to recovery.

The finding that electrocution accounts for 31.2% of known-cause mortality in the Northern Bald Ibis population (Figure 4) is consistent with the broader flyway-scale analysis by Serratos et al. (2024), who reported that electrocution represents 47.2% of human-induced mortality events in Europe and 54.47% for storks and cranes (whole area) — a taxonomic group to which ibises are ecologically analogous in terms of body size, flight behaviour, and power-line interaction risk. Lehman et al. (2007) reviewed the global state of raptor electrocution research and concluded that risk is strongly associated with pole design, particularly where bare conductors are in close proximity to grounded structures, a finding supported by the structural characteristics of the most dangerous poles identified in the present study (Bevanger 1994, 1998; Figure 2a & b).

The action carried out as part of the ‘LIFE NBI project’ represents a scientifically grounded and operationally replicable response to this challenge. By combining GPS-derived habitat data with structural risk assessment and targeted retrofitting, the project has secured 170 power poles in the core Austrian breeding range. However, the continued high frequency of electrocution deaths in Italy as well as in Austria underscores the limitations of geographically partial interventions for a migratory species that traverses multiple national jurisdictions.



Figure 6. Northern Bald Ibises on a retrofitted power pole in Salzburg. The power pole was secured using cover caps (black), insulation tubes (red), and insulated cages (red). Picture: C. Esterer

The contrast between Germany, where few electrocution deaths are recorded due to legal requirements for pole securing, and Italy and Austria, where deaths remain frequent in the absence of equivalent legislation, provides one of the clearest possible demonstrations of the effectiveness of regulatory intervention. In June 2025, Switzerland passed a new law including the obligation to retrofit all medium-voltage power poles until 2035 or 2040 (depending on the type of construction). This will also help to reduce the danger of electrocution in the Northern Bald Ibis population as the new migration tradition to Spain is evolving and therefore more birds will be present in Switzerland during the migration.

We strongly advocate for the adoption of mandatory bird-safe power pole design standards – similar to Germany and Switzerland – across all range states of the Northern Bald Ibis, especially in Austria and Italy, where 84 % of all electrocution cases in the population occur.

Acknowledgements

This work was carried out within the LIFE Northern Bald Ibis project (LIFE20 NAT/AT/000049 – LIFE NBI), co-funded by the European Union. We thank the regional grid operators Netz Oberösterreich GmbH, Kärnten Netz GmbH, and Salzburg Netz GmbH as well as the regional government of Land Salzburg for their collaboration in the retrofitting measures, and all partners, sponsors, and collaborators of the Northern Bald Ibis reintroduction project.

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Human-Led Migration: A Unique Approach to Restore the Migratory Tradition of the Northern Bald Ibis *Geronticus eremita*

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Abstract

Since 2001, the Waldrappteam has conducted releases of Northern Bald Ibis *Geronticus eremita* with the aim of reintroducing a migratory population in Central Europe, primarily within EU-LIFE projects (Fritz et al. 2017). Human-led migrations are employed to ensure that juvenile birds acquire knowledge of the migratory route to suitable wintering grounds (Fritz & Janák 2022). The method integrates captive breeding, guided migration, and post-release monitoring into a well-established and refined approach (Fritz et al. 2017). This article presents recent outcomes of the project, including fledging success, migration fidelity, and behavioural training insights. The project demonstrates that an integrative and adaptive reintroduction strategy can substantially contribute to the conservation of this critically endangered species, employing a unique method potentially applicable to the reintroduction of other threatened bird species (Fritz et al. 2024).

Keywords: Northern Bald Ibis, *Geronticus eremita*, human-led migration, reintroduction, captive breeding, migration training, conservation

Introduction

The Northern Bald Ibis *Geronticus eremita* once inhabited large parts of Europe, even north of the Alps, but disappeared by the 17th century, primarily due to intensive hunting and habitat loss (Schenker 1977; Böhm et al. 2021). With the disappearance of wild colonies, the species also lost its migratory traditions. Juvenile Northern Bald Ibis learn migratory routes from experienced adults to reach suitable wintering sites, as conditions in their breeding areas are unfavourable during winter.

To address this loss of migratory knowledge, the Waldrappteam, founded and led by Johannes Fritz and building on the experiences of the Konrad Lorenz Research Station in Grünau, developed a pioneering translocation method over the past two decades: human-led migration. This represents the first successful attempt to teach inexperienced birds to migrate. In this approach, hand-raised juvenile ibises are guided along historic flyways using microlight aircraft, enabling them to acquire migratory traditions that can later be transmitted to their offspring. The overarching goal is to establish a self-sustaining, migratory population capable of autonomously moving between breeding and wintering grounds (Fritz et al. 2017; Sperger et al. 2017).

From 2002 to 2022, fifteen human-led migrations were conducted from breeding sites north of the Alps to Tuscany. In 2011, the first birds returned from Tuscany to their breeding areas in

Germany (Fritz et al. 2017). Since 2023, a second migration route to Spain has been established to accommodate climate change effects, which increasingly impede the birds' ability to cross the Alps (Fritz et al. 2024).

The project is part of the EU LIFE Programme. Following an initial project (LIFE+12 BIO/AT/000143; 2014–2019) led by Förderverein Waldrappteam in collaboration with six international partners, a second LIFE project (LIFE20 NAT/AT/000049) was approved (Fritz et al. 2024). From 2022 to 2028, 60% of the funding is provided by the European Union, with the remainder contributed by project partners. The second LIFE project is currently implemented by ten partners under the leadership of Schönbrunn Zoo. This initiative represents the first successful reintroduction of a migratory bird species.

Methods

Chick Selection and Hand-Raising

Each spring, approximately 34 chicks aged 2–8 days are sourced from European zoo populations, mainly from Rosegg Zoo in Carinthia, Austria. The age range does not exceed ten days to ensure consistent development and training conditions. Rosegg Zoo is preferred because its free-flying Northern Bald Ibis population breeds early, providing maximum training time (Fritz et al. 2017).

Chicks are carefully selected, and nests are never completely emptied to avoid disrupting parental breeding efforts. Once removed from nests, chicks undergo a thorough veterinary examination and are entrusted to two human foster parents, who provide round-the-clock care and wear yellow clothing for recognition by the birds (Fritz et al. 2017).

The diet consists of age-appropriate prepared meat (an age-varied mixture of mice, rats, chicken chicks, and beef heart) and a variety of insects, primarily crickets and mealworms. Hand-feeding continues beyond fledging until the birds reach their wintering area, strengthening the bond between the birds and their foster parents. From the outset, birds are conditioned to respond to a specific call, which is crucial for training and human-led migration. The hand-raising protocol emphasizes both physical and social bonding through tactile interaction and vocal communication. Isolation from other humans during hand-raising ensures strong imprinting while maintaining natural wariness of strangers, a critical requirement for successful release.

Training

Around 40 days of age, fledglings are transferred to a spacious outdoor aviary at the training camp (Fritz et al. 2017). They begin to fledge and gradually acclimatise to ultralight aircraft, equipped with a 60 m² parachute for migrating at 40–50 km/h (Sperger et al. 2017). Habituation starts with engine sound playback and visual exposure to the parachute. Birds are encouraged to follow the aircraft on short training flights, guided by auditory cues and the presence of foster parents (Sperger et al. 2017).

Study Sites

Currently, four breeding sites are established: Kuchl (Austria), Burghausen (Germany), Überlingen (Germany), and Rosegg (Austria). Once the birds reach sexual maturity, beginning in their third year, those released after human-led migration join one of the first three sites,

depending on the location of their training camp and the starting point of migration (Fritz et al. 2017).

Two established wintering areas exist: southern Tuscany (Laguna di Orbetello) and, more recently, Andalusia (Vejer de la Frontera). The WWF Oasis Laguna di Orbetello is a protected area in Tuscany, providing a refuge for numerous migratory bird species during winter. Since 2023, Vejer de la Frontera serves as a second wintering area. Since 2004, Northern Bald Ibis have been released in Vejer de la Frontera as part of the reintroduction project “Proyecto Eremita,” a collaboration between Zoobotánico Jerez and the Andalusian regional environment ministry. The sedentary population now includes three colonies in the region, comprising approximately 300 birds (López & Quevedo 2016; Fritz et al. 2024).

Migration Process

Starting in mid-August, trained juveniles embark on human-led migration to their designated wintering grounds (Fritz et al. 2017; Sperger et al. 2017). Since 2023, a second route to Andalusia has been implemented to mitigate delayed autumn migrations, likely caused by climate change (Fritz et al. 2024).

The route to Andalusia spans 2,600 km through Germany, France, and Spain (Figure 2). This

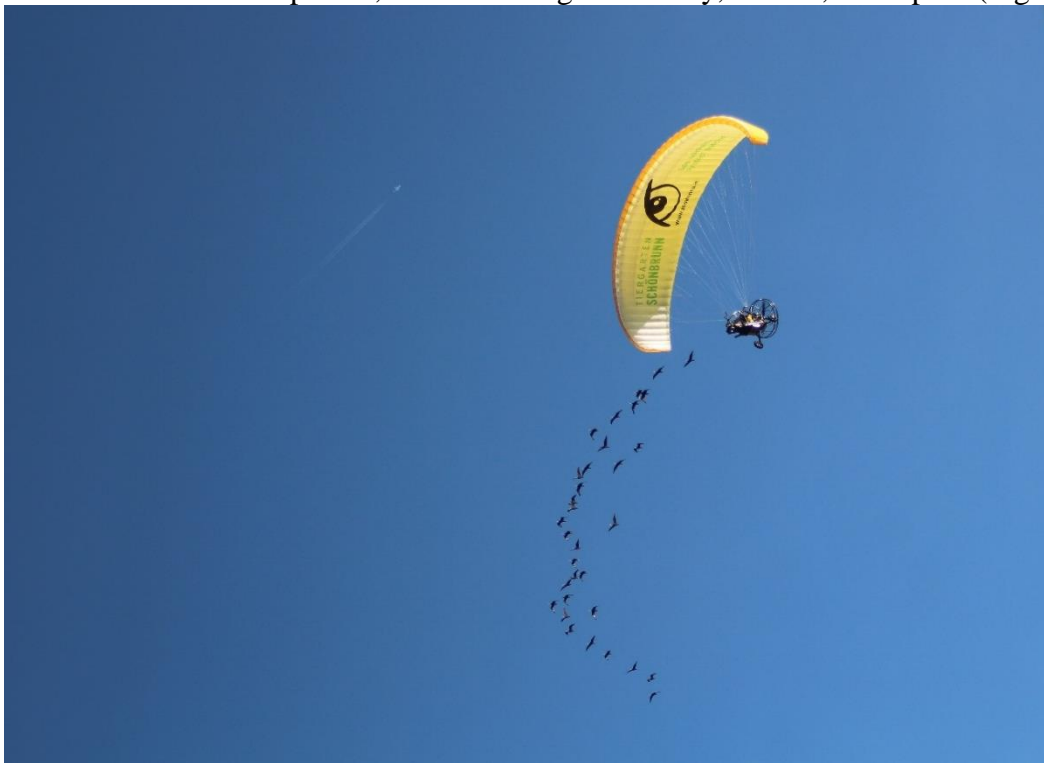


Figure 1. Birds following an ultralight aircraft (B. Steininger, Human Led Migration 2023)

distance is divided into up to 20 flight stages over a period of up to 50 days. During flights, guided by the co-piloting foster parent, birds typically adopt an energy-efficient V-formation (Voelkl & Fritz 2017). Campsites with a mobile aviary (9 × 12 m) provide overnight shelter, and a ground team of up to 16 accompanies the migration by cars.

Upon arrival, birds are held in a release aviary for acclimatisation before integrating with the resident population of Proyecto Eremita. Juveniles remain in the wintering area until sexual

maturity at three years of age, after which they migrate back to their upbringing site and join the nearest breeding colony.

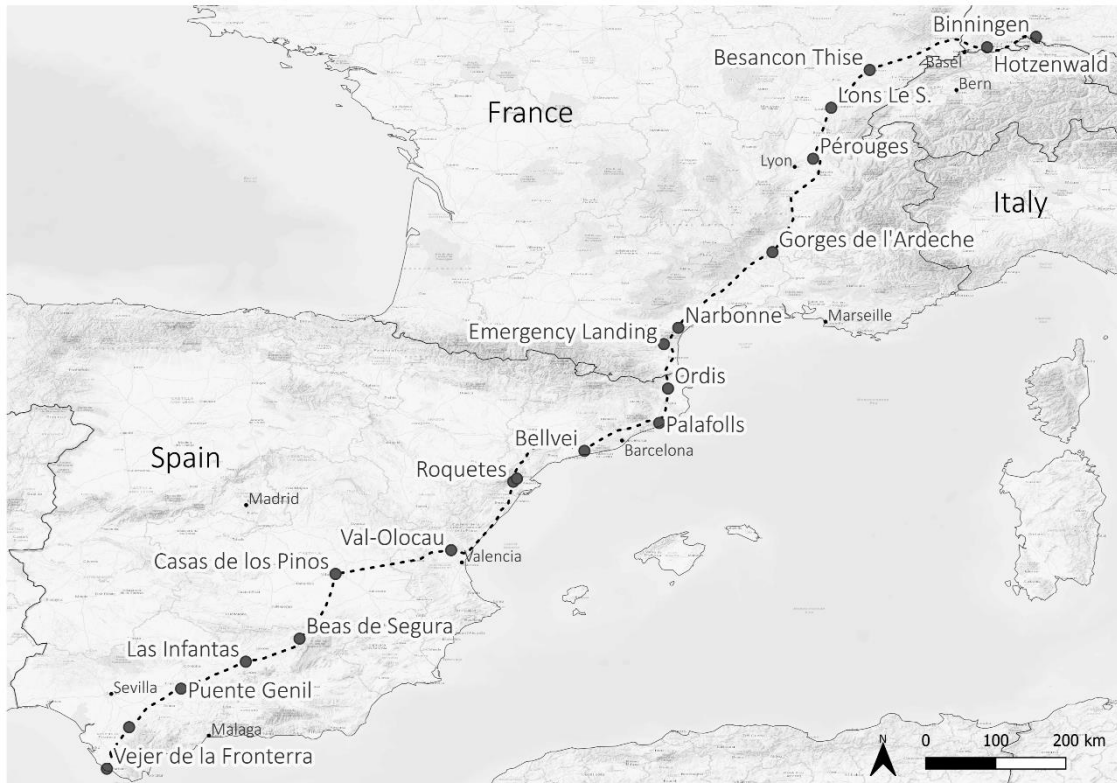


Figure 2. Migration route with stopovers of the human-led migration 2023

Data Collection

Each bird is equipped with a GPS transmitter prior to release, allowing detailed monitoring of movements and migratory behaviour. Locations can also be tracked by the public via the free Animal Tracker app. Birds are continuously monitored post-release by project managers.

Results

Since the first migrations to Tuscany, a migratory population has been established. Four breeding areas have been established (Fritz et al. 2017; Sperger et al. 2017):

North of the Alps: Burghausen (Bavaria), Kuchl (Salzburg), and Überlingen (Baden-Württemberg)

South of the Alps: Rosegg (Carinthia)

Breeding success has steadily increased, with 446 chicks hatched between 2012 and 2024, yielding a total population of 280 birds by the end of 2024. The main causes of mortality are electrocution on medium-voltage power poles, collisions and injuries, and illegal bird hunting in Italy (Figure 3; Fritz et al. 2024). The first migration to the newly established wintering area in Spain occurred in 2023; no birds have yet reached sexual maturity, and as of March 2023, none have returned to their breeding sites (Fritz et al. 2024).

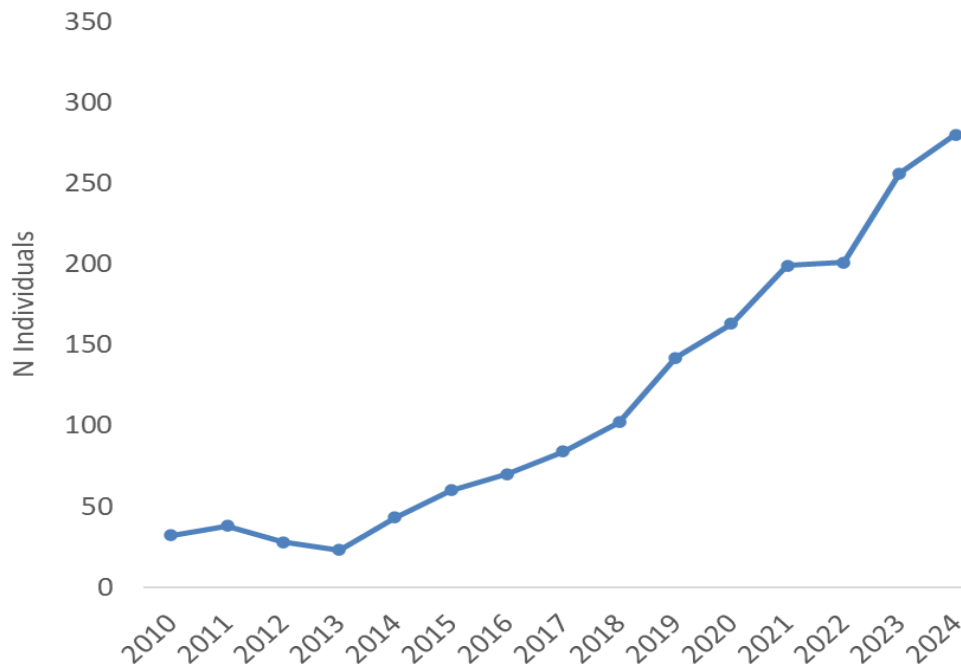


Figure 3. Population growth of the reintroduced Northern Bald Ibis from 2010 to 2024

Conclusion

Human-led migration provides a replicable model for species that have lost their migratory traditions. Its success relies on intense, socially engaged care during hand-raising, adaptive logistics, and a solid scientific foundation. The new migration route to Spain avoids the barrier of the Alps, illustrating how migration strategies can be adapted to geographic and climatic constraints for conservation purposes. This method underpins the first successful reintroduction of a migratory bird species (Fritz et al. 2017; Böhm et al. 2021) and may support the reintroduction of other threatened birds in the future (Fritz et al. 2024).

Acknowledgements

This work was carried out within the LIFE Northern Bald Ibis project (LIFE20 NAT/AT/000049 – LIFE NBI), co-funded by the European Union. We thank all project partners, supporters, and sponsors. Special thanks to Zoo Rosegg for their long-standing cooperation, and to the Proyecto Eremita team for invaluable support in managing the newly established wintering site in Vejer de la Frontera.

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A Flight Path for Science and Conservation: Northern Bald Ibis Citizen Science at the Konrad Lorenz Research Center

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Abstract

We present insights from over 25 years of behavioural research on the Northern Bald Ibis *Geronticus eremita*, bridging classical ethology with modern, interdisciplinary approaches to data collection. Central to our work is the value of long-term datasets, made possible by long-term monitoring of a free-flying colony established in Upper Austria in 1997. Each individual in this population is uniquely marked with coloured leg rings, facilitating life-history tracking across decades. Our research integrates behavioural, physiological, and ecological perspectives, and more recently, participatory methods involving citizen scientists and schoolchildren. This multifaceted approach has advanced understanding of key factors influencing breeding success, mortality risk, and spatial ecology in this endangered species, including movement patterns, roosting behaviour, and foraging site use. Notably, participatory research has fostered lasting interest in science among young participants. We highlight the broader implications of long-term, integrative research and citizen involvement for conservation biology and the sustainable management of threatened species.

Keywords: Northern Bald Ibis, conservation, citizen science, social behaviour, science communication

Introduction

The Northern Bald Ibis *Geronticus eremita* is a colonial and highly social bird species, currently listed as ‘Endangered’ by the IUCN (BirdLife International 2020). Once widespread across Europe, the Middle East, and North Africa, the species experienced a dramatic decline due to habitat loss, hunting, and human disturbance. Today, the last remaining truly wild population—estimated at around 700 individuals—persists in the Souss Massa National Park in Morocco (Oubrou and Bekkay 2018). An additional 230 individuals are maintained in semi-captivity at the Birecik Breeding Centre in Turkey, while the last wild birds in Syria are now considered locally extinct (Böhm et al. 2021).

In recent decades, reintroduction efforts across Europe have re-established Northern Bald Ibis populations in Spain, Austria, and Germany (Quevedo et al. 2004; Unsöld and Fritz 2014). However, these populations remain reliant on human intervention and long-term management. A major milestone in these efforts was the establishment of the first food-supplemented free-flying Northern Bald Ibis colony north of the Alps in over 400 years. This colony was founded in 1997 at the Konrad Lorenz Research Center (KLF) in Grünau im Almtal, Upper Austria (47°48'N, 13°56'E; Kotschal 1999). Over the past 25 years, this population has served as a cornerstone for research and conservation, maintaining a stable number of 10–15 breeding pairs and forming the basis for several experimental restoration projects across Europe.

Research at the KLF, carried out by PhD students, Master's students, and volunteers, has advanced understanding of the Northern Bald Ibis's social behaviour, ecology, physiology, and spatial dynamics. Social network analyses revealed seasonal and age-related variation in affiliative and agonistic interactions (Puehringer-Sturmayer et al. 2021). GPS telemetry studies demonstrated strong site fidelity and consistent movement routes shaped by landscape features and individual age (Puehringer-Sturmayer et al. 2023a). Investigations of physiological stress markers and parasite burdens linked to social interactions highlighted the complex relationships between behaviour, health, and environment (Puehringer-Sturmayer et al. 2018a). Crucially, this research program has integrated citizen science approaches (Frigerio et al. 2019; Puehringer-Sturmayer et al. 2023b). These participatory projects, supported by the contributions of students and volunteers, fostered positive attitudes toward conservation and science, enhanced public awareness, and provided reliable, high-quality data to supplement scientific efforts (Puehringer-Sturmayer et al. 2023b).

Similar “win-win” outcomes have been observed in other citizen science initiatives (Frigerio et al. 2018; Johnston et al. 2023). These efforts provide critical insights into overwintering habitats and migration timing, information vital for conservation planning. At the same time, participation fosters environmental awareness and strengthens the human–nature connection, especially during seasons when wildlife encounters are less frequent (Frigerio et al. 2023). This dual benefit of advancing scientific knowledge while engaging and educating the public mirrors the success of the Northern Bald Ibis program, illustrating the broader applicability of participatory science in avian conservation.

The Northern Bald Ibis is an exemplary model species for such participatory science, combining rigorous behavioural and ecological research with meaningful public involvement. Its charismatic nature, distinctive appearance, and accessible semi-wild population make it ideally suited for educational outreach and citizen engagement.

The aims of this contribution are twofold: firstly, to review what we have learned about the social behaviour of the Northern Bald Ibis; and secondly, to develop future perspectives for integrating this species' extinction comeback with participatory science outcomes. Children, in particular, may act as information multipliers within local communities after being exposed to educational activities (Frigerio et al. 2019). Local schools, kindergartens, and residents have been active in the project. We summarise the activities to date and outline future plans for social engagement.

Methods

Study Population

All Northern Bald Ibises of the KLF colony in Grünau im Almtal are individually marked using combinations of coloured leg rings and a metal ring bearing a unique alphanumeric code issued by the German or Austrian ornithological ringing schemes. This marking system enables detailed long-term individual datasets for this species, facilitating individual identification across life stages and social contexts.

Population Trends

Since its establishment at the KLF in 1997, the colony showed steady population growth until plateauing between 2010 and 2013 (Figure 1). A decline commenced in 2014, culminating in zero successful breeding and increased mortality in 2022, likely linked to springtime logging

activities near the aviary that removed protective tree cover and was associated with eagle owl visitation, predation, and likely physiological stress. Long-term demographic data consistently reveal juvenile mortality peaks during early development, emphasizing spring as a critical period influencing overall population viability (Böhm et al. 2021).

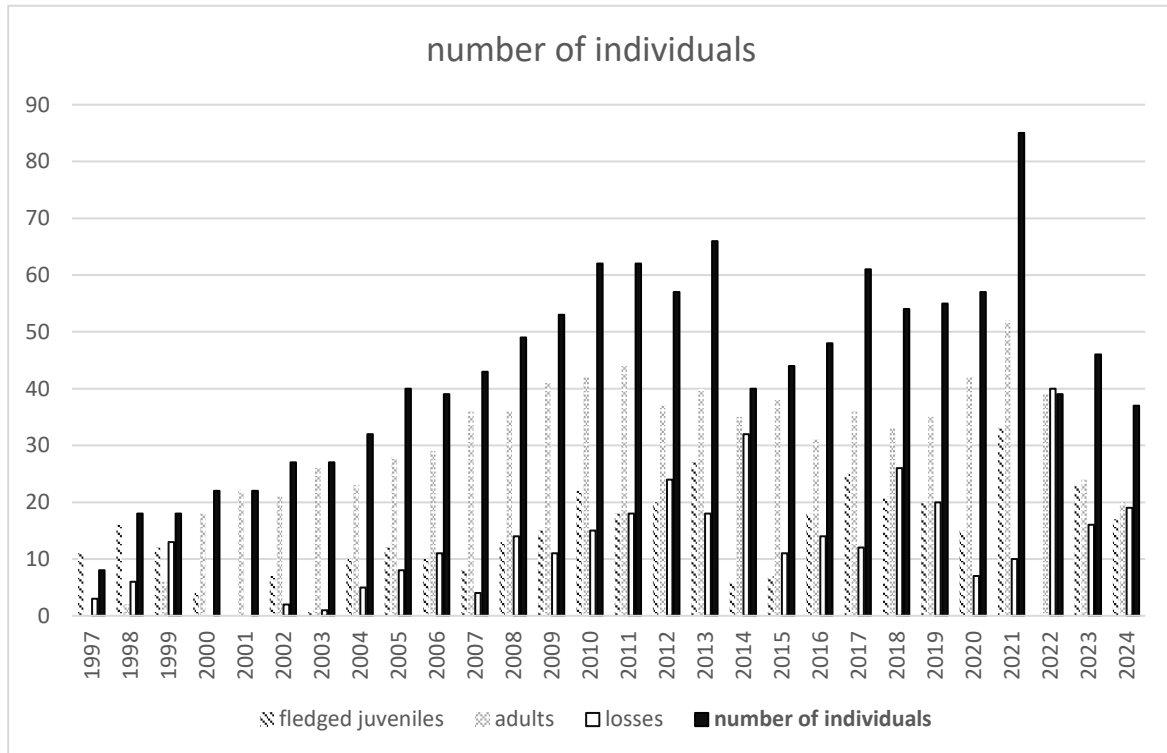


Figure 1. Development of the Northern Bald Ibis population of the Konrad Lorenz Research Center from 1997 to 2024

Supplemental Feeding

Supplemental feeding occurs primarily during winter (November to February) and the breeding season (March to June), delivered at fixed stations within the free-flight aviary and an adjacent meadow near the KLF. Winter feeding is ad libitum, ensuring birds can feed to satiation during periods of natural food scarcity. During breeding, feeding is provided twice daily (08:00 and 15:00), complementing natural foraging. In summer and autumn, birds rely solely on naturally available food sources.

Behavioural and Life-History Monitoring

Regular monitoring protocols include weighing eggs and chicks, tracking chick growth, and documenting family relationships and survival. Detailed records of social dynamics, breeding success, mortality, movement, and dispersal patterns have been maintained over decades, forming a comprehensive life-history database crucial for understanding population ecology (Puehringer-Sturmayer et al. 2023a).

Movement and Dispersal

The colony functions as a food-supplemented free-flying population within an open aviary at Cumberland Wildpark, managed year-round by KLF staff. Birds use adjacent foraging grounds and spend summers in a nearby valley before returning to the aviary in autumn. While the colony does not migrate, approximately 50% of juveniles show spatiotemporal movement patterns in a north or northeast direction prior to summer's end, returning later in the season. This spatial ecology offers a unique opportunity to investigate life-history trajectories, social behaviour, and conservation interventions in an endangered species.

Citizen Science and Educational Outreach

A core element of the project is active collaboration with local schools, kindergartens, and community groups to foster environmental education and participatory research (Frigerio et al. 2019). Children engage in bird observation, identifying individuals by leg rings, and participate in interactive workshops covering animal behaviour, ecology, and conservation principles. Student-led projects, supervised by researchers, contribute to data collection and analysis, enhancing scientific literacy and critical thinking while supplementing long-term behavioural datasets (Frigerio et al. 2020; Puehringer-Sturmayr et al. 2018b).

Evaluations of the impact of these immersive experiences demonstrate significant knowledge gains and reductions in misconceptions, with children becoming multipliers of scientific information within their communities (Frigerio et al. 2019). Moreover, the gained knowledge was preserved over an extended period and gained public visibility—one school transformed the project into a national competition victory at a “Sparkling Science Slam” in Vienna (Hirschenhauser et al. 2019; 2022). The outreach program continues to expand, now encompassing university-level training in behavioural data analysis, social network methodologies, and science communication (Puehringer-Sturmayr et al. 2023b).

Results

Scientific Outcomes

The Konrad Lorenz Research Center's long-term research on Northern Bald Ibises has yielded critical insights into the social behaviour, physiology, movement ecology, and conservation management of this endangered avian species. Pair bonding significantly reduces parasite burdens and physiological stress through affiliative behaviours such as mutual preening and body contact, enhancing immune function and breeding success (Puehringer-Sturmayr et al. 2018a). Social network analyses reveal distinct sex- and age-specific strategies: males maintain dominance via agonistic interactions to secure mates and breeding sites, while females invest in affiliative behaviours and coalition-building (Puehringer-Sturmayr et al. 2021). Seasonal variation in sociality was observed, with winter months showing increased social proximity and affiliative interactions, and older individuals occupying central network positions.

Movement ecology data from GPS telemetry highlight conservative flight routes along valleys and rivers, suggesting habitat familiarity guides movement and reduces energetic risks (Puehringer-Sturmayr et al. 2023a). Juvenile dispersal to neighbouring colonies, especially those managed by the Waldrappteam, underscores the importance of connectivity in metapopulation dynamics and raises considerations for landscape-level management.

Social Outreach and Education Outcomes

Interactive activities designed in partnership with schools significantly increased general knowledge and reduced misconceptions about Northern Bald Ibises. One school's active participation culminated in winning a national "Science Slam" competition in Vienna, exemplifying the project's impact in fostering science literacy and community involvement.

Digital devices enabling in- and ex-situ participation, such as the project 'NestCams' on Zooniverse or the app "Forschen im Almtal" on Spotteron, have engaged children and families directly in observing NBI behaviour, promoting awareness and stewardship (Puehringer-Sturmayer et al. 2023b; Rittenschober et al. 2023). Awards granted to contributors like Didone Frigerio, integrated into programs such as KinderUniOÖ and Science Holidays, highlight the success of these outreach efforts in inspiring young learners. University students benefit from training opportunities involving ibis data analysis, social network methodology, and science communication. Adaptations of scientific manuscripts for the open access journal *Frontiers for Young Minds* extend the project's reach to younger audiences (Frigerio et al. 2024; Gegendorfer et al. 2022; Puehringer-Sturmayer et al. 2020).

Table 1. Summary of Key Outcomes from the Konrad Lorenz Research Center scientific activities of the Northern Bald Ibis Project

Topic	Key Findings	Source/Reference
Social Behaviour & Physiology	Stable pair bonds reduce parasite loads and physiological stress; affiliative behaviour supports survival and immune function.	Puehringer-Sturmayer et al., 2018
Sex- and Age-related Sociality	Males dominate via aggression; females invest in affiliative behaviours; older birds more central in social networks; affiliative interactions peak in winter.	Puehringer-Sturmayer et al., 2021
Movement Ecology	Birds use established flight paths near human infrastructure; juveniles show exploratory dispersal, adults less so, supporting meta-population expansion.	Puehringer-Sturmayer et al., 2023a
Nest Cam & Breeding Success	Nest monitoring revealed fluctuating fledgling success; major breeding disruption in 2022 linked to human disturbance (logging).	Frigerio et al., 2019; Current review
Citizen Science & Education	School programs improved ibis knowledge and attitudes; students became effective conservation multipliers; ongoing outreach via Forschen im Almtal app expanded engagement.	Frigerio et al., 2019; Puehringer-Sturmayer et al., 2023a Hirschenhauser et al. 2019

Discussion

The Northern Bald Ibis serves as a prominent example of a rewilding success story, illustrating both the complexities and potential of restoring species to former ranges. Historically widespread but driven to near extinction by anthropogenic pressures (Böhm et al. 2021), coordinated reintroduction programs across Germany, Austria, and Spain have established viable, breeding populations, showcasing how collaborative conservation can restore migratory species in fragmented landscapes (Drenske et al. 2023; Fritz et al. 2017).

GPS telemetry data reveal highly consistent flight paths, suggesting learned behaviour and potentially culturally transmitted migration routes (Fritz et al. 2017). Juveniles show greater

range shifts than adults, visiting nearby colonies and promoting gene flow and metapopulation connectivity (Puehringer-Sturmayr et al. 2023a).

Emerging technologies—including GPS telemetry, social network analysis, physiological studies, personality research, and individual recognition methods—offer tools for finer-scale monitoring of movement, social behaviour, and health. Integrating these technologies with citizen science initiatives strengthens both data quality and public engagement, exemplifying a model for participatory conservation (Frigerio et al. 2019; Puehringer-Sturmayr et al. 2023b).

Conclusion

Effective ecological restoration extends beyond population recovery to include insights into movement ecology, social behaviour, health, and individual variation, alongside mitigation of human impacts. Transnational collaboration underscores the importance of metapopulation connectivity. Advances in tracking, behavioural and physiological monitoring, and active citizen science form a vital multidisciplinary framework for sustainable conservation. This integrated approach offers a valuable model for global rewilding efforts, demonstrating both the promise and challenges of restoring species in complex modern landscapes.

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Insights into the Northern Bald Ibis *Geronticus eremita* Genetics in European Zoo Populations – Recommendations for Captive Breeding and Reintroduction

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Abstract

The Northern Bald Ibis *Geronticus eremita* is a critically endangered species whose conservation depends largely on European ex situ breeding and reintroduction programmes. We investigated the genetic diversity and population structure of the European zoo population and two reintroduction populations and assessed differentiation between the eastern (Turkey/Syria) and western (Morocco) wild lineages using microsatellites, mitochondrial DNA (ND5 and cytochrome b), and ddRAD sequencing.

While microsatellite data revealed structured clustering within the zoo population, genome-wide ddRAD data showed no complete differentiation between eastern and western populations. In contrast to earlier conclusions based on limited sampling, our results do not support their classification as separate Evolutionarily Significant Units (ESUs). The observed differentiation likely reflects recent geographic isolation rather than long-term evolutionary divergence.

We found no evidence that admixture would currently result in significant outbreeding depression, suggesting that sustainable genetic management of the Northern Bald Ibis should consider integration of genotypes while maintaining precautionary monitoring and expanding sampling of remaining wild populations.

Introduction

Biodiversity is decreasing worldwide. Various factors such as climate change, habitat loss, and invasive species have led to an ever-accelerating extinction of species. Like many other species, birds are also affected by this negative development. It is assumed that by the beginning of the next century, globally, a total of 6–14% of bird species will be extinct (Şekercioğlu et al. 2004).

The intention of this study was to analyse the genetics of the ex situ population of the endangered Northern Bald Ibis *Geronticus eremita*. We therefore conducted a study of the genetic diversity within the European zoo population (ZOO; all individuals belonging to European ex situ projects pooled), the migratory release populations Waldrappteam (WRT; colonies Burghausen in Germany and Kuchl in Austria), and the sedentary release population Proyecto Eremita (PE; Bay of Cádiz, Spain). Furthermore, the study aimed to investigate genetic differences between the wild eastern (Turkey and Syria) and the wild western populations (Morocco) of the Northern Bald Ibis.

First, a species-specific microsatellite primer set was developed to enable genotyping of the Northern Bald Ibis. This set forms the basis for genetic screening of this species and was used

to genotype a large proportion of individuals living in European zoos and managed by the European Endangered Species Programme (EEP). Descendants from Moroccan wild catches represented in European zoos and samples of the extinct wild populations in the Middle East were examined by sequencing two mitochondrial DNA sequences to determine whether they belong to different Evolutionarily Significant Units (ESUs).

In a final step, we aimed to determine whether differences can be found on a genomic level between birds from the eastern and western parts of the Northern Bald Ibis's range and whether the findings would have consequences for future management.

Material and Methods

Blood and salivary samples from 10 captive-bred, five semi-captive, and one wild individual of Northern Bald Ibis were obtained to create a genomic DNA library. A total of 48 loci produced interpretable results when conducting the polymerase chain reaction (PCR). Of these, 15 microsatellite loci that showed the highest polymorphism were selected.

A total of 747 individuals (596 blood samples, 82 buccal swabs, 18 feathers, and 51 tissue samples) were chosen for microsatellite analyses.

In addition to the microsatellite screening, we sequenced the NADH hydrogenase subunit 5 (ND5), which is known to be a highly variable gene, in 98 individuals (five samples of Turkish and Syrian origin and 93 from zoo populations). The cytochrome b gene (cyt b) was sequenced in 16 individuals (five samples of Turkish and Syrian origin and 11 from zoo populations with presumably Moroccan origin).

The construction of the ddRAD library was conducted using a modified protocol by Peterson et al. (2012). A total of 80 samples (62 blood samples, three tissue samples, six buccal swabs, one feather sample, and eight toe pad samples from museum specimens) were analysed.

Results

Using STRUCTURE analysis, $K = 15$ was identified as the most likely number of genetic clusters. Table 1 presents how birds from the various facilities were assigned to corresponding STRUCTURE clusters; Figure 1 illustrates this assignment.

Birds from Goldau Zoo (Cluster 14, Switzerland), Zurich Zoo (Cluster 15, Switzerland), Rheine Zoo (Cluster 3, north-west Germany), and Parco Natura Viva (Cluster 15, northern Italy) each formed their own distinct genetic cluster. It was also evident that birds from three zoos in the United Kingdom (London, Cotswold, and Edinburgh) clustered together, while birds from the nearby Blackpool Zoo (Cluster 7) grouped with individuals from Duisburg Zoo—likely reflecting past exchanges between these facilities—and with birds from Nordens Ark Zoo (Sweden).

Individuals from the WRT population ($n = 62$) were distributed across eleven clusters, with three of them being predominant (Cluster 1: 19.3%, Cluster 6: 21.0%, Cluster 11: 21.0%). Birds from the PE population were assigned to six genetic clusters, one of which dominated (Cluster 13: 42.8%). Wild birds from the western part of the range (WB_W) were distributed across five clusters.

Table 1. Number of individuals in each cluster detected by STRUCTURE (data set 2) and dominating institutions (numbers in parentheses show the number of individuals from the respective zoo/colony belonging to the cluster; eastern wild birds are underlined; reintroduced birds are in bold)

	Number of individuals	Dominating institutions per cluster
Cluster 1	44	Waldrappteam, Germany/Austria (12 of 62 individuals)
Cluster 2	30	Parco Natura Viva Bussolengo, Italy (16 of 16 individuals) Dublin Zoo, Ireland (8 of 23 individuals)
Cluster 3	36	Naturzoo Rheine, Germany (15 of 15 individuals)
Cluster 4	51	Konrad-Lorenz-Forschungsstelle Grünau, Austria (23 of 96 individuals)
Cluster 5	20	Wilhelma Zoologischer Garten Stuttgart, Germany (9 of 12 individuals)
Cluster 6	54	Waldrappteam, Germany/Austria (13 of 62 individuals) Tiergarten Schönbrunn Wien, Austria (12 of 29 individuals) Tierpark Rosegg, Austria (10 of 25 individuals)
Cluster 7	36	Blackpool Zoo, UK (5 of 5 individuals) Zoo Duisburg, Germany(5 of 5 individuals) Nordens Ark Zoo Hunnebostrand, Sweden (8 of 16 individuals)
Cluster 8	52	Bioparc - Zoo De Doué La Fontaine, France (20 of 29 individuals) Zoologischer Garten Berlin, Germany (8 of 14 individuals)
Cluster 9	42	Konrad-Lorenz-Forschungsstelle Grünau, Austria (30 of 96 individuals)
Cluster 10	43	Alpenzoo Innsbruck Tirol, Austria (12 of 26 individuals) Konrad-Lorenz-Forschungsstelle Grünau, Austria (18 of 96 individuals)
Cluster 11	41	Waldrappteam, Germany/Austria (13 of 62 individuals) Tiergarten Schönbrunn Wien, Austria (13 of 29 individuals)
Cluster 12	31	<u>WB_E (8 of 8 individuals)</u>
Cluster 13	55	Cotsworld Wildlife Park and Garden, UK (9 of 10 individuals) RZSS Edinburgh Zoo, Scotland (8 of 15 individuals) Zoobotánico Jerez, Spain (9 of 21 individuals)
Cluster 14	48	Natur- und Tierpark Goldau, Switzerland (17 of 19 individuals) Bioparc - Zoo De Doué La Fontaine, France (7 of 29 individuals)
Cluster 15	59	Zoo Zürich, Switzerland (23 of 26 individuals) Nordens Ark Zoo Hunnebostrand, Sweden (8 of 16 individuals)

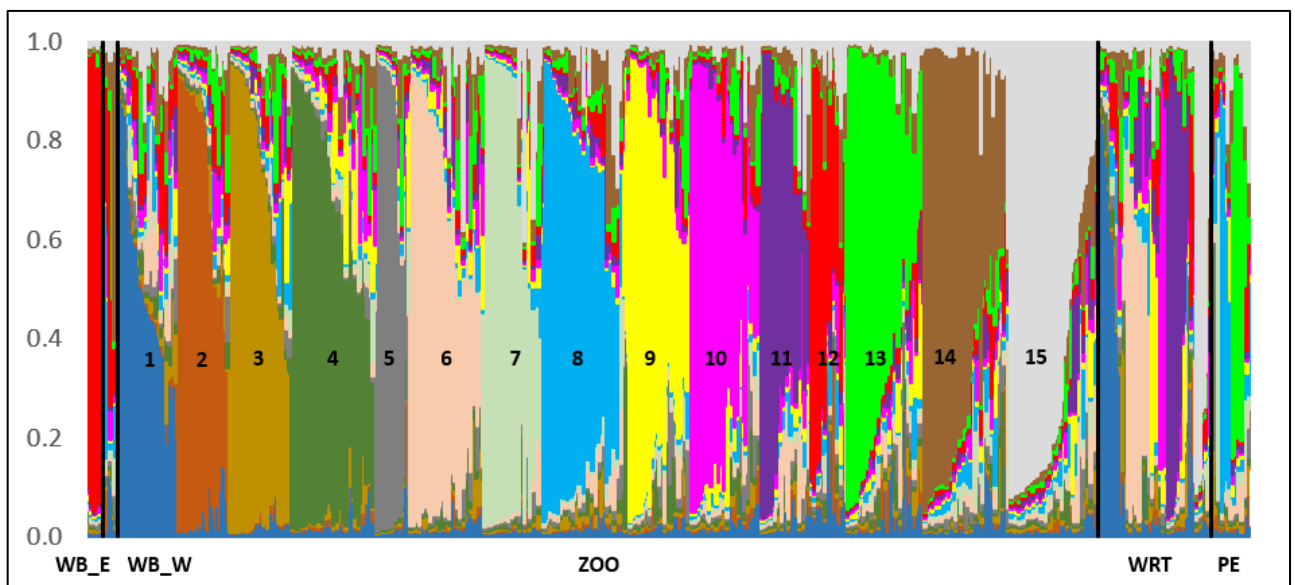


Figure 1. Genetic clusters inferred by STRUCTURE (K = 15). Each individual is represented by a vertical bar, with the colour representing the estimated proportion of membership to the respective cluster (K) (n = 642). Black bars separate the five groups (WB_E, WB_W, ZOO, WRT, PE). The numbers (1–15) indicate the different clusters. The ZOO population is sorted by cluster affiliation

The substitution found in cyt b (position 185) matched the one reported by Pegoraro et al. (2001) and indicated the samples' origin, as it differed between wild eastern and wild western individuals. In contrast, the substitution in ND5 (position 75) showed no association with the origin of the sample. The western cyt b haplotype was present in all ZOO individuals as well as in all WRT and PE individuals (Figure 2).

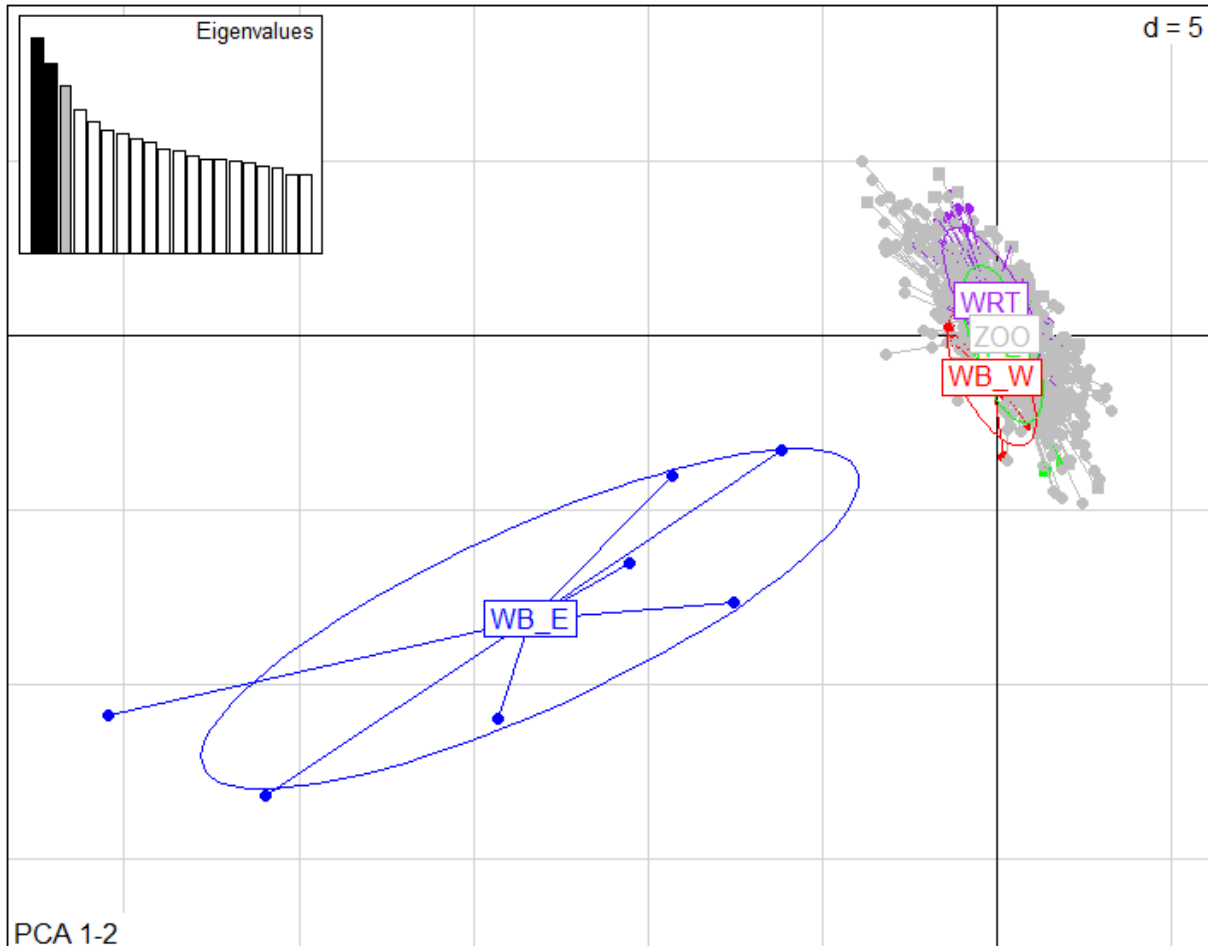


Figure 2. Plot of the first two axes of the Principal Component Analyses including all multilocus genotypes for the five groups (WB_E: blue; WB_W: red; ZOO: grey; WRT: purple; PE: green). The distribution of eigenvalues is shown by the graph in the upper left corner. The length of each line shows the distance of each individual from the group centroid

The number of ddRAD reads obtained averaged 321,147 reads per individual. No locus showed complete differentiation between the eastern population (WILD_east) and the western population (ZOO and WILD_west).

Conclusion

The present study provides robust evidence that, based on current genetic data (mitochondrial DNA sequencing and ddRAD sequencing), the eastern and western populations of Northern Bald Ibis do not constitute two distinct Evolutionarily Significant Units (ESUs). This finding contrasts with the conclusion of Pegoraro et al. (2001), which was based on a very limited sample size. Our results therefore lead to a substantially different interpretation of the population structure.

The clear differentiation between individuals from the eastern and western populations revealed by the microsatellite analysis indicates that the genetic divergence between the two groups is recent and likely results from the substantial geographic distance separating them since the extermination of the European population in the early 17th century (Schenker 1977), which prevents genetic exchange.

Taken together, the results indicate no evidence that admixture between individuals from the two populations would currently result in significant outbreeding depression. Nevertheless, as a precautionary measure, we recommend managing the populations separately as long as no detrimental effects of inbreeding become evident.

The findings of our study suggest that sustainable genetic management of the remaining eastern and western populations should prioritise integration rather than the continued isolation of genotypes, which currently represents the prevailing management strategy (Bowden 2015). However, in our study, samples from the eastern population are underrepresented, and samples from Moroccan wild populations are completely missing due to lack of availability. We therefore consider it a priority measure and an essential basis for sustainable, evidence-based genetic management to analyse samples from birds of the Turkish and Moroccan populations.

Moreover, due to advances in genetic methodology, we also recommend a comprehensive whole-genome analysis, a topic that was also extensively discussed at the symposium.

Acknowledgements

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Veterinary Care of the European Migratory Northern Bald Ibis *Geronticus eremita* Population

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Abstract

This article provides an overview of the scientific collaboration and veterinary tasks involved in the management of the Northern Bald Ibis project (NBI). Scientific results are briefly summarized and the most important tasks in the veterinary care of the population are described.

Preface on the origin of the cooperation

The first contact with the Waldrappteam took place in 2008, when Professor John Dittami (1949–2014, Department of Behavioral Biology, University of Vienna) was looking for partners for a scientific project. Blood samples were planned for physiological studies on the Waldrapp's energy expenditure during migration. We took advantage of this opportunity to combine it with a doctoral thesis on the influence of migration on hematological parameters (Stanclova et al. 2017), as the NBI project offers a unique opportunity to obtain very timely samples from individual migrating birds directly before and after their flight during human-led migration (HLM). The doctoral student participated in the HLM over two seasons and was able to collect a considerable number of samples, resulting in two publications with interesting results (Bairlein et al. 2015; Stanclova et al. 2017).

Stanclova et al. 2017 could show postflight significant decreases in hematocrit, tWBC, lymphocytes (abs., %), heterophils (abs.), eosinophils (abs., %), and monocytes (abs.). In contrast, heterophils (%), basophils (%), and the heterophil/lymphocyte (H/L) ratio increased significantly. With increasing flight duration, the H/L ratio increased further. One day postflight, there were still significant decreases in tWBC, lymphocytes (abs.), and eosinophils (abs., %) and significant increases in heterophils (%) and the H/L ratio. The hematocrit dropped even further. These data show that Northern Bald Ibises *Geronticus eremita* need more than 1 day to reverse the postflight changes in some hematologic values.

Furthermore, Bairlein et al. 2015 could show that migratory birds primarily utilize fat reserves for energy during flight but also rely on protein to a lesser extent. Flight significantly elevates metabolic rate, often 10 times higher than basal levels. Energy expenditure decreases as flight duration increases, suggesting a shift in metabolic pathways. Birds may balance aerobic and anaerobic metabolism during flight, with fat being a primary fuel source for aerobic metabolism. After long flights, birds need to recover from strenuous exercise and replenish energy stores, while also preparing for the next flight bout.

Veterinary healthcare in cooperation with the project and scientific output

This scientific cooperation also initiated the veterinary care for the NBI population. We started to subject all chicks to a veterinary examination when they were removed from the nest for the HLM (beginning of April). In addition to the general clinical examination, the animals undergo a control for parasites and possible pathological bacteria. During hand-rearing and before transfer to the training site, the animals for the HLM are clinically examined again, and blood samples are checked. In many years, we also took blood samples at the training site shortly before migration (August). Furthermore, in the early years, blood samples were always taken in March before the spring migration at the wintering site. Now the population is too large and too dispersed to continue these annual tests except for the birds of the annual HLM. These examinations included clinical control, body weight, blood sampling, and control for parasites. Random samples for bacteria were taken, respectively, in case of abnormalities.

All these studies over many years have provided vast amounts of data, some of which have already been published, while others are still in progress. A paper on the cultivable autochthonous microbiota of the critically endangered NBI (Spergser et al. 2018) examined samples deriving from the choana, trachea, crop, and cloaca, employing a culturomic approach, to identify microbes at each sampling site and to compare their frequency among age classes, seasonal appearances, and rearing types. In summary, this study provides a first inventory of the cultivable microbiota residing in the critically endangered NBI and represents a first step. The results are an important aid in interpreting suspected infections of the birds.

Another study on “Weight development of the NBI in hand-rearing of the Waldrapp project” (working title) is well advanced and is intended to provide guidelines for quality control in hand-rearing based on age-specific target weights.

The blood tests over years yielded an incredible 150–180 data sets, some of which included repeated measurements from the same individuals over the years. This dataset allows not only the establishment of well-founded reference values, but also the evaluation of possible seasonal, age, or gender-specific differences. This work is also well advanced and will be published soon.

Frequently seen health problems, emergencies and special incidents

Soon the collaboration developed into permanent veterinary care for the birds not only for routine health checks, but also in case of emergencies. In fact, we are almost continuously accessible as contact persons for veterinary questions. Due to the large distribution area, not all animals can be brought to the University of Veterinary Medicine Vienna for examination and treatment. Therefore, if necessary, we also try to arrange for veterinary care locally. Over and beyond, a rehabilitation aviary has been set up near Vienna.

Due to the birds' ever-expanding range and the change in the flight route to southern Spain, efforts have been made to further expand the veterinary network along the routes. Fortunately, several well-suited veterinary practices have already expressed their interest and willingness to do so.

Reported medical problems reflect the known mortalities. Between 2014 and 2023, 26% of dead birds died because of trauma. Additionally, human-caused trauma accounted for 34% of deaths, of which 18% were demonstrably caused by illegal hunting, the other large proportion being electrocution.

In almost all cases, X-rays are required to diagnose gunshot wounds; this allows even older or deep-lying shots to be detected. For forensic reasons, all animals found dead or with clinical abnormalities should be x-rayed. Correct positioning is not required for this purpose. X-rays are useful and recommended even for poorly preserved bodies. Many veterinary practices along the migration areas, even those without specialization in avian medicine, are willing to perform such X-rays in suspected cases.

Many birds fall victim to electrocution, but only very few of them survive. The diagnosis is usually determined by the location where the deceased animals were found. Often, entire groups are affected. Diagnosing electrocution in a living bird is not always easy; sometimes, typical feather changes or oedema are found, but more often, birds suffer from internal injuries, which often lead to unspecific symptoms and delayed death. Initiated by the Waldrapp Project, which highlights the problem of electrocution through concrete documented cases, preventive security measures are increasingly being implemented in the birds' distribution area, which also benefits other bird species.

Due to their anatomy, but also because of the birds' curiosity, various beak injuries and fractures are common. If the beak is only injured and not fractured or even broken, these can usually be treated locally and, if necessary, with topical cleaning and analgesics. In defined cases, also systemic antibiotics is indicated. The employed bird managers of the project are on site and already have some experience and practice with this. However, if the beak is fractured, surgery or dressings are indicated. If part of the beak is completely broken off, the other part can be trimmed to the same length if it is not too far proximal. Birds with beaks that are too short for foraging cannot survive in the wild, but mostly in captivity with supplementary feeding.

Fractures of the wings or legs also occur from time to time. The prognosis for these fractures depends on the location, the age of the animal, whether they are closed or open, and the degree of contamination. Prompt initial treatment with wound cleansing and a bandage for stabilization can significantly improve the prognosis. Prompt veterinary care is essential. The bird managers are trained accordingly and, if the animal is found in time, they are trained to prepare medical care, for example with bandages and wound cleaning. Fracture treatment for the NBI is otherwise carried out in the same way as for other bird species. During the healing phase, the bird is usually kept still, but afterward a rehabilitation period is required to regain mobility and strength before the bird can be released again.

Another problem that NBIs often suffer from is bumblefoot and toe injuries. If detected early, these changes can usually be successfully treated on-site by the bird managers.

It is well known that NBIs are very fond of ingesting foreign bodies of various materials and sizes. This is frequently discovered incidentally on X-ray images. If a bird also shows symptoms of illness, it is often difficult to determine whether these are caused by a foreign body, as these are often discovered incidentally in healthy birds.

Many injuries, as well as behavioural changes, are difficult to assess accurately from a distance using photos and videos. In these cases, a veterinary consultation is usually required.

Although potentially pathogenic bacteria and endoparasites are occasionally detected during routine examinations, these rarely cause clinical symptoms. In all these years, there has never been a major outbreak of infectious disease or parasitosis. Such problems have primarily been observed in individual birds previously weakened by other causes and are therefore considered secondary.

One condition should be mentioned here in some detail. In the year 2016, we noticed a previously unknown eye condition in some NBIs, characterized by opacity in one eye. Some of the affected birds were subjected to several special examinations to evaluate possible reasons. The birds underwent a thorough ophthalmological exploration including ultrasonography of the eye, blood control, cytology from the anterior chamber, microbiological testing for bacteria and viruses, and histology of one enucleated eye. The diagnoses uveitis, lens degeneration, and partial liquefaction of the lens of unknown reason could be made. It was found that all affected (n=25) birds carried biologging devices on their upper back. Birds with devices on the lower back did not show this symptom. In two early cases of birds, where the device was not immediately removed, the condition worsened progressively until the birds lost all sight in the affected eye. In one case, the affected eye even had to be removed due to severe inflammation. In consecutive cases, when a causal influence of biological agents was already suspected, removing or repositioning the device led to recovery within a few months. From this, it could be concluded that there is a connection to the location of the loggers. The birds naturally roost with their head resting on their back. When a device is placed on the upper back, it can press against or come into direct contact with the eye. The device, particularly those with GSM modules, may cause a slight temperature increase in the corneal tissue and also have a microwave effect. Moreover, the device can also mechanically irritate the cornea. This can cause an opacity of the cornea; in severe cases, it can end up in blindness. The issue could be mitigated by relocating the devices to the lower back or removing them altogether. If the opacity is not too severe, the symptoms can disappear after the device is removed (Fritz et al. 2020).

Conclusions

The collaboration between species conservation projects and veterinary medicine yields a lot of important insights that can significantly support the projects. Medical care of animals contributes to the health and vitality of the population. Such collaboration yields a wealth of important data that can be of great importance for future projects. Such interdisciplinary collaboration broadens the horizons of all disciplines involved and should therefore be pursued.

Acknowledgements

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Remote Sensing for Conservation of the Northern Bald Ibis: Ongoing Studies and Opportunities

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Abstract

Earth observation and satellite-based remote sensing data are connected to GPS tracking of Northern Bald Ibises across Europe to monitor ongoing reintroduction efforts as well as support new conservation strategies. The Northern Bald Ibis has already been a study species for interdisciplinary projects (Bowden et al. 2008; Fritz et al. 2019) and is a study species for ongoing projects (Wehner et al. 2022; Fritz et al. 2024). Both will be presented through brief insights into research aims, methods, challenges, and opportunities. The basis for this research is set by freely available Earth observation satellite imagery, e.g., the North American Landsat and the European Sentinel fleet, as well as GPS transmitters used for the monitoring of the NBI colony (Wehner et al. 2022; Wehner et al. 2022; Fritz et al. 2024). Foraging-area habitat studies have been conducted using a random forest model (Wehner et al. 2022), and migration behaviour analysis as well as additional foraging-area habitat studies are ongoing, applying step selection functions and a random forest model, respectively (Avgar et al. 2016; Forrest et al. 2025a,b).

Introduction

Satellite-based Earth Observation (EO) enables environmental data collection across large scales on a regular basis. Common EO satellites have a revisiting time of up to once a day. The Northern Bald Ibis (NBI) went extinct in the European wild in the 17th century. Today, this Ibis species is reintroduced by two projects in Europe. Proyecto Eremita aims to establish a sedentary colony in Andalusia, Spain. Waldrappteam Conservation & Research set up a migratory population. Breeding sites are located in the Northern Alpine Foothills, and wintering sites are in southern Tuscany, Italy. Since 2023, the two projects are connected by a new migration corridor between the already established breeding sites north of the Alps and the sedentary colony in Andalusia (Bowden et al. 2008; Fritz et al. 2024).

To reintroduce the NBI as a migratory bird species, Waldrappteam Conservation & Research hand-raise chicks yearly. The chicks are socially imprinted to two human foster parents. By this method they are able to train the birds to follow the foster parents beside a microlight airplane (Figure 1, left), in which one foster parent is flown by an experienced pilot. After reaching the wintering site, the birds are equipped with GPS transmitters before release (Figure 1, right). These transmitters enable constant monitoring of the newly introduced NBI. They are monitored regarding their integration into the wild NBI colony, movement behaviour in the wintering site, areas used for foraging, and most interestingly, the start of the first migration back north to the breeding site at the age of two to three years (Wehner et al. 2022; Fritz et al. 2024; Fritz et al. 2019).

GPS transmitter positions can be combined with EO data to investigate habitat use and spatiotemporal movement behaviour in general. Habitat studies, well-known research cases regarding interdisciplinary work between EO and wildlife ecology, have been conducted for the NBI in the Northern Alpine Foothills. An ongoing analysis extends the model to the Spanish NBI habitats, split by breeding seasons. Influences of snow cover on successful or failed Alps crossing are investigated, because how environmental factors influence the start of autumn migration and the crossing of the Alps by the NBI is not yet fully understood. An automated set-up plans to systematically investigate shifts in migration start, observed synchronized migration starts between different breeding sites, and how air temperature and air pressure might have an influence. Foraging area habitat analyses are highly relevant for the reintroduction of a species that was extinct for more than 300 years, to prove still-existing habitat areas in their historically known home ranges. Nevertheless, early springs and warm autumns seem to influence the migration behaviour of the reintroduced NBI colonies. By the described studies we want to showcase the relevance of climate-change adapted conservation management.

The NBI is a suitable case species because of the constant monitoring of the whole reintroduced population and >80% GPS tracking of all individuals, as well as citizen science-based monitoring via the Animal Tracker App and sponsorships. In the following, we showcase the use of EO data in combination with GPS tracking data for climate-change adapted conservation measurements through an already published foraging area habitat study (Wehner et al. 2022) and insight into ongoing studies on shift of migration starts and migration behaviour relative to environmental changes observed by weather and EO data.

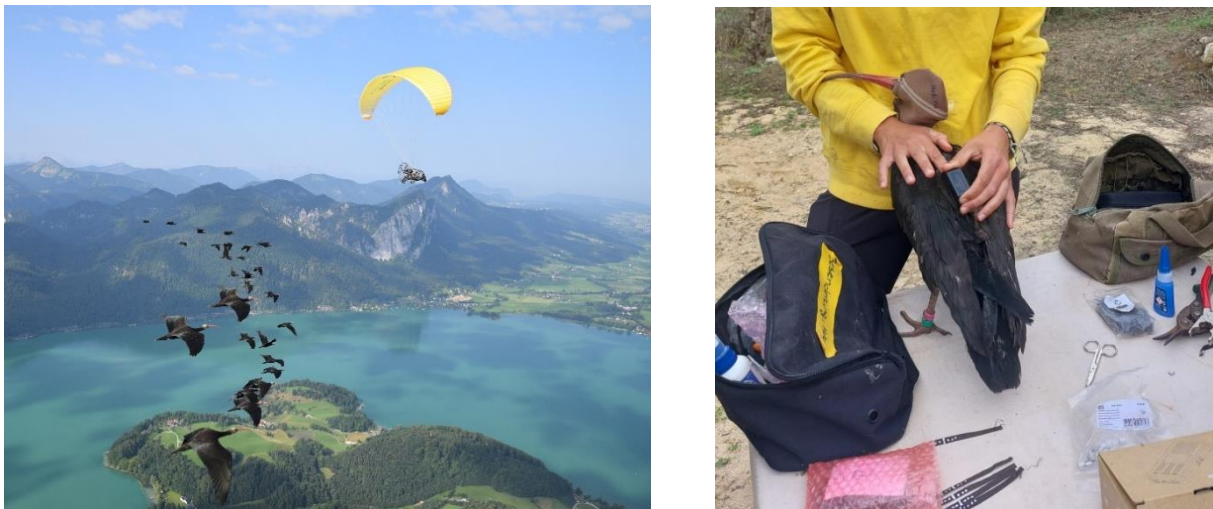


Figure 1. Northern Bald Ibises (NBI) following their foster parent in the microlight plane (left) and GPS transmitter attachment (right).

Methods

First, habitat and foraging area analyses are conducted by combined use of Northern Bald Ibis (NBI) tracking data and diverse EO datasets that give insight into the use of the environment. Table 1 gives an overview of all environmental datasets that were used for the quantification of foraging areas in the Northern Alpine Foothills (Wehner et al. 2022). Those EO datasets were combined with NBI positions of juveniles, breeders and subadults north of the Alps during summer 2020. For model preparation, the environmental information is extracted at each raster cell of all EO datasets each NBI position falls into. In a random forest model areas occupied by the NBI for foraging are compared against areas without GPS positions of the NBI and therefore

not evidently occupied. The final model is applied to project the suitability of foraging areas across the whole possible breeding area in the Northern Alpine Foothills.

Table 1. Environmental data generated by EO satellites used for foraging area habitat modelling (Wehner et al. 2022)

Index	Full Name	Satellite/Source Mission	Resolution (Meters)	Year of Data Collection
EVI	Enhanced vegetation index	Landsat-8	30 m	2021
TC Brightness	Tasseled cap brightness	Landsat-8	30 m	2021
TC Wetness	Tasseled cap wetness	Landsat-8	30 m	2021
NDWI	Normalized difference water index	Landsat-8	30 m	2021
Grass cover	Grass cover fraction	CORINE Landcover Inventory	100 m	2018
Elevation	Elevation	Shuttle Radar Topography Mission	30 m	2000
Slope	Slope	Shuttle Radar Topography Mission	30 m	2000
VV intensity	Intensity of vertical send and vertical received radar data	Sentinel-1	10 m	2021
Surface Temperature	Surface Temperature	[40]	1000 m	2021
Water	Water Mask	[41]	30 m	2015
World Settlement Footprint	Impervious/urban areas	DLR	10 m	2015

Secondly, as part of an ongoing analysis NBI migration start is investigated by the net-squared displacement method. Thereby, we aim to prove a shift of autumn migration start. In a second step we analyse migration movement decisions by step selection functions (Avgar et al. 2016; Forrest et al. 2025; Forrest et al. 2025). A first case study was conducted as part of a master thesis. During NBI position data preparation all points have been filtered accordingly to managements. That specifically describes the cut-off of GPS tracking data as soon as birds are manipulated by the project's bird management team. For example, after a bird has been handled, e.g. transferred to another place or was caught for another reason, data was excluded from further analysis. All remaining points during August–December 2021–2023 were included in a step selection analysis. The step selection model was fit with EO data elevation (slope and aspect) and daily Global Snow Pack provided by the German Aerospace Center beside the NBI position data (Dietz et al. 2015). EO data was accessed and preprocessed in Google Earth Engine, analysis was conducted in RStudio and maps were either made in RStudio or QGIS (Gorelick et al. 2017; R Development Core Team 2025). The GPS transmitters attached to the leg-loop position of the NBI are manufactured by Ornitela and, by full battery power, new GPS positions can be acquired every 15 minutes. The temporal resolution of the NBI GPS transmitters is regularly adapted by the bird management team of Waldrappteam Conservation & Research relative to the battery power and the bird's movement behaviour. During the wintering season, when the NBI stay in the vicinity of the wintering site, battery power is saved and data is collected every two hours. In contrast, during autumn and spring migration the temporal resolution is set to 15 minutes interval.

Results

Figure 2 displays the final foraging area habitat suitability map for the Northern Bald Ibis (NBI) in the Northern Alpine Foothills. Values close to 1 describe suitable habitat patches and values close to 0 describe habitat patches that are not suitable at all. All three breeding sites, Überlingen at Lake Constance, Burghausen and Kuchl close to Salzburg, are located in highly suitable areas. High mountain areas are not suitable due to steep slopes. Alpine valleys of extensive agriculture are suitable, notably in areas like Bad Ragaz in Switzerland where there is information about historic breeding sites. To the north suitable habitats become more fragmented. In this area more intensively used crop agriculture and missing extensively used meadows are found.

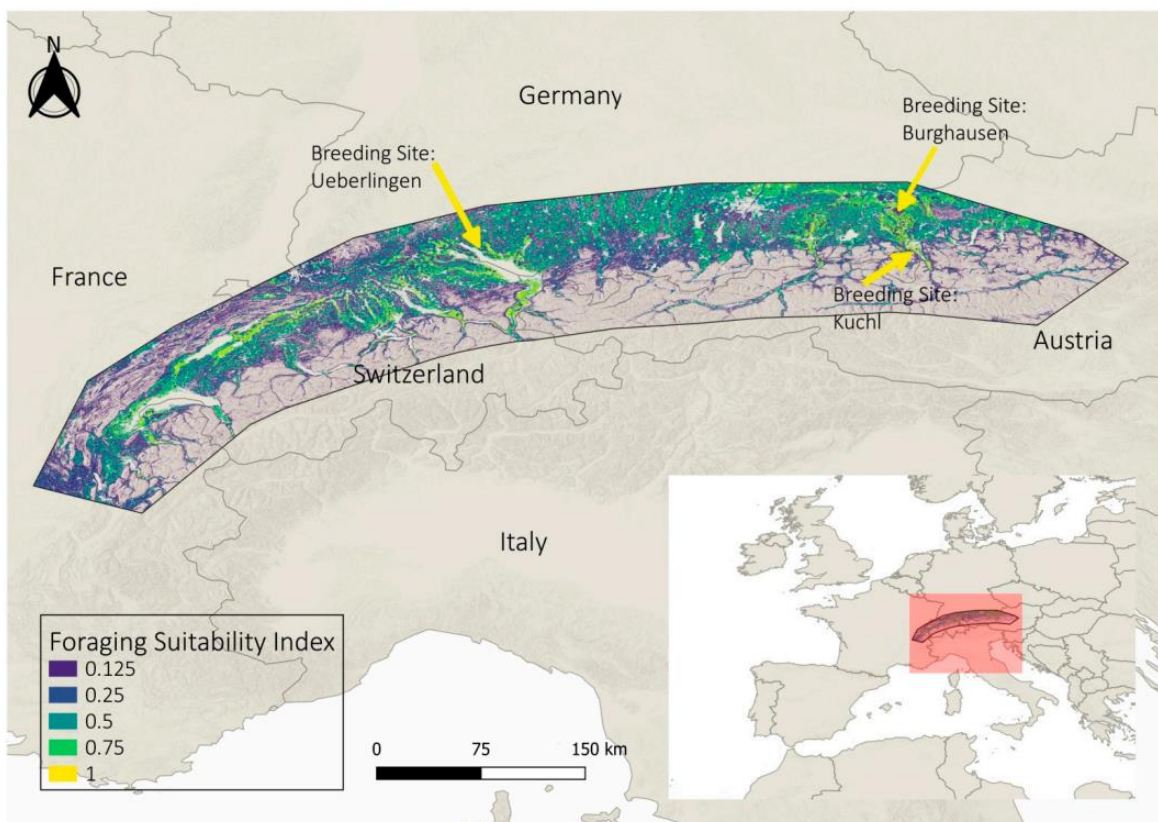


Figure 2. Foraging area habitat suitability map of the Northern Bald Ibis across the Northern Alpine Foothills (Wehner et al. 2022)

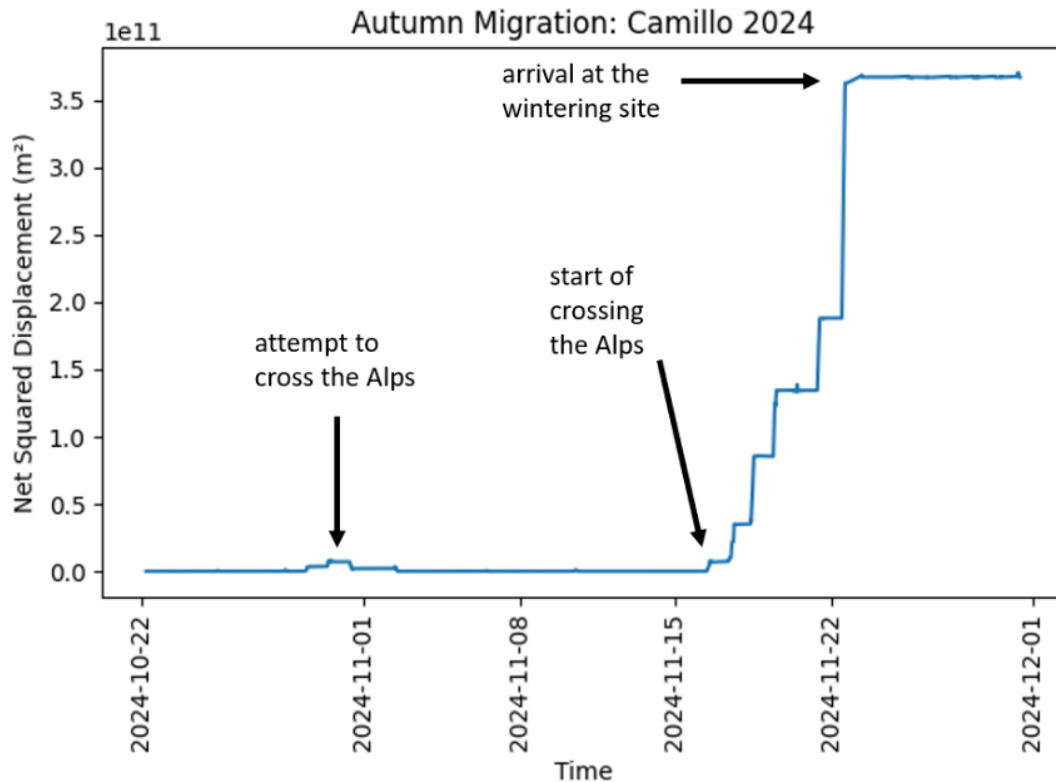


Figure 3. Net-squared displacement of Camillo in autumn 2024

Figure 3 illustrates net-squared displacement (NSD) patterns of an adult NBI, showing distinct changes in movement behaviour that coincide temporally with management-recorded behavioural shifts. Camillo, an adult NBI, is shown as an example.

Whenever a change in the movement behaviour was noted by the bird management team, the change is also detected by the automatic methods. Rising values of the NSD show displacement of the bird relative to the starting point. The starting point is defined by the breeding site. The start of the Alps crossing is visible by stepwise rising NSD values. Every stable line in the NSD values describes a time neither displacement increase nor decrease relative to the starting point. End of November the bird seems to have reached the final site for wintering, because the NSD is at the highest value and shows no more changes.

Figure 4 displays the results of the step selection analysis case study. NBI movement data is depicted against daily global snow cover values. The higher the value of step selection strength the more a movement decision was made related to that specific environmental variable. We compared the results of snow cover in more detail to movement behaviour that was manually noted by the bird management team. Interestingly, snow cover seems to greatly influence a successful or failed crossing of the European Alps. In October 2021, when the snow cover step selection values are the lowest, a big group of NBI managed to cross the Alps. The same happened in November 2023. Against this, in 2022, the NBI failed to cross the Alps on their own and had to be transported in boxes by cars across the main alpine ridge. In that year the step selection values of snow cover are generally higher compared to 2021 and 2023.

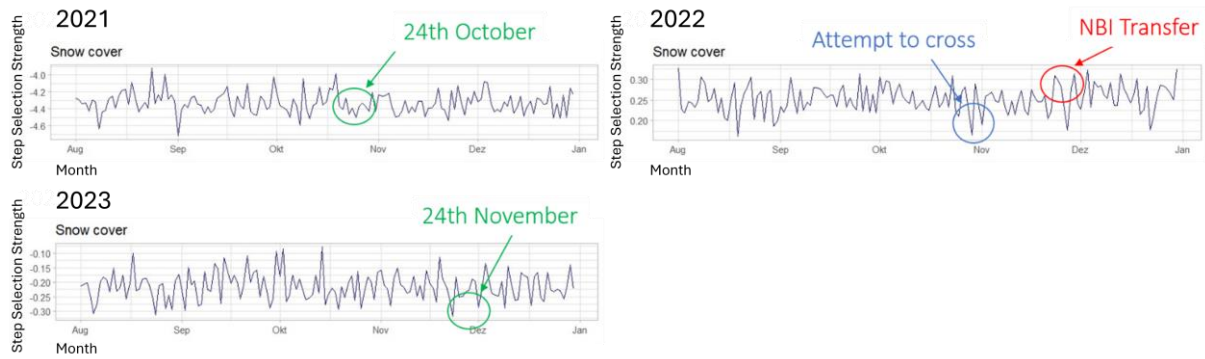


Figure 4. Step selection function results related to snow cover between August and December 2021–2023

Discussion & Outlook

The result published in the foraging are habitat model maps suitable for the NBI in the Northern Alpine Foothills. Reintroduction sites (Überlingen, Burghausen, Kuchl) were chosen well. Other historically known breeding sites, e.g. Bad Ragaz in Switzerland have high suitability values too. In an ongoing project that method is extended to Spain and France in coarser spatial resolution. Specific areas of interest like the wintering site in Andalusia and planned releasement sites along the migration route from southern Germany to Andalusia in the vicinity of Valencia and Barcelona are investigated in more detail.

The net-squared displacement example shows the ability of that method to time important movement behavior changes. Therefore, in next steps this method will be used to statistically investigate a shift in the start of the autumn migration of the NBI. That migration shift has only been shown in a less automated way and by checking the time of Alps crossings (Fritz et al. 2024).

The conducted step selection case study gave a first glimpse into how this method can be used for a more detailed analyses about which environmental factors do mostly influence the successful or failure of Alps crossing by the NBI. In a following analysis the whole population tracking data between 2014 and 2024 is investigated by the described method. Data analyses start from 2014, because GPS equipment starts more intensively in that year. In addition, EO data will be expanded to world settlement footprint data, air temperature, air pressure data and multi-sensor and multi-parameter data. The project is conducted in cooperation with the University of Würzburg, the German Aerospace Center and the Max Planck Institute of Animal Behavior as part of a bigger research unit, funded by Deutsche Forschungsgemeinschaft (DFG 2025).

EO data has helped to showcase suitable foraging areas of the NBI in the present, areas of which were known historic suitable breeding sites, too. In an ongoing step EO data shall help for adapting conservation measurements to a changing environment caused by changing climate. Because the NBI reintroduction is still ongoing and the released population is precisely monitored, this species is excellent for analysing changes of movement patters across time. EO data is collected up to daily basis and 10m spatial resolution. Still, EO data is not always easily accessible, preprocessing and analysis steps are not easily done by non-expert users and spatial and temporal resolutions to not always match spatial and temporal needs of users. Therefore, additional to migration pattern analysis of the NBI, the ongoing analysis aim to showcase the use of large-scale, multi-parameter and multi-sensor EO data that is developed in reusable workflows. The project combines the knowledge of EO experts as well as the precise ecological knowledge of the NBI by Waldrappteam Conservation & Research.

Acknowledgements

Thanks to the very good and uncomplicated connection to Johannes Fritz and Waldrappteam Conservation & Research, it is always uncomplicated to access the Northern Bald Ibis tracking data for analysis. In addition, great thanks are sent to Foerderverein Waldrappteam for constant support in financing analyses projects. Thanks to Claudia Künzer of the University of Würzburg and the German Aerospace Center for constant support in bridging science and active conservation work. This work was carried out within the LIFE Northern Bald Ibis project (LIFE20 NAT/AT/000049 – LIFE NBI), co-funded by the European Union.

Ethical Approvals

The GPS transmitters are put onto the birds backs by experienced employees of Waldrappteam Conservation & Research. Close monitoring after GPS transmitter attachment and releasement allows readjustments or complete removing to assure the safety of the birds.

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The Northern Bald Ibis *Geronticus eremita* in Europe: New Findings on the Historical Occurrence and Migratory Behaviour

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Previously unknown historical breeding sites in France – consequences for migration route

A systematic search for potential historical documentations of the Northern Bald Ibis *Geronticus eremita* (Roland 2024) led to the medieval Latin text by Petrus Berchorius (around 1300–1362), a Benedictine monk from the Vendée department in western France.

In his work *Reductorium morale*, book 14, he describes the nature and wonders of the world (Samarin and Montfrin 1962). Chapter 43 on the Poitou region contains a section on the Northern Bald Ibis. Berchorius reports a previously unknown breeding site of the Northern Bald Ibis in France, based on his own observations and information from reliable contemporaries. For transcription and translation see Schenker et al. 2024.

According to Berchorius, a number of black birds with long red, pointed beaks appear every year, which the locals call ‘corgalerans’ in French. Their nests are built on high towers. The stone buildings of Mallesiacum (Maillezais Abbey), Cosdreium (Château Le Coudray-Salbart) and Claravalle (Château Scorbé Haut-Clairvaux) are described as nesting sites. Every year, the birds retreat as winter approaches and reappear for the breeding season. Their young are fat and delicious, while the adults are dry, unpalatable, and chewy. Berchorius mentions that some of these Northern Bald Ibises were raised in the houses of the rich and how these birds pulled earthworms out of the ground with their pointed beaks.

This text by Berchorius from the 14th century is the only written source so far to confirm the presence of the Northern Bald Ibis in France (Figure 1). Bones from a small cave in the Ardèche valley in southern France were the only reliable evidence of its occurrence to date (Mourer-Chauviré et al. 2006).

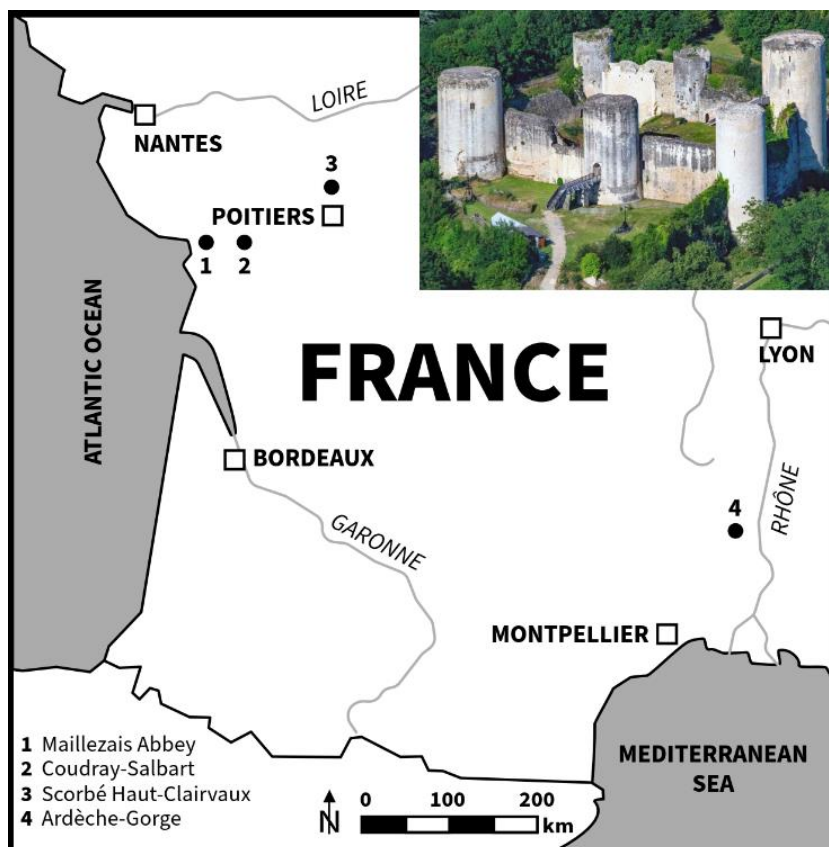


Figure 1. Locations of the three medieval breeding sites of the Northern Bald Ibis in western France, according to the report of Petrus Berchorius (around 1300–1362). Inserted picture: the well-preserved medieval fortress of Coudray-Salbart (No. 2)

The choice of nesting sites on large medieval stone buildings is obviously due to the lack of suitable natural rock structures in the flat landscape of Aquitaine-Poitou.

The described migration behaviour of this Northern Bald Ibis population suggests a new, significant conclusion. The previous assumption that the historical Northern Bald Ibis population colonised its breeding sites exclusively from the east (e.g., Schenker 1977: 21 Figure 2) must be revised. By analogy with the known migration routes of other migratory birds in Europe, an east–west migration division is most likely, comparable to that of large diurnal migrants such as the White Stork or Black Stork (www.migrationatlas.org). Thus, the historical breeding area of the European Northern Bald Ibis population may have been linked to both a western and an eastern migration route.

New evidence for a historical occurrence of the Northern Bald Ibis in the French–Swiss Jura

In Central Europe, the Northern Bald Ibis became extinct before the middle of the 17th century (Schenker 1977, Böhm and Pegoraro 2011). Numerous records document the presence of the Northern Bald Ibis in the Middle Ages and Early Modern Period in Switzerland (Schenker 1977, Häslér 1977).

An illustration of the Northern Bald Ibis, so far unknown to science, is part of a collection of bird illustrations from the 16th century. The collection was later adopted by the New-York Historical Society in 1889 (inventory number 1889.10.1–4).

The colourful depiction of an adult Northern Bald Ibis (Figure 2) was made by Pierre Eskrich (Pierre Vase alias Cruche). The extraordinarily high quality of the illustration suggests that the artist painted a dead specimen and not a mounted bird. This naturalistic medieval illustration is one of the best, perhaps even the most accurate from that time. In comments by B. Textor, the names of the Northern Bald Ibis are given in Greek, Latin, and French, and its striking external features are emphasized: head with feather crest, large curved red bill, and red legs. Meadows and marshes are mentioned as habitat. Its tasty meat is also praised.

The origin of the illustration was dated to 1561 (Roland and Schenker 2023), based on the still existing correspondence and participants mentioned therein. Their residences and a noted journey to the Jura mountains suggest a previously unknown occurrence of the Northern Bald Ibis in the French–Swiss Jura in the area around Geneva or near Neuchâtel.



Figure 2. Pierre Eskrich (Pierre Vase alias Cruche), naturalistic and detailed illustration of an adult Northern Bald Ibis, probably from 1561 (New-York Historical Society, Inventory number 1889.10.1.1.)

Reintroductions – a long way to success.

Successful reintroduction of animal species to their former range is usually a long-term process. A project duration of 30–50 years is not unusual (Table 1). This is also likely for the ongoing reintroduction project with the Northern Bald Ibis in Central Europe. Learning the migration route, which requires joining migrating adult birds, is an additional challenge.

Table 1. Examples from Switzerland of successful or ongoing reintroductions of three mammal and bird species with details of the project duration until the establishment of a self-sustaining population. The question marks indicate a partial lack of genetic variability (Lynx) or possible negative anthropogenic influences (Bearded Vulture).

Examples of Reintroduction Projects for Wildlife Species in Switzerland

Species	Extinction (CH) Direct, indirect	Steps for Reintroduction					Implementation Duration (years)
		1870/1890	1900	1950	2000	2020	
Mammals							
Alpine Ibex ^{1,2} <i>Capra ibex</i>	around 1650/1820	S	F	R	P		40 – 50
European Lynx ³ <i>Lynx lynx</i>	1909			S+F	R	(P)	40 – 50?
European Beaver ^{4,5} <i>Castor fiber</i>	around 1800			S	F	R	P
Birds							
White Stork ⁶ <i>Ciconia ciconia</i>	around 1950			S	F	R	P
Bearded Vulture ^{7,8} <i>Gypaetus barbatus</i>	late 19th century			S	F	R	(P)
Osprey ^{9,10} <i>Pandion halliaetus</i>	after 1911				S	F	

1 = Giacometti 2006
 2 = Brosi et al. 2020
 3 = Vogt et al. 2025
 4 = Rahm & Baettig 1996
 5 = BAFU 2016
 6 = Kestenholz et al. 2010
 7 = Robin et al. 2004
 8 = Schaub et al. 2024
 9 = Kruppenacher et al. 2009
 10 = Strahm & Ladenbergue 2024

S = Start of reintroduction activities
 F = First releases
 R = Regular reproduction in the wild
 P = Self-sustained population

[Illustration: André Schenker]

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External Breeding Areas and Extraordinary Nesting Sites of the Northern Bald Ibis

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Introduction

The Northern Bald Ibis *Geronticus eremita* has long been considered a species with strong breeding-site fidelity, typically nesting in traditional rock niches within established colonies. However, recent developments in the reintroduced European migratory population suggest unexpectedly high flexibility in nesting-site selection. Alongside the establishment of migratory and climate-adaptive migration routes, an unexpected expansion of breeding activity beyond traditional breeding areas has been observed. These developments raise important questions about ecological adaptability, dispersal behaviour, and the long-term resilience of the population in a changing environment.

This study provides an overview of breeding activity both within and outside the four established breeding areas, with particular attention to extraordinary and novel nesting sites.

Methods

Breeding data were collected across the four established breeding areas and from newly formed extraterritorial sites in Italy and Switzerland. Monitoring combined systematic field observations with reports from local observers and citizen scientists, allowing detailed documentation of nest locations, clutch sizes, and fledging success. In some cases, such as nests located on windowsills, direct visual inspection of eggs and chicks was possible from nearby buildings. Reproductive success was assessed based on the number of fledged juveniles per nest.

Results

Breeding activity within the four established breeding areas remains stable at 25 nests, matching the previous year. In 2024, these nests produced 71 fledglings, corresponding to an average reproductive rate of 2.8 chicks per nest. Similar success is anticipated for the current season.

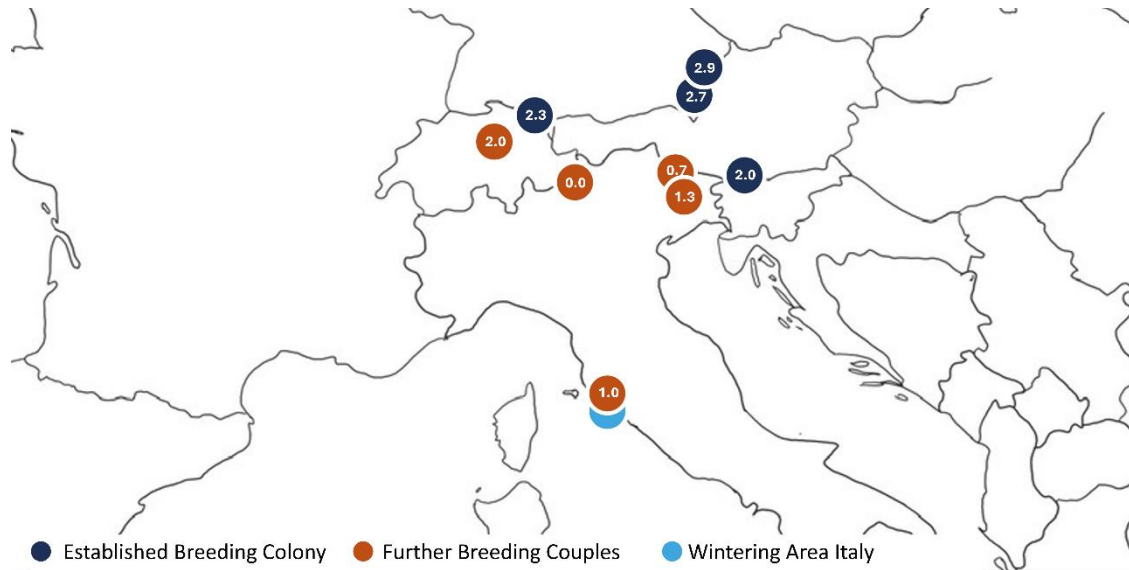


Figure 1. Locations of the four established breeding colonies, their wintering area, and breeding attempts outside traditional sites. Numbers indicate reproductive success as mean fledglings per nest (established areas: 2020–2024 mean; other sites: mean across all attempts)

A remarkable development, however, is the rapid expansion of breeding outside the traditional colonies. This trend began in 2023, when two fledglings were raised from a single nest in Switzerland and two fledglings from eight nests in Italy. Notably, the first successful breeding event in Switzerland in over 400 years took place on the windowsill of a commercial building (Figure 2).

In 2024, breeding success increased in Italy, with 12 chicks fledging from 12 nests, while no breeding was recorded in Switzerland. By 2025, numbers had risen dramatically: three fledglings were raised from one nest in Switzerland, and 19 fledglings from 21 nests in Italy.

Nesting sites were highly diverse and often unconventional. In addition to typical rock niches, birds bred on towers, churches, windowsills, abandoned stork nests, dead palm trunks, and even in tree forks (Figure 2). Some locations were highly exposed, such as stork nests, while others—like windowsills—offered surprisingly structured and sheltered conditions. These observations contradict the long-standing assumption that Northern Bald Ibises are strictly conservative in nest-site choice.



Figure 2. Left: Various pairs use niches on buildings, like this breeding couple in the canton of Zurich, Switzerland; these sites come closest to the classical nest sites with protection from at least 2 sides; picture AG Schmalstieg. Right: A tree as an extraordinary breeding site for the species; picture D. Lauzzana

Two main drivers may explain this development. First, the migratory nature of the European population increases spatial range and exploratory behaviour compared to sedentary populations. Second, climate-related management interventions—such as transporting juveniles across the Alps—may reduce the likelihood of strict natal philopatry, thereby promoting the establishment of new breeding sites.

Conclusions

The observed expansion of breeding beyond established colonies demonstrates remarkable ecological flexibility in the Northern Bald Ibis. Contrary to previous assumptions, the species shows substantial adaptability in nesting-site selection, including the use of anthropogenic structures. This behavioural plasticity not only reflects flexibility in nesting-site selection, but also strengthens the species' capacity for climate-adaptive behaviour, enabling the birds to adjust more effectively to changing environmental conditions.

While many of these unconventional nesting sites may not be suitable for long-term colony formation, their increasing frequency reflects an important adaptive response to environmental change. The combination of stable reproductive success within core colonies and dynamic expansion into new areas suggests that the European Northern Bald Ibis population possesses the ecological resilience necessary to cope with ongoing climatic and anthropogenic pressures.

These findings highlight that successful reintroduction today must account not only for historical ecology, but also for behavioural flexibility and adaptive potential in a rapidly changing world.

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Can Migratory and Sedentary Populations Merge Successfully? A Space-Use Perspective

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Introduction

Reintroduction efforts in Europe have established both migratory and sedentary populations of Northern Bald Ibises *Geronticus eremita*. As climate change increasingly disrupts the traditional migration route of the migratory population to Tuscany, establishment of a new migration corridor to Andalusia was initiated in 2023. This represents a novel conservation strategy aiming not only to create a climate-adaptive migration route, but also to connect migratory and sedentary populations. The central questions concern breeding-site fidelity, differences in spatial behaviour, and the potential long-term integration of birds with distinct movement strategies.

Methods

We analysed high-resolution spatial movement data from juvenile Northern Bald Ibises within the Iberian Peninsula. Home-range size, dispersal distance, and exploratory behaviour were compared among three groups:

1. Wild-hatched sedentary Andalusian juveniles (N=11)
2. Zoo-hatched sedentary juveniles released in Andalusia (N=15)
3. Migratory juveniles that were hand-raised and completed a human-led migration (HLM) prior to their release in Andalusia (N=21)

Particular attention was given to return movements toward breeding areas and to interactions between birds from different colonies. Case-based movement trajectories were used to illustrate orientation capacity and migration route fidelity.

Results

Spatial analyses reveal pronounced differences in dispersal behaviour. Migratory juveniles undertook extensive exploratory flights, covering areas of up to 230,000 km², while wild-hatched and zoo-hatched sedentary juveniles remained within a considerably smaller area of ~60,000 km². These findings confirm distinct space-use strategies between the two groups (Figure 1).

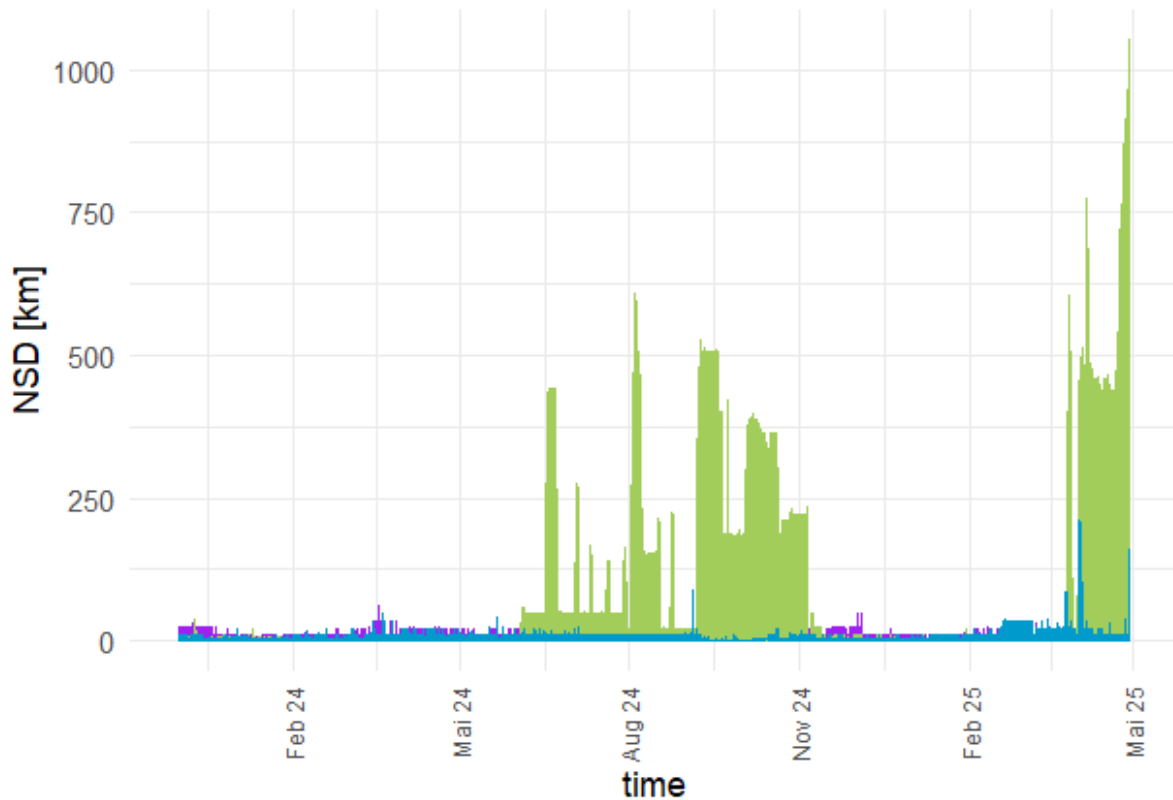


Figure 1. Distance to colony centre in terms of net squared displacement (NSD) from 06.12.23 to 30.04.25; comparison of three juvenile groups: wild-hatched sedentary (violet), zoo-hatched sedentary (blue), and migratory (green)

The case of “Ingrid,” a juvenile that migrated to Andalusia in 2022 and initiated a northward return in 2024, provides initial evidence of route fidelity. Despite being raised in human care, she followed independently the large European migration corridor towards Andalusia, indicating strong orientation capacity.

More recently, two subadult females provided decisive confirmation of breeding-site fidelity. In 2025, Dr. Saurier became the first individual to independently return from Andalusia to the breeding area at Lake Constance, completing a 3,200 km journey. Later, Espi successfully crossed the Pyrenees and likewise returned north, becoming the second subadult to complete this route independently. Both birds had wintered alongside the sedentary Andalusian colony, demonstrating that migratory individuals maintain long-distance orientation and reconnect with breeding populations despite prolonged contact with sedentary conspecifics.

Additionally, three sedentary juveniles were observed joining migratory birds in flight, indicating emerging behavioural interactions between the two groups.

Conclusions

Our findings confirm clear spatial and behavioural differences between migratory and sedentary Northern Bald Ibises, with migratory birds exhibiting significantly larger dispersal ranges. Documented return events—particularly those of Dr. Saurier and Espi—provide compelling evidence for route fidelity and breeding-site return after wintering within the area of a sedentary colony. These cases indicate that the newly established Andalusian migration corridor is functional and capable of producing self-orienting, returning individuals.

Combined with observed inter-population flight interactions, these results support the feasibility of gradual integration between migratory and sedentary populations. The emerging connectivity between groups suggests that merging dynamics are possible, making the Andalusian route a promising model for climate-adaptive conservation and the long-term stabilisation of mixed migratory systems.

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Establishing the AEWA International Working Group for Northern Bald Ibis, Its Role & Conservation Outcomes

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Background

The status and population trends for the Northern Bald Ibis *Geronticus eremita* (NBI) can be summarised over the past hundred years as a long and widespread story of declines and regional extinctions. The species was once widespread across the Mediterranean and North Africa, but the sequential declines have been attributed to a variety of human-induced factors. The multiple causes and key threats can be summarised as pesticide use (DDT etc.), loss of steppe feeding habitats, particularly through agricultural intensification, and direct persecution—along with human disturbance, especially at the cliff nesting sites (Boehm et al. 2020). The other key threats recognised in more recent times are electrocution and collision with various power infrastructure (Bowden 2015). There is evidence that the species has faced population declines for over 4,000 years (Janak 2011), a timeline that marks it as one of the most enduring examples of species conservation challenges.

Recognising the multiple threats and declines, there have been a number of initiatives for NBI conservation involving activities and collaborations of governments, NGOs, research institutions, and local communities. The aim here is to document the roles played by the diverse set of interested stakeholders and how these have been formalised through the process of development and implementation of an international single species action plan. This action plan provides a framework which engages the key range state governments as well as wider stakeholders, and all of this channelled and overseen by the International Working Group (IWG) for the species. The IWG was established under the auspices of AEWA, the African-Eurasian Waterbird Agreement, a convention under the United Nations Convention on Migratory Species.

The Status of the Northern Bald Ibis

Unlike the majority of Globally Threatened Species, the NBI formerly had a wide distribution (Collar and Stuart 1985; Boehm et al. 2020). Much of the population of this highly social and colonial species was migratory, distributed from alpine parts of Europe and much of North Africa to the Middle East, Arabia and Northeast Africa. Over the centuries, however, the population has been severely diminished, primarily due to human-induced feeding habitat destruction (intensification of agriculture and urbanisation), overhunting, and the use of harmful pesticides such as DDT. Disturbance and destruction (and even direct competition) of nest sites have also had a negative impact, and more recently power infrastructure (electrocution and collision) has emerged as an important threat (Bowden 2015). The species' decline is not just a modern phenomenon; there are indications of decline going back thousands of years. By the 20th century, the NBI breeding range was confined to Northwest Africa (Morocco and Algeria), Turkey and Syria, but by the early 21st century it was restricted to a tiny but very slowly expanding relict sedentary population breeding in two coastal colonies in southern Morocco (Boehm et al. 2020). The even smaller recently rediscovered Syrian population (Serra et al.

2004) appears to have meanwhile been lost. The species has been classed by IUCN Red List authorities as Critically Endangered until 2017, when recognition of the recent conservation efforts in Morocco and the stabilisation and slight recovery of that population over the previous twenty years improved the Red List status slightly to 'just' Endangered (BirdLife International 2021).

Early Coordination of the Conservation Effort

There was an early presence of WWF and Udo Hirsh in the late 1970s and 1980s. This was followed by the highly significant designation by the Moroccan Government of the Souss-Massa National Park in 1991, which incorporated the main remaining NBI breeding colony and related steppe feeding grounds. The first established network for the conservation of the NBI was formed in 1999, when a diverse group of experts and stakeholders gathered in Agadir, Morocco, to discuss the future priorities for the species. The meeting resulted in the establishment of the International Advisory Group for Northern Bald Ibis (IAGNBI), a highly diverse informal collaborative network of experts, government representatives, NGOs and other institutions interested and involved in securing the long-term survival of the species.

IAGNBI provided an important platform for sharing knowledge, discussing conservation priorities and monitoring the species' population and health. There were periodic newsletters, a public website information source and other communications among the members, but more importantly there were in-person meetings approximately every three years. Presentations from contributors were compiled and published as detailed reports and an important record, all with support and coordination of the participating organisations, particularly the Royal Society for the Protection of Birds (RSPB). Each meeting also received additional support from the various hosting organisations or governments. Experts from the two main European release projects, Proyecto Eremita (Spain) and Waldrappteam (Austria, Germany, Italy), were among the regular participants and indeed hosts of these meetings from early on. There has been a growing sense of community among participants alongside an increasing global profile for the species, generated particularly by those projects. The meetings, meeting reports and regular communications among the group all helped steer focus towards identifying key actions needed to conserve the species.

However, as valuable as IAGNBI's work was, it was clear that the conservation of the NBI required stronger engagement and ownership by range state governmental authorities with high-level political and institutional support. This was a key factor in the formation of an intergovernmental International Working Group.

International Single Species Action Plan and Establishment of the Intergovernmental International Working Group (IWG)

AEWA first approached IAGNBI in 2003 to supply expertise and host a workshop to develop the first International Single Species Action Plan (ISSAP) for the species. AEWA also provided most of the support for the meeting hosted by SEO/BirdLife in Madrid in 2004. All participants were part of IAGNBI, and the action plan was finalised and approved as an AEWA ISSAP in 2006 (Jiminez-Armesto et al. 2006). Despite significant engagement of governments through IAGNBI, particularly from Morocco and Turkey, and the idea that IAGNBI could formally take on the role of overseeing the implementation of the ISSAP, it was already apparent that this required more direct and formalised government ownership of the plan. With these considerations in mind, and with support from the Government of Saudi Arabia, AEWA organised the inaugural meeting leading to the establishment of the International Working

Group for NBI. The meeting was held in Jazan, Saudi Arabia, in November 2012 and was duly documented (AEWA 2012). It was at this point that the IWG was formally created.

Morocco, Algeria and Saudi Arabia were prominent leads within this newly created IWG framework, with Morocco naturally playing a pivotal role, as it hosts the main remaining population of the species. Morocco also hosted the second in-person meeting, where the action plan was fully revised (Bowden 2018). Saudi Arabia was instrumental in providing leadership for the IWG, with Mohamed Shobrak serving as the initial chair of the group, succeeded by the Moroccan Administration of Water and Forests since 2017.

The IWG structure is chaired by one of the range state governments, with the range countries of Morocco, Algeria, Turkey, Syria, Saudi Arabia, Yemen and Ethiopia. The AEWA focal point in each country has appointed a country representative and a national expert. There is a regional coordinator for the eastern and western populations and an overarching coordinator who reports to the AEWA Secretariat in Bonn.

The IWG provides the framework for bringing together national governments and international stakeholders and ensuring that the species receives the attention needed at the highest levels. It is also a mechanism for seeking relevant expertise which may not always be available in the countries concerned. One example concern defining translocation options, where there is clear progress and expertise from Europe and elsewhere that may be relevant. Likewise, for other aspects and priority actions, it may be appropriate to propose exchange visits of experts between or outside the range states.

The IWG has also helped secure funding for ISSAP priority actions that were not otherwise resourced. Through AEWA, the European Union has recently, for example, provided some funding for key ISSAP priority actions in Morocco and Algeria.

Evolution and Scope of the ISSAP

The ISSAP has evolved over time, with significant updates in 2017 and the development of an updated implementation plan in 2022, reflecting the changing needs of the species and taking into account the progress made for NBI conservation.

The ISSAP outlines priority actions that have been critical in advancing the conservation of the NBI. These include increasing formal protection for the Tamri colony and surrounding habitats, breeding cliff management, and above all the maintenance of wardening and protection of the existing colonies. These actions focus primarily on Morocco, but are also relevant for Turkey and, to an extent, Syria, Saudi Arabia and Ethiopia. In Algeria, the focus has mainly been on the feasibility and prospects of establishing a population through translocation. In Turkey, the priority is to secure and increase the semi-wild population, while also scoping and establishing a second population in a viable area for future translocation. The plan also highlights key ongoing monitoring and research needs, as well as the engagement of local communities in focal areas. Learning valuable lessons from the European release projects (*Proyecto Eremita*, Waldrappteam) is also mentioned as important. However, the scope of the ISSAP does not include countries outside the more recent and current range states, so European countries are not covered.

Conclusion

The conservation of the NBI is an ongoing and evolving effort, and significant progress has been made. From the early days of IAGNBI's formation to the development of the ISSAP, and most recently the formation of the IWG, the conservation community together with the range state governments has demonstrated the power of international collaboration. The downlisting of the Northern Bald Ibis to “Endangered” on the IUCN Red List is testament to the hard work of governments, NGOs, scientists and local communities who have dedicated themselves to the species' recovery.

Looking ahead, the future of the Northern Bald Ibis remains uncertain, but there is cause for hope. The next steps in the conservation process will involve the continued implementation of the ISSAP, with a focus on maintaining habitats, securing stronger protection status, exploring translocation options, and ongoing monitoring, research and engagement with local communities. In addition, new opportunities for collaboration and funding will be explored. The ultimate goal is to ensure the long-term survival of the species, not only in Morocco and Algeria but across its entire range.

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The Bald Ibis in Algeria: Between the Past and the Future

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The Northern Bald Ibis *Geronticus eremita* is one of the most iconic and endangered bird species across North Africa and parts of the Middle East. It is renowned for its striking appearance, with a distinct bald head and long, curved beak, a bird whose ecological and cultural significance has endured throughout the centuries. However, the Ibis has faced an alarming decline in its population due to a variety of anthropogenic factors, including habitat loss, hunting, and changes in climate. In Algeria, the Northern Bald Ibis was once widespread in certain regions, especially the Saharan Atlas and pre-Saharan areas, but by the 1980s it had largely disappeared from the country's landscapes, making its conservation a matter of increasing urgency.

Despite these challenges, the story of the Northern Bald Ibis in Algeria is not one of irreversible loss. Over the past two decades, concerted efforts to rediscover the bird's breeding sites, analyse its ecological requirements, and develop viable reintroduction strategies have provided hope. These efforts have included field investigations, historical research, collaboration with local communities, and international conservation partnerships. The resulting conservation initiatives aim not only to understand the past of the Northern Bald Ibis but also to secure its future through careful reintroduction and restoration of its habitat.

This paper outlines the trajectory of the Northern Bald Ibis in Algeria, beginning with its decline and the subsequent rediscovery of critical sites, moving through the challenges of conservation, and concluding with the current and future efforts to reintroduce the bird into its former habitats. Central to this effort is the role of local knowledge, governmental support, scientific research, and international cooperation. Through a holistic approach to conservation that combines biological research with community engagement and financial support, there is growing optimism that the Northern Bald Ibis will one day again thrive in the wilds of Algeria.

Introduction: The Significance of the Northern Bald Ibis in Algeria

Historically, the Northern Bald Ibis was distributed widely across North Africa, from Morocco and Algeria to Tunisia, and even as far as the Middle East. The bird, whose presence is closely linked with the rugged cliffs and semi-arid ecosystems of the region, has become a symbol of Algeria's unique biodiversity. It holds cultural importance to local communities who have long regarded it as a symbol of the natural world's resilience.

In Algeria, the bird was last known to breed in the 1980s. Despite occasional sightings in the intervening years, its status remained uncertain, with no significant records of breeding populations within the country for decades. The causes behind the decline were multifaceted, involving a combination of direct human pressure (such as hunting and disturbance) and indirect pressures (like habitat degradation and climate change).



Figure 1. Historical distribution of the Northern Bald Ibis in Algeria (Fellous, 2006)

The situation has, however, evolved over the past few decades. The rediscovery of historical breeding sites and new data from local residents and ornithologists have provided key insights into where and how the bird once thrived. The aim now is to restore viable populations through active conservation measures and to ensure that future generations of Algerians can experience the Northern Bald Ibis in the wild.

Rediscovery and Investigation: Unearthing the Past

The story of the Northern Bald Ibis in Algeria has been as much about uncovering lost histories as it has been about safeguarding the future of the species. The first step in the restoration of the Ibis population was the rediscovery of the bird's historical breeding sites, many of which had been abandoned or forgotten. The early 2000s marked the beginning of a systematic investigation into the bird's former habitat. This effort was sparked by a lack of concrete data regarding the bird's disappearance and prompted a series of field investigations to piece together the bird's past presence.

The primary objective during this phase was to identify where the last populations of the Northern Bald Ibis had bred and to understand the ecological conditions that had supported them. Working in collaboration with the International Northern Bald Ibis Group (IGNABI) and local institutions, researchers conducted extensive surveys across Algeria's Saharan Atlas and pre-Saharan regions, as well as in areas close to Algiers. Local knowledge proved indispensable in this process, as community members shared stories of the bird's presence in the 1980s, providing critical clues as to where the Ibis may still be found.

Fieldwork was not limited to modern-day observations. The research also extended to historical documents, photographs, and engravings. Archaeological studies revealed ancient depictions of the Northern Bald Ibis, which were found in prehistoric rock engravings across the region. These engravings, dated to thousands of years ago, provided vital evidence that the bird had once been widespread across the region, offering a glimpse into the ecological history of North Africa.

By compiling information from these varied sources, researchers began to map out the bird's past distribution and identify areas where restoration efforts could be concentrated. The most significant rediscovery occurred when researchers found evidence of a potential breeding site located 80 km south of Algiers, a site where the bird had last been recorded in the 1980s.

Challenges to Conservation: Habitat Loss, Poaching, and Climate Change

Despite the optimism generated by the rediscovery of breeding sites, the path toward effective conservation has been fraught with obstacles. One of the most significant challenges is habitat loss. The Northern Bald Ibis requires specific habitat conditions, including tall cliffs for nesting, open landscapes for feeding, and access to water sources. Over the past decades, the region has undergone significant ecological changes, driven by both human activities and climate change.

The construction of roads, urban expansion, and the spread of agriculture have all contributed to the destruction of suitable habitat for the Ibis. In particular, the clearing of land for agriculture has diminished the availability of food sources, while human settlements and infrastructure have fragmented the landscape, making it more difficult for the Ibis to find uninterrupted breeding grounds.

Furthermore, poaching and human disturbance have also been major threats to the Northern Bald Ibis. In the past, the bird was hunted for its feathers, which were highly valued in local markets. Although hunting has decreased in recent years, the Ibis remains vulnerable to disturbance from tourists, farmers, and other land users who may inadvertently damage its nesting sites. Even more concerning is the risk of direct harm during the breeding season, when the birds are most vulnerable to human interference.

Additionally, climate change poses a growing threat to the species. Changing weather patterns, increased temperatures, and altered rainfall regimes affect the availability of food sources, nesting sites, and suitable conditions for breeding. The effects of climate change have been particularly pronounced in the arid regions of Algeria, where increasing temperatures and droughts could disrupt the delicate balance required for the Ibis to thrive.

A Collaborative Approach: International Partnerships and Reintroduction Efforts

Despite the formidable challenges, the conservation of the Northern Bald Ibis in Algeria has benefited from both national and international collaboration. Central to the conservation efforts has been the involvement of various stakeholders, including local communities, government agencies, non-governmental organisations (NGOs), and international experts. One of the most significant steps forward came with the establishment of a national action plan for the reintroduction of the species in 2020.

This plan, developed in collaboration with the European Wildlife Alliance (EWA), the Algerian government, and conservation experts, outlines the strategies needed to reintroduce the Northern Bald Ibis to its former range. The national action plan incorporates the findings of extensive fieldwork, stakeholder consultations, and the experiences of other reintroduction projects. It focuses on three key areas: identifying potential reintroduction sites, creating sustainable conservation strategies, and engaging local communities in the process.

The identification of potential reintroduction sites was a crucial first step. Conservationists identified nine sites, each with unique ecological features and historical significance. After a series of detailed surveys and assessments, three potential sites were selected for further

investigation (Figure 2). These sites were chosen based on their suitability for supporting Ibis populations, including factors such as vegetation, topography, and the availability of food sources. The three selected sites were presented to international experts for evaluation, marking the beginning of the next phase in the Ibis' reintroduction.

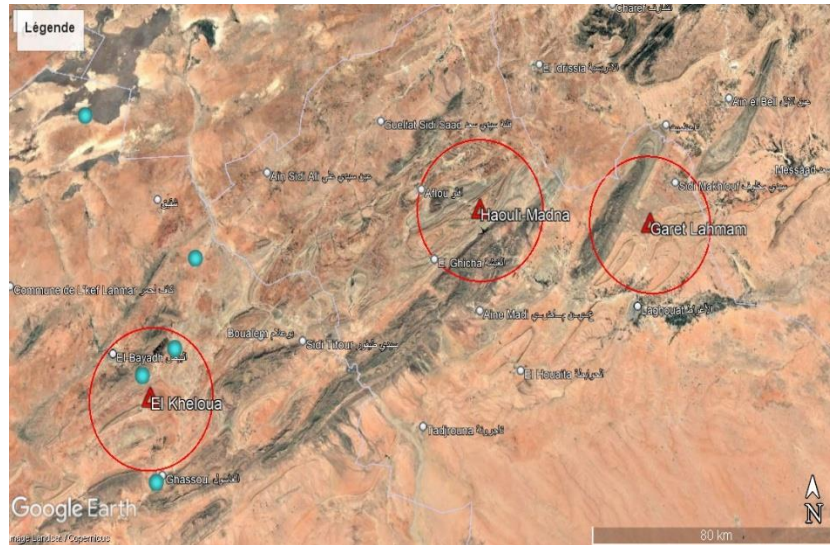


Figure 2. Three proposed reintroduction sites

One of the key successes of the project has been the involvement of local communities, many of whom have invaluable knowledge of the bird's past presence and ecological role in the region. Local names for the bird, such as *Gharab al-Arjun* ("the bald crow"), reflect a deep cultural connection to the species that has survived despite its near disappearance. These communities are integral to the success of the conservation efforts, as they provide both historical context and practical support for conservation actions.

International partnerships have also played a crucial role in ensuring the success of the project. The expertise of global conservation organisations, such as the International Union for Conservation of Nature (IUCN), as well as individual researchers, has facilitated the development of a scientifically sound conservation strategy. Additionally, financial support from these organisations has allowed for the necessary fieldwork, research, and logistical support to carry out the reintroduction programme.

The Future: Towards a Stable Population and Sustainable Conservation

The future of the Northern Bald Ibis in Algeria holds promise, but much work remains to be done. The next steps include continued monitoring of the selected reintroduction sites, further research into the bird's ecological needs, and the establishment of formal protected areas to safeguard its habitat. One of the primary objectives is to ensure that the selected sites can support a viable population of Ibis, which will require ongoing management of the landscape, regular monitoring, and careful regulation of human activities in the area.

Long-term conservation success will depend on the establishment of strong partnerships with local communities, the government, and international conservation organisations. Engaging local populations in the protection of the Ibis' habitat is crucial to ensuring the bird's survival. Additionally, the development of ecotourism initiatives that highlight the importance of the Northern Bald Ibis could provide a sustainable source of funding for ongoing conservation

efforts, while also fostering a greater appreciation for the bird's ecological and cultural significance.

In conclusion, the story of the Northern Bald Ibis in Algeria is one of hope and perseverance. Despite facing numerous challenges, the collaborative efforts of local communities, governmental bodies, and international experts have laid the groundwork for the bird's successful reintroduction. Through continued research, habitat restoration, and the involvement of local stakeholders, there is growing optimism that the Northern Bald Ibis will once again thrive in the wilds of Algeria. This effort not only aims to secure the future of a critically endangered species but also serves as a model for other reintroduction projects across the region, demonstrating the power of collective action in preserving biodiversity for future generations.

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The Wild Northern Bald Ibis: Expanding from Souss-Massa National Park to the World

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Introduction

Conservation of biodiversity is one of the most pressing environmental challenges of the 21st century, and effective management of species at risk of extinction requires a deep understanding of their ecological needs, the threats they face, and the most effective ways to address those threats. Species that inhabit sensitive ecosystems or face anthropogenic disturbances—whether from urbanization, agricultural expansion, or predation—are at heightened risk of population declines and, in some cases, extinction. Such species require focused, adaptive conservation efforts that consider not only their biological needs but also the social and economic factors that may influence conservation success.

The case in question pertains to a species, the Northern Bald Ibis *Geronticus eremita*, that has been severely impacted by human activity, resulting in a significant reduction in its population. This species' survival depends on the successful implementation of a suite of well-designed intervention strategies aimed at mitigating anthropogenic pressures, protecting vital habitats, enhancing reproductive success, and expanding the scientific knowledge base surrounding the species. As such, we will explore a comprehensive, integrated conservation plan designed to ensure the long-term survival of the species in its natural habitat. The intervention strategies presented will focus on four key areas: protecting vital habitat, reducing human-induced disturbances, enhancing breeding success, and improving knowledge of the species through research and monitoring. Each of these strategies will be underpinned by specific, actionable measures intended to achieve a sustainable and ecologically resilient future for the species.

Protecting Vital Habitat

A central tenet of any conservation plan is habitat protection, as the loss and degradation of habitat is often the primary driver of species decline. In many cases, species' habitats are destroyed or fragmented due to human activities such as urban development, agriculture, and resource extraction. For species that rely on specific ecosystems for food, shelter, and breeding, the destruction of these habitats can lead to a decline in population size, genetic diversity, and overall health.

For this particular species, Souss-Massa National Park hosts several colonies and already provides a significant level of protection, given its status as a national park. However, the Tamri region contains some of the most critical habitat for the species' survival. It offers essential resources, including feeding grounds, shelter, and breeding sites. Although this area is already recognized as a Site of Biological and Ecological Interest, which affords it a certain degree of protection, further strengthening its legal status remains a conservation priority. Accordingly, one of the actions planned in the conservation strategy is the formal designation of Tamri as a protected area under national legislation, in accordance with Morocco's Law 22-07 governing

protected areas. This law establishes the legal framework for the creation of protected areas within the country and presents an opportunity to safeguard this important habitat from further human encroachment.

Designating Tamri as a protected area would ensure that future human activities within the region are regulated, with clear guidelines on permissible land use. This designation would also facilitate the sustainable management of the area, ensuring that conservation objectives are integrated into land-use planning. By legally protecting the habitat, it will be possible to control illegal activities such as poaching, logging, and construction, which pose significant threats to the species and its habitat.

In addition to formal legal protection, enhancing monitoring efforts is crucial for ensuring that the protected area is effectively managed. One of the key actions in this strategy is the deployment of eco-guards to monitor and enforce regulations within the protected area. Eco-guards, equipped with the necessary training and resources, will be tasked with ensuring that illegal activities such as poaching or illegal construction are detected and addressed promptly. Eco-guards will also monitor the ecological health of the habitat, ensuring that the species' habitat remains suitable for its needs.

Moreover, the management of this protected area requires active coordination with local authorities to ensure effective enforcement of regulations. This may include developing partnerships with local governments, law enforcement agencies, and other stakeholders to ensure that the protected area's boundaries are respected and that any violations are swiftly addressed. Regular meetings with local stakeholders will be important for maintaining open lines of communication and strengthening collaboration on conservation initiatives.

Another significant challenge in the region is the ongoing urbanization of the surrounding areas. With rapid growth in infrastructure development, urban sprawl poses a direct threat to the species' habitat. To mitigate the risks posed by urban expansion, the conservation strategy advocates regulating urban development near the protected area. Urban planners and developers should be encouraged to direct growth away from critical habitats and to integrate green spaces and biodiversity corridors into their development plans. This approach not only reduces pressure on wildlife habitats but also ensures that human settlements coexist with nature.

In addition to urbanization, agricultural expansion is another key driver of habitat degradation. The cultivation of monoculture crops, particularly those that require the use of pesticides and chemical fertilizers, can degrade the surrounding ecosystem and reduce food availability for the species. To counteract these negative effects, the strategy involves promoting open-field farming techniques that are more sustainable and beneficial to the species. By encouraging the cultivation of native or species-friendly crops, it is possible to create agricultural landscapes that work in harmony with conservation goals. This approach promotes agroecological practices, which can help reduce soil erosion, improve water retention, and enhance biodiversity.

Reducing Disturbance from Human Activities

Human activities, particularly those that result in direct disturbance or disruption of the species' habitat, are a significant threat to species at risk. Disturbances such as noise, human traffic, poaching, and illegal construction can not only cause immediate harm to the species but also disrupt critical behaviours such as foraging, nesting, and reproduction. To reduce human-

induced disturbances, it is essential to implement a series of interventions that mitigate these impacts and allow the species to thrive in its natural environment.

One of the first measures in this strategy is to minimize harmful human interactions in sensitive areas, particularly during critical periods such as breeding and nesting seasons. This can be achieved by designating specific zones as no-entry areas for humans, particularly during times when the species is most vulnerable. By restricting access to these sensitive zones, it is possible to prevent disturbances that could lead to nest abandonment, injury, or population decline. Zoning restrictions should be clearly marked and enforced by eco-guards, who can monitor and prevent unauthorized access to these areas.

Public education campaigns play a crucial role in reducing disturbance from human activities. Many disturbances to wildlife come from well-meaning individuals who do not understand the consequences of their actions. Raising awareness among local communities, tourists, and stakeholders about the importance of respecting wildlife and their habitats can significantly reduce human-induced threats. Educational programs can also highlight the role of the species in the local ecosystem, fostering a sense of stewardship and responsibility among the people who live and work in the area.

Regulating tourism activities is another critical component of reducing disturbance. While ecotourism can bring economic benefits to local communities, poorly managed tourism can result in habitat degradation, pollution, and increased stress on wildlife. The strategy proposes implementing measures to control the number of tourists allowed in sensitive areas, establishing visitor quotas, and ensuring that tourism activities are conducted in an environmentally responsible manner. This includes ensuring that tour operators follow guidelines on how to observe wildlife without disturbing them and promoting low-impact recreational activities such as guided nature walks or wildlife watching from a distance.

To support these efforts, the presence of eco-guards and rangers will be strengthened during peak tourist seasons or during vulnerable periods for the species, such as the breeding season. These rangers will not only monitor illegal activities but also educate tourists on the importance of respecting the environment and the species' needs.

Enhancing Breeding Success

One of the key factors influencing the survival of any species is its ability to reproduce successfully. For endangered species, breeding success is often a significant challenge due to various factors such as habitat degradation, predation, disease, and disturbance. By enhancing the breeding success of this species, it is possible to increase population numbers and improve the species' long-term viability.

The first action in this strategy is to improve the quality of the species' breeding habitats. In many cases, the degradation of habitat quality can lead to reduced breeding success due to factors such as a lack of suitable nesting sites, decreased availability of food resources, and increased exposure to predators. Habitat restoration efforts, such as planting native vegetation, removing invasive species, and rehabilitating damaged ecosystems, can help restore critical breeding sites and improve overall habitat quality.

Predator control is another important aspect of enhancing breeding success. Invasive species, such as non-native predators, can severely reduce the survival rates of eggs, chicks, and adults.

The strategy therefore proposes the implementation of targeted actions to mitigate predator pressure and enhance the species' breeding success.

Another approach to enhancing breeding success involves the establishment of artificial nesting sites or breeding programs. While direct intervention such as captive breeding may be necessary in some cases, these methods should be used cautiously and in conjunction with habitat restoration efforts to ensure that the species can eventually breed successfully in the wild. Artificial nest boxes or platforms can be provided to support the species during the early stages of recovery.

Expanding Research Efforts

Effective conservation is built on a solid foundation of scientific knowledge. Without a deep understanding of a species' ecological requirements, behaviour, and interactions with its environment, it is difficult to design and implement effective conservation strategies. For this reason, expanding research efforts is a critical component of the intervention plan.

Research initiatives should focus on gathering detailed data about the species' distribution, population dynamics, diet, habitat use, reproductive biology, and social behaviour. These data will help conservationists better understand the specific needs of the species and identify areas where conservation interventions are most urgently needed. Long-term monitoring programs that track changes in the species' population and habitat quality will allow researchers to assess the effectiveness of conservation actions over time and make necessary adjustments to management strategies.

In addition to gathering basic ecological data, research efforts should also focus on understanding the threats faced by the species. This includes studying the impacts of climate change, human activities, and disease on the species' survival. Research on the effectiveness of different conservation measures—such as predator control, habitat restoration, or sustainable land-use practices—will help refine strategies and ensure that the species receives the most appropriate interventions.

Discussion

The survival of species at risk of extinction depends on the implementation of comprehensive, well-coordinated conservation efforts that address both immediate and long-term challenges. By focusing on protecting vital habitats, reducing human-induced disturbances, enhancing breeding success, and expanding scientific knowledge, it is possible to ensure that species are given the best chance for survival and recovery. The strategies proposed in this intervention plan provide a roadmap for managing this species' conservation needs, with an emphasis on sustainable habitat management, community involvement, and adaptive research. Through ongoing efforts and collaboration, it is possible to achieve a future where this species thrives in its natural habitat, contributing to the biodiversity and ecological health of the region.

Northern Bald Ibis in Turkey

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Introduction

The Northern Bald Ibis *Geronticus eremita* once widespread across Europe, North Africa and the Middle East, is one of the most threatened avian species globally. Recognised by its distinctive bare red head, iridescent black plumage and long-curved bill, the species holds deep cultural and religious significance in several civilisations, where it has symbolised fertility, abundance and even divine guidance. Despite this reverence, anthropogenic pressures drove the species to the brink of extinction across most of its historical range by the mid-20th century.

Historically, the Turkish town of Birecik, located on the banks of the Euphrates River, harboured one of the most significant breeding colonies of the Northern Bald Ibis. The region's cliffs provided ideal nesting sites, while the surrounding semi-arid landscape offered abundant foraging grounds. However, rapid agricultural intensification, including the unregulated use of pesticides—particularly DDT—in the mid-20th century, led to catastrophic population crashes. By the 1970s, the once-flourishing colony had been reduced to a few dozen individuals, bringing the species to the verge of local extinction.

Over the past five decades, targeted conservation interventions have partially reversed this decline. The establishment of the Birecik Breeding Station, collaboration with NGOs, universities and zoos, as well as scientific monitoring, have helped stabilise the population. Yet significant challenges remain. This extended abstract reviews the historical context of the Birecik population, examines conservation efforts and scientific advances at the breeding station, discusses the complexities of re-establishing migratory behaviours and considers future strategies for the species' long-term survival.

Historical Decline and the Establishment of the Birecik Breeding Station

The Northern Bald Ibis was once a familiar sight along the Euphrates River, with estimates suggesting over 500 breeding pairs in the Birecik area by the mid-20th century. However, the introduction of harmful agricultural chemicals, habitat alteration and hunting decimated the population. The most significant blow came in the 1960s and 1970s when pesticide use—particularly DDT—led to eggshell thinning, reproductive failure and direct mortality. Within just a few years, nearly 70% of the population was lost, leaving only 50 individuals by the 1970s.

Recognising the severity of this ecological crisis, the Turkish Ministry of Forestry and the General Directorate of National Parks and Hunting, supported by local and international environmental organisations, launched an emergency conservation programme. In 1977, the Birecik Breeding Station was established with the aim of preventing complete extinction and providing a controlled environment for population recovery. The station was strategically located near the species' traditional nesting cliffs, enabling access to natural habitats while ensuring security for breeding efforts.

Initially, the programme focused on maintaining a captive colony, facilitating breeding and protecting the remaining wild birds. Over time, the station expanded its activities to include habitat restoration, environmental education and scientific monitoring. Despite the challenges, these efforts successfully prevented the extinction of the Birecik population, creating a foundation for gradual recovery.

Today, the breeding station comprises two large aviaries, a veterinary clinic and a visitor centre opened in 2019. Although temporarily closed during the COVID-19 pandemic, the centre now welcomes approximately 50,000 visitors annually, serving as a vital tool for public engagement and awareness. The facility represents one of the longest-running and most significant conservation projects for *Geronticus eremita* globally.

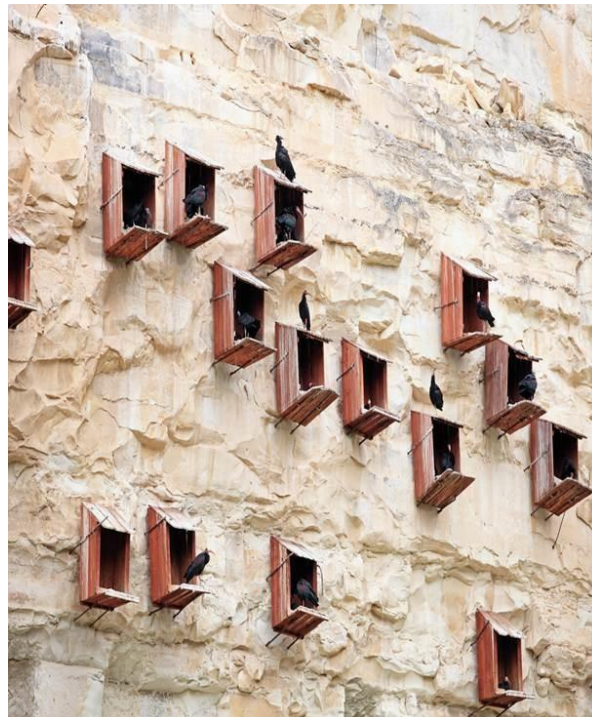


Figure 1. Northern Bald Ibises breeding in Birecik, Turkey

Scientific Monitoring, Population Management, and the Role of Zoos

Scientific research and systematic monitoring have become integral to the Birecik conservation programme, providing data to inform adaptive management. Since 2000, the station, in collaboration with universities and NGOs, has implemented a comprehensive ringing programme. The initial effort began with 40 individuals; by 2024, over 700 birds had been ringed, creating a robust dataset essential for tracking individual lifespans, reproductive success and survival rates.

Complementing this, satellite tracking was introduced in 2023, marking a significant advancement in monitoring capabilities. Supported by WWF, the station fitted four individuals with GPS transmitters, enabling real-time tracking of movement patterns, habitat use and potential migratory attempts. Early data from this initiative have provided new insights into the spatial ecology of the species, informing both local management and broader conservation planning.

Another critical component is genetic management through sex determination. Beginning in 2013, Middle East Technical University conducted molecular analyses to determine the sex of

birds, allowing the station to balance breeding pairs and maintain genetic diversity. This practice is now routinely carried out in collaboration with local universities, underscoring the integration of conservation with academic research.

Ex-situ conservation efforts further strengthen the species' survival prospects. Three Turkish zoos — Faruk Yalçın Zoo, Bursa Zoo and Gaziantep Wildlife Park — maintain small captive populations of *Geronticus eremita*, collectively housing 36 individuals (Figure 2). These zoos contribute approximately 10% of the national population and serve as genetic reservoirs and education centres. Breeding success has varied, with Faruk Yalçın Zoo reporting three chicks annually in recent years, while Bursa Zoo has faced breeding failures.

The integration of zoo-based populations with the wild and captive colony in Birecik represents a holistic approach, ensuring that conservation is not confined to a single location but distributed across multiple institutions, thereby enhancing resilience against localised threats.

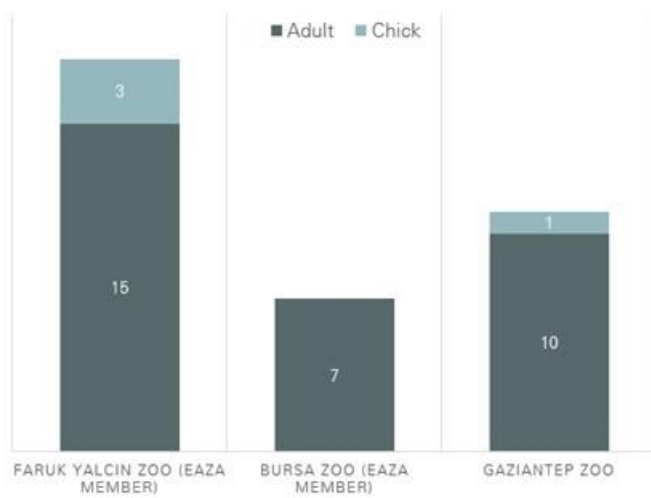


Figure 2. Actual number of Northern Bald Ibises in zoos in Turkey (2024)

Migration Challenges, Habitat Pressures, and Future Directions

One of the most contentious and biologically complex aspects of the Birecik Northern Bald Ibis population is the question of migration. Historically, the species was migratory, traversing vast distances to wintering grounds likely located in East Africa. However, decades of captivity, habitat fragmentation and environmental hazards have disrupted these migratory traditions.

While the Birecik station releases some individuals annually in experimental migratory trials (Figure 3), success remains limited. According to project leaders, including Mr. Reşat and Mr. Taner from the General Directorate of National Parks, true migration is neither a current management priority nor advisable given the risks. Modern landscapes are increasingly hostile to long-distance avian migration, with urbanisation, intensive agriculture and infrastructural barriers posing lethal threats. Additionally, the loss of traditional knowledge — once culturally transmitted among ibises — hinders the re-establishment of migratory routes.

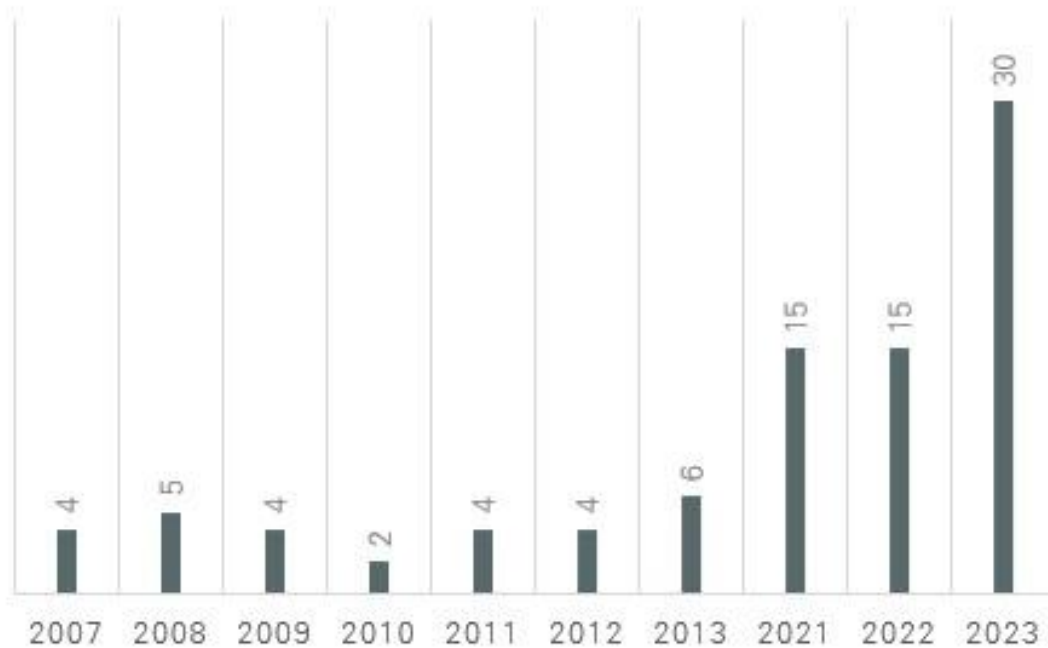


Figure 3. Annual number of juvenile Northern Bald Ibises released in Birecik for migration

Despite these challenges, the potential rewilding of migratory behaviour remains an open question. International examples, such as European reintroduction projects using human-led migrations, offer models that could inform future efforts in Turkey. However, these projects are resource-intensive and require careful consideration.

Simultaneously, habitat pressures in the Birecik region persist. Ongoing development projects along the Euphrates, agricultural intensification and changing land-use patterns threaten the foraging and nesting habitats of the ibises. Continued habitat protection and enforcement of the designated protected area are therefore crucial.

Encouragingly, the Turkish government, supported by NGOs such as WWF, is revisiting the national *Geronticus eremita* Species Action Plan, first developed in 2019. The revision, scheduled for 2024, will incorporate recent scientific findings, re-evaluate management strategies and reinforce conservation targets. This plan represents a vital opportunity to align national efforts with global best practices and ensure that conservation remains proactive and science-driven.

Conclusion

The story of the Northern Bald Ibis in Birecik is emblematic of both the fragility of endangered species and the power of sustained conservation action. From a population reduced to fewer than 50 individuals, the Birecik colony now stands at over 336 birds, with an additional 36

supported in Turkish zoos (Figure 4). This recovery, while modest, underscores the effectiveness of integrated conservation strategies combining in-situ and ex-situ efforts, scientific research and community engagement.

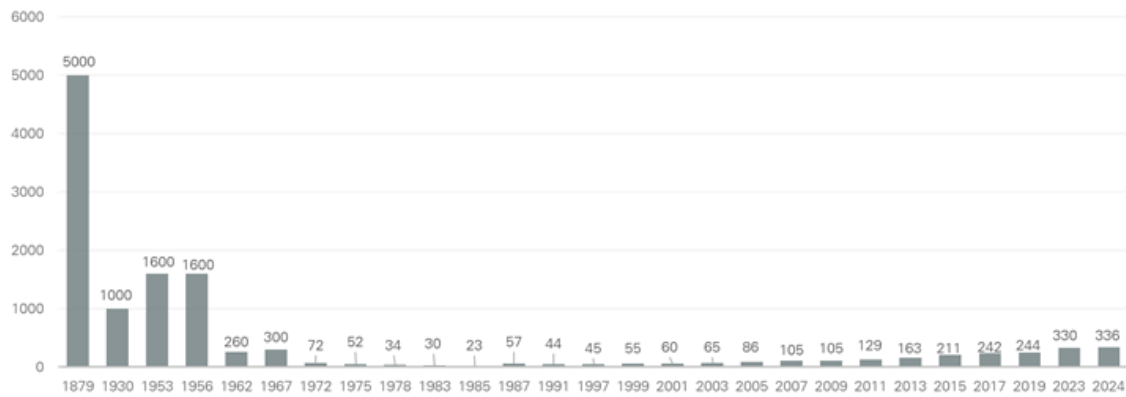


Figure 4. Population status of the Northern Bald Ibis in Turkey from 1879 to 2024

Nevertheless, the species' future in Turkey remains uncertain. Habitat loss, environmental changes and the unresolved issue of migration continue to pose significant challenges. The revision of the Species Action Plan offers a timely opportunity to reassess priorities, strengthen protections and explore new scientific interventions, including expanded satellite tracking and genetic management.

Birecik’s experience serves as a model for similar programmes worldwide, illustrating that even species pushed to the brink can recover with dedication, collaboration and adaptive management. Ensuring the long-term survival of *Geronticus eremita* in Turkey will require continued investment, public support and international cooperation. With these elements in place, the Northern Bald Ibis may continue to grace the skies over Birecik for generations to come — a living testament to successful conservation in action.

Reintroduction of the Northern Bald Ibis *Geronticus eremita* in Catalonia: Environmental Feasibility, Institutional Framework, and Strategic Implications for Restoring the Western Mediterranean Flyway

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Abstract

The Northern Bald Ibis *Geronticus eremita* is a species of high conservation concern whose former range extended across Europe, North Africa, and the Middle East. After centuries of anthropogenic pressure, the species disappeared from the wild in Europe, though it survives today through a sedentary reintroduced population in Andalusia, developed through Proyecto Eremita, and several managed migratory colonies in central Europe, including those established through the Waldrappteam project in the Alps. This manuscript presents the scientific, institutional, and operational framework for a new reintroduction initiative in Catalonia, promoted by Fundació Alive. Environmental modelling, landscape assessment, predator risk evaluation, and governance alignment indicate that the Empordà region offers highly favourable conditions for establishing a breeding nucleus. The project has secured formal authorisations from both the Spanish Ministry for Ecological Transition and the Government of Catalonia and enjoys the support of the Aiguamolls de l'Empordà Natural Park. A phased soft release of approximately 50 individuals between 2025 and 2026, financed through an initial €155,000 investment almost entirely funded by Fundació Alive, creates a solid foundation for long-term viability. By restoring a missing segment of the western Mediterranean flyway, which the species presumably used in the past for long-distance migrations, the initiative aims to reconnect fragmented European populations and contribute to the broader recovery of the species at the continental scale.

Introduction

The Northern Bald Ibis is one of the most threatened bird species historically associated with pastures and Mediterranean and semi-arid ecosystems of the western Palearctic (Fritz & Janák 2022). Once widespread across southern Europe (Sánchez 2006; Schenker 1977; Schenker et al. 2024), the species experienced a dramatic collapse due to habitat loss, direct persecution, pesticide use, and intensifying agricultural practices. Although it vanished from the wild in Europe centuries ago, contemporary conservation programmes have successfully established a sedentary breeding colony in Andalusia through Proyecto Eremita (Quevedo 2016) and managed migratory populations in Austria, Germany, and Italy through the Waldrappteam project in the Alps (Fritz et al. 2017). These efforts demonstrate the species' ability to adapt and recover when ecological requirements are met and appropriate management strategies are implemented.

Despite these advances, a key biogeographical gap persists. The western Mediterranean flyway, presumably used by the species during long-distance movements, remains elusive. Restoring this corridor is essential for enhancing genetic exchange, facilitating natural dispersal, and improving the resilience of the European metapopulation. Catalonia is uniquely positioned to

contribute to this goal. Situated on the Mediterranean coastline and directly linked to the Pyrenees, it serves as an ecological bridge between central European migratory colonies and the sedentary Andalusian population.

This manuscript synthesises the environmental evidence, methodological foundations (IUCN/SSC 2013), institutional alignment, and expected conservation outcomes associated with the Catalonia Northern Bald Ibis Reintroduction Programme. It provides an integrated assessment of the viability and relevance of re-establishing the species in this region.

Methods

Environmental and climatic benchmarking

Climatic suitability was assessed by comparing monthly average temperatures for the Empordà region with established reference sites used by current Northern Bald Ibis populations. These included Jerez, representing conditions for a stable sedentary colony; Orbetello, the primary wintering site for Alpine migrants; Milan, representative of northern Italian plains used irregularly; and Burghausen, a core breeding location for the central European migratory colonies. Annual temperature profiles were analysed to determine whether Empordà's winter conditions align with thresholds known to support successful overwintering and foraging.

GIS-based habitat suitability analysis

A multi-layered GIS model was developed to evaluate habitat quality across the landscape. The analysis incorporated land-use categories and pasture distribution that correlate with invertebrate abundance. Emphasis was placed on identifying natural and low grass pastures near extensive cattle operations, as these environments provide the most favourable feeding grounds for the species. Morphological features of the landscape were also considered to evaluate accessibility and ecological connectivity. The resulting suitability index allowed the identification of priority areas for the placement of release infrastructure.

Predator and infrastructure risk assessment

To understand predation pressures, records of breeding territories of Eurasian Eagle Owl *Bubo bubo* and Bonelli's Eagle *Aquila fasciata* were mapped and validated through field surveys. Zones with elevated predation risk were excluded from suitability considerations. The electrical network was then examined to determine collision and electrocution risks, allowing the development of a targeted mitigation plan involving insulation upgrades and the installation of visibility markers on selected powerlines.

Reintroduction protocol

The operational design follows a phased soft-release strategy, EAZA husbandry guidelines (Böhm 1999), and EAZA's Long-term Management Plan for the species (Pokorni 2024). A large open-netted aviary will provide acclimatisation space for the founding individuals, while two elevated towers mimic natural cliff structures commonly used for roosting and nesting. The founder population will consist of hand-raised birds from Jerez Zoo (Proyecto Eremita), individuals arriving from the assisted migration programme of the Waldrappteam project, and parent-reared birds from EAZA institutions. All birds will be fitted with GSM-GPS transmitters to facilitate continuous monitoring of movement patterns, behaviour, and survival. The initial

group will be consolidated in mid-2025 and retained in the aviary until March 2026, when the release is scheduled.

Institutional involvement and regulatory framework

Fundació Alive leads the project and has successfully secured the formal authorisations required for the reintroduction. These include approval from the Spanish Ministry for Ecological Transition and the Government of Catalonia, confirming that the initiative aligns with national and regional conservation priorities as well as EU biodiversity directives. The Aiguamolls de l'Empordà Natural Park has assessed the project positively and supports its implementation as an opportunity to enhance both ecological function and public engagement within the protected area. Local municipalities, livestock owners, and NGOs have contributed constructively throughout the consultation process, strengthening the project's social licence.

Budget and financial governance

The initial implementation phase has a budget of approximately €155,000, which covers infrastructure construction, monitoring equipment, operational staffing, and logistics. Fundació Alive will finance nearly the entire amount, ensuring financial stability during the critical establishment period. Subsequent phases are expected to rely on a combination of grant funding, institutional partnerships, and public engagement, including an "Adopt an Ibis" programme designed to support long-term monitoring and maintenance activities.

Results

Climatic suitability

The comparative climatic analysis demonstrates strong alignment between Empordà and regions where the Northern Bald Ibis is known to thrive. Empordà experiences winter temperatures significantly milder than those of the northern Alps and northern Italy, where extended periods of frost often limit foraging opportunities. Instead, the region's temperature profile closely matches that of Orbetello, a well-established wintering location for the Alpine population, and is only slightly cooler than conditions observed in Jerez, where a stable sedentary colony has developed. These findings illustrate that Empordà offers favourable year-round conditions for foraging and thermoregulation and is unlikely to impose climatic stress that could impede survival or breeding performance (Figure 1).

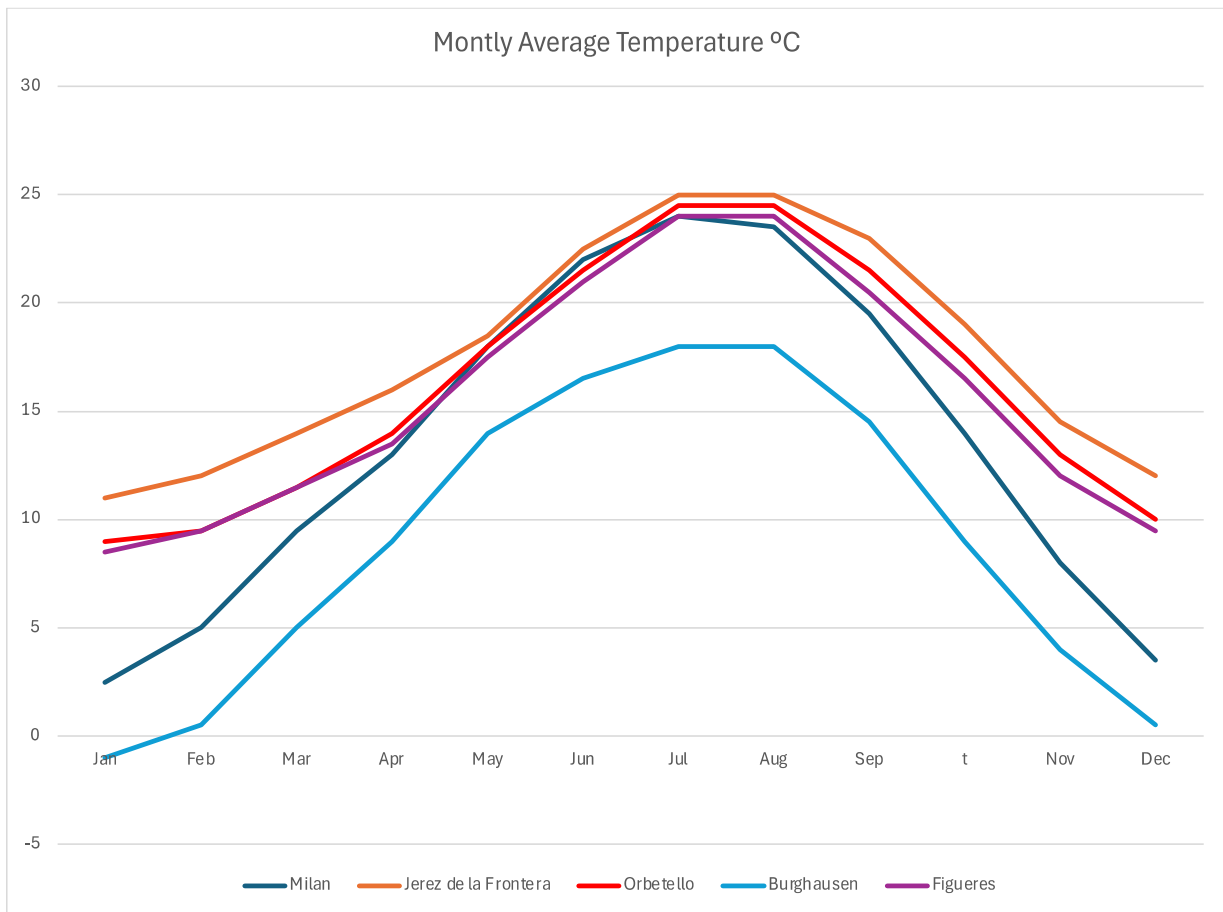


Figure 1. Comparative climatic analysis demonstrates strong alignment between Empordà and regions where the Northern Bald Ibis is known

Habitat suitability and landscape structure

The GIS-based habitat model identified two major clusters of high-quality pasture landscapes characterised by nutrient-rich soils and consistent invertebrate availability (Figure 2). These clusters are strongly associated with organic and extensive cattle-grazing systems that maintain vegetation at optimal heights for ibis foraging. The Torre Mornau site, located in the municipality of Pau, lies centrally within the largest of these clusters (Figure 3). Its landscape configuration provides a contiguous matrix of high-quality foraging areas with minimal human disturbance and adequate ecological connectivity. The site’s proximity to the Aiguamolls de l’Empordà protected area reinforces its strategic value by embedding the future population within a broader conservation landscape.

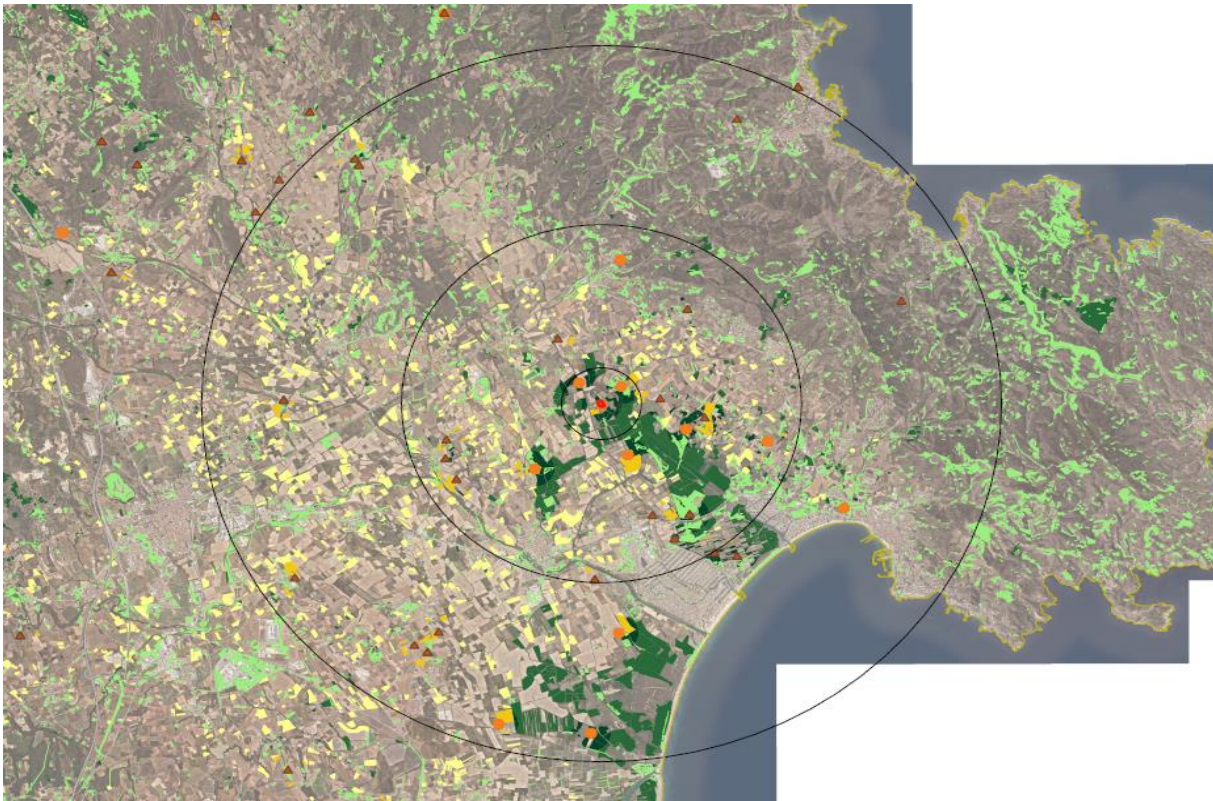


Figure 2. Habitat model shows two major clusters of high-quality pasture landscapes



Figure 3. Torre Mornau site

Predator pressure and infrastructure risks

The evaluation of predator presence indicates that neither Eurasian Eagle Owl nor Bonelli's Eagle maintain territories within the high-risk radius of the proposed release area. Although these raptors are present in the broader region, their nesting locations and hunting ranges do not overlap significantly with the selected site. This reduces the likelihood of predation-driven mortality during the establishment phase.

Analysis of electrical infrastructure shows that while some medium-risk powerlines exist within the region, the overall density of hazardous structures is low. Planned mitigation, including insulation and the installation of diverters, is expected to reduce collision and electrocution risk to acceptable levels. The risk environment is therefore manageable and conducive to supporting a reintroduced population.

Institutional and social readiness

The strong institutional alignment supporting the project constitutes one of its most favourable characteristics. Governmental authorisations were granted following formal technical review processes at both national and regional levels, demonstrating regulatory confidence in the project's ecological soundness. The Natural Park's support further integrates the initiative within a protected-area management framework and ensures long-term institutional anchoring.

Local communities, livestock owners, and land managers expressed positive interest during the consultation phase, recognising the project's compatibility with existing land-use practices and potential to generate educational and ecotourism opportunities. These outcomes suggest a favourable social environment for long-term coexistence between human activity and the reintroduced species.

Operational preparedness

The project's operational components are fully developed and ready for implementation. The aviary and tower structures have been designed to meet welfare and behavioural requirements for the species, providing an environment that encourages social bonding, safe acclimatisation, and natural roosting behaviour. Agreements with partner institutions ensure the availability of a genetically diverse founder group with appropriate behavioural profiles (Wirtz et al. 2018). The GSM-GPS monitoring system is prepared to provide real-time data upon release, enabling adaptive management and rapid response to emerging threats. Overall, operational readiness is high, and the project is positioned to begin implementation within the established timelines.

Discussion

The reintroduction initiative in Catalonia is well supported by environmental evidence, institutional alignment, and sound operational planning. The climate of the Empordà region is demonstrably favourable and avoids the severe winter conditions that challenge populations in more continental environments. The structural composition of the landscape, dominated by pastures associated with organic livestock operations, provides ideal feeding conditions throughout the year. Predator risks and infrastructure hazards are both present at manageable levels and can be effectively mitigated.

Fundació Alive's leadership, combined with governmental authorisation at both national and regional levels, ensures regulatory stability and strategic alignment with conservation policy.

The enthusiasm expressed by the Aiguamolls de l'Empordà Natural Park and local agricultural stakeholders embeds the project within an interconnected institutional network essential for long-term sustainability.

The initiative contributes directly to continental-scale conservation objectives by attempting to restore a missing segment of the presumed Mediterranean flyway. Should individuals from Catalonia eventually connect with populations in central Europe or Andalusia, the metapopulation would gain new potential for genetic exchange, natural dispersal, and demographic resilience.

The financial structure, anchored by Fundació Alive's commitment to fund the initial investment, ensures that the project can proceed without uncertainty during the critical establishment period.

Conclusion

Environmental, institutional, and operational assessments support the suitability of Catalonia for the reintroduction of the Northern Bald Ibis. The region offers favourable climatic conditions, high-quality foraging landscapes, manageable ecological risks, and strong institutional backing. By establishing a breeding nucleus in Catalonia, the project has the potential to restore ecological functionality to the western Mediterranean corridor and strengthen the species' European metapopulation.

Acknowledgements

The author gratefully acknowledges the essential contributions of Miguel Ángel Quevedo, Johannes Fritz, Proyecto Eremita, Waldrappteam, Zoo de Jerez, Ayuntamiento de Jerez, Consejería de Medio Ambiente de la Comunidad Andaluza, Generalitat de Catalunya, and the Parc Natural dels Aiguamolls de l'Empordà. Their scientific expertise, institutional support, and long-standing commitment to the conservation of the Northern Bald Ibis have been fundamental to the development of this reintroduction programme.

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Proposal for the release of Northern Bald Ibis in the region of Valencia (Comunidad Valenciana)

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Introduction:

Since 2023, human-led migration (HLM) crossed the Iberian Peninsula twice, connecting the central European population of Northern Bald Ibis *Geronticus eremita* with the population in Cádiz (Fritz et al. 2024). A habitat suitability analysis is currently underway, which may help to identify more suitable areas for new colonies in Spain, so that a wildlife corridor could be established between the two main Northern Bald Ibis populations. There is evidence of Northern Bald Ibis fossils in several sites on the Mediterranean coast of Spain. Fossils have been found at the archaeological site called Almenara-1 in Castellón, just 40 km north of the city of Valencia (Sanchez-Marco 1996), and in the Sierra de Quibas, Murcia, 180 km south of Valencia (Montoya et al. 1999). These findings strongly suggest that the Levantine Iberian area was inhabited by this species. Gorham's Cave also provides evidence of historical occurrence (Finlayson et al. 2006).

Bioparc Valencia, a full EAZA member, has been involved in HLM-2023 and HLM-2024, providing logistical support and staff during the journey over Spain. Bioparc Valencia works with the Wildlife Unit of the Veterinary Faculty (Universidad CEU Cardenal Herrera in Valencia). We recently presented to the local administration (Conselleria de Medio Ambiente, Generalitat Valenciana) the proposal of reintroducing the Northern Bald Ibis in the region of Valencia based on the avian fossils found, and the previous successful experiences of both Proyecto Eremita and Waldrapteam. The administration showed immediate interest in this.

Until the results of the habitat suitability analysis are available, we suggest an area called *Reserva Valenciana de Caza Muela de Cortes* as a potential site for the reintroduction of Northern Bald Ibis. This reserve is managed by the Conselleria de Medio Ambiente, has an extension of 36,000 ha, and is located about 50 km southwest of the city of Valencia. It is included in the Special Protection Area for Birds (Natura 2000) Sierra de Martés–Muela de Cortes (total extension of more than 150,000 ha), and very close to the Natural Park of Hoces de Cabriel. It is an area of rocky slopes, Mediterranean scrubland, and open olive tree plantations. The reserve is a controlled big-game hunting area (ibex, mouflon, wild boar, red deer, and fallow deer). This activity is well regulated, and hunters are always accompanied by experienced wildlife rangers. The Wildlife Unit of the University has been working there for years and has excellent connections with the municipalities and wildlife rangers.

Conclusion:

In conclusion, recent human-led migration efforts have strengthened the connection between the central European and Cádiz populations of Northern Bald Ibis, opening new opportunities for establishing a functional wildlife corridor across Spain. Fossil evidence from the Levantine coast confirms the species' historical presence in the region, supporting the ecological and biogeographical rationale for reintroduction in Valencia. With strong institutional backing from

Bioparc Valencia, the Universidad CEU Cardenal Herrera, and the Conselleria de Medio Ambiente, and building on the proven success of previous reintroduction projects, the proposed site at Muela de Cortes represents a promising candidate for the species' return. Pending the results of the habitat suitability analysis, this initiative offers a realistic and scientifically grounded step toward restoring the Northern Bald Ibis to its former range in eastern Iberia.

The Northern Bald Ibis EEP – An Overview and Current Data

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Abstract

The Northern Bald Ibis *Geronticus eremita* has undergone a dramatic population decline across its historical range due to anthropogenic pressures. In response, the European Association of Zoos and Aquaria (EAZA) established an ex-situ conservation program (EEP) for this species in 1988. This article presents an overview of the status of the EEP population, recent management activities, and future priorities.

As of March 2025, the zoo-managed population comprises 1,300 individuals across 94 institutions, with a stable demographic structure and a genetic diversity of 95.6% relative to the founder population. A 2024 husbandry survey revealed strong institutional engagement, with 96% participation in the survey and broad support for future reintroduction efforts. The recently published Long-Term Management Plan (LTMP) outlines key recommendations for sustainable population management, including minimum colony sizes, improved parentage tracking, and genetic sampling. Despite overall genetic diversity in the Northern Bald Ibis population, there is a risk of elevated inbreeding levels within institutions, which calls for targeted transfers and improved data quality through accurate parent identification.

Keywords: Northern Bald Ibis, *Geronticus eremita*, EEP, studbook data, population management, genetic diversity, LTMP, conservation

Introduction

The Northern Bald Ibis *Geronticus eremita*, once widespread across Europe, North Africa, and the Middle East, has experienced a severe population decline due to habitat loss, hunting, and other anthropogenic pressures. Conservation efforts began in the mid-20th century, with the first successful captive population established from 38 Moroccan birds imported to Basel Zoo in the 1950s. Further imports in the 1970s expanded the captive gene pool, resulting in the registration of 74 wild-caught founders. The EAZA ex-situ programme (EEP) for the Northern Bald Ibis was launched in 1988, overseeing a growing zoo population that had already reached 330 individuals across 40 institutions. After 35 years of coordination by Christiane Böhm, curator at the Alpenzoo Innsbruck-Tyrol, the EEP as well as the curator position at the Alpenzoo were handed over to Juliane Pokorny in 2023. This article presents current studbook data and highlights some EEP activities from the past two years.

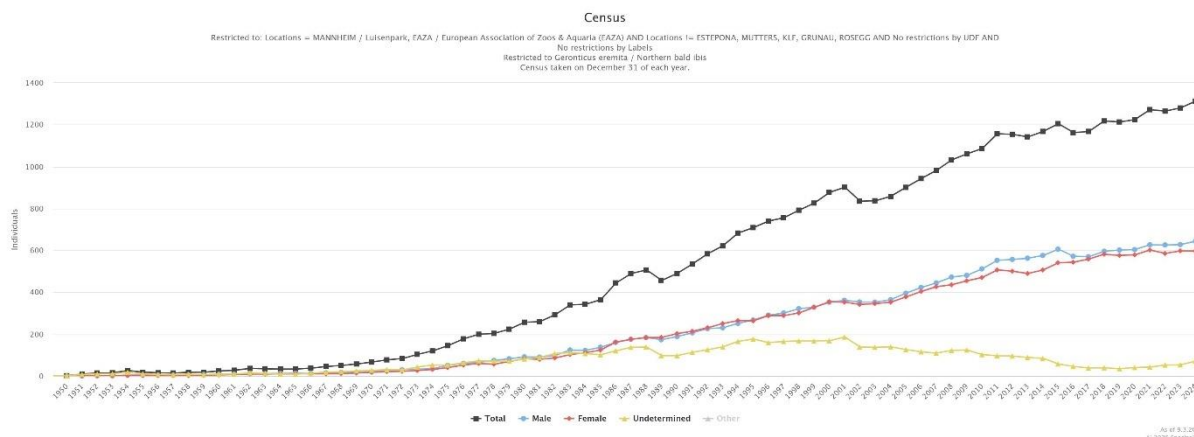


Figure 1. Development of the Northern Bald Ibis population in captivity from 1950 to 2024

Methods

The studbook population data were obtained through regular monitoring and breeding records, collected from various EEP member institutions. Management strategies were evaluated based on guidelines provided by the EEP coordinator and the EEP species committee, the EAZA Pelecaniformes, Ciconiiformes, and Phoenicopteriformes taxon advisory group (TAG), and the EAZA population biologists.

Results

At the time of the symposium in March 2025, the Northern Bald Ibis EEP comprised 97 member institutions, including 93 EAZA institutions and 4 non-EAZA institutions (Luisenpark Mannheim, Konrad Lorenz Research Center (KLF), Tierpark Rosegg, and Waldrappteam). The KLF, Tierpark Rosegg, and Waldrappteam represent the “free-flying” or “released” populations. Until now, the coordinator has entered their data, such as yearly losses and hatched chicks, into the studbook on an individual basis. As data from the last three years have not yet been fully entered into the studbook, the present analysis only includes the captive, non-free-flying populations. Although the Proyecto Eremita birds are also free-flying, they have been documented differently from the other free-flying populations, as they were registered as transferred to Jerez Zoo and recorded as released to the wild from there. Efforts are already underway to establish a unified documentation for all free-flying populations in the future.

The zoo-managed Northern Bald Ibis population consists of 1,300 individuals across 94 institutions with an almost equal sex ratio of 638 males and 590 females, and 72 unsexed additional individuals. The population has remained relatively stable over the last 10 years, with only a slight increase. On average, around 185 chicks are born annually, following breeding recommendations, while approximately 125 deaths are recorded each year, representing individuals of all age classes.

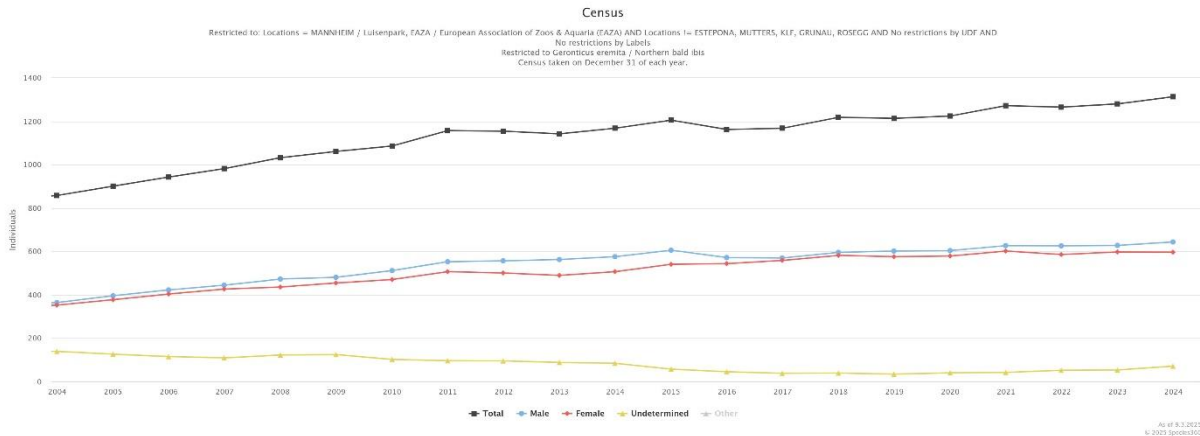


Figure 2. Captive Northern Bald Ibis population over the last ten years (2004–2024)

The population shows a healthy age structure. The oldest living bird, currently 42 years old, is kept at Schönbrunn Zoo, Vienna.

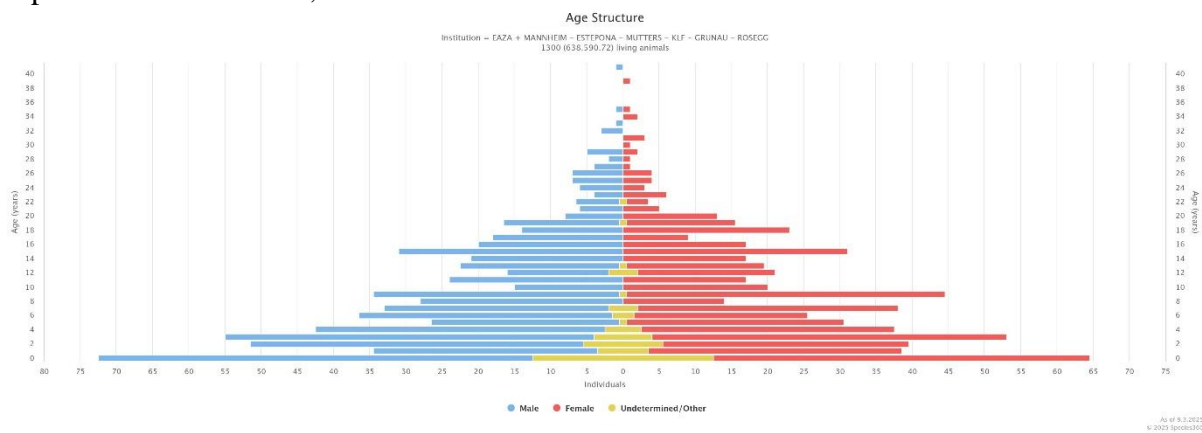


Figure 3. Age structure of the zoo-managed Northern Bald Ibis population (as of March 2025)

One ongoing challenge involves data inconsistencies resulting from the transition from the Single Population Analysis and Records Keeping System (SPARKS) to the Zoological Information Management System (ZIMS). While much of the data was already cleaned by the previous coordinator, further corrections are still underway.

To gain a clearer understanding of the current status of EEP member institutions and their Northern Bald Ibis populations, a comprehensive husbandry survey was conducted in January 2024. The survey aimed to verify the accuracy of studbook records, assess breeding potential, and evaluate the spatial capacity of participating zoos.

A total of 96 out of 100 institutions responded, representing a high participation rate. The survey revealed that 1,205 Northern Bald Ibises are currently housed in 93 zoos (excluding free-flying populations), with an estimated additional capacity for 330 individuals. Approximately 300 breeding pairs were identified, highlighting the need for carefully managed breeding recommendations to maintain population stability and avoid exceeding spatial limits. Among the responding institutions, 71 reported housing Northern Bald Ibises in mixed-species aviaries, most commonly with Griffon Vultures *Gyps fulvus*, Scarlet Ibises *Eudocimus ruber*, and Sacred Ibises *Threskiornis aethiopicus*. While interspecies conflicts were generally minimal, the Sacred Ibis was noted as particularly dominant. Six institutions reported nutrition-related issues, including deficiencies, skin conditions, sticky plumage, and inappropriate chick feeding behaviors. Veterinary concerns were reported by 23 institutions, with the most common issues

being beak fractures, trauma, ingestion of foreign objects, and skin problems. Two cases of West Nile virus were documented in two institutions.

Encouragingly, 85 institutions expressed interest in supporting future reintroduction programs. Most are willing to contribute birds for release, and approximately one-third of these institutions indicated readiness to provide financial or logistical support, including staff funding, monitoring, energy costs, and equipment such as transmitters.

In a collaborative effort by the EEP Coordinator, the 16-member EEP Species Committee newly established in January 2024, the EAZA Pelecaniformes, Ciconiiformes, and Phoenicopteriformes TAG, and the EAZA Population Management Centre (PMC), the Northern Bald Ibis Long-Term Population Management Plan (LTMP) was finalized in November 2024 and published on the TAG page of the EAZA website in January 2025. This Plan outlines key recommendations for sustainable population management within EEP institutions. At the LTMP's core is the recommendation for a minimum colony size of ten individuals to ensure social stability and breeding success. Institutions are encouraged to ring and sex all individuals and to conduct detailed nest observations to accurately identify parentage. Where precise identification is not possible, all possible parents should be recorded in MULTs (meaning recorded multiple times).

The LTMP also emphasizes the importance of collecting blood samples during veterinary procedures, transfers, or post-mortem examinations, and submitting them to the EAZA Biobank to support future genetic research. Additionally, institutions are encouraged to contribute to studies on sex determination by recording beak length and depth measurements planned by the EEP Coordinator and the EEP Species Committee and supported by the TAG.

Veterinary concerns regarding behaviours observed in captive populations, such as feather pecking and chronic dermatitis, are highlighted as areas requiring further investigation. Institutions encountering such cases are encouraged to report them to support coordinated research efforts.

The LTMP also provides updated genetic data critical for breeding and transfer recommendations. As of November 2024, the EEP captive population (excluding free-flying groups) retains 95.6% gene diversity relative to the founder population. PMx projections indicate that, under current demographic conditions, genetic diversity could potentially increase to 98.3% if under-represented lineages are prioritised in future breeding. Modelled long-term retention suggests that >90% genetic diversity can be maintained for approximately 780 years, assuming a stable population size and optimal breeding management. Approximately 80 of the 94 EEP institutions show elevated pedigree-based inbreeding coefficients, partly due to uncertainties in the studbook where many individuals have MULT (multiple possible parents) assignments. These uncertainties can inflate apparent inbreeding and reduce the accuracy of kinship estimates. To mitigate this, the EEP Coordinator is implementing targeted transfers and breeding recommendations, focusing annually on the institutions with the highest inbreeding coefficients and those with limited space or small group sizes.

Genetic assessments of the three free-flying Northern Bald Ibis populations (data as of 2021) show that KLF and Rosegg maintain genetic diversity around 89% with inbreeding coefficients of 10%, supported by relatively complete pedigrees. Both institutions are advised to introduce new individuals from EAZA zoos. The Waldrappteam population shows higher genetic diversity (94.4%) and lower inbreeding (5.3%), though its lower pedigree completeness limits

confidence in these estimates. Plans for coordinated transfers from EAZA institutions are currently under discussion.

Key future tasks for the Northern Bald Ibis EEP include the continued development of annual transfer and breeding recommendations, ideally incorporating exchanges between EU and UK institutions—an aspect that has been limited in recent years. Another priority is the full integration of data from free-flying populations into the studbook. Further objectives include the creation of a Best Practice Guidelines (BPG) document and the development of a dedicated EAZA EEP webpage to enhance communication and transparency. Lastly, ongoing efforts will focus on resolving the remaining data quality and completeness issues within the studbook to ensure accurate and reliable population management.

Conclusion

The Northern Bald Ibis EEP represents a successful and evolving model of ex-situ conservation. With a stable and genetically diverse population, the program has laid a strong foundation for long-term species management. The implementation of the Long-Term Management Plan (LTMP) provides a strategic framework to address current challenges, including inbreeding, and incomplete pedigree data. Continued collaboration among EEP member institutions, improved data quality, and the development of best practice guidelines will be essential to ensure the sustainability of the population. The strong institutional commitment and willingness to support future reintroduction efforts further highlight the potential of the EEP to contribute meaningfully to the conservation of the Northern Bald Ibis.

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