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Breeding range expansion of White Storks *(Ciconia ciconia)* in the Algerian Sahara: Adaptation to hot hyper-arid environments

Messaoud Gueddoul[1,2,3]*, Aicha Mouane[1], Mehdi Selmane[1,2], Abdelwahab Chedad[4] & Abdelhakim Bouzid[5,6]

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Abstract The breeding population of the White Stork in Algeria has historically been confined to the northern part of the country. During the 2025 breeding season (February to June), confirmed nesting occurred in El Oued (2 nests), Ouled Djellal (1 nest), and Menea (1 breeding attempt in 2003) provinces. The observed Southward expansion of the White Stork breeding population into the hot and hyper-arid climate of the Sahara represents a notable ecological shift in its known breeding range. Moreover, old datasets and historical records further indicate significant expansions of migratory flyways into southeastern Saharan regions. These findings highlight the White Storks' adaptability to climate change and anthropogenic pressures under extreme aridity conditions, but also underscore the rapid ecological transformations occurring under climate change and human activity. They emphasized the critical role of Saharan ecosystems in providing foraging resources and optimal nesting sites for this resilient population.

Keywords: climate change, migration, avifauna, nesting success, phenology, wetland

Összefoglalás A fehér gólya algériai költőpopulációja történelmileg az ország északi részére korlátozódott. A 2025-ös költési időszak alatt (február–június) bizonyított fészkelés történt El Oued (2 fészek), Ouled Djellal (1 fészek) és Menea (1 költési kísérlet 2003-ban) tartományokban. A fehér gólya költőpopulációjának megfigyelt déli irányú terjeszkedése a Szahara forró és rendkívül száraz éghajlatába jelentős ökológiai változást jelent ismert költési területén. Ezen kívül régi adatbázisok és történelmi feljegyzések további jelentős vonulási útvonal-bővüléseket jeleznek a délkeleti szaharai régiókba. Ezek a megállapítások kiemelik a fehér gólyák alkalmazkodóképességét az éghajlatváltozáshoz és az antropogén nyomásokhoz szélsőséges szárazság körülményei között, ugyanakkor rámutatnak a gyors ökológiai átalakulásokra, amelyek az éghajlatváltozás és az emberi tevékenység hatására zajlanak. Kiemelték a szaharai ökoszisztémák kritikus szerepét a táplálkozási erőforrások és optimális fészkelőhelyek biztosításában ezen ellenálló populáció számára.

Kulcsszavak: éghajlatváltozás, vonulás, madárvilág, fészkelési siker, fenológia, vizes élőhely

[1] Department of Biology, Faculty of Natural Sciences and Life, University of El-Qued, P.O. Box 789, El-Oued, Algeria
[2] Laboratory of Biology, Environment and Health, Faculty of Natural Sciences and Life, University of El-Qued, P.O. Box 789, El-Oued, Algeria
[3] Directorate of Forest Conservation of El Oued (General Directorate of Forestry), 39000, Algeria
[4] Laboratoire de Recherche Agronomie Environnement (LRAE), Université Ahmed Ben Yahia El Wancharissi, Tissemsilt, Algéria
[5] Laboratory of Saharan Bio-Resources, Preservation and Valorization, University Kasdi Merbah Ouargla, Ouargla Road 30000, Algeria
[6] LCZH laboratoire de conservation des zones humides, Univ. Guelma, 24000, Guelma, Algeria
** corresponding author, e-mail: gueddoul-messaoud@univ-eloued.dz*

Introduction

Climate is a fundamental determinant controlling the spatial distribution of biodiversity (Pecl *et al.* 2017). Climate change manifests in shifting rainfall and temperature patterns (Coumou & Rahmstorf 2012, Robinson *et al.* 2021), profoundly impacting life on Earth (Khezzani 2021). They are intensifying other simultaneous anthropogenic threats to wildlife, like habitat loss and land use alteration, thereby amplifying the challenges confronted by species and their ecosystems (Kim & Weaver 1994, Greening *et al.* 2025). These changes cause degradations in habitats and geographical redistribution for many animal species (Stocker *et al.* 2014, Pecl *et al.* 2017), imposing them to change their distribution ranges by migrating to newly suitable climatic habitats (Koufaki *et al.* 2024). Avifauna, mainly migratory birds, are influenced by environmental conditions across their distribution ranges (Arizaga *et al.* 2006). These species exhibit high vulnerability to habitat modifications (Thongsoulin *et al.* 2019) and their phenological patterns are shifting in response to climate change (McDermott & DeGroote 2017). Consequently, populations of migratory birds with limited adaptive capacity or those failing to exhibit behavioral plasticity in response to shifting ecological factors are declining and augmenting their extinction risk (Møller *et al.* 2008). Long-distance migrant birds, including trans-African migratory, appear to be more susceptible to climate change (Both & Visser 2001, Both *et al.* 2010). Undoubtedly, avian species, particularly waterbirds, serve as good bioindicators of environmental and ecosystem health in the context of climate change, urbanization and anthropogenic modifications (Gregory & Strien 2010, Bensizerara *et al.* 2013).

Algeria is a vast North African country encompasses a bioclimatic gradient from the Mediterranean coastline to hyper arid Saharan zones, where rainfall values increase from west to east (longitudinal gradient) and from north to south (latitudinal gradient) (Bouaoune & Dahmani-Megrerouche 2010, Chenchouni *et al.* 2025). This geographic location within the Palearctic region's migration network establishes the country as a critical role in the trans-Saharan migrations interconnecting between Eurasia and tropical Africa and an important habitat for 406 migratory and sedentary birds (Isenmann & Molai 2000).

Recent ornithological studies in the Saharan region, particularly in the northeastern Algerian Sahara, has revealed that these regions, with their oasis and wetlands, function as essential sites for maintaining both resident and migratory avian species (Farhi & Belhamra 2012, Guezoul *et al.* 2013, Chedad *et al*. 2023a). Consequently, new observation of several bird taxa across Saharan regions (Chedad *et al.* 2022b, 2023b, Bouzid *et al.* 2023a), and shifting in wintering or breeding geographical distribution of other species have documented (Chedad *et al.* 2022a, 2022b, 2022c, 2023c, 2023d, Bouzid *et al.* 2023b, 2023c, Gueddoul *et al.* 2024). Nevertheless, significant knowledge gaps persist regarding the ecology of Algerian avifauna, particularly for waterbirds, where there are deficiencies in data on population status, seasonal migration dynamics, current range distribution and habitat use (Samraoui & Samraoui 2008).

Urban growth patterns significantly influence the functioning of ecological systems in local and global Earth, offering appropriate foraging and nesting habitats for many bird species globally (Alberti 2005, Mainwaring 2015). The White Stork *(Ciconia ciconia)*, is a

long-distance, trans-African migratory bird breeding in a variety of habitats across Europe and North Africa, and wintering in sub-Saharan regions (BirdLife International 2024). They exhibited a feeding strategy adapted to severe conditions of aridity and anthropogenic landscapes, and phenological flexibility in breeding ground arrival times in response to climate change across its migratory range (Ptaszyk *et al.* 2003, Chenchouni 2017, Athamnia *et al.* 2022). Their nesting, particularly the success of reproduction is influenced by the quality of habitat (Moali-Grine *et al.* 2013).

The present research investigates the ecological situation of the White Stork in Algeria, with a focus on its first nesting success in hot hyper-arid environments, evaluating its resilience to harsh climatic conditions in the northeastern Saharan region, and providing updated range distribution data for Algerian White Stork breeding populations.

Nest monitoring and data collection

The study was conducted during 2024 and 2025 in El Oued province, locally known by Oued Souf located in Northeastern Algerian Sahara *(Figure 1)*. The region has a hyper-arid climate characterized by hot and dry summers and mild winters (Barkat *et al.* 2023).

In late breeding period (June) 2024, we documented the nest of White Stork for the first time. To assess their breeding success, a monitoring of the nest was conducted during the subsequent breeding season, from February 2025 to July 2025. We employed direct counts for flocks under 200 individuals and visual estimation for larger or distant groups (Blondel 1975).

Breeding success is determined by counting the number of fledglings standing on the nest and able to fly. Additional insights have been provided through interviews with citizens and farmers inhabiting in areas adjacent to the nesting site.

We mapped the recent range expansion of the White Stork in Algeria by integrating the known geographic distribution from BirdLife International (2016), studies reported on White Stork nesting beyond historical breeding limits (Farhi 2014, Zoubiri *et al.* 2018), and species presence records in Algeria during the period 1962–2025, with geographical coordinates obtained from observations by international network members in the Global Biodiversity Information Facility database (GBIF.org 2025).

Results

During international census of migratory waterbirds in Algeria (January 2024), we have observed important flock of White Storks in El Oued province (estimated at 350 individuals), using wetlands, waste discharges and agricultural zones as foraging and stopover sites during its migratory passage across the Sahara. Individuals (5–10) remain during the breeding period, were observed in urban wetland "Chott El Oued" and wastewater treatment plant of Kouinine.

During the 2025 season, we confirmed successful breeding of the White Stork in the northeastern part of Algerian Sahara *(Figure 2A)*. The nest was built on a mobile phone pole at the top of the communication antenna *(Figure 2B)*, in an urbanized area in El Oued province, northeastern Algerian Sahara (33°23'33.72" N, 6°52'5.33" E, alt.: 68 m). Potential

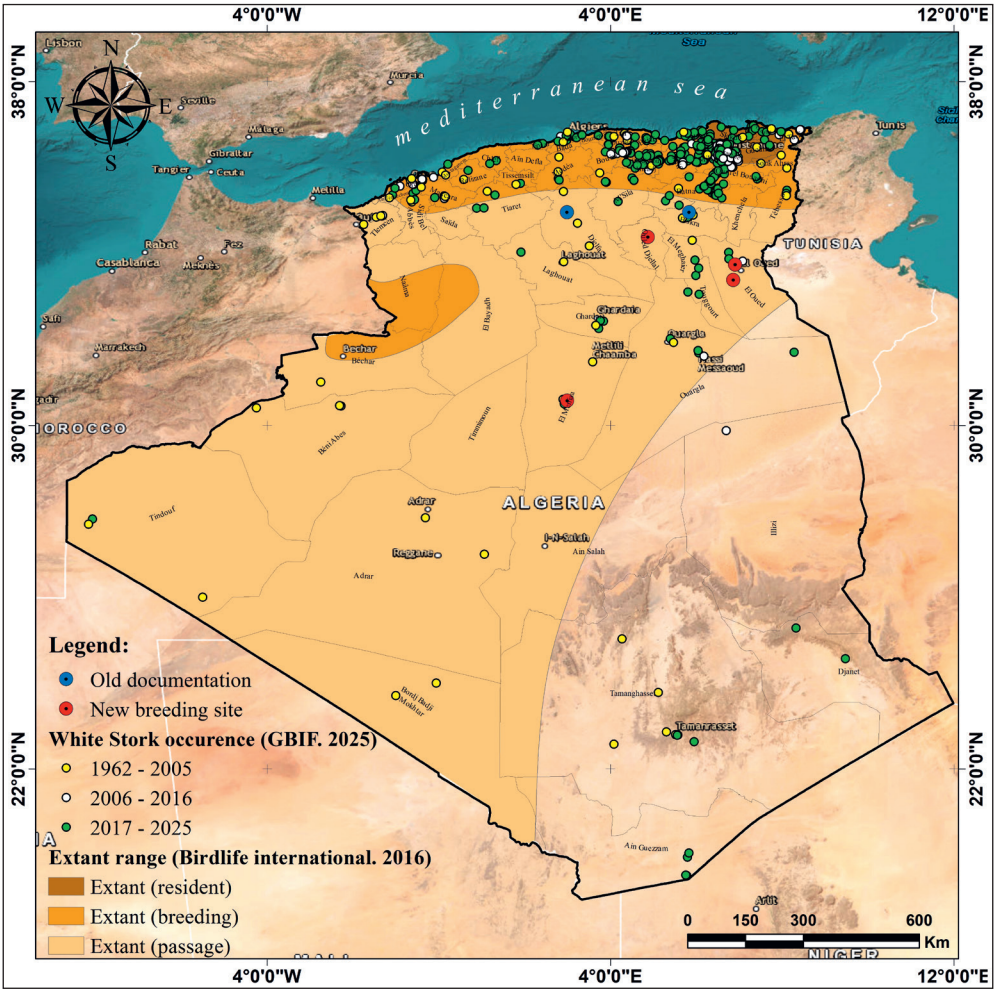

Figure 1. Geographical situation of the new breeding site in El Oued province, Northeastern Sahara and known and new range of White Stork in Algeria

1. ábra Az új költőhely földrajzi helyzete El Oued tartományban (Északkelet-Szahara), és a fehér gólya ismert és új elterjedési területe Algériában

feeding areas near the nest included Chott El Oued, a natural urban wetland located 900 meters away, the Kouinine wastewater treatment plant located 3.5 kilometers from the nest, and the Oued El Alenda public waste disposal site 11 kilometers away.

The arrival of the pair on its nest (nest occupancy confirmed) was in mid-February (15 February), and the start of incubation began in late-March (observed on 21 March). The increase in adult activity began on 13 April, indicating the hatching of eggs. The appearance of two juveniles, with black flight feathers indicated successful breeding *(Figure 2C)*. Fledging took place on 10 June 2025, all the juveniles fledged steadily and the nest was completely vacated over the following days (successful fledging). In addition, a second nest was observed on a high-voltage electricity pylon (33°44'41.91" N, 6°54'28.94" E, alt.: 10 m)

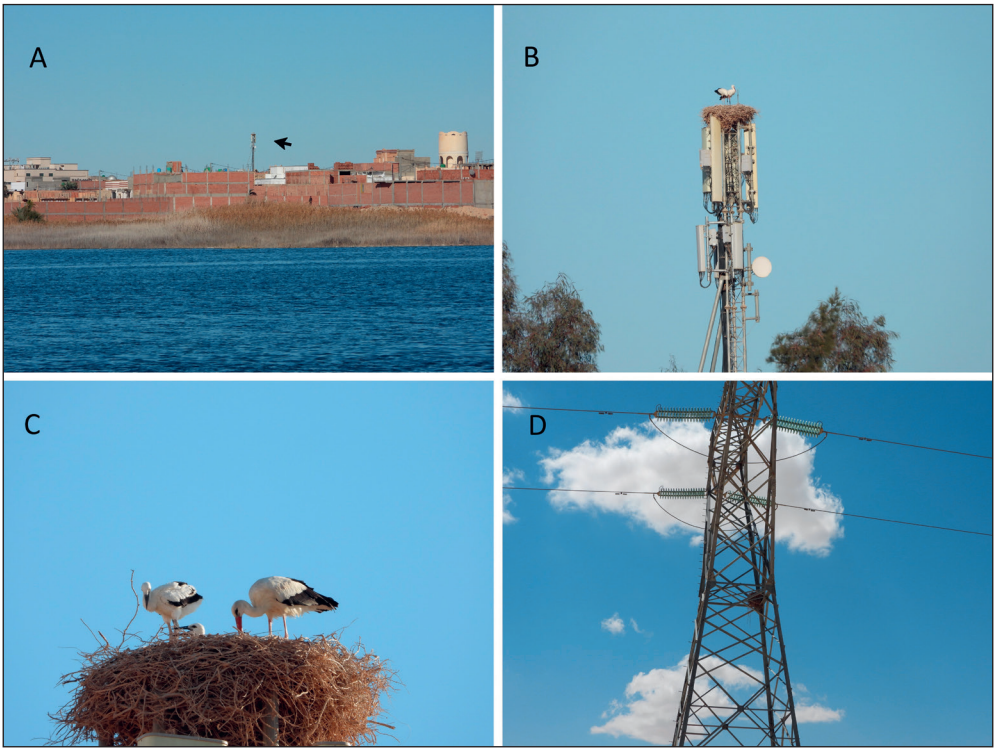

Figure 2. Nesting site in urban habitat near urban wetland chott El Oued (A), nest on a mobile phone base station (B), adult with two juveniles (C), nest on a high-voltage electricity pylon (D)

2. ábra Fészkelőhely városi élőhelyen a Chott El Oued közeli vizes élőhelynél (A), fészekrakó hely mobiltelefon bázisállomáson (B), felnőtt példány két fiókával (C), fészek nagyfeszültségű távvezeték oszlopán (D)

near an artificial wetland namely Chott E'Dhiba wastewater outlet *(Figure 2D)*, although it remained incomplete. The nest was located 4 km from the Chott E'Dhiba wastewater outlet, 11 km from agricultural areas, and 19 km from the Hassi Khalifa public waste disposal site.

Our findings were supported by a confirmed successful nesting case during 2025 breeding season in Ouled Djellal province, representing westernmost of our study area (5°3'53.81" E, 34°25'30.28" N, alt.: 194 m) and an old breeding attempt since 2003 documented in Menea province in southwest of our study area (2°55'0.20" E, 34°25'17.86" N, alt.: 371 m). All these sites situated in northeastern part of Algerian Sahara.

Discussion

White Stork breeding distribution in Algeria follows a bioclimatic gradient from Mediterranean coastal plains (Tell region) through semi-arid regions (High Plateaus) to the extreme border of Northern Sahara, when two pair observed during the census in 1993 in Biskra (Isenmann & Molai 2000). In 2008, seven breeding pairs were documented by Farhi (2014) in some

regions in Biskra province (El Kantra, Biskra, Lioua and Saada). National censuses were conducted since 1995 to 2007 as part of a project to study avian population dynamics in Algeria (Moali-Grine 2007, Moali-Grine *et al.* 2013). These surveys focused on quantifying breeding populations of White Stork across their distribution range, highlighted a substantial growth in Algerian population size and increasing gradient of their abundance from west to east with higher densities recorded in eastern regions, which are primarily influenced by climatic conditions, and anthropogenic pressures affecting their breeding habitat quality. These demographic trends are driven not only by migratory breeding populations but also by the expansion of resident breeders (local population), given the significant range-wide population increase recorded in recent years (Moali-Grine 2007, Thomsen & Brust 2025).

As a synanthropic species exploiting human-altered ecosystems for nesting and opportunistic feeder while maintaining wild population dynamics. Algerian White Storks demonstrate facultative habitat plasticity, employing both natural (wetlands, floodplains), and anthropogenic (irrigated farmlands, landfills) sites as foraging grounds, and adopting available artificial structures in urban or suburban areas (rooftops, electricity poles, pylons, mobile phone base stations) as nesting supports, owing to the decrease of natural nesting structure (Moali-Grine *et al.* 2013, Si Bachir *et al.* 2013, Benharzallah *et al.* 2015, Mammeria *et al.* 2019, Babouri *et al.* 2020, Soualah *et al.* 2021, Sakraoui *et al.* 2023).

The frequency of these feeding areas varied seasonally and directly correlated to the abundance and the reproductive phenology of prey species (Boukhemza *et al.* 2006). The diversity of prey in White Stork diets decreased significantly with increasing aridity, showing higher richness in sub-humid and semi-arid climates compared to arid regions defined by low productivity (Chenchouni 2017). The White Stork exhibits a highly opportunistic feeding strategy, adapting its diet to environmental constraints by foraging across diverse habitats, including waste discharges, to secure a stable food supply. This flexibility allows the species to balance prey abundance and diversity, ensuring nutritional adequacy despite challenges such as climatic aridity and anthropogenic pressures (Chenchouni *et al.* 2015). The dietary composition analysis reveals a large trophic spectrum, which the invertebrates dominate the diet in terms of the number of individuals consumed (mostly arthropod insects), and at the same time, scavenged chicken remains from landfills and small mammals (mainly rodents) predominate in terms of biomass and energy (Cheriak *et al.* 2014, Chenchouni 2017). Landfills offer a consistent resource and easy accessibility to food sources for both resident and migratory birds, including the White Stork, throughout the year (Soualah *et al.* 2021).

The important flock of White Stork reported in our study area represent the return of wintering populations from tropical Africa to Eurasia and North Africa breeding grounds. This post-wintering storks are crossing the Sahara during December, January, and February through the significant flyway migration along eastern Algeria via Menea, Ain Salah, Arak and Tamanrasset (Isenmann & Molai 2000). The El Oued region in the northeastern Sahara located within this trajectory. They feature diverse categories of land use, including irrigated farmlands and pastoral lands, expanding urbanization with anthropogenic pressures and both natural and artificial wetlands. These landscape alterations have made our region a new suitable habitat for the distribution range of a variety of species and stopover for migrant White Stork populations.

The documented breeding success of White Storks in a new breeding range represents a significant latitudinal range expansion into the south of the known distribution limit in Algeria, by approximately 220 km compared to previous records in Biskra and an adaptation to the hot and hyper-arid conditions of Saharan ecosystems. However, a systematic survey across all Saharan regions in Algeria during the breeding season, especially those that sustain suitable nesting features for White Storks, would fill significant gaps in our understanding of White Stork population dynamics and their geographical distribution in these poor environments. Furthermore, these ecological significances contribute to updating the breeding distribution range of White Storks in Algeria and Northwest Africa. This expansion of breeding range are mentioned by Azafzaf (2002) in Tunisia from northwest to east and south.

Recently, Algerian Saharan regions (particularly the study area) have experienced rapid agricultural transformation characterized by the development of irrigated crops through the exploitation of groundwater (Ouendeno 2019, Djouhri *et al.* 2023). The population in the Souf region has depended on groundwater resources for their needs and activities, particularly agriculture. The unsustainable extraction of groundwater resources by intensive irrigation practices have driven a rising water phenomenon, that has affected densely populated localities, notably El Oued, El Bayadha and Kouinine (Diaf *et al.* 2024). Consequently, several water bodies have emerged in these urban areas such as Chott El Oued. Moreover, artificial wetlands were established, encompassing wastewater treatment plants and final wastewater outfalls like Chott E'Dhiba. In addition, numerous legal or illegal landfills were established around urban sites, as a result of the growth of human activities (mostly greater is the public discharges in Oued El Alenda). These anthropogenic modified habitats support significant biodiversity such as small mammals (rodents) and insects (Selmane & Benslama 2015, Selmane *et al.* 2016, Alia *et al.* 2025), and serve as a foraging, wintering or breeding habitats for several bird species (Guezoul *et al.* 2013, Gueddoul *et al.* 2024). Consequently, these local key habitat features support White Stork populations and directly affect their reproductive success by providing both diversified foraging resources and optimal nesting opportunities. Generally, bird species exhibited varied responses to recent environmental changes, some rapidly changed their ecological needs, while others preserved stable niches. These patterns were partially predictable based on the physical and behavioral characteristics of species, underscoring how biodiversity adapts to global change (Avidad *et al.* 2025).

Undoubtedly, the reproductive success of the White Stork in the northeastern Algerian Sahara offers new insights into the geographical distribution of species and reveals a significant southward range expansion than its traditional breeding range. Our findings underscore the critical role of both natural and artificial habitats, especially wetlands in sustaining migratory bird populations across the Sahara. In addition, suggests adaptive responses to climate change and increasing resilience to extreme desert conditions.

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