

Effects of captivity on the morphology, nesting success, and growth of the Libyan Falcon (*Falco biarmicus*)

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ABSTRACT

Understanding raptor breeding biology is essential for conservation. This study assessed the captive breeding of the Lanner Falcon (*Falco biarmicus*) and raptor presence in Libya. A pair acquired in 2018 was provided with artificial nests and monitored throughout the 2024 season. Clutch size ranged 4–6 eggs with a 32-day incubation. In 2024, all eggs hatched, producing three fledglings independent after four months. Between 2018–2025, the pair laid 35 eggs, yielding about 25 fledglings, confirming high captive success. Field surveys in October–November 2024 recorded 53 raptors: *Falco peregrinus* (39; Least Concern), *F. biarmicus* (6; resident), and *Falco cherrug* (8; Endangered, migratory). *F. peregrinus* was the most frequent, with Al Kufrah identified as the main hunting area. Results highlight the effectiveness of captive breeding for Lanner Falcons and underline urgent threats to wild populations, particularly habitat loss and poaching. Strong conservation actions are critical for sustaining both resident and migratory raptors.

Keywords: Captive breeding, falcon morphology, Libya raptors, nesting success, sustainable wildlife management.

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Introduction

Falcon hunting in Libya holds deep cultural and economic importance, with the rarest falcons commanding prices as high as half a million US dollars, driven by strong international demand (Malcolm *et al.*, 2015; Di Vittorio *et al.*, 2015). The practice once rooted in tradition and fuelled by passion, has gradually evolved into a means of livelihood in the face of economic challenges. Falconers now craft specialized traps, known as "Al-Ramka" to capture migratory birds like the Lanner Falcon (*Falco biarmicus*), a species native to the arid Mediterranean deserts of Libya (Di Vittorio *et al.*, 2017; Amato *et al.*, 2021). Libya's position along the Mediterranean coast serves as a vital waypoint for many migratory bird species, such as falcons, eagles, ducks, geese, and cranes (Etayeb *et al.*, 2023; Amar *et al.*, 2018; Leonardi and Luke, 2020). These species are under growing pressure from habitat alterations, hunting, and

poaching, leading to population declines that jeopardize critical ecosystem functions like pest management and disease control (Salvo, 2019; Ali, 2019; Moleón *et al.*, 2011; Martínez-Ruiz *et al.*, 2023). Although certain conservation initiatives have been implemented, existing protective measures fall short, leaving both resident and migratory raptor populations vulnerable (Ogada *et al.*, 2016; Guilherme *et al.*, 2022).

Although conservation efforts have been made, existing protective measures are still inadequate, underscoring a significant lack of understanding about the breeding biology and captive care of *F. biarmicus*. Bridging this knowledge gap is crucial for devising effective conservation strategies. To that end, this study focuses on assessing the success of captive breeding, growth, and survival of the Lanner Falcon in Libya, while also monitoring seasonal

trends in both resident and migratory raptors to help shape future conservation priorities.

Materials and methods

Research design

In 2018, a mature female *F. biarmicus* was captured around Umm al-Asqaf, situated approximately 150 kilometres southwest of Ajdabiya, Libya. The avian had dimensions of wing chord 13 cm, body girth 14 cm and a weight of 650 g. Furthermore, a male specimen of similar measurements, weighing 600 g, was captured in Sabha. Both birds were in excellent health, sexually mature, and selected through careful physical evaluations. An investigative study combining experimental and observational techniques was conducted to analyse their courtship, breeding behaviours, nesting dynamics, and chick development under captive circumstances Table 1. Each experiment was restricted to a single breeding pair at a time. While the initial endeavour in 2018 proved unsuccessful due to insufficient management proficiency,

improved conditions resulted in the success of a second trial executed in 2023. The falcons were housed in sizable aviaries with climate control systems to ensure optimal living conditions. Prereading behaviours started to arise in mid-December, including increased interaction and closeness between the pair during feeding periods. Strict dietary protocols were implemented to prevent obesity, alternating between two meals each day during the winter months and one meal per day in summer. Their diet comprised pigeons or quails, provided alive or pre-killed as suitable.

Behavioral data gathering spanned over two years, utilizing advanced 4K surveillance cameras equipped with 20× optical zoom for detailed observations. Researchers standardized ethograms and daily logs to maintain uniformity across observations. Biometric and reproductive metrics were analysed using descriptive statistics, while activity budgets were compared between captive and wild settings to gain a more nuanced comprehension of behavioural adaptations.

Table 1. Data collection adhered to a standardized timetable, maintaining consistency throughout the two-year study duration

Time period	Recording frequency	Data collected
Daily	Continuous 24 h video recording	All behavioral events: feeding, mating, incubation, chick care, flight training
Twice weekly	Direct biometric measurements	Body weight, wing length, tail length, beak length, feather condition
Weekly	Environmental parameters	Temperature, humidity, light intensity
Breeding season	Detailed ethogram logging (3×/day)	Courtship displays, food exchange, mating frequency, nest attendance
Chick stage	Growth monitoring (every 3 days until fledging)	Weight gain, feather development, prey handling skills

Notes:

1. Data from 2018 contributed to management enhancements but were excluded from the quantitative analyses.
2. Metrics from 2023 were standardized to ensure uniformity throughout the entire observation period.

Capture procedures

Ground trap catcher Bal-Chatrri trap. A compact wire cage holds bait, typically a pigeon, and is draped with fine nylon threads. As the falcon dives toward the bait, its talons become entangled in the threads. Once captured, the bird is secured by its legs to prevent injury from its powerful claws, and its head is gently covered with a light cloth to keep it calm. A swift inspection is then

conducted, which includes recording the bird's weight, taking measurements, and affixing an identification ring. Prior authorization from the Ministry of Environment or the relevant governing body is mandatory, as birds of prey are strictly protected under national legislation and international agreements such as CITES and the Raptors MoU.

Aviary housing conditions

The aviaries were about 8 meters long, 4 meters wide, and 3 meters high. The floors were layered with a natural sand substrate to replicate wild environments. Inside each aviary was a wooden nest box measuring 60 × 60 × 70 cm, filled with straw for nesting purposes. A 12-hour light and dark cycle was maintained, while climate controls ensured a consistent temperature ranging from 18 to 28°C and humidity levels between 40% and 60% throughout the year.

Diet

Falcons were fed locally sourced pigeons and quails, verified healthy and disease-free by veterinary inspection. During winter, they received two meals per day (120–150 g); in summer, one meal per day (150–180 g). Nutritional balance was ensured by alternating between pigeon and quail to prevent.

Camera setup

Hikvision DS-2DF8836I5X-AEL 4K PTZ cameras, equipped with 20× optical zoom and recording at 25 fps, were utilized for the setup. The captured footage was stored on a 16-TB Network Video Recorder (NVR) with backups saved on external drives. Cameras were positioned 3 to 4 meters away from the nest at an approximate height of 2 meters, angled to capture both the perch and the nest box. Recording was conducted continuously, operating 24/7 instead of using motion detection triggers.

Data recording schedule

Behavioral observations were carried out across two distinct phases: the preliminary trial in 2018, which focused solely on qualitative data, and a subsequent, more comprehensive trial in 2023. The latter trial spanned roughly 12 months, featuring rigorous data collection implemented according to the following schedule.

Data analysis

Behavioural biometric and reproductive datasets were evaluated using R (version 4.2.2) and SPSS (version 27). Measurements and breeding parameters were summarized through descriptive statistics, including mean ± SD and range values. Activity budgets of captive versus wild falcons underwent comparison using either independent t-tests or Mann–Whitney U tests for non-normally distributed samples, with statistical significance set at $p < 0.05$. Falcon distributions across various Libyan sites were illustrated using

heatmaps generated in R (ggplot2), employing colour gradients to indicate relative density levels. This approach facilitated quantitative behavioural comparisons and spatial visualization of species distribution patterns.

Result

Mating activity occurred at a frequency of one to three times per day and continued for approximately a month. The nest-building process incorporated branches and feathers, following which the female started laying eggs. Egg-laying took place over a seven-day period, with intervals of one to two days between each egg. The incubation phase lasted 32 days, during which both parents alternated between incubating the eggs and foraging. Once the eggs hatched, parental efforts were concentrated on providing frequent feedings, with the most intensive feeding observed during the first 45 days (Figure 1). Plumage development began with white down in the first 20 days and steadily advanced as growth proceeded (Figure 2) (Zuberogitia *et al.*, 2013; Corso, 2018).



Figure 1. Female *F. biarmicus* feeding her nestlings inside the nesting cavity in Ajdabiya, Libya.

At this stage, the chicks started getting fed outside the nest, encouraging their gradual move out of the cavity. By the time they reached two months old, their average wing chord 13.5 cm, body girth 13 cm, and they began practicing flight with direction from their parents. By four months of age, they had achieved full flight capability, began hunting on their own, and no longer depended on their parents for food (Figure 3). Sexual maturity was typically achieved within two years.



Figure 2. Plumage development in *F. biarmicus* nestlings. Initial coverage consisted of white down.

During October and November, three falcon species were recorded at various locations across Libya: *F. peregrinus*, *F. biarmicus*, and *F. cherrug*. The primary focus of observations was on *F. peregrinus*, with nearly all identified individuals classified as migratory. Their distribution extended from southern regions like Sebha and Tazirbu to northern areas such as Tripoli and Sirte. *F. peregrinus* displayed characteristic size measurements ranging from wing chord 12.5 cm, body girth 12.5 cm to wing chord 16 cm, body girth 15.5 cm, with weights measuring between 550 and 1,100 grams.

F. biarmicus was observed solely as a resident during November in areas including Tripoli, Al-Kufrah, and Al-Awainat. The individuals exhibited specific characteristics or dimensions between wing chord 13 cm, body girth 12.5 cm and wing chord 14 cm, body girth 13.5 cm, with weights ranging from 600 to 700 grams.



Figure 3. Fledglings demonstrated full flight capacity and independent hunting behavior

Assessments of *F. cherrug* were chiefly recorded throughout its migratory season from October and November. Viewings were observed in locations like Misrata, Zliten, and nearby the Algerian Libyan frontier. This falcon variety demonstrated somewhat greater sizes, with typical dimensions existing within the scope of between wing chord 14 cm, body girth 14 cm and wing chord 17 cm, body girth 16.5 cm, and weights between 730 and 1,140 grams.

These species *F. peregrinus* exhibits the broadest geographic distribution, with sizable populations observed in Derna, Tobruk, Misurata, and Ajdabiya. In contrast, *F. biarmicus* shows a more restricted occurrence, principally focused in areas such as Al Kufrah, Al-Awainat, and Tripoli. *F. cherrug*, classified as Endangered (EN), is sparsely distributed but detected across various sites, including Misurata, Ajdabiya, Awjila, and Zliten (Figure 4).

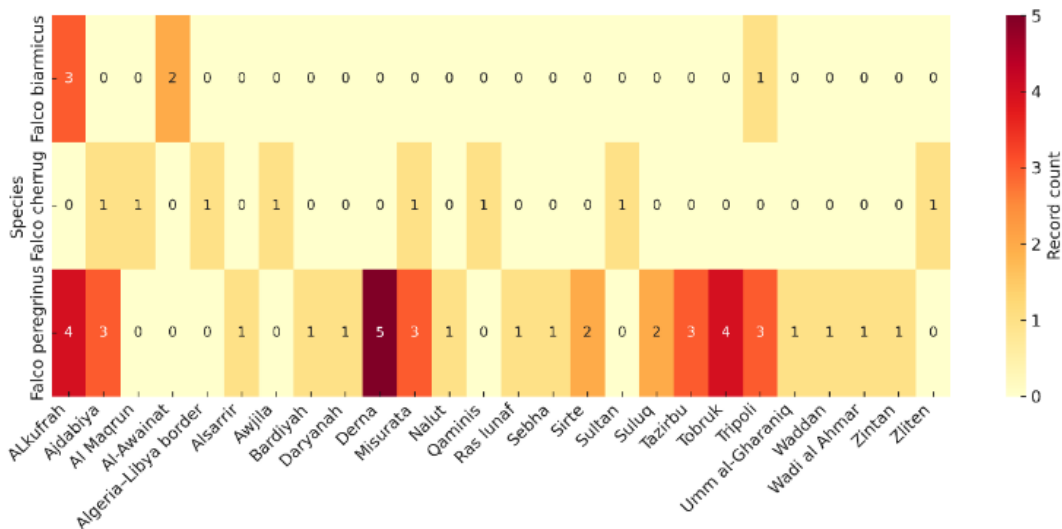


Figure 4. Heatmap representing the distribution densities falcon types throughout numerous sites in Libya

Discussion

Notably, *F. cherrug* has an EN (Endangered) classification from the IUCN, emphasizing the vital importance of observing and conserving this species as it journeys through Libya. Raptors in Libya face significant threats stemming from habitat destruction, excessive hunting, and exposure to pesticides, as highlighted by recent research. These ongoing pressures could lead to marked population declines, disrupting the region's ecological equilibrium. Since many raptor species are migratory, their challenges in Libya may ripple across Africa and Europe, affecting broader populations. This highlights the importance of coordinated regional actions through international conservation frameworks. Key strategies such as enhancing habitat protection laws, curbing harmful chemical usage, and promoting community-driven awareness programs are crucial to ensuring the survival of these birds (Oppel *et al.*, 2015; O'Bryan *et al.*, 2022).

The results of this study corroborate previous research highlighting Libya's importance as a key transit route for migratory birds of prey moving through the Sahel and North Africa. Many sightings pertained to migratory species, with *F. peregrinus* standing out prominently. This highlights Libya's function as an essential ecological link between Eurasian breeding habitats and African wintering regions, where raptor migration bottlenecks frequently take place, as noted by (Zwarts *et al.*, 2023). In comparison to prior research, studies of North African raptors often downplayed the presence of this species, especially in Tunisia and Algeria (Kenward, 2009).

Recurrent observations in areas such as Misrata and Ajdabiya suggest systematic use of these sites by the species, underscoring the urgent need for targeted monitoring and site-specific conservation efforts. Recent conservation research highlights the importance of providing artificial nest structures when natural nesting sites are limiting increasing breeding success and productivity (Catry *et al.*, 2009; Mainwaring, 2015; Zhang *et al.*, 2024).

Captive falcon breeding programs play a crucial role in conservation efforts by aiding in the

preservation of threatened species and alleviating pressure on wild populations. These initiatives offer sustainable, legal alternatives to hunting, thereby supporting broader ecological balance (Watson, 2018). These programs also offer chances for scientific investigation and ecological education and furnish a durable economic and cultural aspect that corresponds with the significance of falconry as a modern human legacy. Consequently, captive breeding is not confined to species protection solely, it also functions as a method for merging the environmental aspect with societal and financial worth (Greggor *et al.*, 2018).

A well-rounded diet, suitable housing, and routine veterinary observation are vital for captive falconry. These factors assist in disease prevention and animal welfare (Magalhães *et al.*, 2024). Such practices not only offer environmental and health advantages, but also have wider social and financial effects, since falconry is a revenue source and creates job openings, improves local livelihoods, and represents a cultural heritage that reinforces community identity (Castagna *et al.*, 2024). Thus, handling falconry sustainably, akin to other livestock industries, finds an equilibrium between safeguarding public health, preserving biodiversity, and assisting the local economy.

Conclusion

The results of this research validate that Libya is a crucial connection in the migration paths of raptors between Europe and Africa, rendering it a vital zone for the preservation of global biodiversity. Still, persistent stresses resulting from habitat destruction and poaching risk depleting these birds, including species categorized as endangered, like *F. cherrug*. This emphasizes the significance of enacting rigorous conservation policies, reinforcing long-term monitoring initiatives, and harmonizing efforts across international structures to sustain ecological equilibrium. Concurrently, captive breeding programs aid in lessening pressure on wild populations and protecting endangered species, besides their scientific, educational, and financial aspects. Proper care of falcons, including diet, accommodation, and veterinary follow-up, fits within the scope of the "One Health" approach,

which connects the well-being of animals, people, and the ecosystem. Consequently, combining environmental preservation efforts with social, economic, and cultural factors offers a workable route toward genuinely sustainable raptor conservation in Libya and further afield.

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