

Positive effect of power line mitigation on reintroduced red kite (*Milvus milvus*) population in southern Spain

Pozitívny vplyv mitigačných opatrení na elektrických vedeniach pre reintrodukovanú populáciu haje červenej (*Milvus milvus*) v južnom Španielsku

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Abstract: Electrocution is one of the main causes of unnatural mortality among European raptors and poses a significant threat to vulnerable species such as the red kite (*Milvus milvus*). This study assessed the combined effects of mitigation measures on hazardous power line infrastructure and the red kite reintroduction programme aimed at restoring its breeding population in Jaén (Andalusia, southern Spain), where it had previously become extinct as a breeding species in the early 2000s. Between 2021 and 2025, 186 individuals were released following habitat suitability assessment, of whom 181 were fitted with GPS transmitters to monitor survival and spatial ecology. In parallel, a high-risk power line previously associated with elevated raptor mortality was retrofitted with anti-electrocution devices across 48 pylons located within the release area of the tagged red kites. A total of 80 mortality events of monitored red kites were recorded during the study, of which 72 were assigned a cause. Natural mortality accounted for 54.2%, with predation as the dominant factor (n = 34). Anthropogenic causes represented 45.8%, mainly poisoning (n = 9) and electrocution (n = 8). Notably, 21 reintroduced individuals used the mitigated power line area, generating 802 GPS fixes, with no recorded mortality associated with these structures, indicating effective reduction of electrocution risk. Population recovery was rapid, transitioning from complete absence to three breeding pairs in 2023, six in 2024, thirteen in 2025, and twenty-two in 2026. These findings demonstrate that integrating targeted infrastructure mitigation with reinforcement-based reintroduction can substantially improve survival rates and accelerate population recovery, highlighting an effective conservation strategy for raptors in human-modified environments.

Abstrakt: Elektrokúcia patrí medzi hlavné príčiny neprirodzenej úmrtnosti európskych dravých vtákov a predstavuje významnú hrozbu pre zraniteľné druhy, ako je haja červená (*Milvus milvus*). Štúdia hodnotí kombinovaný účinok mitigačných opatrení na nebezpečnej infraštruktúre elektrických vedení a reintrodukčného programu haje červenej, s cieľom obnovy jej hniezdnej populácie v provincii Jaén (Andalúzia, južné Španielsko), kde začiatkom 21. storočia ako hniezdiaci druh vyhynula. V rokoch 2021 až 2025 bolo po posúdení vhodnosti biotopu vypustených 186 jedincov, z ktorých 181 bolo vybavených GPS vysielačmi na sledovanie prežívania a priestorovej ekológie. Súbežne bolo na 48 stĺpoch nachádzajúcich sa v oblasti vypúšťania označených hají, v minulosti spájaných so zvýšenou úmrtnosťou dravcov, nainštalované ochranné prvky proti zásahu elektrickým prúdom. Počas štúdie bolo zaznamenaných celkovo 80 úmrtí sledovaných hají červených, z ktorých pri 72 bola určená príčina. Prirodzená úmrtnosť tvorila 54,2 %, pričom dominantným faktorom bola predácia (n = 34). Antropogénne príčiny predstavovali 45,8 %, najmä otrava (n = 9) a zásah elektrickým prúdom (n = 8). Významným zistením je, že 21 reintrodukovaných jedincov využívalo oblasť so zabezpečeným elektrickým vedením, čo vygenerovalo 802 GPS bodov, pričom v spojitosti s týmito štruktúrami nebola zaznamenaná žiadna úmrtnosť. To poukazuje na efektívne zníženie rizika elektrokúcie. Obnova populácie bola rýchla – z úplnej absencie vzrástla na tri hniezdne páry v roku 2023, šesť v roku 2024, trinásť v roku 2025 a dvadsaťdva v roku 2026. Tieto zistenia ukazujú, že integrácia cieľenej úpravy infraštruktúry s reintrodukciami založenou na posilňovaní populácie môže výrazne zvýšiť mieru prežívania a urýchliť obnovu populácie, čo podčiarkuje účinnosť tejto ochranárskej stratégie pre dravé vtáky v prostredí pretvorenom človekom.

Key words: electrocution, mortality rate, population growth, satellite tracking, Accipitriformes, Andalusia,

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Introduction

Electrocution on power lines is widely recognised as one of the leading causes of non-natural mortality in raptors across Europe, affecting both common and threatened species (Ferrer et al. 1991, Tintó et al. 2010, Guil & Pérez-García 2022). Most electrocution events occur when birds simultaneously contact two energised conductors or when they perch on grounded structures while touching a live wire, thereby causing an electric shock (Ferrer et al. 2022). The design of medium-voltage distribution lines, particularly certain pole configurations, can substantially increase the risk of electrocution, creating mortality hotspots that may have significant population-level consequences (Ferrer & Negro 1992, Pérez-García et al. 2015, Galis et al. 2019).

For example, the Spanish imperial eagle (*Aquila adalberti*) and the Bonelli's eagle (*Aquila fasciata*) are among the raptor species most severely affected by electrocution on power lines in Southern Europe, which remains one of the leading anthropogenic causes of mortality and a major threat to their conservation. In the Spanish imperial eagle, electrocution accounted for approximately 40–60% of recorded mortality, depending on the study period, whereas in Bonelli's eagle it accounted for approximately 55% of documented mortality (Real et al. 2001; López-López et al. 2011). The red kite (*Milvus milvus*) is especially vulnerable to electrocution due to its ecological and behavioural traits, including frequent use of perching structures in open landscapes (Harness & Wilson 2001). This species has experienced marked population declines in parts of Spain and is currently classified as endangered in several regions. These declines have been attributed to multiple anthropogenic pressures, including illegal poisoning, habitat alteration, and mortality associated with power infrastructure (Tavecchia et al. 2012, Crespo-Luengo et al. 2020). Within this context, electrocution represents

a significant source of non-natural mortality that may hinder ongoing conservation and recovery efforts (Dwyer 2009).

Identifying and mitigating electrocution hotspots is therefore a key component of raptor conservation strategies. Targeted retrofitting of hazardous power-line structures has been shown to reduce mortality and facilitate the recolonisation of previously unsuitable areas (Guil et al. 2011, Chavko et al. 2022). However, the combined contribution of electrocution mitigation and population reinforcement to species recovery has rarely been evaluated.

Here, we assess the outcome of two complementary conservation initiatives that have promoted the recovery of the red kite in Jaén Province (Andalusia, southern Spain): (i) the retrofitting of the region's most hazardous power lines to reduce electrocution mortality, and (ii) the release of captive-bred individuals to accelerate recolonisation of the study area by the target species. By evaluating these actions in combination, we provide evidence of their effectiveness in restoring a red kite breeding population in an area where the species had previously disappeared.

Material and methods

Following a habitat suitability assessment conducted in 2020 to identify an optimal release site and define release protocols, reintroduction efforts began in 2021 in the Sierras de Cazorla, Segura and Las Villas Natural Park, Jaén (Spain) (37°53'N, 2°58'W). The selected site is characterised by open landscapes (Fig. 1), with abundant agricultural meadows and well-developed tree cover, making it a potentially suitable habitat for red kites (Seoane et al. 2003).

Individuals used in our reintroduction program are sourced from multiple populations to enhance genetic diversity and population viability. These include rehabilitated birds from GREFA's Wildlife Hospital,



Fig. 1. Landscape of the study area with the power line prior to retrofitting; note the electrocuted bird of prey on the ground (© Manuel Rodríguez).

Obr. 1. Krajina študovaného územia s elektrickým vedením pred inštaláciou ochranných prvkov; všimnite si usmrteného dravca na zemi po zásahu elektrickým prúdom (© Manuel Rodríguez).

individuals translocated from the Madrid-Barajas airport area for aviation safety purposes, and chicks taken from wild nests in the same location within the Madrid population. Additionally, some individuals were bred in captivity at the La Alfranca breeding centre (Government of Aragón), while others were translocated from surplus nests on Mallorca. In the latter case, one nestling was removed from broods containing multiple chicks. This diversity of origins is a key component in the success of reintroduction efforts.

Individuals were released using a Hacking Cage (Viada & Iglesias 2018), allowing acclimatisation to the environment prior to release after several months in captivity. From 2021 to 2025, a total of 181 out of 186 released individuals were equipped with GPS transmitters using a 0.44-inch Teflon pectoral harness (García et al. 2021). The tracking devices used in the study were from the commercial brands Ornitela (Lithuania), Anitra (Czech Republic), and Interrex (Poland). All transmitters weighed less than 25 g, representing less than 3% of the birds' body mass, thereby minimising potential effects on survival and avoiding interference with their natural behaviour (Kenward 2000).

In 2021, the Regional Government of Andalucía notified GREFA of a privately owned power line outside the scope of Royal Decree 1432/2008. A coordinated action involving the landowner (Las Yegüas, Linares, Jaén), GREFA, funding from the EU project AQUILA a-LIFE (LIFE16 NAT/ES/000235), and the Regional

Government led to corrective measures on 48 electricity pylons (Fig. 2, 3). These structures had previously caused the deaths of over 50 endangered birds in five years, including Spanish imperial eagles, Bonelli's eagles, and red kites (Fig. 4).

The power line, 2.5 km in length, is situated between a riparian forest and an agricultural landscape dominated by olive groves, an area with a high density of European rabbits (*Oryctolagus cuniculus*), the main prey of many Iberian raptors (Delibes-Mateos & Gálvez-Bravo 2009). This prey availability attracts raptors, which frequently use the pylons as perching sites, increasing the risk of interactions with the infrastructure (Dixon et al. 2017).



Fig. 2. Retrofitting action agreed upon with the Andalusian government and carried out within the framework of the LIFE AQUILA a-LIFE project, coordinated by GREFA (© Juan José Iglesias-Lebrija).

Obr. 2. Inštalácia ochranných prvkov elektrického vedenia dohodnutá s Andalúzsou vládou a realizovaná v rámci projektu LIFE AQUILA a-LIFE pod koordináciou organizácie GREFA (© Juan José Iglesias-Lebrija).



Fig. 3. Bird-safe utility pole after retrofitting to prevent bird electrocution in the study area (© Rafael Hernández).

Obr. 3. Stĺp elektrického vedenia s ochrannými prvkami proti zásahu vtáctva elektrickým prúdom po úprave (rekonštrukcii) v študovanom území (© Rafael Hernández).



Fig. 4. Signs of electrocution on the talon of a red kite released as part of the reinforcement project (© Rafael Hernández).

Obr. 4. Stopy po zásahu elektrickým prúdom na pazúre haje červenej vypustenej v rámci projektu posilňovania populácie (© Rafael Hernández).

Given that the GPS transmitters used have a mean positional error of approximately 10 m, and that GPS fixes were recorded at discrete intervals rather than continuously, individuals may have been perched at a hazardous location between consecutive fixes without being detected (Ripperger et al. 2020). To account for both GPS uncertainty and potential gaps in the tracking data, a 50 m buffer was generated around each electricity pole. This buffer was used to identify all instances in which red kites could have been perched on the structure and, therefore, exposed to the risk of electrocution. Spatial analyses were conducted using the QGIS software (version 3.40.7).

The deployment of GPS tracking devices on red kites enabled the detection of most mortality events and facilitated the determination of their causes. Recovered carcasses were transported by environmental authority personnel to wildlife rehabilitation centres, where necropsies were conducted to ascertain the cause of death. All conservation activities, including bird capture, handling, transport/relocation and release, were authorised by the competent environmental authorities and carried out under the relevant permits in accordance with applicable national and regional legislation (Ref: 10/685733.9/23; c2023620000002832; Ref: 10/406265.9/25; BndJAE7 ZVTWFQ9YQPGNN57AZ5F2AWF; Exp.: TRA 01/2025; Exp.: TRA 07/2026).

An AI-based language model was used exclusively to improve the manuscript's clarity and linguistic quality. No AI tools were used in the generation, analysis, or interpretation of data, or in the production of figures or results.

Results

In the province of Jaén (eastern Andalusia) and surrounding areas, the red kite had previously been extirpated as a breeding species in the early 2000s (Viñuela 2004). Two years after the releases began (2021), three breeding pairs were recorded in 2023, increasing to six in 2024, thirteen in 2025, and twenty-two in 2026. An average annual population growth rate of approximately 100% was estimated over the study period.

Of the 181 individuals released with GPS transmitters, 80 were reported dead. In 72 cases, the cause of death could be determined. Anthropogenic causes accounted for 45.8% ($n = 33$), whereas natural causes accounted for 54.2% ($n = 39$). Predation was the most frequent cause of mortality ($n = 34$). In some cases, the predator responsible for the mortality could be identified. The principal predators were the Eurasian eagle-owl (*Bubo bubo*), the golden eagle (*Aquila chrysaetos*), and Bonelli's eagle. Among anthropogenic causes, poisoning ($n = 9$) and electrocution ($n = 8$) were the most prominent. A secondary group of causes comprised drowning ($n = 5$) and disease/weakness ($n = 5$). Drowning events occurred predominantly in summer and were associated primarily with irrigation reservoirs and firefighting water ponds. By contrast, cases classified as disease or weakness were generally difficult to interpret, as the primary cause of morbidity or mortality could rarely be determined (Table 1).

The tracking data showed that 21 monitored individuals used the area where the mitigation measures were implemented along the power line at least once. A total of 802 GPS locations were recorded in this area following the retrofitting of the line, with no electrocution events detected for the kites included in this study. Monthly surveys were conducted to detect electrocuted raptors of other species not equipped with GPS transmitters, and no individuals were found. Notably, one breeding pair of red kites established its nesting territory approximately 150 m from the corrected power line (Fig. 5), whereas a breeding pair of Spanish imperial eagles settled approximately 1.5 km away. Both territories were established within the area where anti-electrocution measures had been implemented following the retrofitting of the power line.

Discussion

The decline of the red kite population in southern Spain has been widely documented and has largely been attributed to anthropogenic pressures (Sergio et al. 2019). Historically, direct persecution was considered the principal driver of this decline, particularly during the mid-twentieth century, when government-supported

Tab. 1. Known causes of mortality among individuals released (n = 186) under the red kite reinforcement project in Andalusia (2021–2026).

Tab. 1. Známe príčiny mortality vypustených jedincov haje červenej (n = 186) v rámci projektu posilňovania jej populácie v Andalúzii (2021 – 2026).

Category	Subcategory	Frequency
Anthropogenic Causes	Drowning	5
	Secondary poisoning	1
	Electrocution	8
	Collision	
	Wind turbine	2
	Vehicle collision	3
	Undetermined	3
	Direct persecution	
	Poisoning	9
	Trap	1
	Shooting	1
Subtotal (Anthropogenic)		33
Natural causes	Predation	34
	Weakness/Disease	5
Subtotal (Natural)		39
Total		72

vermin eradication campaigns promoted the systematic removal of predators perceived as harmful to human interests (Newton et al. 1986; Villafuerte et al. 1998). Other anthropogenic threats, including secondary poisoning, vehicle collisions and electrocution on power lines, also contributed substantially to the species' regression, ultimately leading to its disappearance from eastern Andalusia (Molina 2015; Panter et al. 2025). Our results suggest that direct persecution is no longer the principal constraint on the red kite recovery in the study area. Nevertheless, anthropogenic activities still accounted for nearly half of all recorded mortality events, a pattern consistent with recent studies from other European populations (Katzenberger et al. 2019; Panter et al. 2025). Electrocution was the leading cause of unintentional mortality in our study. This threat extends well beyond the red kite and affects a wide range of European raptor species. Guil et al. (2011) recorded 952 electrocuted raptors from 14 species during a survey of 6,304 electricity pylons in central Spain, with approximately 65% of the carcasses being medium-sized species such as the Eurasian eagle-owl, the black kite (*Milvus migrans*), and the common buzzard (*Buteo buteo*). Although these species have substantially larger populations than the red kite, the demographic consequences of electrocution are

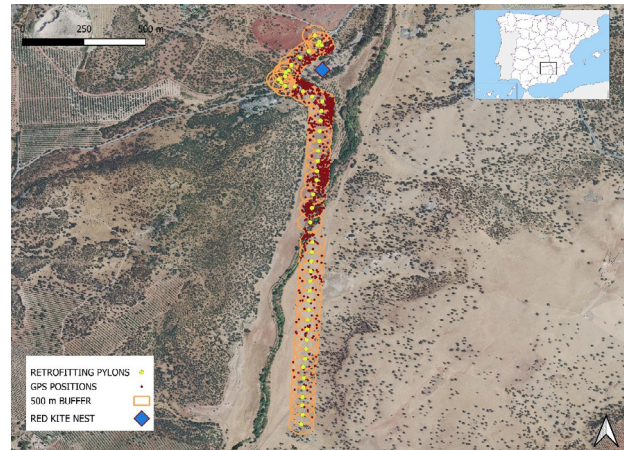


Fig. 5. Power line (yellow dots) with 500 m pylon buffers (orange circles) retrofitted with anti-electrocution measures in 2021, and recorded locations of 21 red kites (red dots) that used electricity pylons as perching/roosting sites after mitigation are shown. Note the presence of a red kite nest (blue square) established in 2024 at a distance of 150 m from the power line.

Obr. 5. Elektrické vedenie (žlté body) s 500-metrovou zónou okolo stĺpov (oranžové kruhy) vybavené ochrannými prvkami proti zásahu elektrickým prúdom v roku 2021 a zaznamenané polohy 21 háj červenej (červené body), ktoré po úprave využívali stĺpy vedenia ako miesta na sadanie a hradovanie. Všimnite si prítomnosť hniezda haje červenej (modrý štvorec) založeného v roku 2024 vo vzdialenosti 150 m od elektrického vedenia.

expected to be proportionally more severe in small or recovering populations.

The present study suggests that, based on GPS monitoring of released individuals, at least 21 kites (11.3%) associated with the reintroduction program would likely have died in the absence of these mitigation measures, as they were recorded on the pylons of the retrofitted power line. Targeted, site-specific mitigation actions on high-risk power lines, such as the one described in this study, are essential for the recovery of threatened species, confirming that not all power lines pose the same level of risk and that interventions focused on the most hazardous sections are the most effective. Furthermore, the ecological niche previously constrained by this mortality source appears to have been rapidly occupied by breeding pairs of red kites and Spanish imperial eagles, the latter of which is a critically endangered species (López-Jiménez 2021). In this context, retrofitting the most hazardous power line in the province of Jaén with anti-electrocution measures has been a key factor in the successful recolonisation of the species, following a reintroduction programme involving non-governmental organisations and regional administrations.

The Andalusian breeding population within the release areas has almost doubled annually. This trend highlights the effectiveness of the reintroduction programme and demonstrates the species' capacity to establish and expand under favourable management conditions. Consequently, these results provide strong evidence that the conservation measures implemented to date are contributing positively to population recovery and long-term viability in this and other species (Reid 1997, Rawat & Agarwal 2015).

Competing interest

The authors declare no competing interests.

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