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DISTRIBUTION, POPULATION DYNAMICS AND BREEDING BIOLOGY OF THE WHITE STORK (*CICONIA CICONIA*) IN NORTH-WESTERN ALGERIA

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Abstract. The White Stork (*Ciconia ciconia*) is a widely distributed Palearctic migrant and an established bioindicator of habitat quality. This study examined how environmental and temporal factors shaped its distribution and breeding dynamics in the north-western High Plateaus of Algeria. Monitoring conducted between 2021 and 2023 revealed a marked increase in population size, with the average number of breeding pairs rising from 12.2 to 17.8 across study sites, accompanied by a rise in population density from 2.37 to 3.60 pairs/100 km². These trends appeared closely linked to local habitat conditions, particularly the availability and proximity of foraging sites (3–5000 m from nests), and the agricultural productivity characteristic of the semi-arid landscape. Temporal patterns also emerged as significant determinants of breeding success: mixed-effects modelling showed that interannual variation significantly influenced stork density, hatching rates, and fledgling output, whereas nest-site landscape categories had no detectable effect. Correlation analyses further indicated that higher stork densities were strongly associated with larger breeding populations and greater total fledgling productions, although per-nest productivity remained unaffected. Our findings highlighted the importance of temporal environmental fluctuations, resource availability, and human-mediated landscape features in driving the regional dynamics of White Stork populations. Local community awareness may further contribute to the conservation of this emblematic species in its North African range.

INTRODUCTION

Understanding how long-lived birds respond to environmental variability is a central question in population ecology, particularly in human-dominated landscapes where rapid ecological shifts can alter breeding performance and distribution patterns (Bialas et al. 2025; Moullec et al. 2025). In semi-arid ecosystems, where resource availability fluctuates sharply across space and time, colonial and wide-ranging species offer valuable insights into how ecological pressures shape reproductive strategies and population dynamics (Dobson et al. 2025). Large migratory birds, in particular, provide suitable ecological models because their breeding success integrates local habitat quality, landscape heterogeneity, and broader climatic gradients (Andrade et al. 2025). Against this conceptual background, the White Stork *Ciconia ciconia* (Linnaeus, 1758) stands out as an indicator species capable of reflecting both fine-scale environmental conditions and broader regional ecological change.

The White Stork is a large Palearctic migrant easily recognizable by its contrasting plumage, long red legs, and straight bill. It breeds across wide regions of Europe, western and central Asia, and North Africa (Schmölcke and Thomsen 2025). As a generalist predator, it feeds on a broad range of prey, including insects, earthworms, molluscs, small mammals, amphibians, reptiles, and occasionally small birds (Chenchouni et al. 2015), thus contributing significantly to natural pest regulation and trophic balance in agroecosystems (Mustafa et al. 2025). Its foraging ecology is closely tied to land-use practices, especially agricultural regimes, wetland dynamics and man-made habitats, particularly landfills, making it particularly sensitive to environmental degradation, hydrological change, and habitat fragmentation (Golawski and Kasprzykowski 2021; Bezzalla et al. 2024; Bihałowicz et al. 2024; Bjedov et al. 2025).

The White Stork has long attracted scientific and public interest due to its imposing size, conspicuous nests, and strong cultural symbolism (Kronenberg et al. 2017). Although research on the species spans several decades, behavioural studies remain surprisingly limited (Bocheński and Jerzak 2006). This gap is especially evident in regions outside Europe, where breeding conditions differ markedly and where the species' ecological responses to climate, food availability, and human activity may follow distinct patterns (Chenchouni 2017b; Hmamouchi et al. 2020; Athamnia et al. 2022). These deficiencies are more pronounced in North Africa, particularly the High Plateaus of Algeria, where environmental conditions differ substantially from the well-studied European breeding territories. The High Plateaus constitute a transitional zone between Mediterranean and Saharan climates characterized by recurrent drought, unpredictable rainfall, and rapid land-use change (Negm et al. 2020; Amrouni et al. 2022), all of which are likely to influence breeding ecology and colony stability (Si Bachir et al. 2013). These ecological contrasts, combined with growing anthropogenic pressures, highlight the need for region-specific assessments of the species' reproductive biology and population trends.

On a global scale, numerous studies have examined the demographic patterns and long-term monitoring of White Stork populations. The landmark work of Schulz (1999), based on coordinated international censuses in 1984 and 1994/1995, provided the first comprehensive overview of the species' distribution and population status. Subsequent research (Tortosa et al. 2002; Peris 2003) strengthened understanding of the factors shaping population dynamics in Europe. These studies highlighted that European populations are strongly influenced by environmental conditions in African wintering grounds, linking breeding success to migration ecology and climate variability (Tryjanowski et al. 2002, 2024). More recent analyses have drawn attention to shifts in migratory strategies, changes in wintering areas, and altered breeding phenology driven by global climate change, agricultural intensification, and modifications in food availability (Schmölcke and Thomsen 2025). These findings illustrate the species' capacity for behavioural flexibility, but also underline its vulnerability to ecological disruption (Bjedov et al. 2025), which emphasizes the need for up-to-date regional studies capable of detecting fine-scale environmental effects on breeding performance (Martins 2024).

In Algeria, the White Stork's breeding distribution and population structure have been monitored for more than three decades. The first national-scale census dates back to 1993 (Moali-Grine et al. 1995) and was followed by several complementary studies focusing on regional population trends, nest-site selection, and habitat occupation (Moali-Grine et al. 2004; Moali-Grine 2009; Moali-Grine et al. 2013; Djerdali 2010; Si Bachir et al. 2013; Chenchouni 2017a; Khelili 2019; Touati et al. 2023). Although the species is well studied in Europe, its ecology in North Africa remains insufficiently documented. From 2011 to 2022, long-term monitoring in the Algerian High Plateaus revealed important fluctuations in breeding success and colony structure, underscoring the scientific value of African populations for conservation planning (Si Bachir et al. 2013; Chenchouni 2017b; Athamnia et al. 2022). Despite this growing body of research, many aspects remain poorly understood, including how landscape composition around nest sites, annual climatic variability, and human pressures interact to shape colony performance. Furthermore, little attention has been devoted to understanding how breeding parameters such as productivity, fledging success, and colony density covary under the ecological constraints of semi-arid steppe environments (Chenchouni 2017a; Khelili 2019).

Given these knowledge gaps, there is a strong need for integrative studies combining descriptive population monitoring with analytical approaches capable of disentangling environmental and temporal influences on breeding success. This is particularly relevant in the High Plateaus of Algeria, where rapid agricultural expansion, land abandonment, and climatic instability (Amrouni et al. 2022) may be reshaping the ecological conditions faced by White Stork colonies. The present study contributes to filling this gap by linking field-based breeding data with quantitative analyses designed to clarify how density-dependent processes and habitat context influence reproductive performance in western Algeria.

As a recognized bioindicator of habitat quality (Arizaga et al. 2022; Bjedov et al. 2023, 2025), the White Stork exhibits ecological flexibility comparable to other synanthropic species that succeed in landscapes shaped by human activity (Chedad et al. 2021). Its dependence on a mosaic of agricultural fields, wetlands, pastures for foraging, and anthropogenic structures for nesting renders it particularly responsive to environmental fluctuations, making the species an insightful model for evaluating ecological conditions in semi-arid steppe regions. Building on this ecological relevance, the present study investigated the distribution and breeding performance of the White Stork across the High Plateaus of western Algeria, particularly within the provinces of Tiaret and Tissemsilt. The research aimed to understand how temporal variation and landscape context influence colony structure and reproductive output, while also clarifying the extent to which breeding parameters covary across space and time. Specifically, the study addresses the following questions: (i) How do stork density and key reproductive metrics covary within and among colonies and what do these correlations reveal about local breeding constraints? (ii) To what extent do annual fluctuations and differences in nest-site landscape (rural, or urban) shape variation in breeding parameters? (iii) Does the interaction between year and landscape produce detectable shifts in colony performance, reflecting the sensitivity of the species to environmental instability? To answer these questions, we examined linear associations among core breeding metrics using Pearson correlation analysis and evaluated temporal and landscape effects through generalized linear mixed-effects models (GLMMs). These approaches enabled a robust investigation of the ecological drivers underpinning White Stork breeding success, while offering insights into how environmental change and human-modified habitats may continue to influence the species across the Algerian High Plateaus.

MATERIALS AND METHODS

Study area

The study area covered a total surface of 23,151.37 km² across the cities of Tissemsilt and Tiaret, including five municipalities: Tissemsilt, Khemisti, Hamadia, Sidi Hosni, and Machraa Safa (Figure 1). Situated in north-western Algeria on the High Plateaus, this region forms a transitional zone between the Tellian Atlas and the Saharan Atlas. It is characterized by a semi-arid bioclimate, with average temperatures ranging from 5°C to 25°C and annual precipitation concentrated at higher elevations of 400–500 m (Amrouni et al. 2022).

The area is widely recognized for its ecological and economic significance, particularly as an extensive steppe ecosystem and a highly productive agricultural landscape. The steppe vegetation is dominated by xerophytic and hemicryptophytic species adapted to arid conditions, with *Stipa tenacissima* L. and *Artemisia herba-alba* Asso forming the characteristic plant cover. These are accompanied by other drought-tolerant taxa such as *Lygeum spartum* Loefl. ex L., *Atractylis serratuloides* Cass., and scattered shrubs including *Retama sphaerocarpa* (L.) Boiss. This mosaic of perennial grasses, chamaephytes, and open shrublands reflects the typical structure of Algerian High Plateau steppes and underpins the region's ecological productivity and pastoral value (Chenchouni et al. 2025).

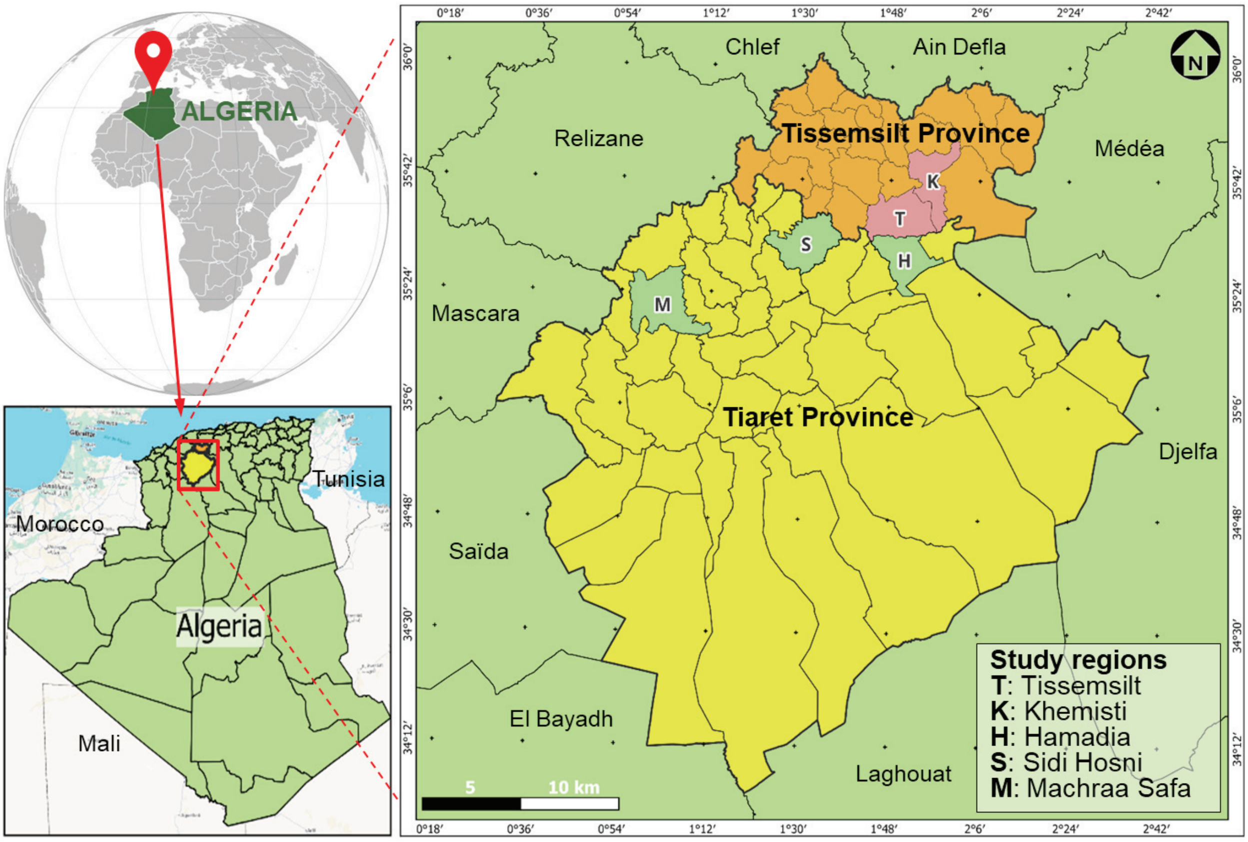

Figure 1. Geographic location of the study regions in the provinces of Tissemsilt and Tiaret in north-western Algeria.

White Stork census

The assessment of the White Stork's distribution area was carried out to supplement historical information on nest density and population censuses (Moali-Grine et al. 2013). However, the precision of nest locations was occasionally limited, as some sites were recorded using descriptive information rather than exact GPS coordinates. To ensure consistency and reliability in subsequent analyses, all spatial data were standardized to a uniform resolution. Surveys conducted in the study area employed a direct assessment methodology, consistent with protocols used in European White Stork monitoring programs (Schulz 1999). This approach involved multiple successive visits to nesting sites, from the arrival of the first storks in December until their departure in August, with nest occupancy determined based on the presence of individuals and field observations. Additional information was gathered from local communities and authorities to refine the census results.

Historically, White Stork populations in North Africa experienced declines followed by periods of notable growth. In Algeria, population counts since the early censuses conducted by Bouet (1936, 1956) and Bloesch (1989) documented significant increases between 1995 and 2001 and again in 2007. These censuses were supported by the forestry services, which established organizational structures and personnel across most localities to facilitate monitoring (Mammeria et al. 2012; Moali-Grine et al. 2013; Mammeria et al. 2019). In the present study, censuses conducted in north-western Algeria from 2021 to 2023 covered five communes across the provinces of Tissemsilt and Tiaret. This region has been relatively understudied, and the scarcity of data is further compounded by research restrictions imposed during the COVID-19 pandemic, which limited fieldwork and monitoring activities.

To ensure the reliability of our results based on the available data, we used the parameters defined by Schulz (1999):

- HPa: Number of breeding pairs,
- HPm: Number of successful breeding pairs,
- HPx: Number of breeding pairs with unknown success,
- JZG: Total number of fledged young.

Based on the compiled data, the following values were calculated:

- JZa: Productivity (breeding success): the mean number of fledged young per breeding pair (JZG/HPa),
- JZm: Mean fledged brood size: the mean number of fledged young per successful nest (JZG/HPm),
- Std: Stork density or population density: the number of breeding pairs (HPa) per 100 km².

The number of adult and juvenile individuals per breeding pair was estimated through direct field observations using a Canon EOS Rebel T6 camera, complemented by information obtained from local residents. Nest locations and altitudes were recorded with a GPS device (GPS Coordinates 6.23(370)) and the UTM Geo Map 4.2.7 application. All nests were photographed to support documentation, and spatial maps of nest distribution were generated using GIS software. Food availability and foraging behaviour were assessed by observing individual White Storks during feeding activities, with detailed notes and photographs taken to document foraging strategies and habitat use.

Statistical analysis

Pearson correlation analyses were performed to assess the relationships between stork density and key breeding parameters. Stork density (Std), expressed as the number of breeding pairs per 100 km², was tested against other breeding parameters including HPa, HPm, HPx, JZg, JZa, and JZm. The spatial resolution the data used in the analysis was set at the colony size. Prior to analysis, all variables were examined for normality to ensure compliance with the assumptions of the Pearson test. Correlation coefficients (r) and corresponding significance levels (p-values) were computed to determine the strength and direction of linear associations between parameters. The threshold of significance was set at alpha = 0.05. All statistical analyses were conducted using standard procedures for parametric correlation testing.

A set of generalized linear mixed-effects models (GLMM) was fitted to evaluate the influence of the year, nest site landscape, and their interaction on the six breeding performance variables (Std, HPa, HPm, HPx, JZg, JZa, and JZm). For each response variable, a mixed model was implemented using the lme function from the {nlme} package version 3.1–168 in R software version 4.5.1 (R Core Team 2025), specifying 'nest site' as a random intercept to account for non-independence among observations from the same locality. Fixed effects included the main effects of the year and landscape, as well as their interaction. Model outputs were examined through standard summaries, and significance testing of fixed effects was conducted using *Type II F*-tests via the 'Anova()' function. This approach allowed robust assessment of temporal and environmental influences while properly modelling the hierarchical structure of the data.

RESULTS

Nest location and distribution

Our surveys and monitoring of White Stork nests used a GPS device to record the latitude and longitude coordinates of each nest to visualize nest distribution (Figure 2). The site preview has revealed that the nests were located across rural, urban, and mixed landscapes, as nest clustering was observed in some areas, while some nests were dispersed and scattered in others. This appeared to correlate with the availability of food resources in foraging sites used by the White Stork, such as dump rubbish, landfill and agro-fields.

Furthermore, climatic conditions and the region's agricultural potential have provided essential resources for White Stork reproduction. Additionally, human activities such as the presence of waste dumps have offered alternative food sources that align with the stork's opportunistic diet, which made this study contribute to understanding the species' distribution and bioecological aspects by identifying key environmental and anthropogenic factors. Our findings have offered valuable insights and contributed to the regional ornithological research, which enriched the limited documentation of White Stork's studies in this region.

Population dynamics of the White Stork according to the number of breeding pairs

Though population dynamics of the White Stork have been extensively studied in its range, regular updates through censuses were deemed necessary to assess its status in Tiaret and Tissemsilt, as these regions remain insufficiently investigated despite their high ecosystem potential for storks' breeding. The number of White Stork nests has increased in different habitat types in the region. The census operation covered 356 individual White Storks across five sites over three consecutive years, starting in 2021 and concluding in 2023.

Stork density (Std) and HPa exhibited clear temporal increases across all study sites from 2021 to 2023 (Figure 3). In 2021, population density ranged from 1.09 pairs/100 km² in Hamadia to 3.88 pairs/100 km² in Sidi Hosni, whereas by 2023, densities rose markedly, reaching 2.33 and 5.58 pairs/100 km² in Machraa Safa and Sidi Hosni, respectively. Correspondingly, the number of breeding pairs increased at all sites, with Sidi Hosni supporting 16 pairs in 2021 and 23 pairs in 2023, while the numbers in Tissemsilt rose from 10 to 18 pairs over the same period.

The HPm followed a similar pattern, indicating that the majority of nests remained productive across the study years. This HPa increase reflected a combination of anthropogenic and ecological factors: the expansion of urban infrastructure, including telecommunication and electrical pylons, provided additional nesting platforms; in rural areas, local awareness and positive cultural attitudes toward wildlife promoted species protection; and the reduced human activity during the COVID-19 lockdown period offered a calm and favourable environment for breeding. These results demonstrate a notable expansion of the White Stork population in the High Plateaus, reflecting both an increase in local abundance and successful colony persistence over time (Figure 3).

Despite these increases in population size, measures of per-nest reproductive output remained relatively stable throughout the study period. Productivity (JZa), expressed as the mean number of fledglings per breeding pair, remained close to two fledglings per pair across all sites and years, while JZm also showed minimal variation, generally ranging between 2 and 2.5 fledglings per successful nest (Figure 3). The JZg, however, increased in parallel with population growth, rising from 32 in Sidi Hosni in 2021 to 46 in 2023, reflecting a higher number of active nests rather than changes in per-nest success. The observed population growth was closely tied to the rise in stork density and the increasing number of breeding pairs, rather than improvements in individual reproductive performance, underscoring the role of habitat availability, human tolerance, and ecological opportunities in shaping local population dynamics.

Breeding dynamics across years and nest-site landscapes

Across the three breeding seasons, White Stork population density and reproductive parameters showed a clear temporal variation (Table 1). Stork density increased steadily from 2.37 ± 1.25 pairs per 100 km² in 2021 to 3.61 ± 2.02 in 2023. Similarly, HPa and HPm rose over time, from 12.20 ± 3.70 and 12.20 ± 3.70 in 2021 to 17.80 ± 3.27 and 17.80 ± 3.27 in 2023, respectively. The JZg also increased from 24.60 ± 7.06 in 2021 to 35.60 ± 6.54 in 2023, while JZa and JZm remained relatively stable around 2.0–2.1 fledglings, indicating that per-nest reproductive output did not fluctuate markedly despite population growth (Table 1). These results suggest that the observed increase in population size over the three years primarily reflected larger colony sizes rather than changes in per-nest productivity.

When examining the influence of nest site landscape, both rural and urban environments supported comparable breeding outcomes. Rural sites exhibited slightly higher stork density (3.19 ± 1.86) and total fledglings (29.50 ± 12.52) compared to urban sites (2.65 ± 1.49 and 28.67 ± 5.83, respectively), but differences were minor. Across years and landscapes, the interaction between temporal and spatial factors did not markedly affect breeding performance, as similar trends in density and reproductive parameters were observed in both rural and urban settings (Table 1). Overall, these findings highlight that interannual variation exerted a stronger influence on population size and reproductive output than the type of nest-site environment, reinforcing the importance of temporal drivers in shaping White Stork breeding dynamics in the High Plateaus of western Algeria.

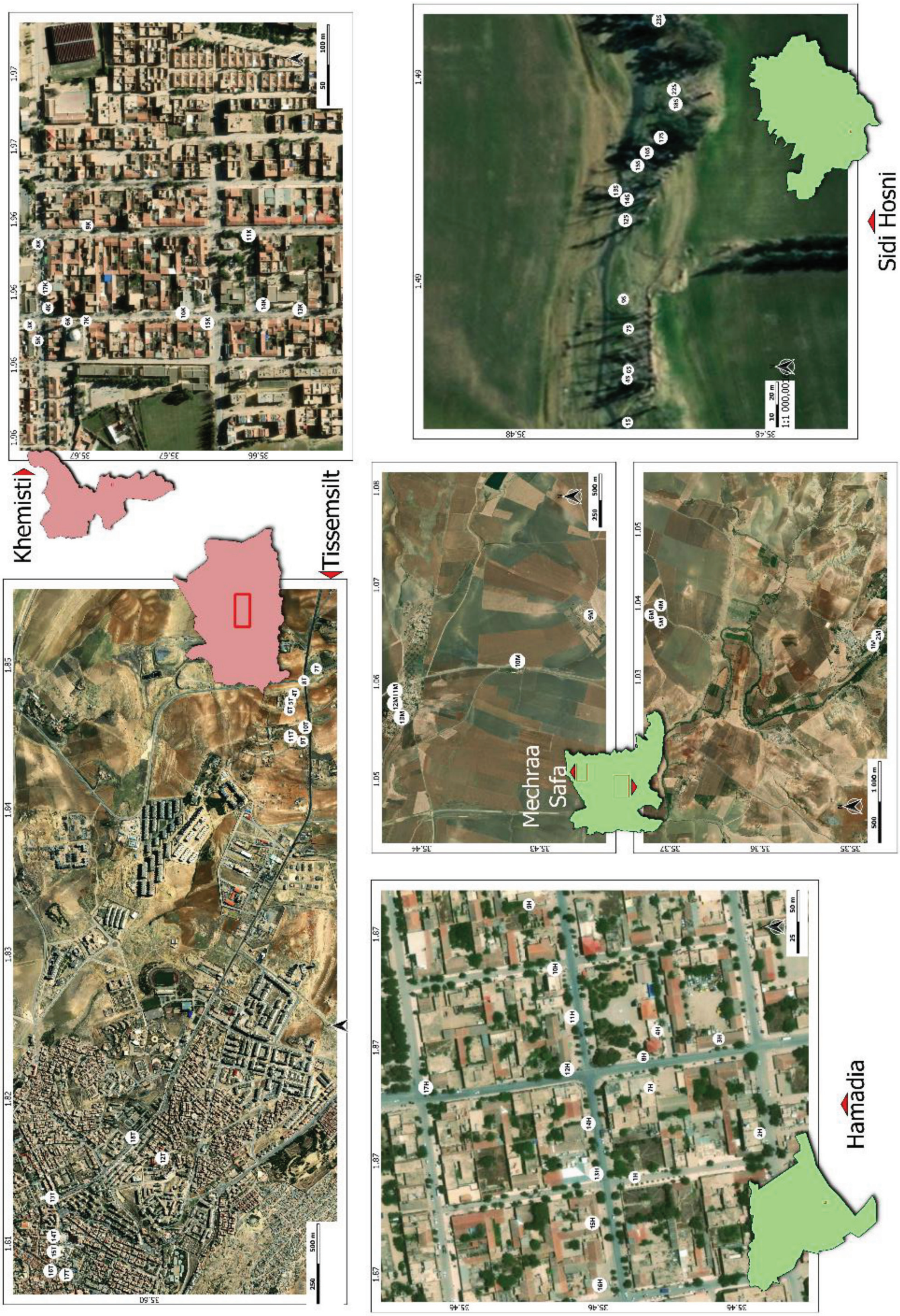

Figure 2. The study area map for the location and distribution of occupied White Stork nests.

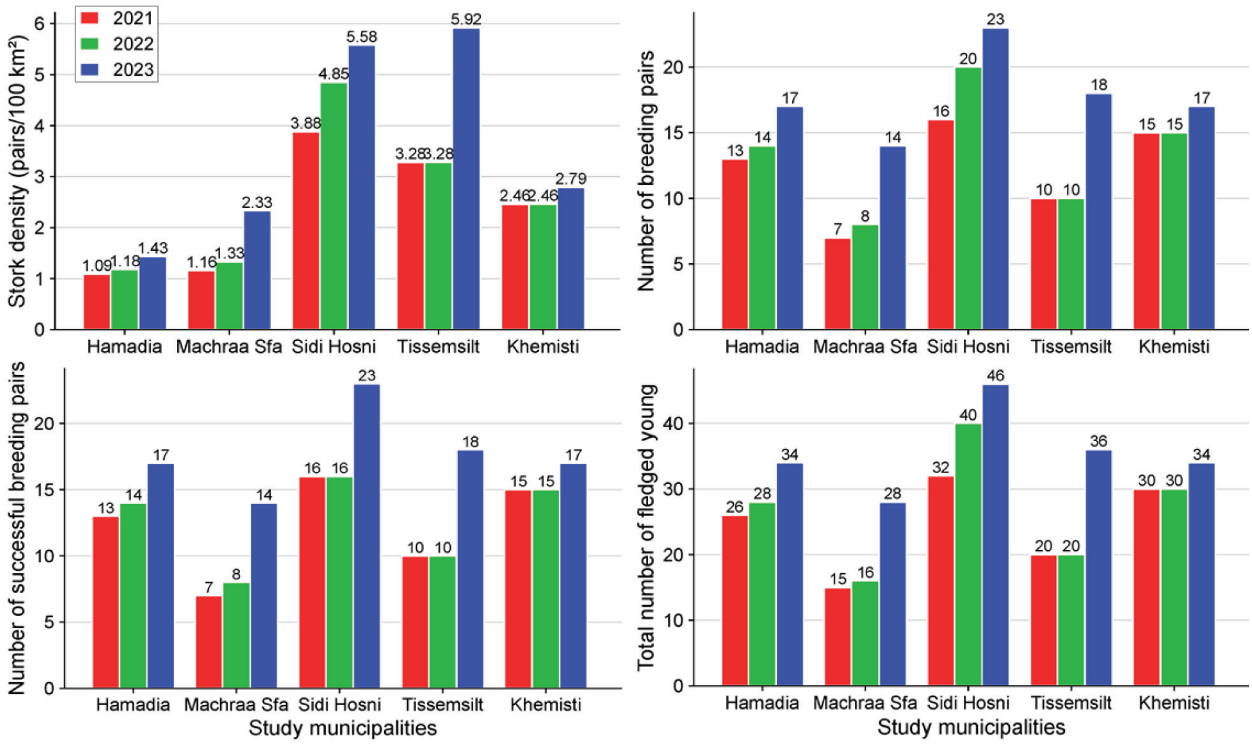

Figure 3. Temporal variation in White Stork population density and breeding parameters across five municipalities of western Algeria during the 2021–2023 breeding seasons.

Table 1. Breeding parameters of the White Stork breeding in north-western Algeria. Data were expressed as means ± standard deviations grouped for surveyed years and nest site landscapes. Statistics of the generalized linear mixed-effects models (GLMM) are expressed as χ^2 and *p*-value.

Variables	Level	Breeding parameters					
		Std	Hpa	HPm	Jza	JZg	JZm
Study year							
Year	2021	2.37 ± 1.25	12.20 ± 3.70	12.20 ± 3.70	2.03 ± 0.06	24.60 ± 7.06	2.03 ± 0.06
Year	2022	2.62 ± 1.51	13.40 ± 4.67	12.60 ± 3.44	2.00 ± 0.00	26.80 ± 9.34	2.10 ± 0.22
Year	2023	3.61 ± 2.02	17.80 ± 3.27	17.80 ± 3.27	2.00 ± 0.00	35.60 ± 6.54	2.00 ± 0.00
Nest site landscape							
Landscape	Rural	3.19 ± 1.86	14.67 ± 6.38	14.00 ± 5.90	2.02 ± 0.06	29.50 ± 12.52	2.11 ± 0.20
Landscape	Urban	2.65 ± 1.49	14.33 ± 2.92	14.33 ± 2.92	2.00 ± 0.00	28.67 ± 5.83	2.00 ± 0.00
Year × landscape							
2021	Rural	2.52 ± 1.92	11.50 ± 6.36	11.50 ± 6.36	2.07 ± 0.10	23.50 ± 12.02	2.07 ± 0.10
2021	Urban	2.28 ± 1.11	12.67 ± 2.52	12.67 ± 2.52	2.00 ± 0.00	25.33 ± 5.03	2.00 ± 0.00
2022	Rural	3.09 ± 2.49	14.00 ± 8.49	12.00 ± 5.66	2.00 ± 0.00	28.00 ± 16.97	2.25 ± 0.35
2022	Urban	2.31 ± 1.06	13.00 ± 2.65	13.00 ± 2.65	2.00 ± 0.00	26.00 ± 5.29	2.00 ± 0.00
2023	Rural	3.96 ± 2.30	18.50 ± 6.36	18.50 ± 6.36	2.00 ± 0.00	37.00 ± 12.73	2.00 ± 0.00
2023	Urban	3.38 ± 2.30	17.33 ± 0.58	17.33 ± 0.58	2.00 ± 0.00	34.67 ± 1.15	2.00 ± 0.00
Overall (years and landscapes combined)							
Overall	Total	2.87 ± 1.60	14.47 ± 4.41	14.20 ± 4.16	2.01 ± 0.04	29.00 ± 8.69	2.04 ± 0.13

Std: White Stork density per 100 km², Hpa: number of active nests or breeding pairs, HPm: mean number of hatchlings per nest, Jza: number of fledglings that successfully leave the nest, JZg: total number of juveniles produced on a colony scale, and JZm: mean number of fledglings per breeding pair.

Spatio-temporal drivers of breeding performance

The generalized linear mixed-effects models revealed that the year exerted a significant influence on most breeding parameters (Table 2). Temporal variation affected stork density (Std: $p = 0.002$), the number of hatched eggs per active nest (HPa: $p < 0.001$), the number of hatchlings per monitored nest (HPm: $p < 0.001$), and the number of fledglings per successful nest (JZg: $p < 0.001$). In contrast, landscape did not show a significant effect on any of the reproductive variables, indicating that nest-site environmental categories did not independently shape breeding outcomes. The interac-

Table 2. Generalized linear mixed-effects models (GLMM) testing the variation of breeding parameters of the White Stork across the years, nest-site landscapes and their interaction. Summary statistics of each model are expressed as χ^2 and *p*-value.

Variables	Statistics	Breeding parameters					
		Std	Hpa	HPm	Jza	JZg	JZm
Year (Yr)	χ^2	9.701	24.436	18.630	1.920	22.741	0.114
	p-value	0.002	<0.001	<0.001	0.166	<0.001	0.735
Landscape (Ls)	χ^2	0.110	0.007	0.010	1.800	0.012	2.314
	p-value	0.740	0.932	0.923	0.180	0.914	0.128
Yr × Ls	χ^2	0.168	1.018	0.776	2.880	0.783	0.171
	p-value	0.682	0.313	0.378	0.090	0.376	0.679

Std: White Stork density per 100 km², Hpa: number of active nests or breeding pairs, HPm: mean number of hatchlings per nest, Jza: number of fledglings that successfully leave the nest, JZg: total number of juveniles produced on a colony scale, and JZm: mean number of fledglings per breeding pair.

tion between the year and landscape was likewise non-significant across all parameters, although a marginal trend was observed for fledglings per active nest (JZa: $p = 0.090$). These results suggested that interannual variability, rather than landscape type or its interaction with time, primarily drove fluctuations in White Stork breeding performance across the study area.

Relationship between stork density and reproductive parameters

The correlation analysis revealed clear associations between stork density and some reproductive parameters (Figure 4). Stork density showed a strong and statistically significant positive relationship with both the number of breeding pairs ($r = 0.66$, $p = 0.008$) and the number of successful breeding pairs ($r = 0.61$, $p = 0.016$), indicating that areas with higher densities tended to support larger breeding populations and a greater number of successful nests.

A similarly strong and significant correlation was observed between stork density and the total number of fledged young ($r = 0.66$, $p = 0.008$), suggesting that denser populations also produced more fledglings overall. In contrast, stork density was not significantly related to productivity per breeding pair (JZa: $r = -0.29$, $p = 0.29$) or mean fledged brood size (JZm: $r = 0.25$, $p = 0.36$), indicating that higher population density did not translate into greater reproductive output at the nest level. Likewise, the correlation between stork density and the number of breeding pairs with unknown success (HPx) was weak and non-significant ($r = 0.34$, $p = 0.21$). The results of correlation highlighted that density was closely tied to the scale of the breeding population and total fledgling production, but not to per-nest reproductive performance.

Proximity of foraging sites

The observed increase in the White Stork population in the cities of Tiaret and Tissemsilt in recent years, as revealed above, could be explained by the proximity of foraging sites to nesting areas (Figure 5). In rural areas, this distance ranged from 3 m to 1000 m and included agricultural fields and water ponds, locally known as '*Merdja*'.

In contrast, in urban and mixed landscapes, the distance ranged from 500 m to 5000 m, with foraging sites consisting of rubbish dumps and small swamps formed by rainfall, wind, and runoff. These food availability conditions might play a significant role in the population growth dynamics.

DISCUSSION

This study offered one of the most comprehensive recent assessments of White Stork breeding ecology in the north-western High Plateaus of Algeria, a region that has remained largely understudied despite its high ecological potential. It integrated systematic censuses over three consecutive breeding seasons with detailed spatial analyses of nest distribution and habitat structure. This work provided new insights into the drivers underpinning local population dynamics in semi-arid landscapes. The use of standardized survey protocols, precise geolocation of nests, and the combined evaluation of demographic parameters enabled us to document not only the notable resurgence of the species in this region but also the mechanisms that facilitated this expansion. Importantly, the study revealed how landscape configuration, food availability, and anthropogenic features interact to shape colony establishment and reproductive output. Through this multi-scale analytical approach, our findings advance the current understanding of how a long-distance migratory species responds to changing environmental conditions in North Africa and position the High Plateaus as an emerging stronghold for White Stork conservation. The White Stork has a wide breeding distribution across Europe (Shephard et al. 2013) and commonly nests in the Mediterranean part

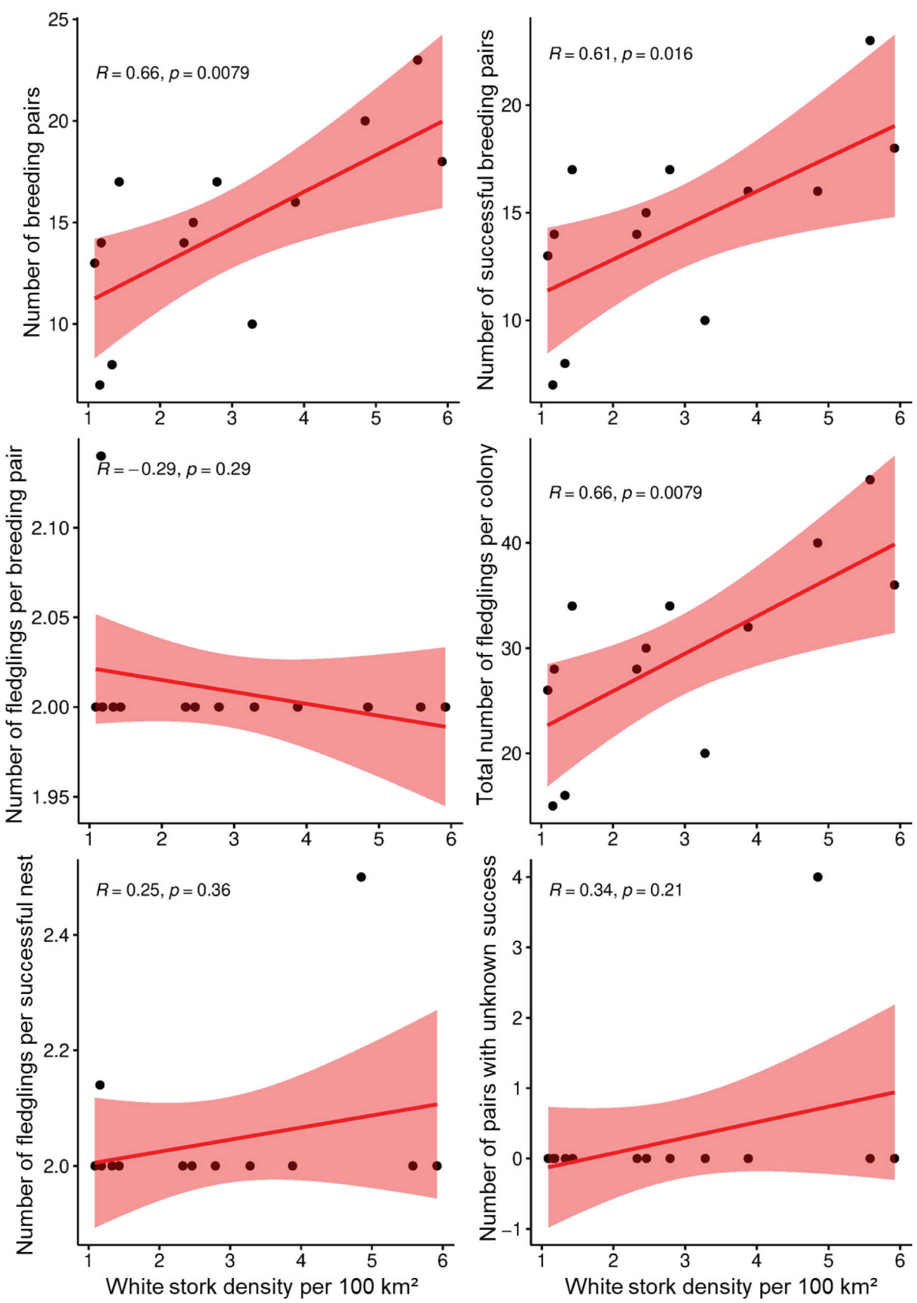

Figure 4. Scatterplot correlations between stork density and six breeding performance parameters. The solid red lines represent fitted linear model regression curves with 95% confidence intervals in light red. Pearson correlation tests are summarized using *R* (correlation coefficient) and *p* (*p*-value).

of Algeria, from the coastal plains to the steppe, which is characterized by a mosaic of habitats. In Algeria, the White Stork mainly inhabits humid, sub-humid, and semi-arid regions, although some colonies are also found in hot-arid conditions (Mammeria et al. 2019; Chenchouni 2017a).

Our results on nest location and distribution suggest that the ecological characteristics of our region make it an important area for attracting White Storks for breeding. The climatic conditions of the semi-arid zone, along with the landscape's potential, support this distribution. Furthermore, weather conditions in both the breeding areas and the African wintering grounds such as early warming periods and habitat changes associated with agricultural intensification and other anthropogenic factors influence the population dynamics of the White Stork (Tobolka et al. 2018; Wuczyński et al. 2021).

The distribution of White Stork nests in the five study sites varies between clustering and dispersion, depending on the type of environment (urban or rural) where we observed a greater concentration of nests in urban areas, notably in Hamadia, Tissemsilt and Khemisti, while Machraa Sfa, a rural area, shows a more marked dispersion. However, Sidi Hosni, although a rural area,

Figure 5. Photographs showing: A. a White Stork foraging next to a Common Raven (*Corvus corax* Linnaeus, 1758) in a rubbish dump in Tissemsilt. B. general view of a wild garbage dump in Machraa Safa. C. a White Stork foraging in a recently tilled agricultural field in Machraa Sfa. D. a White Stork foraging near a Wadi within agricultural fields in Sidi Hosni.

also shows a significant clustering of nests. This can be explained by the availability of foraging points in the region, particularly in private agricultural fields and the Merdja wetland. At the same time, in urban areas, the presence of these points of food supply are often associated with landfill sites and household waste.

The availability of food resources likely has a direct influence on the distribution of nests. Indeed, the White Stork is an opportunistic predatory species with a high trophic potential, which breeds and feeds mainly in agricultural areas (Orłowski et al. 2026) as well as in rubbish dumps (Mikula et al. 2024). In Algeria, varying numbers of breeding pairs in the northern regions were reported by previous authors since the first censuses conducted by Bouet (1936 and 1956), followed by Bloesch (1989) and later by Moali-Grine (1994) and Mammeria et al. (2019).

White Stork populations may increase or decrease depending on environmental conditions that either support their development or contribute to their decline (Goriup and Schulz 1991). In North Africa, an increase in stork numbers was noticed between 1995 and 2001, although continued fluctuations were seen until 2007 (Moali-Grine 2009; Mammeria et al. 2012). Specifically, in the Tissemsilt region the numbers of breeding pairs were reported rising from four individuals in 1995 to nine individuals in 2001, then declining back to four individuals in 2007. Corresponding population densities were recorded as 0.12/100 km² (1995), 0.28/100 km² (2001), and 0.27/100 km² (2007). The Tissemsilt region shares similar ecological conditions with its western neighbouring area as Tiaret (Moali-Grine et al. 2013).

The recent increase in White Stork population dynamics in our region (2021–2024) may be explained by the effects of climate change observed since 1994 through the late 2000s, particularly in our semi-arid bioclimatic zone (DGF 2023). The early onset of high temperatures and delayed winters allows White Storks to remain in the region for up to 9 months per year. In addition, increased food availability contributes to this trend. These factors likely explain a significant rise to 89 breeding pairs recorded in 2023, with a population density of 3.59/100 km². Both the size and geographic distribution of species globally were profoundly altered by such external factors (López-García and Aguirre 2023).

This increase of White Stork population relates to breeding and population dynamics. It is important to monitor changes that may provide significant insights into long-distance migratory birds and their possible responses to climate change. Indeed, a common concern is that the impact of global warming on communities may lead to a decoupling of phenological relationships between species and their prey, resulting in mismatches and population decline (Durant et al. 2007; Møller et al. 2008). Many birds, including White Storks, regularly rely upon urban food subsidies during the breeding season (Gilbert et al. 2016; Evans et al. 2020; Martins 2024). Feeding conditions in both the breeding and wintering areas and on the migration routes are considered responsible for the global and regional changes in the population size of the White Stork. Nevertheless, a strong dependence of White Storks on food wastes entails other perils (Wuczyński et al. 2021; Athamnia et al. 2022).

The presence of reliable, human-generated food sources near landfills attracts opportunistic bird species to breed nearby, this reduces foraging effort and explains the short distances to feeding sites observed in our region, ranging from as little as 3 m to as much as 5000 m in some locations. As a result, birds can invest more in parental care and improve the survival of their offspring (López-García and Aguirre 2023). Considerable attention on the relationship between the diet of the White Stork and the types of foraging habitat and their availability of food resources was received by researchers (Alonso et al. 1991; Boukhemza et al. 2006; Sbiki 2017). However, the presence of various anthropogenic waste items was revealed by the analysis of regurgitated pellets that are used to study the diet (Bjedov et al. 2024), which explains the storks' attraction to landfills as a food source. The results remain inconclusive when considering spatiotemporal variations as well as the species' nutritional requirements (Chenchouni 2017b).

CONCLUSION

This study examined the spatial distribution, population dynamics, and breeding performance of the White Stork (*Ciconia ciconia*) across the High Plateaus of western Algeria by using multi-year field surveys and quantitative analyses. It further assessed nest occupancy patterns and reproductive success in relation to environmental and anthropogenic factors shaping this semi-arid landscape. The recent population increase is a significant finding, especially given the previous lack of monitoring of this species within this potentially important ecosystem. This development serves as a strong indicator that the breeding of the White Stork may mark a new chapter in the region's ecological history. Moreover, its presence could revitalize the socio-economic landscape by enhancing the value of agro-landscapes and urban expansion, as well as promoting biodiversity-related benefits. To accomplish the conservation of the White Stork, we must also include preserving and restoring natural wetlands while promoting customary agricultural practices and develop sustainable solutions to ensure that future generations are able to continue witnessing the spectacle of White Storks soaring over the North African skies. As a transboundary migratory species, the White Stork requires international cooperation related to biodiversity conservation, climate change, and the coexistence of humans and nature.

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Author Contribution

Soulaf Aicha Beldjouher: Conceptualization, Data Curation, Funding Acquisition, Investigation, Methodology, Resources, Visualization, Writing – Original Draft, Writing – Review & Editing. Djamel Bendjoudi: Conceptualization, Methodology, Project Administration, Supervision, Validation. Abdelwahab Chedad: Supervision, Validation, Writing – Review & Editing. Haroun Chenchouni: Formal Analysis, Visualization, Writing – Original Draft, Writing – Review & Editing.

Conflict of interests

The co-authors report no conflicts of interest.

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Data availability

The data used to support the findings of this study are included within the article.

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