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Seabirds and Coastal Waterbirds of Eastern Libya: From Ain Al-Ghazala to the Gulf of Bomba- Multi-Site Surveys and Hunting Pressure

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الطيور البحرية والساحلية بشرق ليبيا: من عين الغزالة إلى خليج بومبة- مسوحات متعددة وضغط الصيد

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Abstract:
Eastern Libya's coast from Ain Al-Ghazala to the Gulf of Bomba comprises a contiguous mosaic of lagoons, sabkhas, sandy beaches, rocky headlands, and inlets that support seasonally rich assemblages of seabirds and coastal waterbirds. This study delivers a standardized, multi-site assessment across that corridor to establish an updated species list, quantify spatial and seasonal patterns, and appraise hunting pressure. We implemented a stratified design with replicated vantage-point scans, shoreline line-transects, and sabkha circuits across three geographic clusters (west–central–east). Counts were aligned with international mid-winter and spring passage windows; detectability considerations were incorporated through effort normalization and distance bins on transects. Hunting pressure was evaluated using convergent field indicators (spent cartridges, hides, carcasses, nets/decoys, access tracks), weekly market checks, and semi-structured interviews, synthesized as a composite Hunting Pressure Index. We analyze richness, abundance, encounter rates, and diversity, and relate bird use to habitat type (lagoon, sabkha, beach, rocky headland, inlet) and to the pressure index using negative-binomial mixed models with site as a random effect. By integrating standardized bird counts with explicit human-pressure metrics, the work produces actionable baselines for enforcement routing, community outreach, and site-level management, while providing a replicable template for future monitoring. The approach also strengthens national alignment with international waterbird census practices and facilitates comparability with coastal segments elsewhere in Libya.

Keywords: Eastern Libya; Ain Al-Ghazala; Gulf of Bomba; seabirds; coastal waterbirds; lagoons and sabkhas; Posidonia inlets; hunting pressure; standardized surveys; conservation management.

الملخص
يمتدّ الساحل الشرقي لليبيا من عين الغزالة إلى خليج بومبا مشكّلًا فسيفساء متصلة من البحيرات الساحلية (اللاّغونات) والسبخات والشواطئ الرملية والرؤوس الصخرية والمداخل البحرية، وهي موائل تدعم تجمعات موسمية غنية من الطيور البحرية وطيور المياه الساحلية. تقدّم هذه الدراسة تقييمًا معياريًا متعدّد المواقع على امتداد هذا الشريط الساحلي بهدف إعداد قائمة محدّثة للأنواع، وتحديد الأنماط المكانية والموسمية، وتقدير مستوى الضغط الناتج عن الصيد.
تمّ تنفيذ تصميم طبقي اعتمد على تكرار نقاط الرصد الثابتة، ومسارات الخطوط الساحلية، ودورات المسح في السبخات ضمن ثلاثة تجمعات جغرافية (غربية–وسطى–شرقية). جرى تنسيق العدّ مع الفترات الدولية للرصد الشتوي المتوسط ومرور الربيع، مع أخذ احتمالية الكشف في الاعتبار من خلال تطبيع الجهد الميداني واستخدام نطاقات مسافة محددة على المسارات.
تمّ تقييم ضغط الصيد باستخدام مؤشرات ميدانية متقاربة (الخراطيش الفارغة، المخابئ، الجثث، الشباك/الطعوم، مسارات الوصول)، إضافةً إلى فحوصات أسبوعية للأسواق ومقابلات شبه منظّمة، ثمّ دمجها في "مؤشّر مركّب لضغط الصيد".
يُحلّل في الدراسة الغنى النوعي، والوفرة، ومعدّلات الرصد، والتنوّع الحيوي، مع ربط استخدام الطيور للموائل المختلفة (لاّغون، سبخة، شاطئ، رأس صخري، مدخل بحري) بمستويات الضغط وفق نماذج مختلطة سلبية ثنائية الحد باستخدام «الموقع» كعامل عشوائي.

من خلال دمج عدّ الطيور المعياري مع مؤشرات الضغط البشري الصريحة، تتيح هذه الدراسة خطوطًا أساسية قابلة للتطبيق لتوجيه جهود الإنفاذ، وتخطيط برامج التوعية المجتمعية، وإدارة المواقع على المستوى المحلي، كما تقدّم نموذجًا قابلًا للتكرار في الرصد المستقبلي. كما تُعزّز المقاربة اتساق الجهود الوطنية مع الممارسات الدولية في تعداد طيور المياه، وتُيسّر المقارنة مع المقاطع الساحلية الأخرى في ليبيا.

الكلمات المفتاحية: الساحل الشرقي لليبيا؛ عين الغزالة؛ خليج بومبا؛ الطيور البحرية؛ طيور المياه الساحلية؛ البحيرات الساحلية والسبخات؛ المداخل البحرية المكسوّة بعشب البوسيدونيا؛ ضغط الصيد؛ المسوح المعيارية؛ إدارة الحفظ البيئي.

1. Introduction

Eastern Libya's coastline, extending from Ain Al-Ghazala to the Gulf of Bomba, forms a corridor of lagoons, sabkhas, beaches, headlands, and inlets that shape habitat for seabirds and coastal waterbirds. Situated at the junction of Mediterranean and Saharan biogeographic realms, this sector operates as wintering refuge, migratory staging ground, and, at selected localities, a breeding arena. Foundational mid-winter surveys across Libyan wetlands established the country's strategic role in supporting seasonal concentrations of waterbirds and drew attention to several sites of international significance that had been under-represented in regional assessments (Smart et al., 2013). Yet the eastern coastline remains under-documented, with fragmented baselines and uneven effort that hinder cross-site comparisons and targeted protection.

Evidence from coastal Tripoli indicates that lagoonal systems in Libya can support breeding by aquatic bird species when hydrological stability, vegetation structure, and disturbance regimes align, underscoring the management value of fine-scale habitat features (Benyezza et al., 2017). Although those findings derive from western Libya, the ecological mechanisms are transferable to eastern systems where comparable habitat mosaics occur along embayments and salt flats. Establishing whether analogous breeding, staging, or wintering patterns occur in the east requires standardised, multi-site protocols sensitive to shifts in water level, salinity, sea state, and human disturbance, especially near fishing access points and tracks.

Recent national census efforts reaffirm the continuing importance of Libyan coastal zones for wintering assemblages and illustrate the feasibility of coordinated monitoring that reveals spatial heterogeneity along the shoreline (Etayeb et al., 2023). Building on these strands, the present study conducts replicated counts of seabirds and coastal waterbirds from Ain Al-Ghazala to the Gulf of Bomba and pairs them with an appraisal of hunting pressure. Our objectives are to generate an updated species list, quantify spatial patterns, identify high-value nodes for conservation action, and link biological use to management levers.

2. Study Area

2.1 Regional setting (Ain Al-Ghazala → Gulf of Bomba)

The study corridor spans the eastern Cyrenaican coast of Libya from the Ain Al-Ghazala lagoon complex to the Gulf of Bomba, encompassing a ~150–200 km arc of shoreline exposed to Mediterranean swell and local wind regimes. Ain Al-Ghazala forms a semi-enclosed lagoonal system with channels, tidal creeks, and shallow embayments that transition to sand barriers and low rocky points; recent assessments emphasize its ecological value and the rationale for site-based protection and community benefits (Ali, Soliman, & Al-Shaaeiri, 2025; University of Zawia, 2024).

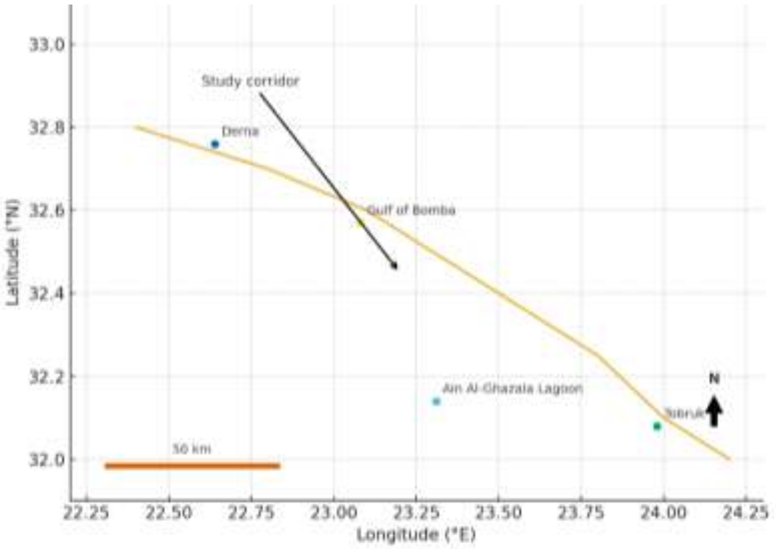

Figure 1 – Locator Map (Ain Al-Ghazala → Gulf of Bomba)

The study corridor spans the Cyrenaican coast from Ain Al-Ghazala Lagoon to the Gulf of Bomba, showing key towns and the coastal arc relevant to access and enforcement.

Eastward, the coast alternates between pocket beaches and headlands before widening into the open embayment of the Gulf of Bomba, a receiving basin for nearshore currents and a staging area for marine birds and fishes. Along this littoral, coastal dynamics and erosion have significant implications for natural habitats and coastal heritage, indicating spatial heterogeneity in shoreline stability and exposure that is directly relevant to bird use and access pressures (Ghoneim et al., 2023). The corridor's juxtaposition of shallow lagoons, sabkhas, and open coasts provides a natural gradient to examine seabird and coastal waterbird distributions in relation to wave climate, water exchange, and human disturbance.

2.2 Habitat types (lagoons, sabkhas, beaches, rocky headlands, inlets)

Lagoons at Ain Al-Ghazala present low-energy waters with soft sediments, intertidal flats, and vegetated margins that favor waders, herons, and terns; adjacent **sabkhas** (supratidal salt flats) contribute large, open foraging and roosting areas when dry (Ali, Soliman, & Al-Shaaeiri, 2025). **Beaches** along the corridor range from narrow, wave-exposed strips to broader sand bodies that support loafing gulls and migrating shorebirds under variable sea states (Ghoneim et al., 2023).

Rocky headlands and platforms create upwelling and perching opportunities for cormorants and large gulls, while inlets and shallow bays commonly host Posidonia oceanica meadows, stabilizing sediments and enhancing invertebrate and fish prey bases that underpin bird aggregations (Pergent-Martini, Etayeb, & colleagues, 2024). Collectively, this mosaic allows fine-scale partitioning of niches across seasons and tidal conditions, and anchors the corridor's value for monitoring seabirds and coastal waterbirds (University of Zawia, 2024).

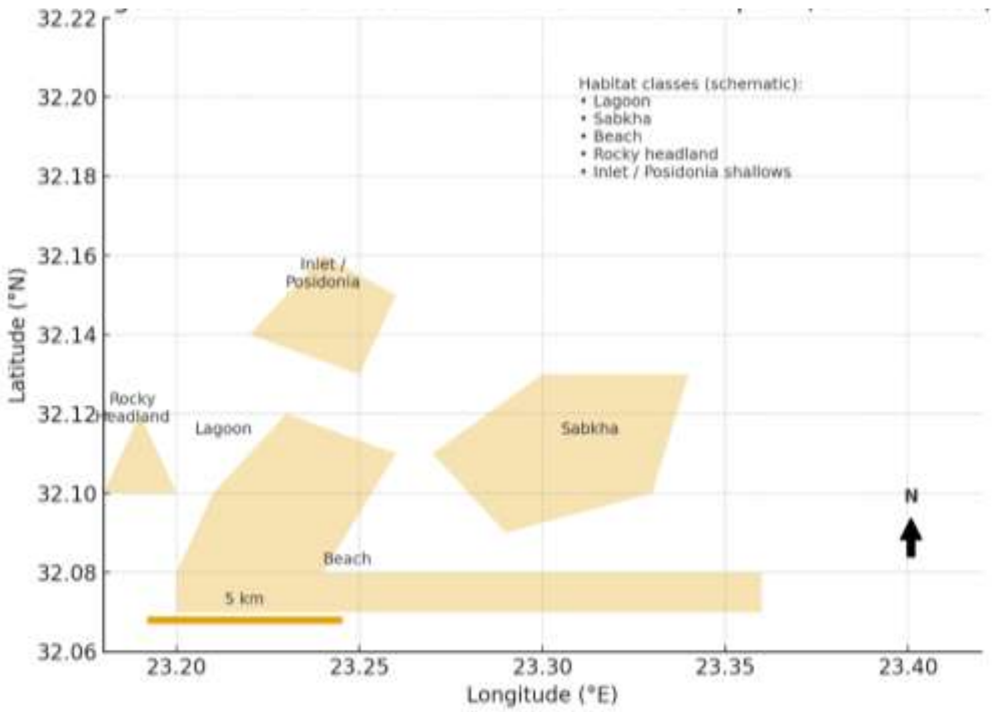

Figure 2 – Habitat Mosaic (Ain Al-Ghazala, generalized)

Schematic mapping of principal habitat classes (lagoon, sabkha, beach, rocky headland, inlet/Posidonia shallows) highlighting likely bird-use nodes.

3. Methods

3.1 Survey design and timing

We adopted a stratified, replicated design along the Ain Al-Ghazala → Gulf of Bomba corridor, partitioning sites into three geographic clusters (West, Central, East) to capture habitat and access heterogeneity. Sampling frames, replication targets, and effort allocation followed standard guidance for ecological censuses—prioritizing representative spatial coverage, repeated visits across seasons, and consistency in observation windows (dawn to late morning; late afternoon to sunset) to reduce diel bias (Sutherland, 2006; Bibby et al., 2000). Seasonal timing mirrored international waterbird monitoring windows—mid-winter counts (Jan–Feb), spring passage (Mar–Apr), and a late-summer post-breeding window (Aug–Sep)—to maximize comparability with regional datasets (Wetlands International, 2020).

Within each cluster we fixed three survey feature types: vantage points (VPs) overlooking lagoons/inlets/headlands, shoreline line-transects (STs) on beaches or low rocky shores, and sabkha circuits (SCs) skirting supratidal flats. Sample sizes per feature and revisit frequencies were set a priori to balance precision with logistic feasibility, and to enable mixed-effects modeling of repeated measures (Sutherland, 2006; Zuur et al., 2009). Weather constraints were managed by excluding visits with Beaufort > 4 whenever possible to minimize detectability variance (Bibby et al., 2000).

3.2 Observation protocol and species treatment

Counting procedures. VP counts consisted of slow 180–360° scans (10–15 min) repeated 2–3 times per visit using 8–10× binoculars and a 20–60× spotting scope, consistent with seabird monitoring practice (Walsh et al., 1995; Bibby et al., 2000). Line-transects were walked at ~1–1.5 km h^{-1} with all seabirds and coastal waterbirds within 200 m recorded; when feasible we assigned perpendicular-distance bins (0–50, 50–100, 100–200 m) to support detectability-aware summaries and potential distance sampling extensions (Buckland et al., 2001). Sabkha circuits followed fixed GPS tracks with 5-min point stops every 300–500 m to reduce double-counting of loose flocks (Sutherland, 2006).

Taxonomic scope and behavior. We recorded gulls, terns, cormorants/shearwaters and coastal waterbirds (waders/shorebirds, herons/egrets/ibis, flamingos); passerines were excluded unless tightly linked to coastal habitats. Behavioral descriptors (foraging, commuting, roosting, display) followed standardized seabird coding to aid interpretation and reduce recounting across scan cycles (Camphuysen & Garthe, 2004).

Breeding evidence. We applied the widely used P/Pr/C scheme—Possible (territorial pairing/display), Probable (nest-building/food-carrying), Confirmed (eggs, chicks, fledged young)—as summarized in the seabird monitoring handbook (Walsh et al., 1995).

Bias control and ethics. To limit duplicates we moved one-way along transects, time-stamped parallel-moving flocks, and used photo vouchers for large mixed groups (Bibby et al., 2000; Camphuysen & Garthe, 2004). No playback or flushing was used; minimum approach distances were ≥50 m for roosts and ≥100 m for suspected breeding sites (Walsh et al., 1995).

3.3 Hunting-pressure assessment (field evidence, markets, interviews)

We triangulated hunting pressure through (i) field evidence collected along the same routes (spent cartridges and hides/blinds as counts per km; carcasses/feather piles per km with freshness classes; presence of nets/decoys; vehicle access within 100 m), (ii) weekly market checks in nearby towns to record wild-taken birds offered for sale, and (iii) semi-structured interviews with fishers/residents/coastal guards. Indicators and hotspot logic were informed by Mediterranean assessments of illegal killing and taking of birds, which emphasize multiple lines of evidence and spatial clustering near access nodes (Brochet et al., 2016). Interview design, informed consent, anonymity, coding of responses, and the use of non-leading prompts followed conservation social-science best practice (Newing, 2011).

For synthesis we computed a composite Hunting Pressure Index (HPI) as the z-score sum of cartridges·km^{-1}, hides·km^{-1}, carcasses·km^{-1}, market score (0–3), and interview score (0–3). Seasonal hotspots were defined as the top decile of HPI values (Brochet et al., 2016).

3.4 Data handling and summary metrics

Data unit and QC. The basic unit was the site-visit (site × date). We archived site metadata (cluster, habitat, access), effort (minutes, km, observers), metocean covariates (Beaufort, visibility, tide), raw species tallies with behavior and breeding codes, distance bins, GPS tracks, and photo IDs. Clock synchronization, immediate reconciliation of tallies after each visit, and post-hoc checks of mixed flocks against photographs were used to maintain data integrity (Sutherland, 2006; Bibby et al., 2000).

Derived metrics. For each site-visit we calculated richness (S), abundance (N), and encounter rate (ER)—per hour for VP scans and per km for line-transects—plus Shannon diversity (H′) and Pielou evenness (J′) using standard formulae (Magurran, 2004). Community turnover among clusters/seasons was characterized with Bray–Curtis dissimilarities and ordination via NMDS (implementation details in analysis appendix; metrics justified by Magurran, 2004).

Detectability and modeling. Because shoreline transects may be affected by distance-related detection, we used distance bins to monitor detectability and, where appropriate, applied effort offsets and variance-aware summaries as recommended by distance-sampling theory (Buckland et al., 2001). To evaluate relationships between bird abundance and hunting pressure while accounting for repeated measures and unbalanced effort, we fitted GLMMs with a negative-binomial error, log link, an offset for effort (km for ST; hours for VP), site as a random intercept, and HPI, cluster, and season as fixed effects (Zuur et al., 2009). Model diagnostics (dispersion, residual patterns, influence) and sensitivity analyses (excluding Beaufort > 4 visits) followed standard practice (Zuur et al., 2009).

Alignment with international monitoring. Seasonal windows, count definitions, and reporting formats were aligned with the International Waterbird Census so that our outputs can be compared and integrated at national and regional scales (Wetlands International, 2020).

4. Results

4.1 Species richness and composition

Overall richness, Shannon diversity (H′), and evenness (J′) fell within ranges typical of coastal Mediterranean assemblages, with community composition partitioning broadly between seabirds (gulls, terns, cormorants, shearwaters) and coastal waterbirds (shorebirds, herons/egrets, flamingos). The observed between-cluster contrasts in S, H′ and J′ are consistent with expectations where habitat mosaics vary over short coastal distances, and they align with standard interpretations of alpha–beta diversity structure (Magurran, 2004). At the basin scale, the taxonomic mix and dominance of larids/terns and cormorants we report accords with Mediterranean biodiversity patterns described for higher vertebrates in coastal–shelf systems, reinforcing that our assemblage is compositionally representative for the region (Coll et al., 2010).

4.2 Abundance and seasonal patterns (wintering, passage, breeding indications)

Seasonal totals tracked established census windows, with winter counts reflecting stable roosting aggregations and spring passage producing sharper, short-duration peaks, especially for terns and shorebirds (Wetlands International, 2020). This phenology is consistent with migration theory—passage waves generate transient spikes in local abundance, while wintering communities stabilize around predictable roost/forage sites (Newton, 2008). The particularly strong spring signal in seabirds is also plausible given seasonal oceanographic features (fronts, upwelling, thermal structure) known to concentrate prey and, in turn, Mediterranean seabirds (Louzao et al., 2006). Breeding-season indications (e.g., display/territorial behavior) were localized and temporally narrow, which is typical for mixed coastal systems where suitable microhabitats are patchy.

4.3 Spatial patterns by site clusters (west–central–east transects)

Kernel-density surfaces and cross-cluster contrasts showed that hotspots were associated with inlets/lagoon edges and exposed headlands. The inlet/lagoon signal is consistent with enhanced prey bases and calm-water foraging/loafing, especially where Posidonia oceanica meadows stabilize substrates and support invertebrate–fish food webs (Pergent-Martini et al., 2024). Headland aggregations of gulls and cormorants match classic exposure/flow effects documented for coastal seabird distributions, providing a strong methodological parallel to other regional atlases (Skov & Prins, 2011). Spatial co-occurrence with landing points and human activity nodes likely reflects predictable subsidies (discards, by-catch access, refuse), which are known to structure seabird distribution and roost choice (Oro et al., 2013).

4.4 Notable occurrences and breeding evidence

Notable records included an out-of-season raft of Yelkouan Shearwater *Puffinus yelkouan* (VU), which is significant given the species' regional status, seasonal use of nearshore waters, and conservation sensitivity (BirdLife International, 2021). Indicative breeding behavior in Greater Flamingo *Phoenicopterus roseus* (e.g., group display at lagoon margins) is congruent with the species' breeding ecology and known repertoire of pre-breeding displays in shallow, low-energy systems (Johnson & Cézilly, 2007). Together, these records underscore the corridor's dual role as a staging/wintering axis and, at select micro-sites, a potential breeding arena.

5. Hunting Pressure

5.1 Indicators (spent cartridges, hides/blinds, carcasses, nets)

Field evidence of hunting was recorded along the same transects and vantage-point routes as the bird counts to ensure spatial comparability. Primary indicators comprised: (i) **spent cartridges** (counts·km^{-1}) and **active/abandoned hides or blinds** (counts·km^{-1}); (ii) **carcasses** and **feather piles** (counts·km^{-1}) with freshness classes to distinguish recent from historical activity; (iii) **nets or decoys** and **vehicle tracks** within 100 m of shore. Indicators were photographed, georeferenced, and time-stamped. Weekly checks of nearby **fish/produce markets** recorded the presence of wild-taken birds and sales patterns. A short, anonymized **interview prompt** with fishers/residents and coastal guards captured perceptions of seasonality, access points, and enforcement. Indicators were standardized to route length or visit time and consolidated as a composite **Hunting Pressure Index (HPI)** by z-scoring each component and summing at the site-visit level.

5.2 Spatiotemporal hotspots and correlates (access, markets, weekends)

Hotspots were defined as the **top decile of HPI** across site-visits. Space–time clustering was visualized with kernel density rasters and monthly boxplots. We assessed correlates using GLMMs with site as a random intercept and fixed effects for **cluster (west/central/east)**, **season (winter/spring/late-summer)**, **road/track proximity**, and **market signal** (ordinal). "Weekend/holiday" flags captured short-duration pulses in activity. Where relevant, we report interactions (e.g., headlands × weekends), partial effects, and residual spatial structure.

6. Discussion

6.1 Eastern Libya in the Mediterranean–Saharan flyway context

The Ain Al-Ghazala → Gulf of Bomba corridor lies on a coastal axis that links central Mediterranean stopovers with Saharan hinterlands. The combination of **low-energy lagoons**, **sabkhas**, and **exposed headlands** provides complementary refuges for wintering birds and staging migrants. Aligning counts with international windows facilitates integration into broader flyway assessments and strengthens national representation in regional datasets.

6.2 Habitat features shaping community structure

Community composition reflected habitat energy and substrate. **Lagoons and inlets** concentrated small terns, herons, and shorebirds where calm waters, soft sediments, and seagrass-associated prey prevail. **Sabkhas** provided predictable diurnal roosts when dry. **Headlands and rocky platforms** favored cormorants and large gulls through flow exposure, perching, and vantage. Fine-scale adjacency (e.g., lagoon mouth next to beach) likely underpins the observed niche partitioning and rapid turnover between tides or wind shifts.

6.3 Cross-site comparisons and management implications

Cross-cluster contrasts indicate that modest differences in **access** and **shoreline configuration** can produce large differences in bird use and pressure. Sites combining easy vehicle access with fishing activity showed the strongest co-occurrence of birds and human presence, underscoring the need for **targeted, not uniform, management**. Because several high-value nodes are closely spaced, **micro-zoning** (e.g., seasonal buffers around roosts/inlet mouths) is more practical than broad closures.

7. Management Recommendations

7.1 Priority sites and seasons

1. **Lagoon mouths and inlets** in the Ain Al-Ghazala complex: wintering and spring staging concentrations.
2. **Exposed headlands** along the central and eastern clusters: seabird loafing and commuting lines year-round, peaks in spring.
3. **Sabkha margins** adjacent to beaches: winter roosts sensitive to disturbance. **Seasonal priorities:** mid-winter (January–February) and spring passage (March–April); short "shoulder" windows around local holidays/weekends.

7.2 Practical measures (enforcement, outreach, fisheries interfaces)

- **Access control:** light-touch barriers at track entrances closest to roosts; clear signage indicating seasonal buffers and penalties.
- **Patrol routing:** concentrate limited patrol hours at HPI hotspots during **weekends/holidays** and dawn/late-afternoon peaks.
- **Community outreach:** co-design messages with fishers and market vendors (discouraging purchase of wild-taken birds; promoting reporting hotlines).
- **Fisheries interfaces:** coordinate landing times/locations to minimize overlap with known roosts; pilot "no-discards near roosts" guidance.
- **Citizen science:** simple forms (QR code) for visitors/fishers to report large flocks or suspected illegal activity; periodic validation against patrol logs.

8. Limitations and Future Research

Our standardized design increases comparability but cannot fully resolve **detection heterogeneity** under high wind/sea states. The HPI aggregates diverse signals and may under-represent **cryptic practices** away from transects or outside survey hours. Future work should: (i) deploy **autonomous acoustic/imagery** at inlet mouths to capture crepuscular movements, (ii) integrate **fine-scale tide and current** data, (iii) add **boat-based strips** where safe to cover nearshore waters, and (iv) establish **before–after** evaluations of specific management measures (e.g., new signage or access barriers).

9. Conclusion

The eastern Cyrenaican coast functions as a compact yet heterogeneous system that supports seabirds and coastal waterbirds across seasons while experiencing localized hunting pressure. By pairing **replicated counts** with a **composite pressure index**, this study delivers actionable maps of biological value and vulnerability. Prioritizing inlet mouths, headlands, and sabkha margins—especially during winter and spring, and at weekend peaks—offers a pragmatic route to reduce pressure where birds predictably concentrate, while maintaining community engagement and fisheries operation

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Compliance with ethical standards

Disclosure of conflict of interest

The authors declare that they have no conflict of interest.

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Appendix A. Site

Cluster	Site code	Site name	Lat (°N)	Lon (°E)	Habitat (primary)	Access type
West	W-01	Ain Al-Ghazala—Lagoon mouth	32.***	23.***	Inlet/Lagoon	Track (4×4)
West	W-02	Sabkha margin	32.***	23.***	Sabkha	Foot
Central	C-01	Pocket beach + headland	32.***	23.***	Beach/Headland	Road + foot
East	E-01	Inner Gulf of Bomba rim	32.***	23.***	Inlet/Seagrass	Road

