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Back into the wild: establishing a migratory Northern bald ibis *Geronticus eremita* population in Europe

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From the perspective of zoological institutions reintroduction projects offer many possibilities to link conservation and research programmes. An example of the multi-layered and diverse contributions that zoological institutions in general and, specifically, Vienna Zoo, Austria, can make is the reintroduction of the Northern bald ibis *Geronticus eremita* in central Europe. The involvement of zoological institutions ranges from the provision of eggs or birds for release trials, to financial and advocacy support, including with government agencies and non-governmental organizations. Through involvement at a steering level at the coordinative association 'Förderverein Waldrappteam' and as a partner in the EU LIFE+ reintroduction project, Vienna Zoo directly contributes to the shape of the reintroduction project for this Critically Endangered species, and provides much more than technical and infrastructural support. The reintroduction of the Northern bald ibis is broadly in line with the reintroduction guidelines of the International Union for Conservation of Nature. This project provides added benefits not only through its work to prevent the illegal hunting of migratory birds but also the production and dissemination of scientific research.

Key-words: bird migration; conservation; human-led migration; Northern bald ibis; reintroduction; Vienna Zoo.

INTRODUCTION

Reintroduction programmes are generally costly and time-consuming projects that can be spectacular and attract a lot of public attention. From the perspective of a zoological institution such projects offer exciting possibilities for meaningful involvement in long-term conservation activities, not only by using staff expertise but also by contributing public relations and financial support, animals for release, experience in husbandry, animal-health and veterinary expertise, as well as by providing a framework for research.

The need to conserve 'less attractive', economically unimportant and even widely unknown species, which are often far more threatened than the more-popular animals in zoological institutions, has been recently recognized. Such initiatives include the EDGE of Existence programme (for Evolutionary Distinct and Globally Endangered species; ZSL, UK), 'Stiftung Artenschutz' (Münster Zoo, Germany) and several projects emanating from Vienna Zoo, Austria, such as Project Batagur Baska focusing on the rare South East Asian Northern river terrapin *Batagur baska* (Weissenbacher *et al.*, 2015) or the 'Artenschutzprojekt Aphanius' focusing on a group of small fish in the Near East (Zornig & Weissenbacher, 2004). Vienna Zoo has been involved in several conservation projects for extended periods; for example, the reintroduction of the Bearded vulture *Gypaetus*

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barbatus in the Central European Alps, which started in 1978 and is still ongoing (Schaub *et al.*, 2009).

Another long-term project of the Vienna Zoo is the conservation and reintroduction of Northern bald ibis *Geronticus eremita*. This species is generally not regarded as attractive and globally was not a popular bird in zoological institutions. Nonetheless, in 2012 a local newspaper listed the Zoo's involvement in the Northern bald ibis conservation project as one of '10 good reasons to visit Vienna Zoo' ('10 gute Gründe für einen Ausflug nach Schönbrunn', *Wiener Bezirks Blatt*, 16 April 2012). The Austrian project (Waldrappteam), which aimed to establish migratory Northern bald ibis colonies, started in 2002 and proposed that microlight airplanes would be used to lead human-imprinted birds from the breeding sites north of the Alps to the wintering site in Italy. Waldrappteam developed into one of the largest and most well-known European reintroduction projects, co-financed by the European Union (LIFE+). Vienna Zoo, in partnership with other institutions, is still closely involved. This project is an outstanding example of a fruitful collaboration between zoological institutions, zoo associations, scientists and conservationists (Fritz & Unsöld, 2015; Fritz *et al.*, 2016).

This article is published at the midterm of the ongoing LIFE+ Northern bald ibis reintroduction project, which runs until 2019. Therefore, the authors aim to give an overview of the status of the project at the time of writing, including demographic and mortality data, and to review human-led migration, which is the key conservation method developed and implemented during this project.

HISTORIC DISTRIBUTION AND STATUS

The Northern bald ibis is a highly social species that used to nest and breed on cliffs and buildings (Gesner, 1557; Böhm & Pegoraro, 2011; Unsöld & Fritz, 2011) (Plate 1). Larger colonies comprised hundreds or even thousands of individuals (Gesner, 1557; Schenker, 1977; Peter, 1990). Male and female Northern bald ibis both rear chicks, although the pairs are not necessarily monogamous. Up to four greenish eggs are laid per nest (each about the size of a chicken egg) at intervals of 1–3 days. Chicks are fully fledged at 42–50 days, at which point they search for food with the adults and gather with other juveniles in the colony (Böhm & Pegoraro, 2011).

Frequently, breeding colonies have been established close to or even in human

Plate 1. Adult Northern bald ibis *Geronticus eremita* **at Vienna Zoo, Austria.** *Daniel Zupanc*.

settlements; for example, Mönchsberg in the city of Salzburg and Schlossberg in the city of Graz, both in Austria (Schenker, 1977), large colonies in Raqqa and Birecik, Turkey (Kumerloeve, 1978; Peter, 1990), as well as several historic colonies in the Moroccan Atlas region (Pegoraro, 1996; Bowden *et al.*, 2008). This coexistence was certainly not always opportunistic because Northern bald ibis depend on open feeding areas where they can search for food, which mainly consists of worms and larvae, some beetles, locusts or even small vertebrates (Zoufal *et al.*, 2007; Bowden *et al.*, 2008; Serra *et al.*, 2011; Fritz & Unsöld, 2015). Thus, in many areas the birds were dependent on human-cultivated areas as feeding grounds. However, the birds also benefited humans, either as natural pest controllers or as a food resource (Kumerloeve, 1978; Schenker, 1981). The presence of Northern bald ibis in the vicinity of people may be one of the reasons that it became a sacred bird in the Islamic world or in ancient Egypt (Peter, 1990; Janak, 2011).

Northern bald ibis used to be a migratory species with a historic breeding range from the Middle East to Morocco (Kumerloeve, 1978; Bowden *et al.*, 2008; Fritz & Unsöld, 2015). Former wintering sites are known along the African west coast down to Mauretania and Senegal, in Ethiopia and Eritrea, and at the southern end of the Arabian Peninsula (Bowden *et al.*, 2008; Serra *et al.*, 2015). Data on the regulation and patterns of migration for this species are mainly available from a now extinct migratory population observed in the Middle East (Serra *et al.*, 2015) and from our own release population, which comprises descendants from former colonies originating in the Moroccan Atlas (Böhm & Pegoraro, 2011). The birds have a genetic disposition to migrate, which includes premigratory fattening (Bairlein *et al.*, 2015), along with increases in body weight and corticosterone levels (Fritz *et al.*, 2006). In Europe, the birds reach a state of migratory readiness at the beginning of August. There are indications, from different release projects, that juvenile Northern bald ibis during their first autumn migration follow an internal vector that heads them south/south-west (Fritz & Unsöld, 2015; Serra *et al.*, 2015; Yeniyurt *et al.*, 2016). However, as known from studies of White stork *Ciconia ciconia* and other species, juveniles depend on social information from more mature conspecifics to reach common wintering sites for the first time (Chernetsov *et al.*, 2004; Flack *et al.*, 2016).

Under certain ecological conditions Northern bald ibis populations appear to change to a permanent sedentary lifestyle. This may have occurred particularly along coastlines with a year-round temperate climate as is the case for the two remaining Moroccan populations or the release population in Andalusia (Serra *et al.*, 2015; Lopez & Quevedo, 2016). A similar situation has been recorded in other migratory species, such as White stork (Shephard *et al.*, 2015). The remaining Northern bald ibis colonies at the Atlantic coast in Morocco are sedentary and, therefore, none of the individuals in the wild migrate. However, in late summer some juveniles continue to 'disappear', presumably following their natural urge to migrate.

The Northern bald ibis was historically native to Europe (Schenker, 1977; Kumerloeve, 1978; Böhm & Pegoraro, 2011; Unsöld & Fritz, 2011; Fritz & Unsöld, 2015). It is also evident from records that the European Northern bald ibis were migratory but wintering sites were unknown. As far back as 1557, it was suggested that if chicks are removed from a nest, at least one chick should be left to encourage the adults to breed at the same site the following year (Gesner, 1557). Various historic documents indicate that wild Northern bald ibis populations were utilized as food resources, and there were consequent attempts to preserve the species by rules and laws (Gesner, 1557). However, it would appear that the attempts were ineffective and by *c.* 1630 the species was extinct in Europe.

The close relationship with human settlements became ever-more costly for the birds.

It is believed that hunting, disturbance at the breeding sites and use of pesticides in fields have been significant contributors to the consecutive extinction of almost all colonies throughout the whole breeding range (Kumerloeve, 1978; Fritz & Unsöld, 2015). Only two wild populations remain, both of them at the Atlantic coast in Morocco, at Souss-Massa National Park and nearby Tamri. In 2000, the number of birds in these two communicating populations consisted of 238 individuals with 35 breeding pairs (Bowden *et al.*, 2008). In 2014, the total number of birds in Morocco was estimated at 524 individuals, with 115 pairs successfully rearing 192 young that went on to fledge (Hurrell, 2015; SEO/BirdLife Morocco Programme, 2015). This is a significant increase in the population size thanks to international conservation efforts. However, to date, the sedentary colonies in Morocco show no obvious tendency to recolonize former or new areas (Bowden *et al.*, 2008). Therefore, the African–Eurasian Migratory Waterbirds (AEWA) Single Species Action Plan (SSAP) for the species states that the establishment of further colonies in Morocco and in other parts of the former distribution range is a priority in order to make it possible to downgrade the species from its Critically Endangered Red List status (Bowden, 2015; IUCN, 2016).

INTERNATIONAL CONSERVATION EFFORTS

In 1982, a first trial release programme started in Tel Aviv, Israel, with the help of a grant from the Frankfurt Zoological Society, Germany. Twenty-two birds of different ages were released without any specific training. Some remained at the release site for a time but eventually all the birds disappeared (Mendelssohn, 1994). Some Northern bald ibis sightings in the Middle East during the following years may have been evidence of birds from this early release project (Serra *et al.*, 2015).

Several release trials followed, including those for juvenile birds (Birecik and Tel Aviv), juvenile and adult birds (Tel Aviv and Birecik), adult birds only (Tel Aviv) and larger groups of birds of different ages (Birecik and Tel Aviv). In total, more than 200 birds were released, most of which disappeared soon after release and none of the projects managed to establish a self-sustaining colony (Thaler *et al.*, 1992).

Since the early 2000s, the Northern bald ibis has had wide recognition, both in terms of international species conservation and with the public. This is particularly related to the quite unexpected discovery in 2002 of a relict population in Syria. The population comprised only seven individuals, which were still migrating along a historic migration route between Syria and Ethiopia (Serra *et al.*, 2015). Significant international efforts followed to preserve this relict population (Serra *et al.*, 2004, 2011).

In 2010, a major aim was to take young birds from the Turkish breeding colony and release them at the Syrian breeding grounds near Palmyra. At that time the wild population in Syria had shrunk to three adults. On 1 July, after the departure of two adults, three juveniles were released. On 3 July the juveniles were observed following the remaining wild adult southwards to Saudi Arabia until they reached the border with Yemen. There the juveniles became separated from the adult bird, which migrated the rest of the route alone. The young birds remained in the region and disappeared some time after separation (Fritz & Riedler, 2010; Bowden *et al.*, 2011). A continuation of this release project would have been reasonable but did not take place, mainly because of the worsening political situation in the Middle East. Since 2013 there have been no position data or sight reports of the Syrian relict breeding population. Occasionally, there were anecdotal sight reports in Ethiopia, the last one at the end of 2015. Nonetheless, the final wild Northern bald ibis population with a migration tradition has to be considered extinct.

At the other end of the historic breeding range, in the Moroccan Atlas Mountains, European zoos under the lead of Munich

Zoo, Germany, initiated a conservation project in 1999 to re-establish Northern bald ibis in historical breeding grounds. In 2000, breeding facilities were built (Bechar el Kheir station in Morocco) and a founder breeding group with individuals from various European zoos was established (Müller, 2004). Despite international attempts to start up a feasibility study for reintroductions (Fritz & Pfistermüller, 2007), the project had to be terminated in 2012, mainly because of legislative and administrative problems.

Development of European release programmes

In the 1930s, Northern bald ibis started to be kept in European zoos. Once the diet offered to the birds was improved they started to breed successfully (Mendelssohn, 1994). Subsequently, several European zoos [Basel Zoo, Switzerland; Alpenzoo Innsbruck, Austria; Nuremberg Zoo, Germany; Jersey Wildlife Preservation Trust (now Durrell Wildlife Conservation Trust), Channel Islands] invested in research to improve management and reproduction success of the captive breeding colonies (Thaler *et al.*, 1981; Michelmore & Oliver, 1982; Wittmann & Ruppert, 1984; Pegoraro & Thaler, 1985).

In 1991, Ellen Thaler at Alpenzoo Innsbruck initiated a pilot study with hand-reared chicks, significantly supported by the former director of Alpenzoo Innsbruck and Vienna Zoo, Helmut Pechlaner (Thaler *et al.*, 1992). The main aim of the pilot study was to develop a suitable method for releasing the birds. Chicks were deliberately imprinted on two human foster parents. Regularly after fledging, the human foster parents accompanied the imprinted birds when they left the aviary. Using human imprinting it was possible to simulate family structure, which enabled the young birds to become familiar with their habitat and learn how to forage, while they were protected by the human foster parents. Only two people acted as foster parents so the young birds did not become familiar with all humans, they ignored other people and learned to avoid dangerous situations (e.g. cars, roads, dogs). The guidance of the human foster parents augmented the ability of the birds to orientate, and their feeding behaviour, choice of food and use of habitat were identical to what is known about wild-living Northern bald ibis of the same age. The experiences and lessons learned during the pilot study were the basis for other release projects.

In the late 1990s, Kurt Kotrschal, Director at the Konrad-Lorenz Research Station in Upper Austria, initiated the establishment of the first free-flying, sedentary Northern bald ibis zoo colony, on the basis of the release method developed by Thaler and colleagues. After some initial drawbacks, the colony prospered and reached a population size of *c.* 50 individuals, which were free flying and without supplemental feeding over spring and summer, although they were fully provisioned during autumn and winter (Kotrschal, 2004).

In 2004, a second free-flying, sedentary Northern bald ibis zoo colony was founded at Rosegg Animal Park in Carinthia, Austria, using the same protocols (Fritz & Unsöld, 2015). In the same year, a project was also launched in Andalusia, Spain, to establish a self-sustaining sedentary colony, under close involvement of Zoo Jerez (Lopez & Quevedo, 2016). At the time of writing, the Andalusian colony consists of *c.* 100 free-living individuals that breed in the wild (Plate 2).

In 2001, the decision was made to combine the established method of hand rearing and imprinting Northern bald ibis chicks on human foster parents with human-led migration. The founder individuals (F0), which were collected from zoo breeding colonies and reared by human foster parents, were to be provided with information about an appropriate migration route that links the breeding site with the wintering site. Around the same time, Operation Migration commenced in America with the aim of supplementing a wild population of

Plate 2. Breeding cliff for the sedentary release population of Northern bald ibis *Geronticus eremita* **in Projecto Eremita, in Andalusia, Spain.** *Johannes Fritz, Waldrappteam.*

Whooping cranes *Grus americana* with hand-reared birds (Mueller *et al.*, 2013) and a project in Germany aimed to teach hand-reared Lesser white-fronted geese *Anser erythropus* a new migration route from Scandinavia to Germany (www.zwerggans.de). All three projects were inspired by the work of Bill Lishman, who in 1993 used an ultralight aircraft to lead 18 human-raised Canada geese *Branta canadensis* from Purple Hill, Ontario, Canada, to Airlie, Virginia, USA (Ellis *et al.*, 2003), and Christian Moullec, who used this method for the first time in Europe with different species of geese (Moullec, 2001).

A 12 year feasibility study was carried out (2002–2013) to gain experience and develop appropriate methods for releasing Northern bald ibis (Zoufal *et al.*, 2007; Fritz & Unsöld, 2015; Fritz *et al.*, 2016). In 2002, a supporting association – Förderverein Waldrappteam – was founded by a number of Austrian organizations, including Vienna Zoo, Alpenzoo Innsbruck and the Konrad-Lorenz Research Station. During the feasibility study, in total nine human-led migrations were carried out. The first two, in 2002 and 2003, did not reach the wintering site in the Tuscany. These 21 birds were transferred to Rosegg Animal Park in Carinthia to establish the sedentary zoo colony (Fritz & Unsöld, 2015). In the following migrations (2004–2011), 95 hand-reared juveniles were led to the WWF Oasi Laguna di Orbetello wintering site in southern Tuscany and 64 were released (Table 1). The lagoon is a wintering site for various bird species and during the feasibility study it was established that it would also be suitable for the Northern bald ibis. There is no evidence for the specific wintering site of the former migrating European population of the Northern bald ibis (Fritz & Unsöld, 2015).

In 2014, the feasibility study turned into a European reintroduction project, co-financed by the European Union in the context of the LIFE+ programme. Eight partners from Austria, Germany and Italy are working to build up a release population of migratory Northern bald ibis colonies in central Europe, including Vienna Zoo, Alpenzoo Innsbruck, Rosegg Animal Park and Parco Natura Viva (Italy) among others. The lead partner is Förderverein Waldrappteam, which commissioned Johannes Fritz and the Waldrappteam to manage the project and perform migration flights. The implementation is based on the International Union for Conservation of Nature (IUCN) *Guidelines for Reintroductions and*

YEAR	START DATE	START DESTINATION	FLIGHT DISTANCE TOTAL (km)	DURATION (days)	FLIGHTS	PROPORTION FLIGHT: STOPOVER	DAILY FLIGHT DISTANCE MEAN/MAX (km)	NUMBER OF BIRDS START/ RELEASE
2004	17 Aug	Scharnstein (AUT)	914	37	14	1:2.6	61/95	10/7
2005	18 Aug	Scharnstein (AUT)	864	22	10	1:2.2	86/135	12/7
2007	13 Aug	Burghausen (GER)	755	38	12	1:3.2	63/132	17/0
2008	17 Aug	Burghausen (GER)	1205	37	13	1:2.8	93/158	13/10
2009	14 Aug	Burghausen (GER)	1120	40	22	1:1.8	56/150	11/11
2010	18 Aug	Burghausen (GER)	1295	26	7	1:3.7	185/271	16/14
2011	20 Aug	Salzburg (AUT)	1353	36	6	1:6.0	226/360	16/15
2014	25 Aug	Salzburg (AUT)	944	11	4	1:2.7	236/301	14/14
2015	22 Aug	Salzburg (AUT)	794	18	5	1:3.6	159/192	31/28
2016	19 Aug	Salzburg (AUT)	846	27	6	1:5.0	169/297	25/24

Table 1. Statistics for the human-led migration flights with Northern bald ibis *Geronticus eremita* during the feasibility study (2002–2013) and during the first 3 years of the LIFE+ project period (2014–2016). In 2002 and 2003, the initial human-led migrations did not reach the wintering site; in 2006, 2012 and 2013 no human-led migration flights occurred; proportion flight:stopover, the mean number of stopover days per flight stage; AUT, Austria; GER, Germany.

Other Conservation Translocations (IUCN/SSC, 2013). A steering committee, which is advised by international experts, supervises and monitors the implementation.

The aim of the LIFE+ project during its 6 year duration (2014–2019) is to establish three migratory breeding colonies with a total of at least 120 birds. At the time of writing, the establishment of two breeding sites is ongoing, one in the city of Burghausen in Bavaria, Germany, near the border to Austria, and the other near the village of Kuchl in Salzburg, Austria. From 2017, a third colony will be established near the city of Überlingen in Baden-Württemberg, Germany. All three breeding sites are linked with a common wintering site in southern Tuscany, via a main migration corridor leading across the Alps (Fig. 1).

HAND REARING AND HUMAN-LED MIGRATION

Up to 32 nestlings are hand reared annually by two human foster parents and imprinted on them. Hand rearing follows a detailed protocol, which is mainly an accumulation of empirical experiences gained by zoological experts. During the feasibility study, the protocol was continuously updated on the basis of actual experiences. Until release, contact with the birds is limited to the foster parents to ensure optimal imprinting and to avoid human-adapted birds. In the first weeks after hatching, hand rearing mainly takes place at a zoo, principally Vienna Zoo, because of the logistical and technical advantages, as well as for public-relations reasons. Shortly before fledging in May, the birds are transferred for flight training to a campsite, where they are housed in an indoor space 4 m long × 3 m wide with an adjacent flight aviary 9 m × 6 m × 3 m high. Since 2015, the size of the flight aviary has been enlarged to 12 m × 9 m × 3 m high because of the increased number of birds being trained (Table 1).

Flight training begins immediately after fledging. The first stage is to habituate the Northern bald ibis to the microlight, especially the sound of the engine and the huge parachute (Plate 3). Thereafter, the major challenge for the birds is to associate the microlight with the foster parent, who sits on the back seat. To facilitate this learning process, only the foster parents wear yellow shirts. About 1 month after fledging, the first flights from the campsite to nearby meadows take place. During training, the distance of the flights is gradually increased to more than 70 km.

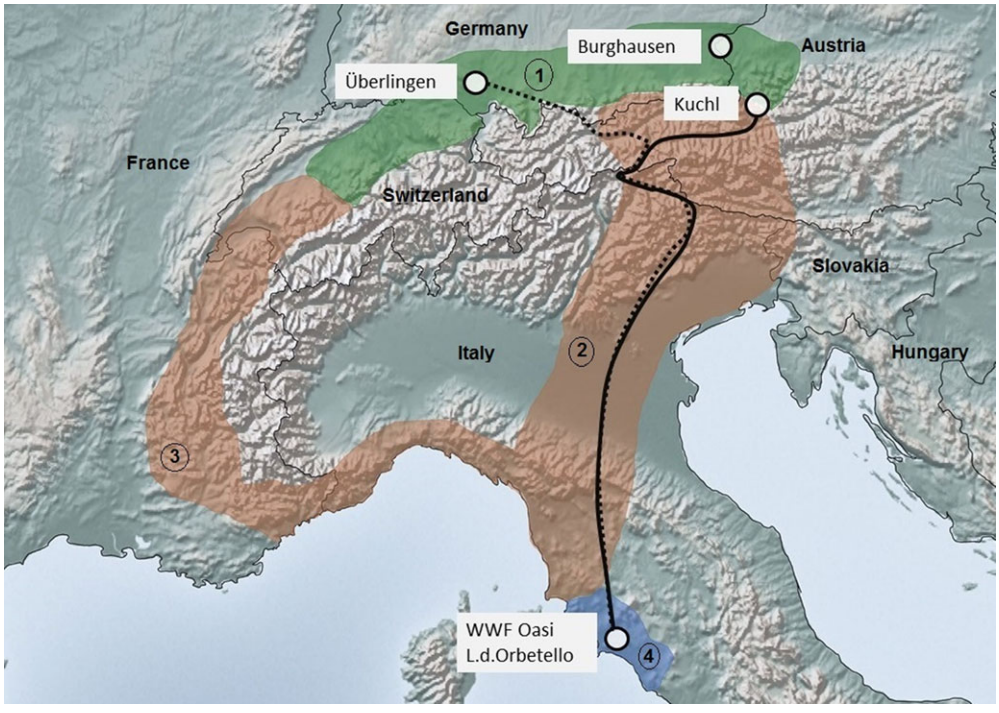

Fig. 1. Activity range of wild-living Northern bald ibis *Geronticus eremita*: 1, breeding range (green); 2, main migration corridor (orange); 3, western migration corridor (orange); 4, wintering range (blue). Human-led migrations follow the main migration corridor (2): solid line, 2016; dotted line, 2017.

By mid-August the training is completed. At that time, the birds are known to turn into a state of migratory readiness (Zugunruhe) where they reach their maximum pre-migration body weight, which is 1467 g (±75 g) for males and 1300 g (±50 g) for females (mean ± SD; n = 25; data 2016). Human-led migrations are started around mid-August (Table 1), which is the time when the free-living birds naturally depart from the two breeding sites at Burghausen and Kuchl.

The key challenges during the early years of the feasibility study were the technical limitations of the microlights and the pilot skills required to match the flight style of the birds. During active wing-flapping flight, Northern bald ibis have a low flight speed of 40–45 km hour^{-1}. Conventional microlight planes turned out to be too fast for the birds. In 2007, after trials with various delta-wing microlight planes, this problem was solved by using a new type of double-seated microlight (a paraplane), with a parachute instead of a delta-wing (Plate 3). A 58 m² wing, instead of the standard 28 m² wing, allows for a flight speed of 35–45 km hour^{-1}, which perfectly matches the speed of the ibis. A grid basket shields the paramotor and protects the birds from injuries, and additional tanks of fuel allow non-stop flights of up to 6 hours duration.

Empirical experiences during the migration flights as well as basic research on bird flight and migration (see below) allowed the two microlight pilots – project leader J. Fritz and professional pilot Walter Holzmüller – to adapt their microlight flight style to the two major flight techniques used by the Northern bald ibis during migration. In calm air conditions or horizontal air movements the ibis fly in a V-formation, while during thermal periods of

Plate 3. Human-led migration flight for Northern bald ibis *Geronticus eremita* **across the Alps; the birds form a characteristic V-formation.** *Pablo Przesang, 2015.*

the day they usually switch to a soaring and gliding technique (Fritz *et al.*, 2016). The variation of the flight technique coincides with energy-use optimization. The metabolic rate of birds flying by flapping their wings is estimated to be eight to 30 times higher than the basal metabolic rate (Newton, 2010). In a V-formation the birds profit from aerodynamic advantages that lower the metabolic rate to an estimated four to eight times the basal metabolic rate (Portugal *et al.*, 2014; Voelkl *et al.*, 2015). The most efficient flight technique in terms of energy consumption is soaring and gliding, estimated at only one-and-a-half to two times the basal metabolic rate (Sapir *et al.*, 2010; Voelkl & Fritz, in press).

In the course of the initial migration journeys, flights during thermal periods of the day were avoided because the microlights were not suitable and the pilots were not used to flying under such conditions. Furthermore, the microlights were faster than the birds, which caused the ibis to follow at maximum speed instead of flying in an energy-saving formation. Technical optimization of the microlights, as described above, and improvement of the flight techniques used by pilots allowed the birds to use both V-formation, and soaring and gliding flight. This, in turn, caused a substantial improvement of the human-led migration process. In 2015, the method was further improved by the fusion of two groups of hand-reared birds before the start of migration flights, resulting in up to 31 birds being led south during one human-led migration (Table 2). On arrival at the wintering site, the birds remain in an aviary for *c*. 10 days. The foster parents gradually reduce their presence and finally leave, and local staff take over the care and monitoring of the Northern bald ibis. After this habitation period, the aviary is opened, and the birds from the human-led migration are released to integrate into the flock of conspecifics at the wintering site and become independent. Each bird only needs to follow the microlight to southern Tuscany once during the autumn of their first year of life. This is sufficient for the Northern bald ibis to be able to find their way back to the breeding sites in Austria and Germany each spring, and continue their migration cycles as adults.

DEMOGRAPHY, BREEDING AND MORTALITY STATISTICS

At the end of 2016, the migratory release population comprises 70 birds, made up of 21 adults (generations 2008–2014), 21 subadults (generation 2015) and 28 juveniles

	DISTANCE PER FLIGHT STAGE (MEAN/MAX) (km)	FLIGHT STAGES PER MIGRATION (MEAN)	NUMBER OF BIRDS PER MIGRATION (MEAN)
Initial	70/135	12	13
LIFE+	188/301	5	23

Table 2. Improvements can be seen in the efficacy of the human-led migration techniques for Northern bald ibis *Geronticus eremita* by comparing the initial flights (2004, 2005, 2007) and the more recent LIFE+ project flights (2014–2016).

(generation 2016). The sex ratio is 36.34 [♂♂·♀♀ (52%.48%)]. About half of the birds are from the breeding site at Burghausen and the other half from Kuchl. Fifty-one (73%) of the birds belong to the release population (F0), hand reared in zoos, while 19 (27%) of the birds have been parent reared in the wild (F1+).

Since 2011, Northern bald ibis regularly migrate between their breeding sites at Burghausen or Kuchl and the common wintering site in southern Tuscany (Table 3). Full migrants perform a complete annual migration cycle between the wintering site and one or other breeding site. Semi-migrants, in contrast, mainly juvenile and subadult birds, leave from the wintering site without reaching the breeding site. These birds usually stay somewhere along the migration flyway and return to the wintering site in autumn. In 2015, there was a substantial slump in the number of full migrants caused by an unexpected loss of adults (e.g. bad weather, power-pole collisions, illegal hunting) in 2014.

Since 2011 Northern bald ibis regularly breed at Burghausen and since 2013 they also breed at Kuchl. Between 2011 and 2016, 60 chicks fledged in 34 nests (a mean 1·8 chicks per nest) (Table 3). Each year, some adult birds are temporarily supplemented at the breeding sites to improve the breeding rate. These supplemented birds are removed at the end of July before the start of the autumn migration. All fledged juveniles remain in the wild and regularly follow their migratory conspecifics to the wintering site.

During the later stage of the feasibility study (2008–2013), 53 birds were released (Table 4). After release, 43 (81%) survived their first year in the wild (until mid-September the year after release), 18 (34%) survived to sexual maturity and ten (19%) have reproduced so far. From 45 birds, released in 2014 and 2015, 31 (69%) survived their first year in the wild. From the 27 birds released in 2016, 24 (89%) survived until the end of 2016. Most of the birds were released in Tuscany in mid-

YEAR	SEMI-MIGRANTS	FULL MIGRANTS	BREEDING PAIRS (M/S)	FLEDGLINGS TOTAL	FLEDGLINGS PER NEST (MEAN)
2011	12	4	1 (0/2)	3	3·0
2012	16	11	5 (4/6)	8	1·6
2013	6	11	8 (6/10)	6	0·8
2014	8	12	8 (7/9)	13	1·6
2015	11	6	6 (2/10)	17	2·8
2016	27	14	6 (5/7)	13	2·2

Table 3. Migration and breeding of the migratory population of Northern bald ibis *Geronticus eremita*; semi-migrants are juvenile and subadult birds that leave from the wintering site but do not reach a breeding site; M, breeding birds of the migratory release population; S, adult birds that are temporarily supplemented at the breeding sites to increase breeding success.

	RELEASED	SURVIVING FIRST YEAR	SURVIVE TO SEXUAL MATURITY	NUMBER OF BREEDERS
Feasibility study (2008–2013)	53	43 (81%)	18 (34%)	10 (19%)
LIFE+ project (2014–2015)	45	31 (69%)		
LIFE+ project (2016)	27	24 (89%)		

Table 4. Survival rate of the released Northern bald ibis *Geronticus eremita* (generation F0); birds reach sexual maturity 3 years after fledging.

September at the end of a human-led migration flight.

During the feasibility study (2002–2013), 43 (71%) of the 'lost' birds disappeared in Italy during the autumn migration period, most probably as a result of illegal hunting, 9 (15%) of the 'lost' birds died as a result of accidents and/or injury, and 4 (7%) were lost to electrocution (Fritz & Unsöld, 2015). The causes of mortality during the first 3 years of the LIFE+ project are shown in Fig. 2. Illegal hunting is still the major cause of mortality. Nonetheless, in 2014–2016 the number of birds that evidently died as a result of hunting or disappeared in Italy during the hunting season was only 19 (23% of all 'lost' birds), substantially lower than the losses during the feasibility study. Thus, a reduction in the number of losses from illegal hunting became apparent and has been attributed to the campaign against illegal bird hunting in Italy, which has been implemented since 2014.

Aside from illegal hunting, electrocution on power lines and injury to the exposed beak are among the greatest causes of mortality. Since the start of the LIFE+ project, continuous veterinary monitoring and an annual veterinary screening of the whole population are carried out to ensure the

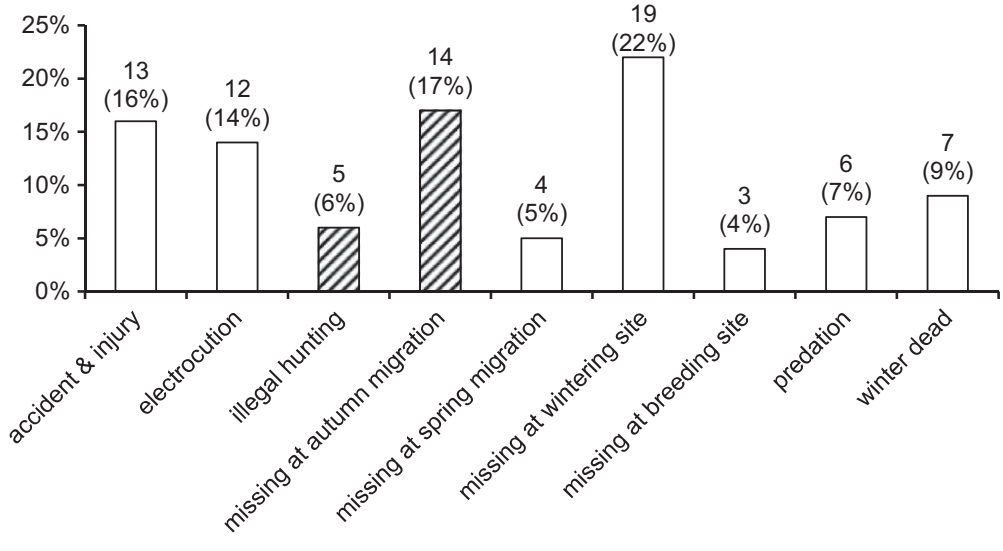

Fig. 2. Causes of mortality for Northern bald ibis *Geronticus eremita* during the LIFE+ project 2014–2016. In total 84 birds were lost during that period. The Northern bald ibis that went missing during the autumn migration are assumed to be lost as a result of illegal hunting activities. 'Winter dead' refers to birds that were lost when the autumn migration was severely delayed and there was a sudden onset of inclement weather. Number of birds and percentage of those lost (n = 84 birds total) are given as data labels.

overall good health of the ibis. In 2017, the aim is to start implementing actions against electrocution. As a first step, and with the support of the government of the state of Salzburg, the power cables in the area of the breeding site at Kuchl will be covered to provide some protection for the birds (Haas *et al.*, 2003; López-López *et al.*, 2011). In future, covering power cables to protect birds from electrocution will be implemented in other areas in Austria where the birds are active. These actions will be of value for all large-sized birds because it is only larger birds that are in danger of creating short circuits on power cables.

ILLEGAL BIRD HUNTING AND BIRD MORTALITY

Globally, the Northern bald ibis is strictly protected. Nonetheless, hunting in Italy is among the greatest threat for the reintroduced European population (Fig. 2). The threat of illegal hunting was the main reason the whole Northern bald ibis population is fitted with GPS tags. The position of every bird is detected at least once a day. In October 2012, a member of Waldrappteam arrived at a place where a hunter shot two Northern bald ibis, just 30 minutes after the incident. This was the first time that a poacher could be identified and a specific complaint made. In September 2016, this hunter, who was a member of the biggest Italian hunting association, was convicted of killing an endangered and protected bird. He lost his hunting licence and was issued with a fine of Euros 2000. A civil action for damages will now follow. Such precedents and the accompanying media attention are part of an extensive campaign against illegal bird hunting carried out in the course of the LIFE+ reintroduction project.

Since 2014, the 'Animal Tracker' App has been available as freeware for Android and Apple devices. The actual position of each bird is published in real time in the app, complete with life-history information. This presentation of individual Northern bald ibis with names and specific personality traits has broad public support and gains much attention (Pschera, 2014). This app is a relevant part of the public-relations campaign against illegal bird hunting, together with broad support among zoological institutions and non-governmental organizations. Through media work, broad public-information campaigns, presentation of the project at hunting exhibitions as well as the use of modern technology to follow and protect the birds in the field, a sustainable reduction of losses caused by illegal hunting should be achieved.

Most Italian hunting associations are involved in the campaign. Furthermore, probably as a result of widespread public and media awareness, these associations are showing an increasing willingness to act against the poachers among their members. It is evident that the campaign against illegal bird hunting is of importance for bird-conservation projects.

GENETICS AND BASIC SCIENCE

The EU-funded LIFE+ project has provided the funding that makes it possible to implement a long-overdue genetic-screening programme, in close collaboration with the European Northern bald ibis studbook keeper at Alpenzoo Innsbruck and the Trier University, Germany. A total of 651 individuals, including 92 Northern bald ibis from the LIFE+ reintroduction projects and the Spanish project, were genotyped at 15 microsatellite loci to identify the genetic variability of the colonies bred in European zoos, the sedentary colonies and the release colonies (Wirtz *et al.*, 2016). The results show that the captive population is well structured. The stock for reintroduction comprises only a fraction of the genetic diversity available in the European zoo colony (S. Wirtz and colleagues, unpubl. data). Based on this outcome, from 2017 onwards the gene pool of the release population will be optimized, mainly by the supplementation of juveniles with a complementary gene profile to the release population.

A particular interrelated attribute of the project is the successful combination of applied species protection and basic research. Portugal *et al.* (2014) published a paper in the journal *Nature*, where a set of data collected during a human-led migration flight was presented, which provided the first empirical evidence that birds flying in a V-formation are able to save energy. In February 2015, a follow-up paper was published (Voelkl *et al.*, 2015), based on the same dataset, describing formation flight as one of the rare examples of genuine cooperation in the animal kingdom.

Another published paper focuses on the energy expenditure and metabolic changes of juvenile Northern bald ibis during their first human-guided autumn migration (Bairlein *et al.*, 2015). Blood samples were taken from the birds immediately prior to and after each flight, and energy expenditure during the flight was estimated using doubly labelled water. The data show that instantaneous energy expenditure decreased with flight duration, and the birds appeared to balance aerobic and anaerobic metabolism by using fat, carbohydrate and protein as fuel. This made flight both economic and tolerable. There were also in-flight benefits that enable power output variation from cruising to manoeuvring.

Further scientific studies in the course of the LIFE+ project are in preparation. In particular, one study aims to measure the individual energy expenditure during the migration flight, using heart rate as a proxy. Various flight techniques, including individual flight, V-formation flight, soaring and gliding, will all be compared.

PUBLIC RELATIONS AND RAISING AWARENESS

The LIFE+ project has a continuous high level of public awareness and media interest. In 2014 and 2015, there were 391 project-related articles published in newspapers and magazines, 21 television productions broadcast information about the project and 12 scientific papers were published.

Eleven public events took place, mainly in zoos, with 49 presentation days in total. One of the major annual events is the public presentation of the hand rearing of Northern bald ibis chicks. Since 2014, the hand-rearing process takes place at Vienna Zoo in a specially adapted enclosure in the visitor area, with an adjacent information centre. The special enclosure is placed close to the Northern bald ibis aviary and complemented by a Northern bald ibis themed playground for children (Plate 4). Visitors can watch the foster parents while they work with the birds. In this way, the relationship between the Zoo breeding programme and the dependent reintroduction project becomes evident to visitors. The presentation is available for around 1 month every year, and more than 200 000 people annually visited Vienna Zoo during these event days. The visitors who attend these public presentations put great value on both the conservation project and the Zoo.

CONCLUSION

The major aim of the LIFE+ project, which will run for 6 years until the end of 2019, is to establish three migratory breeding colonies of Northern bald ibis north of the Alps, which have a tradition of migration to a common wintering area in southern Tuscany and with a total of at least 120 individuals. If the project continues in the way it has been growing to date, this overall aim will be reached. It is not the aim of the ongoing LIFE+ project to establish a self-sustaining population, which is simply not possible over a 6 year period. Effective methods for the release of Northern bald ibis and post-release monitoring, and actions taken to reduce the loss of birds have to be continued and protocols to facilitate these activities have been prepared. We aim to establish the definitive viable size of a migratory population, based on the demographic and genetic data collected over the course of the project.

One of the major drawbacks during the first half of the LIFE+ project was the loss

Plate 4. Northern bald ibis *Geronticus eremita* **themed playground for children at Vienna Zoo, Austria. The playground is near the Northern bald ibis information booth and an area where for a month per year visitors can watch keepers hand rear ibis chicks for the reintroduction programme.** *Daniel Zupanc*.

of birds, particularly experienced adults, in unforeseen events. For example, seven birds were lost during severe weather conditions on a delayed autumn migration in 2014, a total of nine birds were lost during three accidents involving power poles in Bavaria and Austria, and a high number of losses were caused by illegal hunting in Italy in 2016, probably the result of a period of restructuring of the Italian police force and a temporary lack of executive control. Consequently, a larger number of founder individuals must be released to ensure the overall aims of the project are achieved.

Actions against the two major causes of mortality – illegal hunting and electrocution – are ongoing. The campaign against illegal bird hunting in Italy has an increasing number of levels. Five incidents in 2016 received widespread public and media attention, which resulted in the reopening of one case that had been closed by prosecutors without proper investigation. Probably the most remarkable development is the active engagement of the major Italian hunting organizations. For example, the hunting associations have been known to write letters to the prosecutors requesting intensive investigations in cases of poaching and they are in the process of establishing a task force of hunters to stop illegal activities in regions where Northern bald ibis pass by or make stopovers. This engagement is unique and precedential.

In order to address the problem of electrocution on power lines, starting in 2017/2018, power cables in the area of the breeding site at Kuchl will be covered to reduce the possibility of the birds causing short circuits and being injured or killed (Haas *et al.*, 2003). The long-term aim will be to provide a bird-protection system on all power poles in areas of major activity for the migratory Northern bald ibis population. However, this goes beyond the scope of the LIFE+ project.

It is an aim of the LIFE+ project to develop and optimize methodologies for release, conservation and research. This is also regarded as a major contribution to the *International Single Species Action Plan for the Conservation of the Northern Bald Ibis* (Bowden, 2015). In 2003, it was suggested that human-led migration was a concept that would be applied to restore the migrations of birds of many taxa, migratory ungulates and perhaps even arthropods (Ellis *et al.*, 2003). However, 14 years later we are less enthusiastic about this possibility. The US-based Operation Migration project for Whooping cranes was terminated in

2015, mainly because there were indications that the released birds had low reproduction success (C. Bowden, pers. comm.). The Lesser white-fronted geese project in Germany, based on the human-led migration technique, was not even able to begin as it was not approved by the necessary authorities. At the time of writing, only the Northern bald ibis project uses human-led migrations systematically for conservation purposes. There is huge potential for application of these techniques, both in bird conservation and basic research, but the methods need strict protocols and high levels of qualifications. However, the aim of the work reported here is to optimize the methods for future requirements.

Modern and scientifically led zoos are institutions that are used to working innovatively and practically in many areas, including animal husbandry, population management and conservation. In order to survive and flourish, zoos must constantly develop and evolve (Barongi *et al.*, 2015). As single institutions zoos can provide support for conservation projects with infrastructure, experience, technical expertise and logistics, and stimulate and initiate new approaches. Together with other conservation organizations, acting as a conservation network, zoos can also influence and shape public opinions (Barongi *et al.*, 2015). These are essential prerequisites for the survival of many species.

Zoos and aquariums cannot save all species from extinction but they can facilitate many aspects of species conservation; for example, preserving the genetic information of migratory behaviour, as demonstrated by the Northern bald ibis project. However, in isolation such work would be useless in the long term because migration traditions cannot be preserved at a zoo. Therefore, like-minded organizations need to collaborate on innovative reintroduction projects, as shown by Waldrappteam. In this article we aimed to demonstrate that close collaboration between zoo people and conservationists can give us all 'Reason for Hope', even for highly endangered species such as the Northern bald ibis. Nonetheless, wild populations of endangered species and their habitats must be monitored vigilantly because it is most reasonable and effective to assist these species before they disappear from the wild.

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REFERENCES

Bairlein, F., Fritz, J., Scope, A., Schwendenwein, I., Stanclova, G., van Dijk, G., Meijer, H. A. J., Verhulst, S. & Dittami, J. (2015): Energy expenditure and metabolic changes of free-flying migrating northern bald ibis. *PLoS ONE* **10**(9): e0134433.

Barongi, R., Fisken, F. A., Parker, M. & Gusset, M. (Eds) (2015): *Committing to conservation: the world zoo and aquarium conservation strategy*. Gland, Switzerland: WAZA Executive Office.

Böhm, C. & Pegoraro, K. (2011): *Der Waldrapp. Ein Glatzkopf in Turbulenzen*. Magdeburg: Westarp Verlag, Neue Brehm-Bücherei.

Bowden, C. G. (Compiler) (2015): *International single species action plan for the conservation of the northern bald ibis (*Geronticus eremita*). AEWA Technical Series* No. 55. Bonn: Agreement on the Conservation of African-Eurasian Migratory Waterbirds (AEWA).

Bowden, C. G., Smith, K. W., el Bekkay, M., Oubrou, W., Aghnaj, A. & Jimenez-Armesto, M. (2008): Contribution of research to conservation action for the northern bald ibis *Geronticus eremita* in Morocco. *Bird Conservation International* **18**: 74–90.

Bowden, C. G. R., Hamoud, A., Jbour, S., Fritz, J., Peske, L., Riedler, B., Lindsell, J. A., Al Shaiesh, M., Abdallah, A., Boehm, C., Hatipoglu, T., Tavares, J. P., Al Salamah, M., Shobrak, M. & Serra, G. (2011): Attempted supplementation of the relict wild eastern population of northern bald ibis in Syria with Turkish semi-wild juveniles. In *Global re-introduction perspectives: 2011. More case studies from around the globe*: 130–134. Soorae, P. S. (Ed.). Gland, Switzerland: IUCN/SSC Re-introduction Specialist Group, and Abu Dhabi: Environment Agency-Abu Dhabi.

Chernetsov, N., Berthold, B. & Querner, U. (2004): Migratory orientation of first-year white storks (*Ciconia ciconia*): inherited information and social interaction. *Journal of Experimental Biology* **207**: 937–943.

Ellis, D. H., Sladen, W. J. L., Lishman, W. A., Clegg, K. R., Duff, J. W., Gee, G. F. & Lewis, J. C.

(2003): Motorized migrations: the future or mere fantasy? *BioScience* **53**: 260–264.

FLACK, A., FIEDLER, W., BLAS, J., POKROVSKY, I., KAATZ, M., MITROPOLSKY, M., AGHABABYAN, K., FAKRIADIS, I., MAKRIGIANNI, E., JERZAK, L., AZAFZAF, H., FELTRUP-AZAFZAF, C., ROTICS, S., MOKOTJOMELA, T. M., NATHAN, R. & WIKELSKI, M. (2016): Costs of migratory decisions: a comparison across eight white stork populations. *Science Advances* **2**(1): E1500931.

FRITZ, J. & PFISTERMÜLLER, R. (2007): Travel report November 2006 Station Bechar el Kheir, Morocco. In *Northern bald ibis conservation and reintroduction workshop. Proceedings of the 2nd International Advisory Group for the Northern Bald Ibis (IAGNBI) meeting, Vejer, Spain, September 2006*: 100–104. Böhm, C., Bowden, C. G. R., Jordan, M. J. R. & King, C. (Eds). Sandy, Beds: Royal Society for the Protections of Birds. Available at http://www.gianlucaserra.com/2006%20IAGNBI%20Meeting%20Vejer%20Rept%20final.pdf

FRITZ, J. & RIEDLER, B. (2010): Neue Hoffnung für das Überleben einer hoch bedrohten Zugvogelart im Mittleren Osten: Freisetzung von Jungvögeln bei den letzten migrierenden Waldrappen in Syrien. *Vogelwarte* **48**: 417–418.

FRITZ, J. & UNSÖLD, M. (2015): Internationaler Artenschutz im Kontext der IUCN Reintroduction Guidelines: argumente zur Wiederansiedlung des Waldrapps *Geronticus eremita* in Europa. *Vogelwarte* **53**: 157–168.

FRITZ, J., FEURLE, A. & KOTRSCHAL, K. (2006): Corticosterone pattern in northern bald ibises during a human-led migration. *Journal of Ornithology* **147** (Suppl. 1): 168.

FRITZ, J., HOFFMANN, W. & UNSÖLD, M. (2016): Back into European ecosystems: the LIFE+ northern bald ibis reintroduction project in central Europe. In *Proceedings of 4th International Advisory Group for the Northern Bald Ibis (IAGNBI) meeting Seekirchen, Austria, August 2016*: 47–56. Böhm, C. & Bowden, C. G. R. (Eds). Sandy, Beds: Royal Society for the Protections of Birds.

GESNER, C. (1557): *Vogelbuch*. Zürich: Christoffel Froschouer.

HAAS, D., NIPKOW, M., FIEDLER, G., SCHNEIDER, R., HAAS, W. & SCHÜRENBERG, B. (2003): *Protecting birds from powerlines: a practical guide on the risks to birds from electricity transmission facilities and how to minimise any such adverse effects. Report T-PVS/Inf (2003) 15, written by BirdLife International on behalf of the Bern Convention*. Strasbourg: Council of Europe (15 September 2003). Available at https://wcd.coe.int/com.instranet.InstraServlet?command=com.instranet.CmdBlobGet&InstranetImage=1300705&SecMode=1&DocId=1441752&Usage=2

HURRELL, S. (2015): *Record breeding success for critically endangered northern bald ibis*. Nairobi: BirdLife Africa. Available at http://www.birdlife.org/africa/news/record-breeding-success-critically-endangered-northern-bald-ibis

IUCN (2016): *The IUCN Red List of Threatened Species*. Gland, Switzerland, and Cambridge, UK: International Union for Conservation of Nature. Available at http://www.iucnredlist.org

IUCN/SSC (2013): *Guidelines for reintroductions and other conservation translocations* version 1.0. Gland, Switzerland: IUCN Species Survival Commission.

JANAK, J. (2011): Spotting the Akh. The presence of the northern bald ibis in Ancient Egypt and its early decline. *Journal of the American Research Centre in Egypt* **46**: 17–31.

KOTRSCHAL, K. (2004): The Grünau project: establishing a semi-wild colony of waldrapp ibis. *WAZA Magazine* **5**: 12–15.

KUMERLOEVE, H. (1978): Waldrapp, *Geronticus eremita* und Glattnackenrapp, *Geronticus calvus:* Zur Geschichte ihrer Erforschung und zur gegenwärtigen Bestandssituation. *Annalen des Naturhistorischen Museums in Wien* **81**: 319–349.

LOPEZ, M. & QUEVEDO, C. M. (2016): Northern bald ibis reintroduction program in Andalusia. In *Proceedings of 4th International Advisory Group for the Northern Bald Ibis (IAGNBI) meeting Seekirchen, Austria, August 2016*: 57–67. Böhm, C. & Bowden, C. G. R. (Eds). Sandy, Beds: Royal Society for the Protections of Birds.

LÓPEZ-LÓPEZ, P., FERRER, M., MADERO, A., CASADO, E. & MCGRADY, M. (2011): Solving man-induced large-scale conservation problems: the Spanish imperial eagle and power lines. *PLoS ONE* **6**(3): e17196.

MENDELSSOHN, H. (1994): Experimental releases of waldrapp ibis *Geronticus eremita*: an unsuccessful trial. *International Zoo Yearbook* **33**: 79–85.

MICHELMORE, F. & OLIVER, W. L. R. (1982): Hand-rearing and development of bare-faced ibis chicks *Geronticus eremita* at the Jersey Wildlife Preservation Trust; with comparative observations of parent-rearing behaviour. *The Dodo: Journal of the Jersey Wildlife Preservation Trust* No. 19: 51–69.

MOULLEC, C. (2001): *Mit den wilden Gänsen fliegen*. Stuttgart: Franckh-Kosmos Verlag.

MUELLER, T., O'HARA, R. B., CONVERSE, S. J., URBANEK, R. B. & FAGAN, W. F. (2013): Social learning of migratory performance. *Science* **341**: 999–1002.

MÜLLER, H. P. (2004): The reintroduction project "Beshar el Kheir" at Ain Tijja-Mezguitem in North-East Morocco. *WAZA Magazine* **5**: 24–27.

NEWTON, I. (2010): *The migration ecology of birds*. London: Academic Press.

PEGORARO, K. (1996): *Der Waldrapp. Vom Ibis, den man für einen Raben hielt*. Wiesbaden: AULA-Verlag.

PEGORARO, K. & THALER, E. (1985): Zum Verhalten erstbrütender Waldrapp-Weibchen im Alpenzoo. *Zoologischer Garten NF* **55**: 113–123.

PETER, H. (1990): *Waldrappdämmerung am Euphrat*. Heidelberg: Max Kasparek Verlag.

PORTUGAL, S. J., HUBEL, T. Y., FRITZ, J., HEESE, S., TROBE, D., VOELKL, B., HAILES, S., WILSON, A. M. & USHERWOOD, J. R. (2014): Upwash exploitation and downwash avoidance by flap phasing in ibis formation flight. *Nature* **505**: 399–402.

PSCHERA, A. (2014): *Das Internet der Tiere: der neue Dialog zwischen Mensch und Natur*. Berlin: Matthes & Seitz Verlag.

SAPIR, N., WIKELSKI, M., MCCUE, M. D., PINSHOW, B. & NATHAN, R. (2010): Flight modes in migrating European bee-eaters: heart rate may indicate low metabolic rate during soaring and gliding. *PLoS ONE* **5**(11): e13956.

SCHAUB, M., ZINK, R., BEISSMANN, H., SARRAZIN, F. & ARLETTAZ, R. (2009): When to end releases in reintroduction programs: demographic rates and population viability analysis of bearded vultures in the Alps. *Journal of Applied Ecology* **46**: 92–100.

SCHENKER, A. (1977): Das ehemalige Verbreitungsgebiet des Waldrapps *Geronticus eremita* in Europa. *Ornitologischer Beobachter* **74**: 13–30.

SCHENKER, A. (1981): Der Waldrapp – ein historisches Wildbret. *Wildbiologie* **4**: 1–12.

SEO/BIRDLIFE MOROCCO PROGRAMME (2015): *2014 breeding season results: new record*. Madrid: Sociedad Española de Ornitología (SEO)/BirdLife. Available at http://northernbaldibis.blogspot.co.uk/2015/01/2014-breeding-season-results-new-record.html

SERRA, G., ABDALLAH, M., ASSAED, A., ABDALLAH, A., AL QUAIM, G., FAYED, T., ASSAED, A. & WILLIAMSON, D. (2004): Discovery of a relict breeding colony of northern bald ibis *Geronticus eremita* in Syria. *Oryx* **38**: 106–108.

SERRA, G., PESKE, L. & WONDAFRASH, M. (2011): Breeding range of the last eastern colony of critically endangered northern bald ibis *Geronticus eremita* in the Syrian steppe: a threatened area. *Bird Conservation International* **21**: 284–295.

SERRA, G., LINDSELL, J. A., PESKE, L., FRITZ, J., BOWDEN, C. G. R., BRUSCHINI, C., WELCH, G., TAVARES, J. & WONDAFRASH, M. (2015): Accounting for the low survival of the critically endangered northern bald ibis *Geronticus eremita* on a major migratory flyway. *Oryx* **49**: 312–320.

SHEPHARD, J. M., RYCKEN, S., ALMALIK, O., STRUYF, K. & VAN ERP-VAN DER KOOIJ, L. (2015): Migration strategies revealed by satellite tracking among descendants of a population of European white stork (*Ciconia ciconia*) reintroduced to Belgium. *Journal of Ornithology* **156**: 943–953.

THALER, E., ETTEL, E. & JOB, S. (1981): Zur Sozialstruktur des Waldrapps *Geronticus eremita* – Beobachtungen an der Brutkolonie des Alpenzoos Innsbruck. *Journal für Ornithologie* **122**: 109–128.

THALER, E., PEGORARO, K. & STABINGER, S. (1992): Familienbindung und Auswilderung des Waldrapps *Geronticus eremita* – ein Pilotversuch. *Journal für Ornithologie* **133**: 173–180.

UNSÖLD, M. & FRITZ, J. (2011): Der Waldrapp: Ein Vogel zwischen Ausrottung und Wiederkehr. *Wildbiologie* **2**: 1–16.

VOELKL, B. & FRITZ, J. (In press): Relation between travel strategy and social organization of migrating birds with special consideration of formation flight in the northern bald ibis. *Philosophical Transactions of the Royal Society B*.

VOELKL, B., PORTUGAL, S. J., UNSÖLD, M., USHERWOOD, J. R., WILSON, A. M. & FRITZ, J. (2015): Matching times of leading and following suggest cooperation through direct reciprocity during V-formation flight in ibis. *Proceedings of the National Academy of Sciences* **112**: 2115–2120.

WEISSENBACHER, A., PREININGER, D., GHOSH, R., MORSHED, A. G. J. & PRASCHAG, P. (2015): Conservation breeding of the northern river terrapin *Batagur baska* at the Vienna Zoo, Austria, and in Bangladesh. *International Zoo Yearbook* **49**: 31–41.

WIRTZ, S., BÖHM, C., FRITZ, J., HANKELN, T. & HOCHKIRCH, A. (2016): Isolation of microsatellite loci by next-generation sequencing of the critically endangered northern bald ibis, *Geronticus eremita*. *Journal of Heredity* **107**: 363–366.

WITTMANN, U. & RUPPERT, H. (1984): Künstliche Erbrütung und Aufzucht des Waldrapp, *Geronticus eremita*. *Zoologischer Garten NF* **54**: 427–438.

YENIYURT, C., OPPEL, S., İSFENDIYAROĞLU, S., ÖZKINACI, G., ERKOL, I. L. & BOWDEN, C. G. R. (2016): Influence of feeding ecology on breeding success of a semi-wild population of the critically endangered northern bald ibis *Geronticus eremita* in southern Turkey. *Bird Conservation International*. DOI: https://doi.org/10.1017/S0959270916000253.

ZORNIG, H. & WEISSENBACHER, A. (2004): Ursachen für die Degradierung der Azraq Oase und die Gefährdung von *Aphanius sirhani* (Cyprinodontiformes, Cyprinodontidae), Villwock, Scholl & Krupp, 1983; Aktueller Status und Vorschläge zu seinem Schutz [Causes for the degradation of Azraq Oasis and the threats for *Aphanius sirhani* (Cyprinodontiformes, Cyprinodontidae), Villwock, Scholl & Krupp, 1983; current status and recommendations for its protection]. *Denisia* **14**: 395–405.

ZOUFAL, K., FRITZ, J., BICHLER, M., KIRBAUER, M., MARKUT, T., MERAN, I., WOLF, A. & KOTRSCHAL, K. (2007): Feeding ecology of the northern bald ibis in different habitat types: an experimental field study with hand-raised individuals. In *Northern bald ibis conservation and reintroduction workshop. Proceedings of the 2nd International Advisory Group for the Northern Bald Ibis (IAGNBI) meeting, Vejer, Spain, September 2006*: 77–84. Böhm, C., Bowden, C. G. R., Jordan, M. J. R. & King, C. (Eds). Sandy, Beds: Royal Society for the Protections of Birds.

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