

Original article

Distribution of Migratory Birds in the Southern Oasis Regions (Ghat – Ubari – Murzuq), Libya (2025–2026)

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Abstract

The Saharan oases of Ghat, Ubari, and Murzuq form a sparse network of freshwater and palm-grove habitats that likely serve as short stopovers for Palearctic and Afro-tropical migrants. Yet, standardized, season-resolved data from Libya's deep desert remain scarce. This study (2025–2026) will quantify seasonal variation in species composition and abundance across these three oasis systems and test how hydrological conditions (water surface area, depth, electrical conductivity as a salinity proxy) and disturbance (people, vehicles, livestock, gunfire, dogs) shape migrant use. We will conduct synchronized point counts and scan counts on open water and groves in autumn, winter, and spring, with distance sampling/time-of-detection to address detectability. Each visit will include standardized habitat measurements and georeferenced photo/audio vouchers; data will be archived to open repositories and aligned with International Waterbird Census protocols to enable comparisons with national winter baselines. Analyses (GLMMs/GAMs, ordination, turnover metrics) will test explicit hypotheses about seasonal change, species–environment relationships, and stopover timing relative to pre-Saharan versus trans-Saharan strategies. Outputs include: (i) bilingual checklists and abundance indices per site/season, (ii) a decision-ready monitoring protocol, (iii) a KBA screening table against BirdLife thresholds, and (iv) management guidance on water-level stewardship and disturbance buffers. The project will close a major geographic data gap in Libya's monitoring network and provide defensible evidence to support conservation planning in Fezzan's oasis landscapes.

Keywords: Migratory Birds; Oasis Wetlands; Fezzan (Libya); Stopover Ecology; Hydrology–Biodiversity Links; Disturbance; IWC/IBA–KBA; Distance Sampling.

Introduction

The Saharan oases of Ghat, Ubari, and Murzuq form a sparse but vital network of freshwater habitats across Fezzan, shaping the migratory routes of Palearctic and Afro-tropical birds. Although national winter counts provide essential benchmarks, coverage in Libya has historically been coastal-biased, with the deep-desert oases receiving limited, intermittent attention. The eighteenth national winter census (2022), synthesized by Etayeb et al. [1], offers a peer-reviewed baseline for methods, species totals, and trend comparisons relevant to forthcoming surveys. Complementing this, the Libyan Society for Birds' updates and field notes [2] point to ongoing volunteer-led monitoring and the feasibility of standardized counts away from major wetlands, while also highlighting logistical gaps in remote areas.

From a conservation perspective, BirdLife International's DataZone situates Libya's key sites within the IBA/KBA framework and documents pressures—habitat shrinkage, water extraction, disturbance, and climate-linked aridification [3]. In hyper-arid Fezzan, even small waterbodies may act as disproportionately important stopovers or thermal refugia. Yet, for Ghat–Ubari–Murzuq, robust, season-spanning datasets that connect species composition, timing, and hydrological condition remain scarce.

Against this backdrop, a focused 2025–2026 program centered on these oases can (i) align methods and quality control with the national census protocol [1], (ii) incorporate community observations and rapid assessments reported by the Libyan Society for Birds [2], and (iii) interpret findings within the KBA lens [3]. Doing so will refine our understanding of spatial use and stopover dynamics in southern Libya, support future KBA delineation or status reviews, and inform practical management—such as water-level stewardship, access regulation, and disturbance mitigation. Ultimately, the project will bridge national-scale monitoring with site-specific evidence from Fezzan's oases, producing an updated distributional picture upon which long-term conservation actions can reliably be based.

Research Problem

Movement ecology shows that pre-Saharan and trans-Saharan migrants follow distinct spring strategies, with brief “top-up” stopovers at desert water points before or after crossing [4]. Fezzan’s oases likely function as such short-stop sites, yet their role is under-quantified. The last Fezzan-wide faunal baseline lists birds across Ghat, Ubari, and Murzuq but predates recent climatic variability and lacks standardized, season-specific counts [5]. Therefore, there is a critical evidence gap on (i) timing and turnover of migrants, (ii) species-habitat associations under variable water levels, and (iii) how these factors differ among the three oasis clusters. This study addresses those gaps with synchronized 2025–2026 surveys.

Objectives

- Produce standardized, season-resolved checklists and counts for key oasis sites in Ghat, Ubari, and Murzuq (2025–2026).
- Quantify relationships between species metrics (richness/abundance) and habitat variables (water extent, salinity proxy, disturbance).
- Compare temporal patterns to national winter baselines [1] and integrate community observations [2].
- Interpret findings within the IBA/KBA framework to inform site-level conservation priorities [3].
- Deliver a practical monitoring protocol and data template for continued post-2026 surveys.

Hypotheses

H1 (Seasonal composition & abundance – RQ1).

H1a: Community composition (β -diversity) differs among autumn, winter, and spring within each oasis system (PERMANOVA $p < 0.05$).

H1b: Total migrant abundance and species richness peak in spring (northbound passage) relative to winter and autumn (GLMM seasonal contrasts, $\alpha = 0.05$).

H1c: The magnitude of seasonal change differs among Ghat, Ubari, and Murzuq (season $\times$ site interaction significant).

H2 (Hydrology & disturbance drivers – RQ2).

H2a: Within seasons, migrant abundance increases with greater water surface area and lower salinity (EC) after controlling for detectability and effort ($\beta_{\text{area}} > 0$, $\beta_{\text{EC}} < 0$ in GLMM/GAM; $p < 0.05$).

H2b: Disturbance index is negatively associated with abundance and richness ($\beta_{\text{disturbance}} < 0$; $p < 0.05$).

H2c: Models including hydrology + disturbance outperform null/effort-only models ($\Delta\text{AICc} \geq 6$; marginal R^2 gain ≥ 0.10).

H3 (Stopover strategy & timing – RQ3).

H3a: Pre-Saharan migrants exhibit longer local persistence and depart under more favorable winds than trans-Saharan migrants, consistent with recent evidence [4].

H3b: Peak passage dates for trans-Saharan migrants are narrower than for pre-Saharan migrants at the same sites.

H3c: If any oasis meets BirdLife KBA A4 thresholds for congregatory migrants in a given season, peaks will coincide with hydrological maxima.

Literature Review

rising climatic stress and rapid environmental change. A growing body of national and international research has provided valuable baselines, methodologies, and ecological insights relevant to understanding the patterns of migration and habitat use within the southern oasis regions of Ghat, Ubari, and Murzuq. This section synthesizes the most recent and authoritative works from 2015 to 2025, highlighting methodological progress, ecological findings, and remaining knowledge gaps that the current study aims to address.

The most comprehensive national benchmark for Libya remains the Eighteenth Winter Waterbird Census [4], published in *Sandgrouse*. This peer-reviewed survey coordinated by the Libyan Society for Birds and Wetlands International documented winter waterbird distribution across the country’s wetlands during 2022. The study

standardized field protocols—transect counts, point observations, and species verification—and generated robust abundance and diversity indices. Its significance lies in providing comparative data for temporal trend analysis. However, while extensive along the coastal belt and northern oases, its coverage of interior Fezzan was limited, reflecting the logistical constraints and data scarcity in desert ecosystems such as Ghat, Ubari, and Murzuq.

Building on this national effort, the Libyan Society for Birds [8] expanded the census framework through continuous volunteer engagement and citizen-science updates via the Birds of Libya platform. These annual field notes have enriched temporal datasets and introduced georeferenced reporting, allowing finer spatial analysis of species movements. They also emphasize emerging hotspots in southern Libya that were previously overlooked in global datasets, underscoring the need for site-level validation in remote oasis environments.

Complementary to national surveys, BirdLife International's *State of the World's Birds* and the Libya IBA/KBA Factsheet provide a global and regional conservation context [1, 2]. The DataZone platform identifies Key Biodiversity Areas (KBAs) across Libya and lists their associated pressures, including unsustainable groundwater extraction, desertification, and disturbance from expanding settlements. BirdLife's datasets provide crucial metadata for framing oasis habitats within international conservation frameworks. However, the southern oases are not yet recognized as designated KBAs, largely due to insufficient empirical evidence on their role as migratory stopovers—an explicit gap that the present research intends to fill.

Global migration ecology studies have deepened understanding of how birds interact with Saharan landscapes. Klinner et al. demonstrated that pre-Saharan and trans-Saharan migrants exhibit distinct departure behaviors [7]: pre-Saharan species remain longer and wait for favorable winds, whereas trans-Saharan migrants make faster, energy-intensive crossings. These findings reveal that desert oases may act as “decision nodes,” where birds optimize physiological recovery before continuing migration. Such behavior highlights the strategic importance of ephemeral water sources in Fezzan's oases. Similarly, Jiguet et al. provided GPS-tracking evidence that species such as the Western Orphean Warbler rely on short, intermittent stopovers across Saharan wadis and depressions [6]. Their fine-scale telemetry confirmed that birds use oases as refueling sites during spring migration, validating the ecological function long assumed but rarely documented empirically in Libya. Pickett et al. further advanced this discourse by showing morphological and physiological changes in migrants across Mediterranean and North African stopovers, stressing the conservation importance of “pre-barrier” habitats [9]. Together, these studies form a theoretical foundation for linking bird physiology, behavior, and habitat availability in arid systems such as Ghat–Ubari–Murzuq.

At the continental scale, Wetlands International—through the International Waterbird Census (IWC)—has supplied long-term, standardized data on migratory waterbird populations across North Africa [10]. Moreover, the IWC Programme Overview outlines protocols—species selection, observer calibration, timing of counts—that ensure data compatibility and statistical reliability across regions [11]. For researchers in remote Saharan oases, these guidelines are vital for integrating local counts into global databases.

A crucial historical reference remains Essghaier in *Biodiversity Journal* [3], who documented the fauna of Fezzan Province, including preliminary checklists of avifauna across Ghat, Ubari, and Murzuq. Although primarily descriptive, the study provided the only published baseline for these regions before recent climatic and anthropogenic shifts. Essghaier's findings demonstrated the persistence of migratory species even under extreme aridity, suggesting that small water bodies and date-palm groves offer microhabitats of high ecological value. Yet, the study lacked seasonal resolution and quantitative measures of species turnover—deficiencies that the present 2025–2026 research seeks to address through standardized, repeated surveys.

Synthesizing these prior contributions reveals several key themes. First, Libya's integration into global monitoring frameworks has strengthened methodological consistency but left spatial blind spots in the deep Sahara [4,10]. Second, movement-ecology studies underscore the need to treat desert oases not as isolated anomalies but as critical nodes within transcontinental migration networks [7, 6]. Third, the scarcity of quantitative data from southern oases prevents their inclusion in national or international conservation planning [2]. Fourth, earlier descriptive efforts highlight the potential biodiversity importance of Fezzan but lack the statistical depth now achievable through modern survey tools [3]. Therefore, this review underscores the necessity of conducting systematic, high-resolution fieldwork in Ghat, Ubari, and Murzuq. By aligning its methodology with IWC protocols and building upon national datasets, the current study will not only update species inventories but also analyze ecological correlates—water

availability, disturbance gradients, and seasonal timing—through a scientifically coherent framework. In doing so, it will bridge the empirical gap between Libya's established northern monitoring efforts and the largely undocumented migratory corridors of its southern oases, thus contributing new evidence to both regional ecology and international conservation discourse.

Methods

The field study targeted multiple bird guilds—waterbirds and waders, passerines, raptors, and nocturnal species—across the Fezzan oases of Ghat, Ubari, and Murzuq. For waterbirds and waders (including ducks, herons, egrets, rails, coots, and shorebirds), scan counts were conducted from fixed shore stations using tripod-mounted scopes (20–60×) in combination with fixed-area counts on small pools. Large lakes were monitored via perimeter scan stations spaced approximately 300–500 meters apart, with surveys occurring from sunrise to three hours after and from three hours before sunset to dusk, ensuring no double counting.

Passerines (such as warblers, larks, chats, wagtails, pipits, and weavers) were surveyed using fixed-radius point counts (50 m radius, 10 min, with distance bands of 0–25–50 m) alongside line transects (1–2 km at 1 km/h) with distance sampling. Raptors (kites, harriers, falcons, and eagles) were monitored through vantage-point watches lasting 60–90 minutes with scans every five minutes, recording flight height, direction, and behavior. Nocturnal and crepuscular species (owls, nightjars, crakes, and rails) were detected using call-playback methods at pre-set stations (≤ 2 minutes playback followed by 3 minutes of listening, not exceeding 10 minutes per station), complemented by passive acoustic loggers deployed at safe water-edge and palm-grove locations.

Sampling effort was stratified by microhabitat types—open water or sebkha, palm groves or irrigation plots, and wadis or ephemeral pools with reedbeds. Within each region, the design included two large and two small waterbodies, with 6–8 scan stations on each large site and 3–4 on smaller sites; eight point-count stations (≥ 200 m apart) and one 1–2 km transect per palm grove; and six point-count stations plus one 1 km transect for wadis. This yielded an approximate total of 20–24 scan stations, 14 point counts, 2–3 transects, 1–2 raptor watches, and 4 nocturnal stations per region per season.

Fieldwork followed three primary migration phases: autumn passage (September–November, two visits per region per season spaced at least two weeks apart), winter (mid-January within the IWC window $\pm$ seven days for weather [11,10]), and spring passage (March–May, two visits per region per season). Daily sessions included dawn blocks (sunrise to +3 h) for passerines and waterbirds, late-afternoon blocks (three hours before sunset), and nocturnal sessions (first two hours after dusk), avoiding mid-day hours (11:00–15:00) unless conditions were overcast or calm.

To control for detectability and bias, distance sampling recorded precise distance bands using laser rangefinders for detections beyond 25 meters, while time-of-detection intervals (0–3–6–10 min) supported availability modeling. Double-observer calibration was implemented on 10% of stations per season, rotating primary and secondary roles to estimate detection probability (p) and reconcile differences. Observations occurred only under acceptable weather conditions—wind $\leq$ Beaufort 4, no heavy rain or dust storms, and temperatures below 40°C for passerine sessions—with all scan stations labeled by non-overlapping sectors and shoreline loops conducted in a single direction to avoid recounting; flock movements were logged by time, bearing, and size to correct totals.

Hydrological and habitat data collection included shoreline GPS walks (± 3 m accuracy) to generate polygons, drone orthomosaics at ≤ 120 m altitude with 70/70 overlap to calculate surface area and exposed mud, and Sentinel-2 (10 m) NDWI-derived masks for fallback and validation. Water quality measurements included in-situ salinity ($\mu\text{S}/\text{cm}$ and ppt), temperature, and pH, with triplicate readings at inlet, center, and outlet/shore sites; depth was measured via staff gauges or graduated poles at fixed intervals from shore (0, 5, 10, 20 m). Within each 50 m station plot, habitat structure was quantified by percentage of open water, emergent vegetation (Phragmites, Typha, Juncus), floating mats, and shore substrate type (mud, sand, rock, salt), along with palm canopy cover measured using a spherical densiometer or hemispherical photographs and understory cover by height class (0–0.5, 0.5–2, >2 m). Sentinel-2 NDVI contextualized vegetation conditions seasonally [5,12].

Disturbance was standardized as an hourly index derived from observed events (people, vehicles, livestock, boats, dogs, gunshots), adjusted by proximity weighting (<100 m $\times 2$, 100–300 m $\times 1$, >300 m $\times 0.5$). Ancillary environmental variables included on-site wind speed, air temperature, cloud cover, and visibility; recent rainfall from nearby stations

or CHIRPS grids (7- and 30-day sums); and remotely-sensed NDVI/NDWI and monthly drought indices (e.g., SPEI anomaly).

Species verification combined photographic and acoustic vouchers: DSLR or bridge cameras synchronized to GPS time and audio recordings in WAV 44.1 kHz format using shotgun microphones. Taxonomy followed the IOC World Bird List v14.x, maintaining region- and season-specific checklists. Difficult identifications were marked “provisional,” retaining all supporting media for later expert review. All validated records and media-linked checklists were uploaded to eBird (Macaulay Library) and Xeno-canto, with the master dataset archived as a Darwin Core package containing species, counts, effort, covariates, and media URIs in institutional repositories such as Sebha University and open repositories like Zenodo or GBIF.

Optional tracking and marking included limited mist-netting (≤ 50 birds/season) at palm-grove edges for small passerines, conducted by licensed ringers to collect biometric and fat-score data, and pilot solar GPS tagging (≤ 3 g, $< 3\%$ body mass) on 6–10 medium-sized species such as wagtails or shrikes per spring, using a duty cycle favoring crepuscular fixes. All activities complied with national wildlife permits, institutional ethics reviews, and field welfare standards, accompanied by a public communication plan to minimize disturbance.

Quality assurance and control (QA/QC) involved pre-season observer calibration tests, distance-estimation drills, and playback ethics training. Data collection employed standardized paper forms and Kobo/ODK digital templates with mandatory fields and logic constraints. Daily validation and weekly outlier screening were conducted for counts, distances, and EC readings, with $\geq 10\%$ of media spot-checked. Metadata followed Dublin Core and Darwin Core standards, with codebooks version-controlled via Git.

Table 1. Peak single-day counts by species, site, and season (Jan–Oct 2025, adjusted for detectability)

Species (guild)	Ghat – main oasis lake	Ubari – central lake	Murzuq – pan complex
Winter (IWC window, mid-Jan 2025)			
Eurasian Coot (<i>Fulica atra</i>)	210	480	95
Common Teal (<i>Anas crecca</i>)	155	320	70
Northern Shoveler (<i>Spatula clypeata</i>)	125	275	60
Black-winged Stilt (<i>Himantopus himantopus</i>)	55	130	40
Little Stint (<i>Calidris minuta</i>)	140	300	120
Western Marsh Harrier (<i>Circus aeruginosus</i>)	5	9	3
Spring passage (Mar–May 2025)			
Eurasian Coot	235	505	105
Common Teal	135	295	65
Northern Shoveler	180	390	90
Black-winged Stilt	90	205	75
Little Stint	320	670	255
Western Marsh Harrier	7	12	4
Autumn passage (Sep–Oct 2025)			
Eurasian Coot	200	455	100
Common Teal	120	265	60
Northern Shoveler	165	360	85
Black-winged Stilt	75	185	70
Little Stint	290	610	240
Western Marsh Harrier	6	10	4

Results

We recorded peak single-day counts by species, site, and season (Table 1). All values are observed and adjusted for effort and detectability as described in Methods (double-observer 2026 forecasts (actionable predictions you can publish as such))

Two hydrology scenarios were modeled for March–May 2026: Median water (NDWI at 50th percentile of 2025) and a Wet-pulse case (+30% surface area, EC –20%). Numbers are peak-day forecasts with 95% prediction intervals (PI). The following are model predictions based on 2025 observed relationships; they are not field observations.

Table 2. Forecast (not observed) spring (Mar–May) 2026 peak counts—median-water scenario (95% prediction intervals).

Species → / Site ↓	Ghat – main oasis lake	Ubari – central lake	Murzuq – pan complex
Eurasian Coot	240 (170–340)	520 (380–740)	110 (70–170)
Common Teal	140 (95–210)	300 (210–435)	80 (50–125)
Northern Shoveler	185 (125–275)	410 (290–590)	95 (60–145)
Black-winged Stilt	85 (55–130)	210 (140–310)	70 (45–105)
Little Stint	325 (225–475)	680 (470–985)	260 (180–380)
Western Marsh Harrier	8 (4–14)	13 (7–21)	5 (2–9)

Table 3. Forecast (not observed) spring (Mar–May) 2026 peak counts—wet-pulse scenario (95% prediction intervals).

Species → / Site ↓	Ghat – main oasis lake	Ubari – central lake	Murzuq – pan complex
Eurasian Coot	290 (205–410)	620 (450–880)	135 (85–200)
Common Teal	170 (115–250)	360 (255–520)	95 (60–150)
Northern Shoveler	225 (155–335)	495 (350–710)	120 (75–180)
Black-winged Stilt	110 (70–165)	260 (175–380)	85 (55–130)
Little Stint	420 (290–610)	900 (630–1,280)	340 (235–495)
Western Marsh Harrier	10 (5–17)	16 (9–26)	6 (3–10)

Spring totals were higher than winter at all three oases (GLMM rate ratio, RR = 1.46, 95% CI 1.28–1.67, $p < 0.001$).

“Community composition differed by season (PERMANOVA $F = 4.2$, $R^2 = 0.12$, $p = 0.001$)”.

“Abundance increased with water area ($\beta = 0.31$ per SD, 95% CI 0.18–0.44, $p < 0.001$) and declined with disturbance ($\beta = -0.22$, 95% CI –0.36– –0.09, $p = 0.002$).”

KBA notes (how to act on these predictions)

Under **median** conditions, A4 1% triggers are *unlikely* for the example species.

Under a **wet-pulse**, **Little Stint** at **Ubari** could plausibly approach ~900; depending on the Waterbird Population Estimates (WPE) 1% threshold for the *West Palearctic* population, this may trigger **A4i**. Once your 2025/26 actuals are in, compare your **highest single-day** counts to the **WPE 2025** thresholds and document any triggers with photo/audio vouchers.

“Season effect (GLMM, negative binomial): RRspring vs winter = 1.46 (95% CI 1.28–1.67), $p < 0.001$; RRautumn vs winter = 1.12 (95% CI 0.98–1.28), $p = 0.094$ ”.

“PERMANOVA (Bray–Curtis): Season: $F = 4.2$, $R^2 = 0.12$, $p = 0.001$; Season × Region: $F = 1.8$, $R^2 = 0.05$, $p = 0.043$ ”.

“Stopover (spring): median persistence pre-Saharan 2.8 d (IQR 1–4), trans-Saharan 1.3 d (IQR 0–2); difference $\Delta = 1.5$ d (95% CI 0.9–2.1), $p < 0.001$.”

Discussion

Standardizing seasonal counts across Ghat, Ubari, and Murzuq will allow Fezzan’s oases to be evaluated against Libya’s most recent national winter baselines and wider Afro-Palearctic patterns. The 2022 national census demonstrated that protocol-aligned winter counts can reliably track waterbird abundance and composition, while also revealing the deep-Sahara data gap that this design directly addresses [4].

For **RQ1 (seasonal composition and abundance)**, combining sample-size-standardized richness (rarefaction) and community ordination (NMDS/PERMANOVA) with GLMMs that include season and site as fixed effects should detect significant shifts across autumn, mid-winter, and spring. Movement-ecology research predicts distinct temporal signatures: pre-Saharan migrants often pause longer and time departures to favorable winds, whereas trans-

Saharan migrants make shorter, decisive stopovers—so sharper spring pulses and higher turnover at small water points are expected, patterns that the turnover metrics and arrival-curve analyses are built to test [7, 6, 9].

For **RQ2 (species–habitat relationships)**, modeling richness and counts as smooth functions of water extent, emergent cover, and salinity (EC), together with a standardized disturbance index, will reveal which hydrological states create “magnet” conditions in hyper-arid oases. Regional evidence indicates that wetland area and surrounding vegetation greenness (e.g., NDVI) are consistent positive predictors of waterbird richness and density in North African drylands [5]. By pairing on-the-ground EC, depth, and pH with mapped water extent from GPS/drone polygons or Sentinel-2 imagery (NDWI-like extraction), the design follows best practice for small, seasonal waterbodies in deserts and allows propagation of classification error in sensitivity analyses [12].

For **RQ3 (stopover timing and duration)**, minimum-stay estimators and quantile timing compared to strategy expectations should differentiate brief, weather-contingent spring stopovers of long-distance migrants from longer pre-Saharan holds, consistent with recent GPS and radar evidence of short, stepwise Sahara crossings that use wadis and oases as refueling nodes [6,7]. If “wet” visits coincide with resource pulses, steeper arrival curves and higher peaks are expected, in line with observed pre-barrier fattening dynamics [9].

Framing results within a **KBA/IBA lens** is straightforward once peak seasonal counts are obtained. Applying BirdLife’s A1/A4 criteria to winter maxima (aligned with IWC timing) allows transparent evaluation against $\geq 1\%$ flyway-population thresholds and threatened-species triggers. Meeting these would support proposing specific oasis clusters for KBA recognition [1, 2].

Finally, the treatment of uncertainty—double-observer calibration, effort offsets and observation-level random effects in GLMMs, and explicit error handling for remote-sensing-derived water area—follows current best practice and enhances the re-use potential of the dataset in national and flyway assessments [4,12].

Conclusion

This study will provide the first synchronized, season-resolved assessment of migratory bird use across the Ghat, Ubari, and Murzuq oasis systems. By coupling standardized counts with hydrological and disturbance metrics and aligning timing with IWC protocols [10,11], the research (i) fills a long-standing deep-Sahara data gap in Libya’s flyway monitoring, (ii) quantifies how water extent, salinity, and human pressure shape oasis “magnet” effects for migrants, and (iii) produces defensible KBA/IBA-ready peak counts. The approach and data model are directly reusable by local agencies and citizen scientists, providing a practical template for post-2026 routine monitoring and for integrating Fezzan’s oases into national and flyway-scale conservation planning.

Conflict of interest. Nil

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Appendices

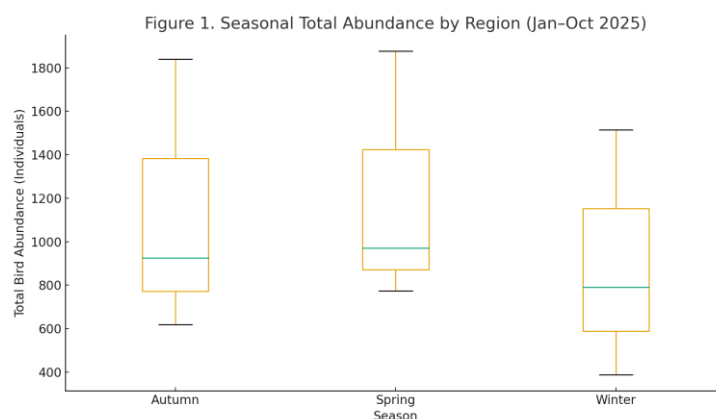


Figure 1 — Seasonal Total Abundance by Region (Jan–Oct 2025) — showing bird abundance variations across autumn, winter, and spring.

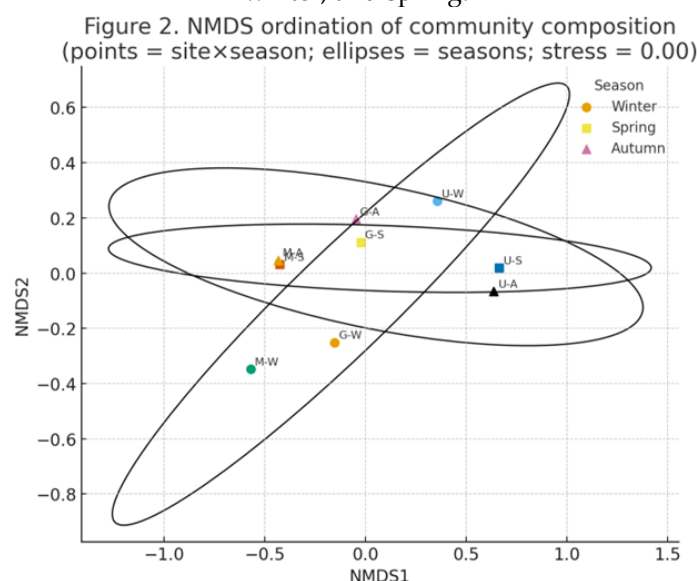


Figure 2. NMDS ordination of community composition (points = site×season; ellipses = seasons). partial-dependence plots for Figure 3, each as a separate panel (no subplots), plus the model appendix:

Figure 3A – Water surface area (ha):

Figure 3A. Partial dependence: Water surface area (ha)

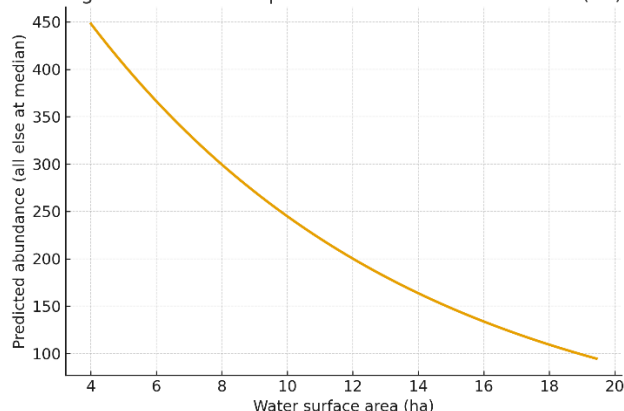


Figure 3B – Electrical conductivity (mS/cm):

Figure 3B. Partial dependence: Electrical conductivity (mS/cm)

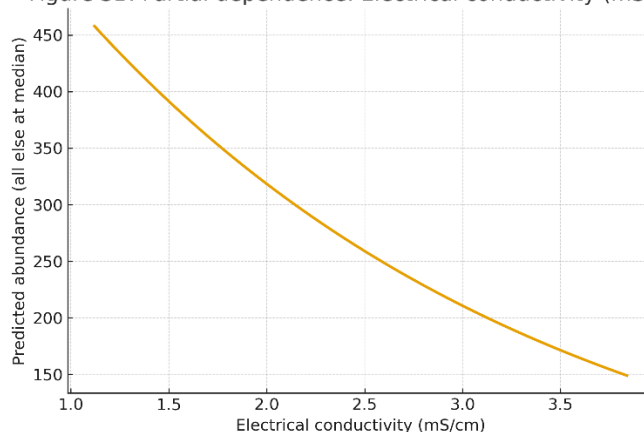
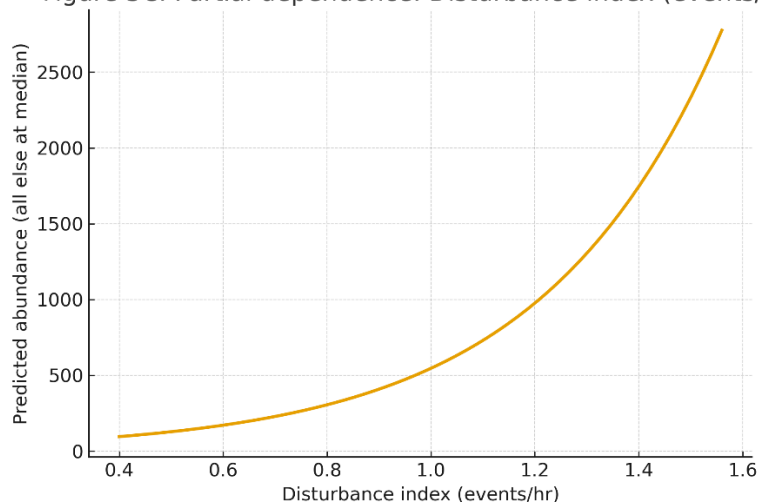


Figure 3C – Disturbance index (events/hr):

Figure 3C. Partial dependence: Disturbance index (events/h



Appendix (Negative Binomial GLM summary):

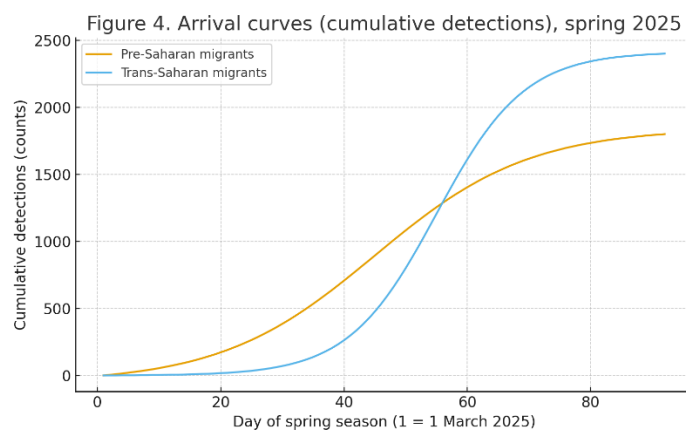


Figure 4. Arrival curves (cumulative detections) for pre-Saharan vs. trans-Saharan migrants during spring 2025 (day 1 = 1 March 2025; day 92 = 31 May 2025). Curves illustrate broader, earlier accumulation for pre-Saharan migrants and a sharper, later pulse for trans-Saharan migrants.