BREEDING ECOLOGY AND REPRODUCTIVE CONSTRAINTS OF THE MAGHREB MAGPIE (*PICA MAURITANICA*) IN NORTHWESTERN ALGERIA

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Abstract. The Maghreb Magpie (*Pica mauritanica*) is endemic to North Africa, but its breeding ecology in Algeria remains undocumented. During the 2023 breeding season at Sidi Chaib (34°35′45″ N, 0°32′39″ W), we surveyed approximately 200 ha of peri-urban agro-pastoral landscape and located 74 nests of which only 13 nests were active, all built in *Lycium shawii* shrubs. For each active nest, we measured height (mean ± SD = 1.59 ± 0.28 m), clearance to crown (0.87 ± 0.43 m), volume (0.22 ± 0.06 m^3), and monitored reproductive parameters biweekly. The breeding season spanned 104 days (26 February–10 June), with a mean clutch size of 5.85 ± 1.34 eggs, a hatching rate of 63 %, and 69 % of nests fledging at least one chick. Egg laying peaked in early March, fledging in mid-April, and first-egg dates were 33 days earlier than at a nearby rural site. We modeled fledgling counts using Extreme Gradient Boosting (100 rounds, max_depth = 6, $\eta = 0.3$) with SHAP interpretation, incorporating predation metrics, nest position, volume, and nearest-nest distance. Predation risk (gain = 64.9 %) and nest volume (28.8 %) were the strongest predictors, while spatial variables were negligible. Our findings underline the value of maintaining dense *Lycium shawii* stands and implementing focused measures to reduce nest predation.

Keywords: *Corvidae, peri-urban ecosystems, breeding phenology, nesting success, nest predation, habitat fragmentation, machine learning, SHAP, Algeria*

Introduction

The Maghreb Magpie (*Pica mauritanica*) is an emblematic corvid endemic to North Africa (Kryukov et al., 2017; Song et al., 2018), where it fulfills essential ecological functions, such as seed dispersal and predator deterrence, and serves as a regional symbol

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of biodiversity. Over the past decades, accelerated habitat loss, fragmentation and climate change have profoundly reshaped the Maghreb landscape (Hirche et al., 2011), highlighting an urgent need for robust reproductive-ecology data to inform conservation planning (Crossin and Williams, 2021).

Historically, *Pica mauritanica* ranged continuously from Morocco's Atlantic coast through northern Algeria to Tunisia's lowland plains (Isenmann et al., 2005; Bergier et al., 2017). Persistent anthropogenic pressures including agricultural expansion, urbanization and infrastructural development have since fragmented this range into isolated patches. Recent analyses reveal a pronounced west-to-east decline in abundance, with eastern Algeria and Tunisia now hosting smaller, more vulnerable populations (Mederbal et al., 2024).

Despite its conservation significance, the breeding biology of *Pica mauritanica* remains almost entirely uncharacterized in Algeria. To date, only one study has examined breeding parameters in Tunisia's relic population (Nefla et al., 2021) and no systematic field monitoring of nesting chronology, clutch size or fledgling survival has been conducted in Algerian populations. The inherent difficulty of locating active nests in peri-urban areas of western Algeria further limits sample sizes and complicates traditional field-based inference.

Species-distribution models for *Pica mauritanica* that incorporate environmental predictors such as the Enhanced Vegetation Index (EVI), elevation and human-settlement data have begun to outline habitat suitability patterns (Mederbal et al., 2024). However, predictive modeling of reproductive outcomes from sparse nest records remains unexplored.

This study addresses these critical gaps by providing the first comprehensive reproductive-ecology dataset for a western-Algerian, peri-urban *Pica mauritanica* population and by pioneering ecological modeling of fledging success from limited field observations. Specifically, we will (1) describe nesting-site selection within the Sidi Chaib peri-urban matrix, (2) compare breeding phenology and clutch parameters with a nearby rural site, (3) quantify hatching and fledgling success and identify primary failure causes, and (4) employ machine-learning methods such as XGBoost with SHAP interpretation to rank ecological and spatial predictors of reproductive success. By integrating novel Algerian data with advanced modeling approaches, we aim to furnish essential benchmarks and predictive tools for targeted conservation of this understudied endemic.

Material and methods

Study area

Fieldwork was conducted in Sidi Chaib (34°35′45.38″N, 0°32′38.82″W; 1100 m a.s.l.), located in Sidi Bel Abbes Province, in northwestern Algeria (*Figure 1A*). The study site covers approximately 200 ha within a Mediterranean semi-arid agro-pastoral landscape (*Figure 1B*). Climate data for the period 2014–2024 indicate a mean annual temperature of 16.3 °C and mean annual precipitation of 291.9 mm, retrieved from Climate Engine (accessed 20 February 2025). The vegetation is dominated by xerophytic woody species, including *Lycium shawii* (commonly forming thorny hedgerows), *Cupressus sempervirens* (used as windbreaks), as well as cultivated *Olea europaea* and *Prunus dulcis* orchards. A second rural site at Ain Nour located at 34 km southeast of Sidi Chaib was also monitored concurrently (*Figure 1C*). This site served only as a comparative reference to assess spatial variation in breeding phenology and evaluate whether observed advances in laying dates were site-specific or regionally consistent.

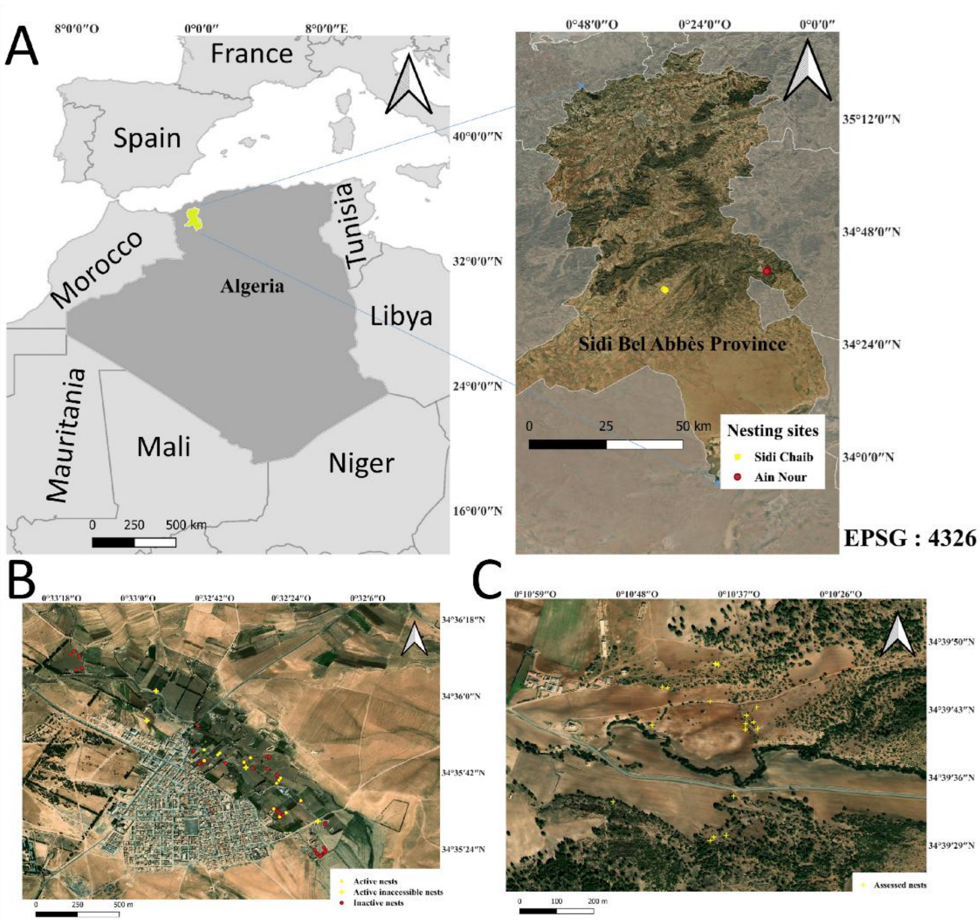

Figure 1. *Distribution of Pica mauritanica nesting sites in Sidi Bel Abbes Province, Algeria. (A) Regional and provincial location maps. (B) Sidi Chaib site showing nest status. (C) Ain Nour site showing assessed nests*

Nest data collection

During the 2023 breeding season, we recorded 74 nest structures across the study area using a GARMIN GPSmap 64 series receiver (WGS84). However, only 13 of these showed clear evidence of breeding activity (eggs or nestlings), and therefore only these active nests were included in the statistical analyses (*Table 1*). Although nests were generally solitary, small groups of closely spaced nests were occasionally observed, consistent with the non-colonial but locally aggregated nesting behavior. For each active nest, we recorded the supporting tree species and measured nest height (ground to base) and clearance to the crown (*Figure 2*). A graduated measuring instrument was placed vertically at the supporting tree so that it appeared in the same plane as the nest; photographs including the visible graduated scale were taken for each nest. Photographs were processed in ImageJ version 5.2: each image was calibrated to the visible scale and the vertical distances from ground level to the nest base, from the nest to the top of the tree, and other relevant vertical measures were measured in ImageJ. Inter-nest distances were computed in QGIS from the recorded GPS coordinates. Radius and width measurements of the nest structure were taken in the field with a measuring tape; nest volume (in liters) was calculated following Soler et al. (1995) using the formula:

$$V = (4/3) \times (\pi \times a \times b2)/1000 \qquad \text{(Eq.1)}$$

where a = maximum radius (cm) and b = half width (cm).

Table 1. *Geographic locations (Latitude and Longitude) of the 13 active nests monitored in this study*

Nest ID	Latitude (DMS)	Longitude (DMS)
Nest 1	34°35′45.48″N	0°32′33.57″W
Nest 2	34°35′39.51″N	0°32′27.46″W
Nest 3	34°35′47.39″N	0°32′44.49″W
Nest 4	34°35′44.44″N	0°32′35.09″W
Nest 5	34°35′46.60″N	0°32′40.77″W
Nest 6	34°35′44.81″N	0°32′44.43″W
Nest 7	34°35′40.20″N	0°32′26.88″W
Nest 8	34°35′40.74″N	0°32′26.47″W
Nest 9	34°35′46.18″N	0°32′41.27″W
Nest 10	34°35′33.51″N	0°32′28.15″W
Nest 11	34°35′31.61″N	0°32′26.76″W
Nest 12	34°35′32.55″N	0°32′25.23″W
Nest 13	34°35′35.39″N	0°32′21.76″W

Figure 2. *Pica mauritanica nesting stages, adult birds, field observation, and rural habitat characteristics in agricultural landscapes*

Reproductive monitoring

Active nests (eggs or nestlings) were checked 2–3× per week using a non-invasive endoscopic camera. Nest locations were recorded with a GPS. The endoscopic camera (5.5 mm probe) was connected to an Android smartphone and recorded images and video, permitting direct visualization of nest contents without disturbing the breeding pair. We recorded dates and counts for first-egg, clutch size, hatching, and fledging (operationally defined as survival to 25 days post-hatch). Photographic documentation and scale references were taken with a Canon EOS 4000D. A complete clutch required no new eggs over two visits; failures were noted when nests were empty prematurely or damage was observed. Incubation was assumed 15 days (Nefla et al., 2021). Predator identity was inferred from nest signs (e.g., snake absence per Klug et al., 2010) and by review of endoscopic footage and photographs. Nest monitoring was carried out until 10 June 2023, marking the end of the final breeding attempt and concluding a 105 day observation period.

Data analysis

Descriptive statistics (mean ± SD, range) characterized nesting and reproductive parameters. To model fledging success (number of fledged chicks), we applied Extreme Gradient Boosting (XGBoost; Chen and Guestrin, 2016) with 100 rounds, max_depth = 6, $\eta = 0.3$, objective = “reg:squarederror,” parallelized on two threads (Rafat, 2024; Laphrom et al., 2024; Rojaz et al., 2024). Predictors were predation metrics (Pred, Pred_eggs, Pred_chicks), nest position (Nest_Ground, Nest_Top), volume (Vol), and nearest-nest distance (Dist_closest_nest). Model performance was evaluated via RMSE (Luo and Li, 2023) and interpreted using Gain and SHAP (SHAPforxgboost; Liu and Just, 2019) to quantify each variable’s contribution. Ecological context informed parameter selection and result interpretation throughout.

Results

Nest characteristics and distribution

All active nests (13) were built in *Lycium shawii* at a mean height of 1.59 ± 0.28 m, with the nest top positioned 0.87 ± 0.43 m below the crown. Nest volumes averaged 0.22 ± 0.06 m³ (range 0.10–0.31 m³). The closest spacing between active nests was 18.5 m, implying a minimum circular territory of 268.7 m² per pair (*Table 2*).

Table 2. *Nest characteristics and spatial distribution of active Pica mauritanica nests in the study area*

Nest characteristics and spatial distribution of active *Pica mauritanica*	
Active nests	13
Replacement clutches	1
Nest height (m) ± SE	1.59 ± 0.28
Nest top (m) ± SE	0.87 ± 0.43
Nest volume (m³) ± SE	0.22 ± 0.06
Nest volume range (m³)	0.10 – 0.31
Distance to the closest nest (m) ± SE	43.19 ± 37.30
Range distance to the closest nest (m)	18.50 – 123.46

Breeding phenology and success

The breeding season spanned 104 days from February 26 to the last fledging. Clutch sizes averaged 5.85 ± 1.34 eggs (77 % of nests held 5–6 eggs). Hatching rate was c. 63%, and 69% of nests fledged at least one chick. Egg laying peaked in early to mid-March (54% of nests), and fledging was concentrated between April 12–22 (67% of chicks). First-egg dates occurred 33 days earlier than at the nearby rural site (Ain Nour). Predation occurring throughout the season was the primary cause of failure, significantly reducing fledging success irrespective of laying date (*Table 3*).

Table 3. *Breeding performance and chronology of Pica mauritanica in the Sidi Chaib colony during the 2023 season*

Breeding performances		**Breeding chronology**	
Range of clutch size	4 - 9	Laying Date Min	26/02/2023
Modal clutch	5 - 6	Laying Date Max	25/04/2023
Total number of eggs laid in the colony	75	Laying Date Range	58
Total number of chicks in the colony	48	Hatching Date Min	12/03/2023
Total number of fledged chicks from the colony	28	Hatching Date Max	08/05/2023
Mean clutch size ± SE	5.85 ± 1.34	Hatching Date Range	57
Egg hatching rate (%)	63.16%	Fledging Date Min	12/04/2023
Hatching success ± SE	3.69 ± 1.80	Fledging Date Max	10/06/2023
Fledging rate (%)	58.33%	Fledging Date Range	59
Fledging success ± SE	2.16 ± 2.15	Season Date Range	104
Breeding success (%)	36.84%		
Egg non-hatching rate (%)	23.68%		

Ecological modeling of fledging success

An XGBoost model trained on all 13 active nests (100 iterations, max_depth = 6, $\eta = 0.3$) rapidly converged (RMSE from 2.03 to 0.0005 by iteration 25) (*Figure 3*).

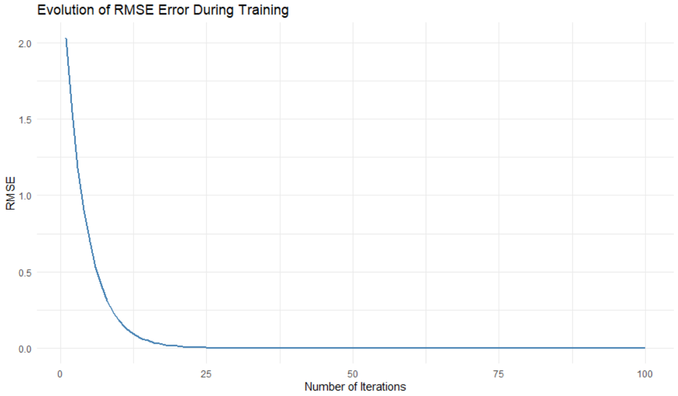

Figure 3. *Evolution of quadratic errors as a function of the number of iterations*

Predation risk (“Pred”) emerged as the strongest predictor (gain = 64.9 %), followed by nest volume (28.8 %) (*Figure 4*).

Predation on eggs and chicks had moderate influence (4.6 % and 1.7 %, respectively), whereas spatial variables (nest height, distance to nearest nest) were negligible. SHAP analysis corroborated these findings (*Figure 5*).

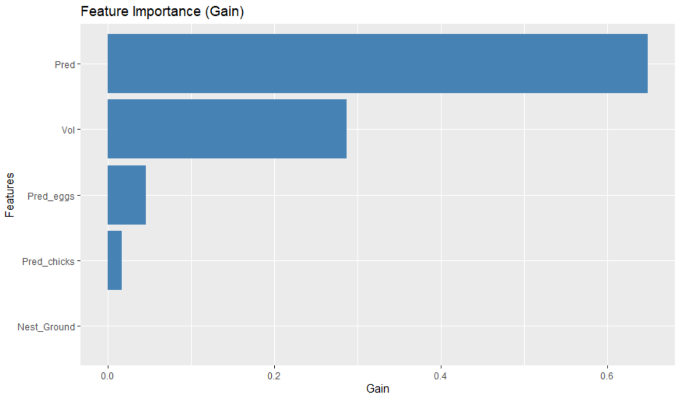

Figure 4. *Relative importance of features during the training phase of the model*

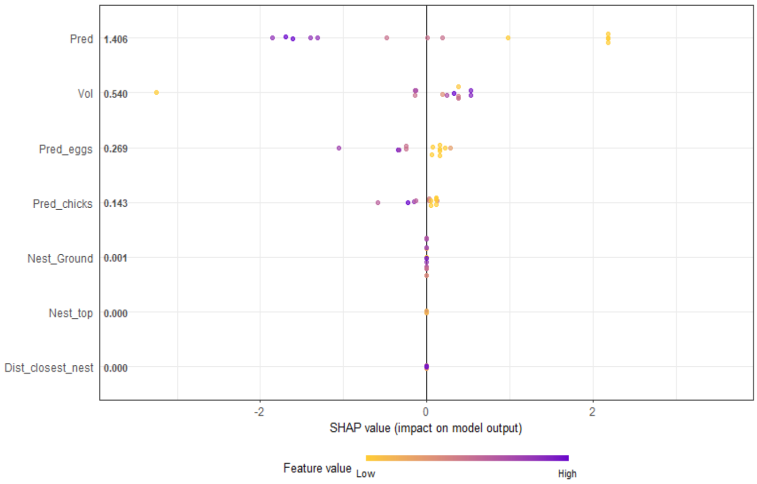

Figure 5. *SHAP value distribution for each feature*

Pred had the highest mean impact (1.41), Vol was second (0.54), and the other features clustered near zero. The model's bias term (2.15) represents the baseline expected outcome before feature effects (*Tables 4 and 5*).

Table 4. *Predation patterns on eggs and chicks of Pica mauritanica in the Sidi Chaib colony*

Predation	
Egg predation rate (%)	19.73%
egg predation ± SE	1.15 ± 1.46
egg predation range	0 - 4
Chick predation rate (%)	43.75%
Chick predation ± SE	1.61 ± 1.76
Chick predation range	0 - 5
Colony predation rate (%)	47.37%
Colony predation ± SE	2.78 ± 2.49
Colony predation range	0 - 6
Mean proportion of eggs predated per nest ± SE	0.20 ± 0.27
Mean proportion of chicks predated per nest ± SE	0.44 ± 0.46
Proportion of Nests Affected by Predation (%)	61.54%
Proportion of Nests Affected by Eggs Predation (%)	46.15%
Proportion of Nests Affected by Chicks Predation (%)	53.85%

Table 5. *Regional comparisons of reproductive metrics (egg size, clutch size, hatching and fledging success) of Pica pica populations in Europe, North Africa, and Asia*

Country	**Egg dimensions (mm) Mean ± SD**	**Average clutch size Mean ± SD**	**Hatching success rate (chicks per egg laid)**	**Fledging success (seedlings per brood) Mean ± SD**	**Laying date**	**References**
Belgium	34.60 ± 23.70	-	-	-	-	Verheyen (1967)
Bulgaria	-	6.38 ± 1.15	0.47	1.57 ± 2.34	Early April	Antonov and Atanasova (2003)
Croatia	33.43 (1.38) x 23.35 (0.52)	5.91 ± 1.08	-	-	-	Dolenec (2000)
Spain	33.10 ± 23.30	6.35	-	1.45	Early April	de Reyna et al. (1984)
Spain	-	6.80 ± 1.14	0.57	1.84 ± 2.28	Mid-april	Ponz and Gil-Delgado (2004)
France	-	5.7	-	-	-	Balanca (1984)
Germany	33.30 ± 23.61	6.7	-	-	-	Hund and Prinzinger (1981)
Germany	-	-	-	1.2	-	Sachteleben et al. (1992)
Japan	-	6.19 ± 1.30	0.62	0.73	Mi-mars	Eguchi (1995)
Kazakhstan	34.50 ± 25.10	6	-	-	-	Smetana (1978)
Netherlands	33.97 (0.16) x 23.94 (0.07)	6.23 ± 0.89	0.54	1.67 ± 1.46	Mid-april	Walters (1988)
Poland	33.33 (2.43) x 22.90 (0.68)	6.00 ± 1.09	-	1.13	Mid-april	Jerzak (1995)
Slovenia	33.60 (2.75) x 23.20 (0.69)	6.00 ± 0.93	-	-	Mid-april	Vogrin (1998)
Tunisia	32.26 (2.05) x 23.01 (3.96)	5.00 (1.09)	0.56	1.69 ± 1.72	Début mars	Nefla et al. (2021)
Uzbekistan	35.50 x 24.10	6.2	-	-	-	Abdreimov (1981)
Great Britain	-	6.15 ± 1.09	0.46	1.72 ± 2.13	Mid-april	Eden (1985)
Great Britain	-	5.60 ±1.44	0.46	1.67	Mid-april	Tatner (1982)
Great Britain	-	-	-	0.69 ± 0.94	Mi-mars	Vines (1981)

Discussion

Our study delivers the first detailed breeding-ecology data for *Pica mauritanica* in northwestern Algeria, revealing clear patterns of nest-site selection, phenology, clutch metrics, and reproductive constraints. Consistent with Nefla et al. (2021), over 83 % of nests were built on *Lycium shawii*, underscoring magpies' tendency to use the most abundant local shrub species (Tatner, 1982; Antonov and Atanasova, 2002) (*Table 1*). The marked preference for thorny vegetation likely reflects a predator-avoidance strategy (Šálek et al., 2020; Ueta, 2001; Ciebiera et al., 2021), as spiny structures both conceal nests and hinder predator access (Šálek et al., 2020).

Breeding chronology in Sidi Chaib commenced earlier than reported for Eurasian magpies (*Table 4*) and Tunisia's *Pica mauritanica* (Nefla et al., 2021). Latitude and temperature gradients are known drivers of laying-date variation (Gibbs, 2007), but our comparison with the rural Ain Nour population which shared latitude yet initiated egg-laying later, suggests peri-urban microclimates mitigate cold-weather delays (Rollinson and Jones, 2002) and that local food availability may further advance laying (Meijer and Drent, 1999; De Neve et al., 2004; Nefla et al., 2021). However, single-season data warrant multi-year monitoring to confirm these drivers.

Clutch sizes in Sidi Chaib fell within the mid-range documented for European and Tunisian populations (*Tables 2 and 4*) (Nefla et al., 2021). Hatching and fledging success here exceeded values from Tunisia's combined 2017–2018 dataset, yet matched 2017 only (Nefla et al., 2021), highlighting potential seasonal or site-specific effects. As in other corvids, reproductive output likely reflects a combination of territory quality (Goodburn, 1991), climatic conditions (Canário et al., 2004), and food resources (De Neve et al., 2004; Ernst, 2015).

Predation emerged as the predominant cause of nest failure. Larger nests, while potentially offering greater insulation, also incur higher visibility and vulnerability to egg predators (Redondo and Castro, 1992; Quesada, 2007; Suvorov et al., 2012) (*Figure 2, Table 3*). Elevated nests may similarly expose eggs and nestlings to both climbing and aerial predators (Šálek et al., 2020) (*Figure 3*). Southern Grey Shrikes (*Lanius excubitor*) were frequently observed preying on magpie chicks, reinforcing interspecific predation dynamics documented by Nefla et al. (2021). Once a nest is discovered, the probability of failure increases steeply (Belkhiri et al., 2024), underscoring predation's cascading impact on fledgling output (*Figure 1*).

Nest predation in *Pica mauritanica* remains incompletely documented in northwestern Algeria; nevertheless, studies of congeneric and regional corvids implicate shrikes (*Lanius* spp.), snakes and small mammals as common nest predators (Nefla et al., 2021). In our study we directly observed predation by *Lanius excubitor* and strongly suspect snake predation on eggs based on characteristic nest damage and parallels with cases reported by Nefla et al. (2021); however, systematic predator identification was not undertaken. Chick-provisioning data from Sidi Chaib are unavailable; comparative studies of related *Pica* species indicate nestlings are provisioned predominantly with arthropods (Coleoptera, Orthoptera, Lepidoptera larvae), supplemented by seeds and occasional small vertebrates, consistent with the genus's opportunistic feeding habits (Díaz-Ruiz et al., 2015).

When overlaid on a backdrop of habitat fragmentation (Mederbal et al., 2024), these biotic pressures amplify local extinction risk. Fragmented peri-urban mosaics limit dispersal and genetic exchange (Lande, 1998), while stochastic events and elevated predation can trigger rapid population decline (Schoener et al., 2001). Anthropogenic land-use change may also introduce or bolster novel predator assemblages (Pyšek et al., 2017), further destabilizing isolated groups.

Conservation implications

Our findings demonstrate that effective conservation of *Pica mauritanica* must integrate both habitat-level management and predator-mitigation strategies. Preserving contiguous, spiny-shrub thickets particularly *Lycium shawii*, will maintain optimal nesting habitat and reduce predation risk. Long-term monitoring of breeding chronology, clutch success, and predator dynamics is essential to capture inter-annual variability and refine predictive models. Ultimately, combining field data with ecological-modeling approaches (e.g., XGBoost with SHAP; Mederbal et al., 2024) offers a powerful toolkit for forecasting reproductive outcomes and guiding targeted management to safeguard this understudied endemic.

Limitations

Several caveats temper our findings. First, the limited sample of 13 active nests from a single season constrains statistical power and may overstate predictor importance in the XGBoost model. Second, geographic scope was restricted to one peri-urban site and a single rural comparison, so generalization across *Pica mauritanica*'s range requires multi-site verification. Finally, nest detection favored more accessible *Lycium shawii* thickets and predator identities were inferred indirectly, introducing potential bias in habitat use and failure-cause estimates.

Conclusion

This investigation fills critical knowledge gaps in the breeding ecology of *Pica mauritanica* by providing the first comprehensive dataset from northwestern Algeria. Our results confirm a strong nesting-site preference for *Lycium shawii* (Tatner, 1982; Antonov and Atanasova, 2002; Nefla et al., 2021) and reveal that peri-urban microclimates and resource availability can advance laying dates by over a month compared to rural conspecifics (Meijer and Drent, 1999; Rollinson and Jones, 2002; De Neve et al., 2004). The mean clutch size and seasonal success rates align with Tunisian and European populations (Gibbs, 2007; Nefla et al., 2021), yet predation emerges as the principal constraint, consistent with prior regional studies (Ueta, 2001; Šálek et al., 2020; Belkhiri et al., 2024). Our machine-learning approach (XGBoost with SHAP) effectively quantified the outsized roles of predation risk and nest volume in fledging outcomes, despite limited sample sizes (Chen and Guestrin, 2016; Liu and Just, 2019).

Conservation efforts should prioritize preserving contiguous *Lycium shawii* thickets to maximize nest concealment and minimize predation, alongside long-term monitoring to capture interannual variability (Goodburn, 1991; Canário et al., 2004; Ernst, 2015). Integrating these field data with advanced ecological modeling (Luo and Li, 2023; Rafat, 2024; Laphrom et al., 2024; Rojaz et al., 2024) offers a powerful framework for forecasting reproductive success under changing land-use and climate scenarios (Hirche et al., 2011; Mederbal et al., 2024). Such predictive tools will be essential for guiding targeted management actions and ensuring the persistence of this emblematic Maghreb endemic.

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