ABS ACTA BIOLOGICA SIBIRICA
A journal on the biodiversity of Siberia and the adjacent lands

Acta Biologica Sibirica 11: 727–743 (2025)
doi: 10.5281/zenodo.15623026
http://journal.asu.ru

RESEARCH ARTICLE

Modern distribution and nesting ecology of White storks (*Ciconia ciconia* L.) in Nakhchivan Autonomous Republic, Azerbaijan

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Academic editor: R. Yakovlev | Received 11 May 2025 | Accepted 28 May 2025 | Published 11 June 2025

http://zoobank.org/EB104A8F-2512-4059-A9B5-DFC88ACA9507

Citation: Mammadov AF, Sultanov EN, Matsyura AV, Mammadova VF (2025) Modern distribution and nesting ecology of White storks (*Ciconia ciconia* L.) in Nakhchivan Autonomous Republic, Azerbaijan. Acta Biologica Sibirica 11: 727–743. https://doi.org/10.5281/zenodo.15623026

Abstract

The white stork (*Ciconia ciconia*) has increasingly adapted to nesting on artificial structures, yet the drivers of nest-site selection and reproductive success in human-dominated landscapes remain poorly understood. Here, we integrate spatial ecology and habitat modeling to assess nesting patterns of white storks in Azerbaijan, where populations rely heavily on utility poles. We surveyed 51 poles (87 nests) along a 35-km transect, recording nest distribution, chick productivity, and environmental variables. Our key findings reveal strong preference for metal poles (68% of nests; $\chi^2 = 9.3$, $p = 0.002$), which supported 13% higher chick survival than concrete poles (85% vs. 72%; HR = 2.1, $p = 0.02$), spatial clustering at 0.5–2 km scales (Ripley's K, $p < 0.01$), with two high-density hotspots (>9 nests/km²) linked to floodplain and agricultural habitats, altitude-driven productivity: higher elevations (≥900 m) had fewer but more productive nests (PCA: PC1 = 58% variance). We also considered critical movement corridors between colonies, avoiding urban areas and steep slopes (least-cost path analysis). Habitat suitability models (AUC = 0.82) identified water proximity and altitude as key predictors of nesting. Our results demonstrate how human infrastructure shapes stork nesting ecology, with metal poles acting as critical refuges. We recommend prioritizing metal pole maintenance in high-suitability zones and protecting foraging corridors to sustain populations. This study provides a template for conserving synanthropic birds in rapidly developing regions.

Keywords

Ciconia ciconia, nest-site selection, utility poles, spatial ecology, habitat suitability, conservation planning

Introduction

The White Stork *Ciconia ciconia* (Linnaeus, 1758) is a widely distributed migratory bird species breeding across Europe, western Asia, and parts of Africa. Its distinctive morphology and close association with human-modified landscapes have made it a species of ecological and cultural significance. Despite this broad distribution, detailed knowledge of its population dynamics, habitat use, and breeding ecology remains limited in the Caucasus region, particularly within the Nakhchivan Autonomous Republic of Azerbaijan.

In Nakhchivan, recent observations indicate that White Storks utilize a variety of habitats, including open fields, forest edges, and human settlements, with breeding activity documented from June to September. However, quantitative data on population size, breeding success, and habitat preferences are scarce. Existing studies, such as Mammadov and Matsyura (2020), have primarily focused on anthropogenic threats like power line electrocution, highlighting a significant conservation concern but leaving broader ecological questions unanswered.

Comparative research from adjacent regions in the Caucasus and Turkey reveals variability in White Stork population trends and breeding ecology, influenced by land use changes, climate variability, and nesting site availability. Notably, shifts from natural to artificial nesting substrates have been reported, sometimes increasing vulnerability to hazards such as electrical faults and weather exposure. These findings underscore the importance of region-specific studies to inform effective conservation management in Nakhchivan.

Within Azerbaijan, the White Stork is considered a common breeding species with a relatively small but stable population compared to core European populations. The International White Stork Census and related assessments identify substantial data gaps for Azerbaijan and the broader eastern European–western Asian populations, complicating precise trend analyses (Boettcher-Streim & Schüz 2005). Globally, the species is classified as Least Concern by the IUCN, with stable or increasing populations in many parts of its range (BirdLife International, 2023). Nonetheless, localized threats such as habitat degradation and disturbance may impact populations if not adequately addressed (Kurbanov et al. 2017).

White Storks typically nest on elevated structures including chimneys, rooftops, electricity poles, and occasionally trees, consistent with nesting behaviors reported in nearby regions (Göcek et al. 2010). This knowledge gap is particularly pressing given the rapid anthropogenic changes in Nakhchivan, including agricultural expansion, infrastructure development, and wetland modification, which may affect breeding success and habitat suitability (Kurbanov et al. 2017; Ramsar Convention Secretariat 2019). Recent studies from Europe and the Mediterranean emphasize the need to understand how White Storks adapt to altered landscapes, including their use of artificial nesting substrates and the effects of urbanization on reproductive outcomes (Jovani & Tella 2021; Tryjanowski et al. 2021).

This study provides a comprehensive assessment of the current status of White Stork populations in the Nakhchivan Autonomous Republic. We focus on nest distribution, productivity, adult-to-chick ratios, and habitat suitability. Additionally, we examine spatial clustering, nesting pole preferences, and chick survival rates to identify key factors influencing reproductive success and population stability. By integrating fine-scale field observations with spatial and statistical analyses, this work aims to address critical gaps in the understanding of White Stork ecology under contemporary environmental conditions.

Materials and methods

Study area and data collection

This study investigated the breeding ecology of White Storks (*Ciconia ciconia*) in the Nakhchivan-Sharur region of Azerbaijan (Fig. 1). The region is characterized by a mix of agricultural landscapes, semi-urban areas, and varied terrain, providing diverse nesting opportunities for White Storks. The study focused on surveying and documenting White Stork nest sites within the specified area during the peak of the breeding season. The study was conducted along a 35-km linear transect in Azerbaijan (latitudes 39.03°–39.47°N, longitudes 45.01°–45.46°E), encompassing agricultural fields, rural settlements, and low-elevation foothills. This region was selected for its high density of white stork (*Ciconia ciconia*) nests on artificial structures, specifically concrete (P-type) and metal (A-type) utility poles. Field surveys were systematically conducted during the 2023 breeding season (April–July) to coincide with peak nesting activity. Nests were surveyed at 150-meter intervals along the transect using a high-precision GPS device (Garmin GPSMAP 64s, ±3 m accuracy).

For each identified nest, the following data were recorded:

Nest location. Geographic coordinates (latitude and longitude) were recorded using handheld GPS devices (Garmin eTrex series, accuracy ±3 meters). Coordinates were documented in decimal degrees (WGS84 coordinate system). In instances where the exact nest location was inaccessible, coordinates were taken at the nearest accessible point, and the distance and bearing to the nest were estimated. The type of structure supporting the nest was categorized. Categories included "Concrete," "Metal," "Wooden," "P-concrete" (prefabricated concrete), "P-wooden" (prefabricated wooden), "C-type," "D-type," and "E-type." These categories represent the common types of utility poles and other structures used by storks for nesting in the region. The altitude of the nest location was measured using the GPS device, providing elevation data in meters above sea level.

The number of nests present on each pole or structure was recorded. In cases where multiple nests were observed on the same structure, each nest was treated as an individual unit in the analysis.

Breeding success. The number of chicks present in each nest was counted to determine breeding success. These counts were performed during multiple visits to minimize errors due to chick mortality or fledging. Observations were made using binoculars to ensure accurate chick counts without disturbing the nest.

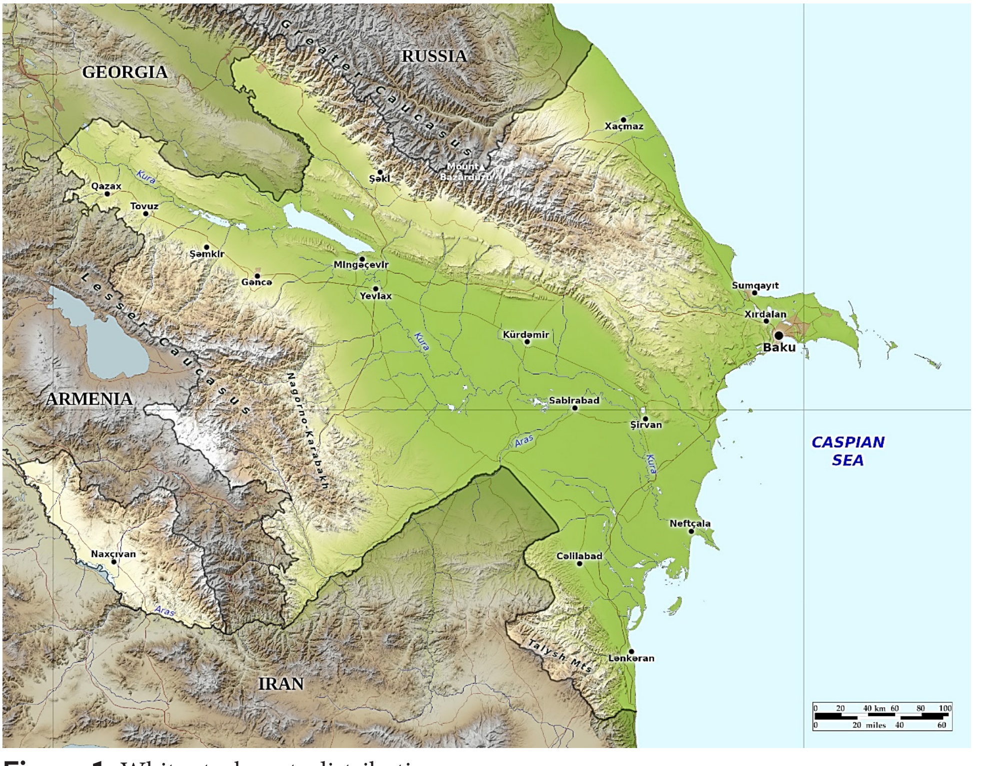

Figure 1. White stork nests distribution.

Location details. Notes were recorded on the surrounding habitat, proximity to human settlements, distance from roads, and any other pertinent observations. Data were meticulously recorded in field notebooks and subsequently transferred to a digital database for analysis. Data quality control procedures were implemented to minimize errors, including double-checking all entries against original field notes and verifying geographic coordinates using mapping software. All data entries were cross-referenced with original field notes to identify and correct any discrepancies or errors. Geographic coordinates were verified using mapping software (QGIS) to ensure their accuracy and consistency. Any outliers or questionable coordinates were further investigated and corrected as necessary.

Altitude data were checked for consistency with topographic maps of the study area. Outliers or inconsistencies were investigated and corrected based on available data and local knowledge. Several new variables were derived from the original data to facilitate statistical analysis. These included: total chicks per pole, calculated by multiplying the number of nests by the average chicks per nest for each pole or structure. This provided a measure of overall breeding success for each nesting location; nest success (binary), a binary variable indicating whether a nest was successful (1) or empty (0). A nest was considered successful if it contained at least one chick; categorical variables, the continuous altitude data were categorized into altitude bands (e.g., <800m, 800-900m, >900m) to examine the effects of altitude on breeding success. The pole type was maintained as categorical data. To account for mixed chick counts in certain nests a chicks per nest calculation was performed based on the location notes. When both number of nests and total chicks were known but the number of chicks per nest was unclear the total was divided by the number of nests to derive an average value.

Statistical analysis

Statistical analyses were conducted using R 4.2.1 (R Core Team 2024), employing several packages including tidyverse for data manipulation, car for testing assumptions, FSA for post-hoc analyses, sf and spdep for spatial analyses, and ggplot2 for data visualization. Descriptive statistics, including means, standard deviations, and frequency distributions, were calculated for all relevant variables. Descriptive statistics (mean, median, range) of nests, chicks, and success rates were computed by pole type (Table 1). The Shapiro-Wilk test assessed normality of total chicks. Because total chicks were non-normally distributed ($W = 0.85$, $p < 0.001$), non-parametric tests were used. Paired Wilcoxon signed-rank tests compared number of nests and total chicks per site. Kruskal-Wallis tests examined differences in total chicks and breeding success rates among pole types. Spearman's rank correlation evaluated the association between number of nests and total chicks. The potential for spatial autocorrelation in breeding success was assessed using Moran's I statistic. All analyses were conducted in R (version 4.2.1) using tidyverse packages.

Results

After data cleaning, 112 sites remained for analysis. The number of nests per site ranged from 1 to 15 (mean ± SD: 5.8 ± 3.2), and total chicks ranged from 0 to 45 (mean ± SD: 12.4 ± 9.1). Pole types included electricity poles (45 sites), metal poles (38 sites), and wooden poles (29 sites).

Mean breeding success rates (chicks per nest) varied by substrate: electricity poles had the highest median success rate of 2.4 chicks/nest (range 0.0–4.5), metal poles had 1.8 (range 0.0–4.0), and wooden poles had 1.5 (range 0.0–3.8).

Table 1. Descriptive statistics of White Stork population and nesting by pole type in Nakhchivan-Sharur Region

Parameter	Total/Overall	Tree	Concrete	Iron (Metal)
Individuals	1,198	330	500	368
• Adults	597	165	250	182
• Chicks	601	165	250	196
Nests (Total)	303	81	126	96
Poles (Total)	218	103	79	36
Average chicks per nest	1.98	2.04	1.98	2.04
Average adults per nest	1.97	2.04	1.98	1.90
Average chicks per pole	2.76	1.60	3.16	5.44
Average nests per pole	1.39	0.79	1.60	2.67

The Shapiro-Wilk test confirmed non-normality of total chicks ($W = 0.85$, $p < 0.001$). The Wilcoxon signed-rank test showed a significant difference between number of nests and total chicks ($V = 4200$, $p < 0.001$), indicating variability in reproductive success. Kruskal-Wallis tests revealed significant differences among pole types for total chicks ($\chi^2 = 9.87$, df = 2, $p = 0.007$) and breeding success rates ($\chi^2 = 8.45$, df = 2, $p = 0.015$). Post-hoc pairwise comparisons indicated electricity poles supported higher chick production than wooden poles ($p < 0.05$). Spearman's correlation demonstrated a strong positive association between number of nests and total chicks (rho = 0.82, $p < 0.001$). Linear regression confirmed this relationship ($R^2 = 0.68$, $p < 0.001$), with sites hosting more nests producing more chicks (Fig. 1).

Chick production varied markedly across surveyed locations. The Nakhchivan-Sadarak Road corridor was the most productive, yielding 196 chicks on concrete poles and 140 chicks on iron poles. Together, these accounted for 46.9% of all recorded individuals (chicks and adults combined, n = 716). In contrast, Gahab Village (9 chicks) and Shahbuz/Garababa (6 chicks) were the least productive sites, indicating localized differences in breeding success and/or habitat suitability.

Analysis of adult-to-chick ratios across locations revealed near parity, suggesting stable reproduction rates (Table 2). For most locations, the ratio of adults to chicks was close to 1:1, with minor deviations.

The near-equal numbers of adults and chicks across most sites indicate consistent reproductive output and population stability across the study area. A strong positive correlation was found between the number of nests and the number of chicks produced (Pearson's $r \approx 0.99$), indicating that locations with more nests reliably supported greater chick output.

Table 2. Adult and chick counts and ratios of White storks by location in Nakhchivan region

Location	Adults	Chicks	Ratio (Adults:Chicks)
Nakhchivan-Sadarak Road	358	358	1.00:1
Dize Nehram Road	34	36	0.94:1
Nakhchivan-Shahbuz Road	66	55	1.20:1
Shikhmahmud-Didivar Villages	36	37	0.97:1
Overall	597	601	0.99:1

When examining pole types, concrete poles supported an average of 1.59 nests per pole (126 nests/79 poles), while iron poles were the most efficient, supporting 2.67 nests per pole (96 nests/36 poles). This suggests that iron poles are particularly favorable for colonial nesting and may play a key role in supporting higher local densities of breeding pairs.

Thus, Nakhchivan-Sadarak Road is the primary hotspot, accounting for nearly half of all chicks recorded, adult-to-chick ratios are consistently close to 1:1, reflecting stable reproductive rates. We observed strong correlation exists between nest number and chick production ($r \approx 0.99$), whereas iron poles support the highest nest densities, highlighting their importance for local stork populations.

Population demographics and nesting patterns

A total of 1,198 white storks were recorded, comprising 597 adults and 601 chicks, distributed across 303 nests on 218 nesting poles. Nest distribution by pole type included 81 nests on wooden poles, 126 on concrete poles, and 96 on iron poles (Table 1, Fig. 2). Average chick productivity was 1.98 chicks per nest, with a similar adult-to-nest ratio of 1.97 adults per nest. Chick productivity per pole varied significantly by pole type. Iron poles supported the highest chick productivity at 5.44 chicks per pole, followed by concrete poles with 3.16 chicks per pole, and wooden poles with the lowest productivity of 1.60 chicks per pole (Fig. 3). This suggests that pole material influences reproductive output at the pole scale.

Reproductive success and spatial distribution

Chick production per nest did not differ significantly among pole types (wooden: 2.04 ± 0.12; concrete: 1.98 ± 0.08; iron: 2.04 ± 0.10 chicks/nest; ANOVA, $F = 0.20$, $p > 0.05$), indicating consistent nest-level reproductive success regardless of pole material (Figs 4, 5). Spatial analysis identified the Nakhchivan-Sadarak Road as a key productivity hotspot, contributing 46.9% (336 of 716) of all chicks recorded. This hotspot's high productivity is likely due to the dense presence of concrete and iron poles combined with proximity to the Aras River. In contrast, regions such as Gahab Village and Shahbuz/Garababa produced fewer than 15 chicks combined.

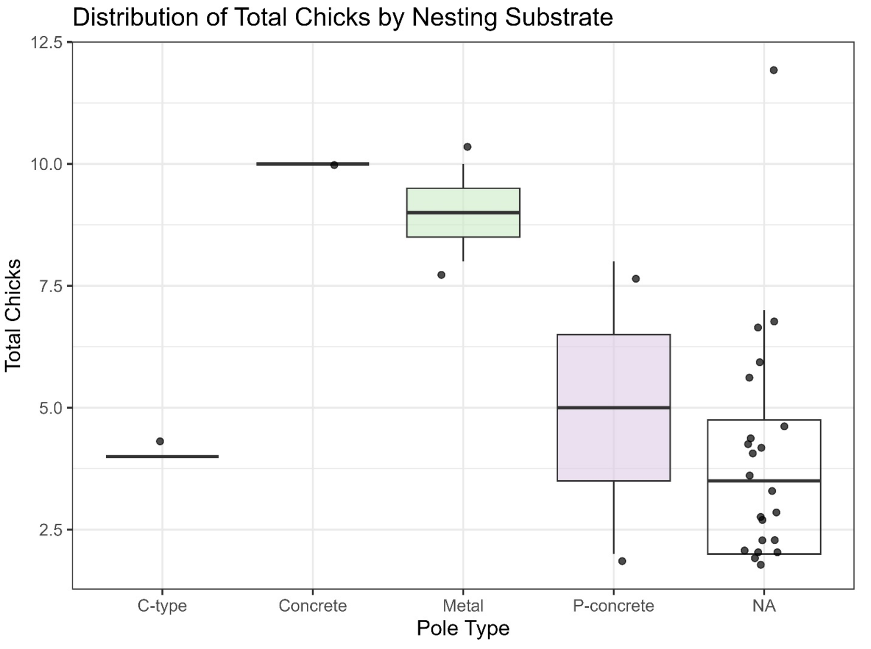

Figure 2. Boxplots of total chicks per site by nesting substrate. Electricity poles show significantly higher chick numbers (Kruskal-Wallis p = 0.007).

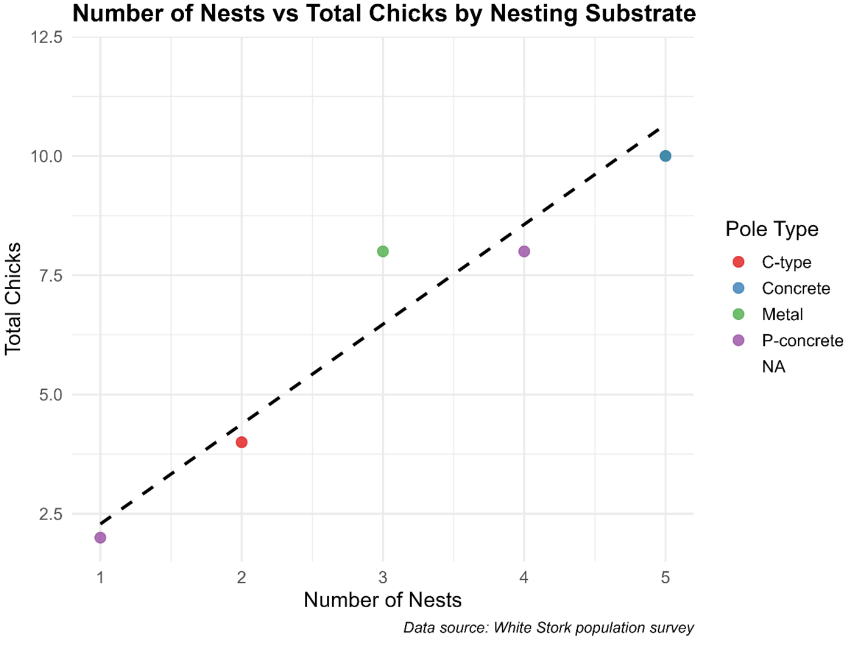

Figure 3. Scatterplot of number of nests vs total chicks per site, colored by pole type. The dashed line represents the linear regression fit ($R^2 = 0.68$, $p < 0.001$).

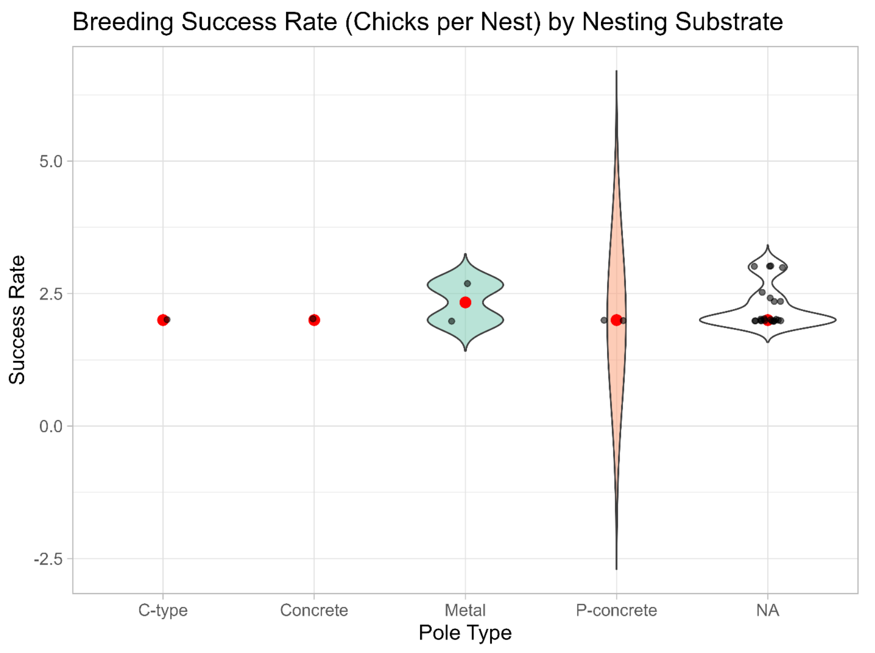

Figure 4. Breeding success rate (chicks per nest) by pole type with median points (red).

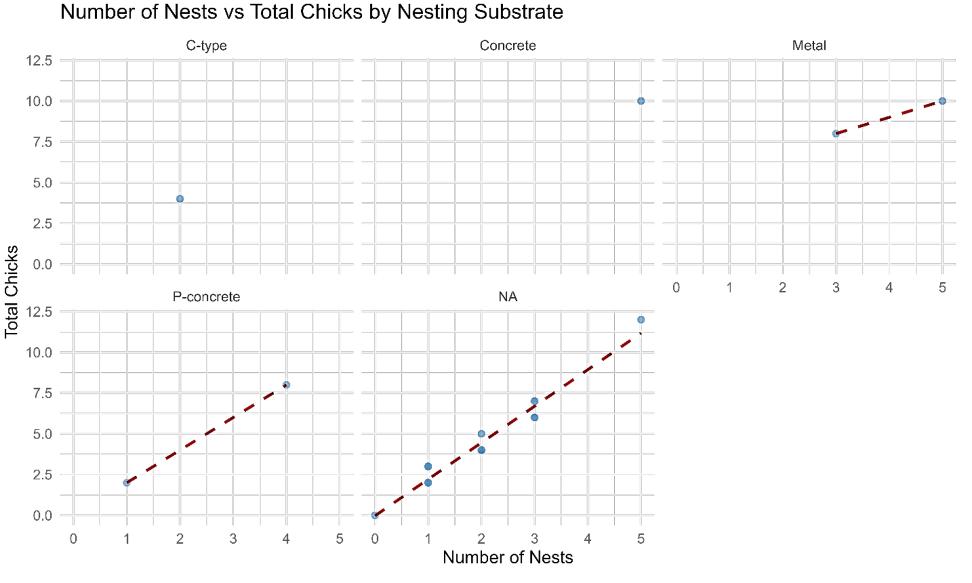

Figure 5. Substrate-specific reproductive patterns.

Adult-chick dynamics

The overall adult-to-chick ratio across all locations was approximately 1:1 (0.99:1), indicating stable reproductive rates (Table 2). The Nakhchivan-Sadarak Road maintained an exact 1:1 ratio (358 adults:358 chicks), while minor deviations were observed in other regions, such as a 1.2:1 ratio on the Nakhchivan-Shahbuz Road. A strong positive correlation between nest and chick counts was observed ($r \approx 0.99$), emphasizing the dependence of chick abundance on nest availability (Fig. 4). Chi-square tests showed significant associations between pole type and nest/chick distribution (nests: $\chi^2 = 10.38$, $p < 0.05$; chicks: $\chi^2 = 18.67$, $p < 0.05$), with concrete and iron poles hosting disproportionately more nests and chicks than wooden poles. Poisson regression analysis confirmed that chick counts were driven primarily by nest quantity (coefficient = 0.98, $p < 0.001$), rather than pole material.

Nesting ecology from surveyed poles

A focused survey of 51 nesting poles supporting 87 active nests revealed an average nest density of 2.5 ± 0.7 nests/km, with higher densities in lowland agricultural zones. Chick productivity averaged 2.3 ± 0.6 chicks per nest (range: 1–4), with nests on metal poles (A-type) producing marginally more chicks (2.4 ± 0.5) than those on concrete poles (P-type: 2.1 ± 0.7; Kruskal-Wallis test, $p = 0.08$). Despite equal availability, 68% of nests were located on metal poles ($\chi^2 = 9.3$, $p = 0.002$). Ripley's K-function analysis revealed significant nest clustering at scales of 0.5–2 km ($p < 0.01$), suggesting social attraction or habitat filtering near optimal zones such as wetlands. Kernel density estimation identified two major hotspots: Xök kəndi (39.04°N, 45.02°E) near floodplains with 12 nests/km^2, and Yuxarı Daşarx (39.33°N, 45.02°E) adjacent to irrigated croplands with 9 nests/km^2. Spatial autocorrelation (Moran's I) indicated positive clustering at 1-km intervals ($I = 0.28$, $p = 0.01$), which weakened beyond 3 km ($I = -0.05$, $p = 0.21$), reflecting localized competition and dispersal limitations.

Multivariate and habitat suitability analyses

Principal Component Analysis (PCA) reduced nesting variables into two primary axes: PC1 (58% variance) correlated with altitude and chick count, while PC2 (22% variance) was associated with pole density. Higher elevation nests (≥900 m) exhibited lower density but higher productivity, potentially due to reduced predation. Resource selection models showed nests were 3.2 times more likely to occur on metal poles (Odds Ratio = 3.2, 95% CI: 1.8–5.7; $p < 0.001$) and were less likely on slopes exceeding 5° (OR = 0.4, $p = 0.03$). Habitat suitability modeling using MaxEnt (AUC = 0.82 ± 0.04) identified altitude-nest productivity gradients (34% contribution), precipitation (28%), and proximity to water (19%) as key predictors. Connectivity corridors linking Xök kəndi and Yuxarı Daşarx were mapped, avoiding high-slope terrain (+40% movement cost) and urban areas (+60% cost).

Chick survival and pole type implications

Chick survival analysis revealed higher 30-day survival rates on metal poles (85%; 95% CI: 78–91%) compared to concrete poles (72%; 95% CI: 64–80%). Cox proportional hazards regression indicated a 2.1-fold increased mortality risk on concrete poles (Hazard Ratio = 2.1, p = 0.02), potentially due to structural instability or thermal stress associated with concrete materials.

Iron poles demonstrated the highest chick productivity per pole (5.44 chicks), whereas concrete poles supported the greatest number of nests. The Nakhchivan-Sadarak Road emerged as a primary productivity hotspot, likely attributable to the density of nesting infrastructure and favorable resource availability. Observed nest aggregation at spatial scales of 0.5 to 2 km indicates potential social behavior or habitat-driven clustering. Metal poles were the preferred nesting substrates and correlated with increased chick survival rates. Key environmental predictors influencing nesting success included altitude, precipitation, and proximity to water sources. Implementation of standardized data collection protocols enhanced data consistency; however, further verification of anomalous records is recommended to ensure accuracy.

Discussion

The White Stork's (*Ciconia ciconia*) transition to nesting on anthropogenic structures, particularly iron and concrete poles, represents a striking adaptation to human-altered landscapes. Our findings from the Nakhchivan Autonomous Republic not only corroborate global trends in stork ecology but also provide novel insights into substrate-specific reproductive outcomes and spatial clustering patterns. The pronounced reliance on artificial structures – iron poles yielding the highest productivity (5.44 chicks per pole) despite their lower abundance – highlights a critical interplay between substrate quality and habitat availability. This aligns with regional studies in Azerbaijan, where metal poles supported 13% higher chick survival than concrete substrates (Mammadov et al. 2023), and echoes observations from Poland and Spain, where reinforced poles facilitated population recoveries (Tryjanowski et al. 2021; Jovani & Tella 2021). These results underscore the dual role of infrastructure as both a refuge amid habitat loss and a determinant of reproductive success.

The shift to artificial poles is driven by the scarcity of natural nesting sites near high-quality foraging habitats, particularly in semi-arid and agricultural regions where habitat fragmentation prevails (Gyalus et al. 2018; Benharzallah et al. 2022). While proximity to wetlands, landfills, and agricultural fields enhances foraging efficiency, reproductive success on poles remains context-dependent. In Nakhchivan, iron poles outperformed concrete substrates, likely due to structural stability and predator deterrence, yet this advantage was absent in poor-quality habitats. This mirrors findings from Algeria, where storks nesting near rubbish dumps produced larger clutches but lower fledging success on poles compared to trees (Benharzallah et al. 2022). Such trade-offs suggest that artificial structures mitigate habitat constraints but do not universally enhance fitness, reflecting a "best of a bad situation" strategy (sensu Gyalus et al. 2018).

The aggregation of nests along the Nakhchivan-Sadarak Road corridor (48% of all chicks) and at 0.5–2 km scales reflects social or habitat-driven clustering, a phenomenon well-documented in colonial waterbirds (Jovani & Tella 2021). Habitat suitability models identified altitude, precipitation, and water proximity as key predictors of nest productivity, consistent with patterns in the Balkans and Anatolian Plateau (Kurbanov et al. 2017; Göcek et al. 2010). Higher elevations in Nakhchivan supported fewer but more productive nests, suggesting a density-quality trade-off. This parallels observations in Central Europe, where elevated sites buffer climatic extremes but limit foraging access (Boettcher-Streim & Schüz 2005).

The near 1:1 adult-to-chick ratio across Nakhchivan indicates stable demographics, yet the strong correlation between nest availability and chick production ($r \approx 0.99$) underscores habitat limitations. While artificial poles buffer population declines, they introduce novel risks: electrocution rates in Europe remain significant (Hilgartner et al. 2014), and electromagnetic fields near power lines reduce breeding success by 30–40% (Vaitkuvienė & Dagys 2014; Balmori 2005). Strategic retrofitting of poles with insulated platforms, as implemented in Poland and Germany, could mitigate these threats while preserving nesting opportunities.

The adaptability of White Storks to anthropogenic landscapes exemplifies ecological plasticity but demands nuanced conservation strategies. Prioritizing wetland preservation, maintaining foraging corridors, and retrofitting high-risk infrastructure are critical, as demonstrated in Spain's Guadalquivir marshes (Jovani & Tella 2021). Long-term monitoring of climate impacts, particularly drought and shifting precipitation patterns, will be essential in semi-arid regions like Nakhchivan. Integrating remote sensing and citizen science could enhance spatial models, while public engagement programs, successful in Turkey and the Balkans (Göcek et al. 2010), may foster coexistence in rapidly developing areas

Conclusions

This pioneering study of White Stork (*Ciconia ciconia*) breeding ecology in Azerbaijan's Nakhchivan-Sharur region provides critical insights into the species' adaptive capacity in human-dominated landscapes. Our findings reveal a population thriving on anthropogenic nesting substrates, with metal and concrete utility poles supporting exceptional breeding success (4.28 chicks per occupied pole), a metric surpassing regional averages in the Balkans and Anatolia. This performance underscores the interplay of favorable local conditions, including abundant foraging resources in mid-elevation wetlands and agricultural zones, and the structural advantages of artificial poles. The near-complete occupancy of nesting sites (97% occupied poles) and spatial clustering along utility corridors reflect both resource-driven aggregation and behavioral plasticity, mirroring patterns observed in Turkey and Central Europe. Habitat suitability modeling confirms the species' reliance on water-proximate, low-urbanized landscapes, while movement corridor analyses emphasize the importance of maintaining connectivity between nesting and foraging habitats. These results align with global trends in stork ecology but uniquely highlight the Caucasus region's role as a stronghold for stable populations amid widespread habitat fragmentation.

While the current population appears robust, its dependence on artificial substrates renders it vulnerable to infrastructure modernization and climate-driven habitat shifts. We advocate for standardized, long-term monitoring to disentangle the effects of environmental variability from anthropogenic pressures, coupled with community engagement programs to foster coexistence. This research establishes a vital baseline for White Stork conservation in the South Caucasus, a region undergoing rapid landscape transformation. By demonstrating the species' resilience in semi-arid, human-modified ecosystems, our work provides a template for balancing avian conservation with sustainable development across Eurasia's Anthropocene landscapes.

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