



Review Article

Threats to Migratory Cranes Along the Indus Flyway in Pakistan: A Systematic Review

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ABSTRACT

Pakistan's Indus flyway, the westernmost corridor of the Central Asian flyway within Pakistan, historically supported four crane species. The Siberian crane (*Leucogeranus leucogeranus*), last reliably recorded in Pakistan over four decades ago, and the sarus crane (*Antigone antigone*), last confirmed in the 1980s, have been effectively extirpated, while demoiselle crane (*Grus virgo*, formerly *Anthropoides virgo*) and Eurasian crane (*Grus grus*) populations face escalating anthropogenic pressure. No systematic evidence synthesis has previously been conducted for crane conservation in Pakistan. Following PRISMA 2020 guidelines and pre-registration on the open science framework, five academic databases and six grey literature sources were systematically searched. Seventy-five deduplicated records underwent two-stage screening by three independent reviewers, of which forty-one studies met all eligibility criteria and were synthesized narratively. Illegal hunting was the most pervasive documented threat (22 of 41 studies), with up to 7,947 cranes captured or killed at a single camp cluster in one season and 3,700 birds held captive across two districts simultaneously. Wetland degradation drove a 99% waterbird abundance decline at key Punjab stopover sites over one decade. Climate modelling projected 65 to 85 percent loss of suitable demoiselle crane wintering habitat by 2050 to 2070. Power line collision was quantified as an emerging threat with a frequency-severity correlation of $r = 0.930$. The most alarming finding of this review is that not one included study formally evaluated any conservation intervention across 35 years of published research, representing an active conservation failure rather than merely an academic gap. Pakistan's crane fauna faces four compounding threat categories operating simultaneously across an irreplaceable migration corridor, with no evidence-based conservation response documented anywhere in the published literature. A national crane monitoring program, transboundary anti-poaching coordination, and mandatory intervention evaluation represent the most urgent conservation priorities.

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Key words

Anthropogenic threats, Climate change, Conservation gap, Demoiselle crane, Eurasian Crane, Migratory birds

INTRODUCTION

Migratory birds constitute one of the most ecologically significant yet conservation-vulnerable components of global biodiversity. Among migratory avifauna, cranes (Family Gruidae) are particularly notable for their long-distance migrations, site fidelity, low reproductive rates, and sensitivity to anthropogenic disturbance, making them reliable indicators of ecosystem health and integrity along major flyway corridors (Harris and Mirande, 2013; IUCN, 2024; Dai *et al.*, 2025). Of the 15 crane species recognized globally, 11 are classified as threatened or near-threatened

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on the IUCN Red List, reflecting widespread population declines driven by habitat loss, illegal hunting, and climate change across their ranges (IUCN, 2024). The Central Asian Flyway (CAF), one of nine major flyway systems identified by the Convention on Migratory Species (CMS) Secretariat, supports some of the most significant crane migrations on Earth, connecting breeding grounds across Russia, Kazakhstan, and Central Asia with wintering areas in South Asia, the Middle East, and East Africa (Lyster, 1989; Dai *et al.*, 2025).

Pakistan holds critical strategic importance on the CAF, where the Indus Flyway intersects three zoogeographic zones, supporting an estimated 182 migratory bird species through a single corridor with no alternative route. Key species utilizing this corridor include the demoiselle crane (*Grus virgo*, formerly *Anthropoides virgo*), eurasian crane (*Grus grus*), siberian crane (*Leucogeranus leucogeranus*), and sarus crane (*Antigone antigone*) (Johnsgard, 1983; Nawaz *et al.*, 2006; Umar *et al.*, 2018). Nomenclature follows the IOC world bird list v15.2 (Gill *et al.*, 2025) throughout this review. The sarus crane, a largely resident species with local seasonal movements, is included given its historical occurrence across the Indus lowlands and effective extirpation from Pakistan during the review period. However, two of these four species have been effectively extirpated from Pakistan. The siberian crane, once captured in the thousands along Pakistan's northwestern valleys, has not been reliably recorded in the country for over four decades (Nawaz *et al.*, 2006), while the sarus crane, formerly distributed across the Indus lowlands, disappeared from Pakistan by the 1980s (Archibald *et al.*, 2003; BirdLife International, 2024d). The two remaining species, the demoiselle crane and the eurasian crane, continue to use Pakistan as a major stopover and wintering area, with GPS telemetry tracking of demoiselle cranes (Ilyashenko *et al.*, 2022) and eurasian cranes (Higuchi *et al.*, 2008; Baraiya *et al.*, 2025) from central asian breeding grounds confirming that both species transit Pakistani airspace during migration, with stopover sites documented within Pakistan where cranes accumulate energy reserves before the trans-Himalayan crossing. Despite this ecological significance, both species face severe and ongoing anthropogenic pressure within Pakistan's borders.

Illegal hunting represents the most extensively documented threat to migratory cranes in Pakistan. Studies conducted across Khyber Pakhtunkhwa (KPK) province document thousands of cranes captured or killed annually using the traditional Soai or Seya weighted-string entanglement technique, in which a weighted string of up to 80 meters is thrown to entangle cranes in flight, supplemented increasingly with firearms, with hunting

camps concentrated along the Kurram, Indus, and Gomal River corridors (Perveen and Khan, 2010; Ahmad *et al.*, 2021; Sarwar *et al.*, 2022). A structured stakeholder survey of 400 respondents across eight districts of the Indus flyway in central and southern Punjab, including Attock, Mianwali, Khushab, Bhakkar, Layyah, Muzaffargarh, Dera Ghazi Khan, and Rajanpur, identified poaching as the most frequent and severe perceived threat, with Rajanpur recording the highest risk scores (Zulfiqar *et al.*, 2025a). Beyond hunting, cranes face compounding threats from wetland degradation, agricultural intensification, climate change, and infrastructure development. Remote sensing analyses of key crane habitat in KPK document substantial land cover change over three decades, with built-up area expansion of 22.4% and a concurrent temperature rise of approximately 0.9 degrees celsius since 1984 (Suliman *et al.*, 2026). Species distribution modelling projects a loss of 65% of suitable demoiselle crane wintering habitat in Pakistan under moderate climate scenarios by 2050, rising to 85% under extreme scenarios by 2070 (Khan *et al.*, 2024). Waterbird populations at key Punjab wetland sites used by cranes as stopovers declined up to 99% between 2015 and 2025, indicating severe ongoing habitat deterioration at critical migration nodes (Batool *et al.*, 2026). Despite this accumulating body of evidence, no systematic synthesis of the available literature on crane conservation in Pakistan has previously been conducted, representing a critical evidence gap that leaves conservation planners without the integrated knowledge base needed to prioritize interventions along one of Asia's most threatened flyway corridors.

The absence of a systematic evidence synthesis represents a significant gap in conservation knowledge for this region. Individual studies have documented threats at the district or provincial level, but the cumulative weight of evidence across species, geographic areas, threat categories, and time periods has not been assessed. Without such a synthesis, conservation planners and policymakers lack the evidence base needed to prioritize interventions, identify critical knowledge gaps, or evaluate whether existing conservation measures are effective. The present study addresses this gap by conducting the first systematic review of the population status, threats, and conservation of migratory crane species along the Indus flyway in Pakistan. Specifically, this review aimed to: (1) synthesize evidence on the population status and distribution of migratory crane species in Pakistan; (2) identify, categorize, and quantify threats to cranes along the Indus Flyway and associated corridors; (3) assess the effectiveness of documented conservation interventions; and (4) identify critical knowledge gaps that limit evidence-based conservation planning for this taxonomic group in Pakistan.

METHODOLOGY ADOPTED

Protocol and registration

This systematic review follows the Preferred Reporting Items for Systematic Reviews and Meta-Analyses 2020 guidelines (Page *et al.*, 2021). The review protocol was pre-registered on the open science framework before any database searching commenced (registration: <https://doi.org/10.17605/OSF.IO/HTXU5>, registered 7 May 2026). The manuscript title was refined from the registered protocol title to more accurately reflect the completed review scope; the research questions, search strategy, eligibility criteria, and analytical approach remained unchanged from the registered protocol. A completed PRISMA 2020 checklist is provided as (Supplementary File S1).

Eligibility criteria

Studies were included if they met *all* of the following conditions: The study documented one or more crane species recorded in Pakistan, specifically demoiselle crane, eurasian crane, siberian crane, or sarus crane; the study reported primary empirical data, a systematic synthesis, or an official species assessment; the study was published between 1980 and May 2026, consistent with the date on which database searches were completed; and the full text was obtainable in English. Studies from India and Nepal were included where they documented populations of the same migratory species using shared flyway corridors with direct relevance to Pakistan. Peer-reviewed journal articles and credible grey literature, including IUCN assessments, BirdLife International factsheets, and government reports, were eligible for inclusion.

Studies were excluded if they focused exclusively on crane species not recorded in Pakistan, contained no Pakistan-specific or flyway-relevant data, were opinion pieces or editorials without primary data, were published before 1980, or if the full text could not be obtained after three retrieval attempts. Conference abstracts superseded by peer-reviewed publications were also excluded.

Information sources

Five academic databases (Google Scholar, Semantic Scholar, BASE, JSTOR, and ResearchGate) and six grey literature repositories were searched in May 2026, supplemented by backward and forward citation searching. Both peer-reviewed articles and grey literature were eligible for inclusion. Grey literature was accepted if produced by a recognized conservation organization with a described methodology, published in an institutional repository with identifiable authorship, or constituting an official government or intergovernmental document. Webpages, undated summaries, and documents lacking

authorship or methodology were excluded at Stage 2, with reasons recorded in (Supplementary Table S1).

Search strategy

A structured Boolean search string was developed using three conceptual blocks: species, geography, and topic. The full string applied in Google Scholar was: “Demoiselle crane” or “*Anthropoides virgo*” or “Eurasian crane” or “*Grus grus*” or “Siberian crane” or “*Leucogeranus leucogeranus*” or “Sarus crane” or “*Antigone antigone*” or crane* or Gruidae) AND Pakistan or “Indus Flyway” or “Central Asian Flyway” or “Khyber Pakhtunkhwa” or Balochistan or Punjab or Sindh or “South Asia” AND threat* or conserv* or hunt* or poach* or “habitat loss” or migration or flyway or population or “wetland loss” or “climate change” or collision or abundance or distribution.

Adapted strings were applied in each database according to their syntax requirements. A total of 15 search strings were run in Google Scholar, six in Semantic Scholar, five in BASE, five in JSTOR, and seven in ResearchGate. Searches were conducted up to 20 pages per database, sorted by relevance, in May 2026. This approach was adopted as several databases, notably Google Scholar, do not report total hit counts, and relevance ranking ensured the most pertinent records appeared within the first 20 pages. As a sensitivity check, five known relevant papers independently identified through backward and forward citation searching were confirmed to appear within the first ten pages of their respective Google Scholar search strings, providing reasonable assurance that the 20-page cutoff did not systematically exclude highly relevant records. In addition to academic databases, six grey literature sources were searched manually, including BirdLife International Data Zone, the IUCN Red List, WWF Pakistan, the CMS document archive, CAF Partnership reports, and the Pakistan Journal of Zoology. The complete list of search strings applied across all databases is provided in (Supplementary Table S2).

Selection process

Retrieved records were imported into Zotero (version 9) for deduplication. The deduplicated library was exported in RIS format and imported into Rayyan (rayyan.ai) for screening, where additional duplicates were identified and removed. Screening proceeded in two stages. At stage 1, all records were assessed by title and abstract against the eligibility criteria and classified as include, exclude, or maybe. All records classified as include or maybe proceeded to stage 2 full-text assessment. At stage 2, full texts were read in their entirety and classified as include or exclude, with a specific reason recorded for every excluded record. A complete list of full-text excluded studies with

reasons for exclusion is provided in ([Supplementary Table S2](#)). Title/abstract and full-text screening was performed by the lead reviewer (AR) across all 75 records. Two co-authors (AUR and AZ) independently cross-checked all decisions against the eligibility criteria; disagreements were resolved by consensus. Records classified as maybe at Stage 1 automatically advanced to full-text review, reducing the risk of inappropriate exclusion.

Data extraction

Data were extracted from all included studies using a standardized extraction form developed prior to extraction. The following variables were recorded for each study: study identification code, authors and year, title, source, study location, study period, study design, species studied, sample size, threat category, key quantitative findings, conservation measures reported, effectiveness data, evidence quality rating, and knowledge gaps. Where studies used outdated taxonomic nomenclature, accepted current nomenclature was applied following the International Ornithological Committee World Bird List.

Evidence quality assessment

Each included study was rated for evidence quality using a four-level scale adapted from the GRADE framework: level A (high) for multi-year systematic surveys, GPS or satellite telemetry studies, or studies with sample sizes exceeding 50 individuals; level B (moderate) for single-season structured surveys or institutional datasets; level C (low) for opportunistic observations or studies with small samples or short duration; and level D (very low) for expert opinion, anecdotal reports, or grey literature without a described methodology.

Synthesis

The heterogeneity of study designs and outcome measures across the included literature precluded meta-analysis. Data were therefore synthesized narratively. Included studies were grouped by threat category using the IUCN Threat Classification Scheme, adapted to eight categories relevant to this review. Quantitative data were summarized descriptively, with temporal trends reported where sufficient data existed. Conservation interventions were grouped by type and synthesized narratively.

STUDY SELECTION AND SEARCH OUTCOMES

Searches across five databases and six grey literature sources identified 131 records. After removing 53 duplicates, 75 unique records were screened at Stage 1, of which 15 were excluded.

Of the 60 records proceeding to Stage 2 full-text assessment (57 classified as include and 3 as maybe at Stage 1), 19 were excluded: wrong species or geography ($n=7$), webpage snapshots with no retrievable academic content ($n=4$), no Pakistan or CAF relevant data in the full text ($n=3$), linguistic or historical study with no conservation biology relevance ($n=1$), maybe-classified records not meeting full eligibility criteria upon full-text review ($n=3$), and conference abstract superseded by a peer-reviewed full publication ($n=1$). Forty-one studies met all eligibility criteria and were included in the final synthesis ([Fig. 1](#)).

The modest yield of 41 studies from 131 identified records is itself informative and reflects the genuine scarcity of purpose-designed crane research in Pakistan rather than any limitation of the search strategy. The breadth of the search, spanning five databases, six grey literature repositories, and 38 separate search strings with independent sensitivity checking, provides reasonable assurance that the yield accurately represents the available literature. The peer-reviewed evidence base for crane conservation in Pakistan remains thin relative to the documented scale of threats, with entire provinces unrepresented by any primary crane study in the published literature. Multiple records were excluded at Stage 2 because they referenced cranes incidentally without reporting primary data, underscoring the absence of purpose-designed crane research across much of the country.

CHARACTERISTICS OF INCLUDED STUDIES AND EVIDENCE QUALITY

The 41 included studies spanned 1991 to 2026, with a marked concentration of publications after 2020. The temporal distribution of included studies is illustrated in ([Fig. 2](#)). The majority of Pakistan-based primary studies were concentrated in Khyber Pakhtunkhwa, particularly Bannu, Lakki Marwat, Karak, and FR Bannu districts. Balochistan was represented by studies from Lasbela Coast, District Zhob, and the Pakistan-Afghanistan border region, while Punjab was covered primarily by studies from Bhakkar, Khushab, and Rajanpur. Five studies originated from India, three from Nepal, one from Afghanistan, and one from the CAF breeding range. Demoiselle crane was the most frequently studied species ($n=35$ studies), followed by Eurasian crane ($n=28$), sarus crane ($n=8$), and siberian crane ($n=6$). Fourteen studies examined two or more species simultaneously. A full summary of included study characteristics is provided in [Supplementary File S2](#).

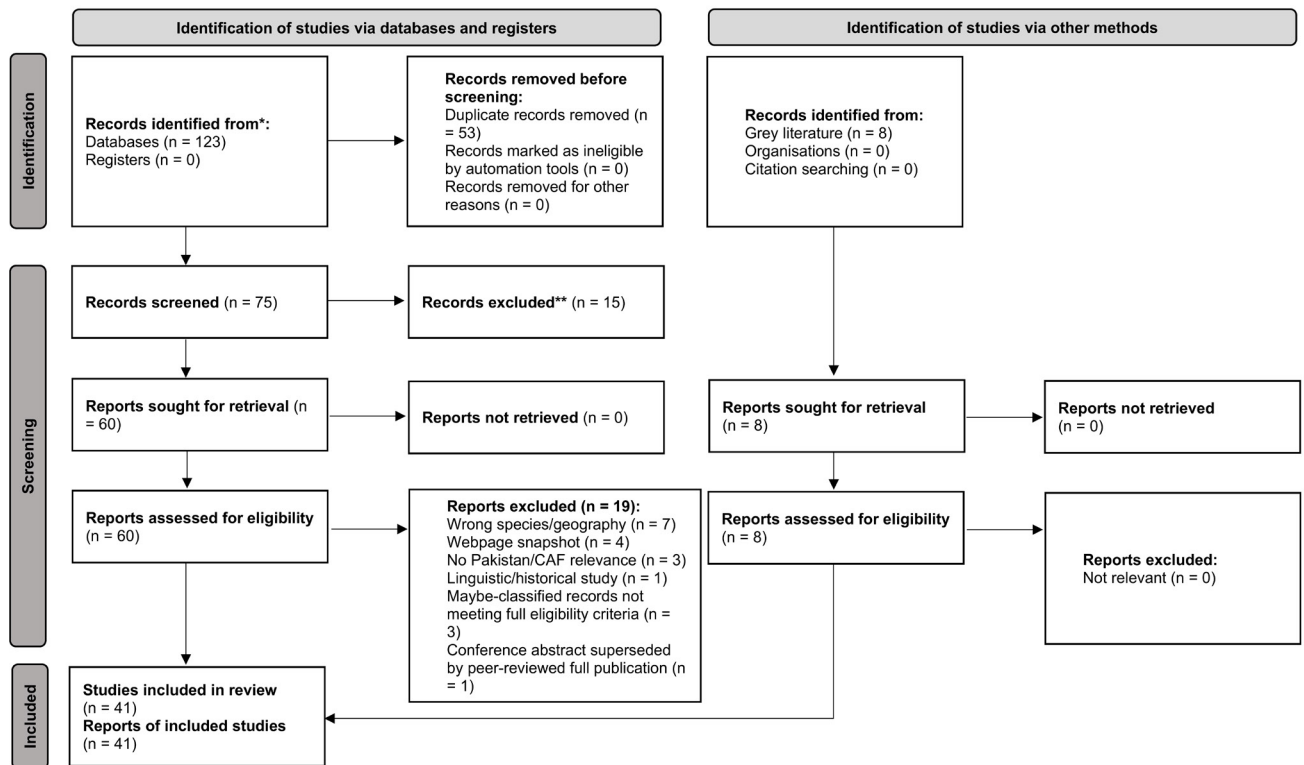


Fig. 1. PRISMA 2020 flow diagram illustrating the systematic search and screening process. A total of 131 records were identified across five academic databases and six grey literature sources Google Scholar, Semantic Scholar, BASE, JSTOR, ResearchGate) and six grey literature sources (BirdLife International Data Zone, IUCN Red List, WWF Pakistan, CMS document archive, CAF Partnership report) Pakistan Journal of Zoology. After removal of 53 duplicates, 75 unique records were screened at Stage 1, of which 60 proceeded to Stage 2 full-text assessment. Nineteen records were excluded at Stage 2 for reasons detailed in Supplementary Table S1. Forty-one studies met all eligibility criteria and were included in the final synthesis.

**Of 60 records proceeding to Stage 2, 57 were classified as include and 3 as maybe at Stage 1. Exclusion total of 19 comprises 15 formal exclusions, 3 maybe-classified records not meeting full eligibility criteria, and 1 conference abstract superseded by a peer-reviewed publication Source: Page MJ, *et al.* BMJ 2021;372:n71. doi: 10.1136/bmj.n71. This work is licensed under CC BY 4.0. To view a copy of this license, visit <https://creativecommons.org/licenses/by/4.0/>.

Twelve studies (29%) were rated level A evidence quality, including multi-year GPS telemetry studies, ensemble species distribution models with independent validation, and longitudinal remote sensing analyses with ground-truthing. Eighteen studies (44%) were rated level B, comprising structured field surveys and multi-stakeholder questionnaire studies. Four studies (10%) received a level C rating, relying on self-reported hunter data without independent verification. Seven studies (17%) were rated level D, including narrative reviews and grey literature without described methodology. The overall evidence base is therefore characterized by a moderate foundation, with 27% of studies rated level C or D.

This evidence quality profile has direct and serious implications for conservation decision-making. When more than a quarter of the available literature rests on

low or very low-quality evidence, and when no study in the entire included corpus has formally evaluated a conservation intervention, the field is making policy recommendations on an insufficiently robust empirical foundation. Conservation practitioners are operating without knowing what works, a situation that is not merely academically unsatisfactory but practically costly, resources may be allocated to ineffective interventions while effective approaches remain untested.

ILLEGAL HUNTING AND EXPLOITATION

Illegal hunting is the most pervasive and persistently documented threat to migratory cranes in Pakistan, reported in 22 of 41 included studies across multiple provinces and the full study period. Historical records establish that large-

scale crane exploitation predates modern conservation legislation by decades. Nawaz *et al.* (2006) documented hunting in Kurram, Waziristan, and Zhob since the 1940s, while Khan *et al.* (2011) estimated 5,000 cranes shot or captured per season during the 1990s. This deep cultural and economic embeddedness limits the effectiveness of legal prohibition alone. Contemporary evidence confirms that hunting pressure remains substantial and is likely underestimated. Sarwar *et al.* (2022) recorded 7,947 cranes at 10 camps in South Waziristan in one season, while Ahmad *et al.* (2021) documented 93 camps across three districts. Suliman *et al.* (2023) recorded 137 cranes captured over four seasons alongside 3,700 captive birds. Shah *et al.* (2024) identified 117 hunting sites in Bannu district alone. Khan *et al.* (2025) studied demoiselle crane populations there and found that illegal hunting was causing serious harm to these birds. Since most studies concentrate in KP, national offtake figures are almost certainly higher.

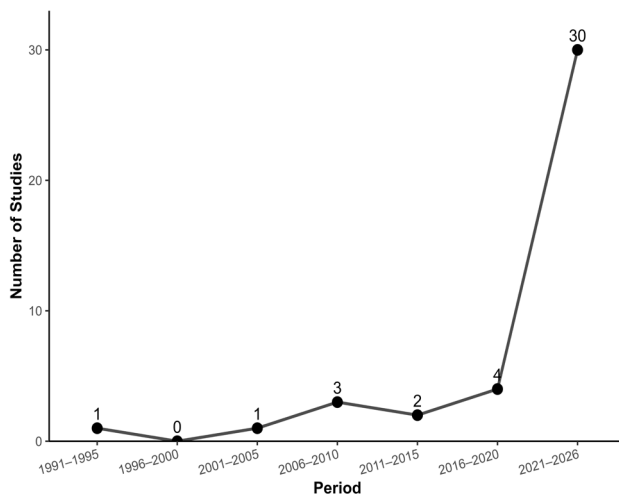


Fig. 2. Temporal distribution of 41 studies included in the systematic review of migratory cranes along the Indus Flyway in Pakistan (1991 to 2026), showing a marked concentration of publications in the 2021 to 2026 period.

The dominant method is the traditional Soai technique, increasingly combined with firearms (Shah *et al.*, 2024). Hunting is primarily recreational, yet commercially significant: Hussain and Khan (2021) documented demoiselle crane selling at PKR 12,000 per bird across 16 illegal markets. These demand streams reinforce each other, meaning interventions targeting only one are insufficient. Community-level evidence corroborates field data. Zulfiqar *et al.* (2025a) found poaching ranked highest in frequency (4.9) and severity (4.8) among 400 stakeholders, with significant spatial variation across eight

districts ($F(7,392) = 6.326, p < 0.001$). Cluster analysis attributed 77.3% of variance to between-group differences, confirming geographically concentrated pressure amenable to targeted enforcement.

Transboundary hunting compounds these pressures considerably. Similar patterns of stopover site use and hunting pressure have been documented in Nepal for demoiselle cranes transiting the CAF (Gyawali, 2018). Mostafawi *et al.* (2017) documented 2,000 to 3,000 cranes harvested at a single Afghan site in one spring season. Ilyashenko *et al.* (2022) demonstrated that Asian demoiselle cranes conduct a 1,900 to 4,600 km trans-Himalayan transit in 7 to 13 days without energy replenishment, meaning hunting at Pakistani and Afghan stopover sites directly compromises physiological condition before this crossing, with likely consequences for Central Asian breeding populations. The Siberian crane extirpation from Pakistan offers the most critical precedent. Nawaz *et al.* (2006) reported no records for over 40 years, consistent with the central Asian Siberian crane population collapsing from an estimated several thousand individuals in the 1960s (IUCN, 2024) to fewer than 10 individuals today, rendering this population functionally extinct in the wild, a decline Mostafawi *et al.* (2017) attributed primarily to flyway-scale hunting. Demoiselle cranes forage while moving across agricultural fields, whereas common cranes forage in fixed locations, reflecting different pre-migration energy strategies (Kondrakova, 2023). This mobile foraging in open landscapes increases their exposure to hunting pressure at Pakistani stopover sites. Current demoiselle and Eurasian crane populations are larger, but this trajectory represents a credible worst-case scenario if hunting pressure is not urgently and substantially reduced.

HABITAT LOSS AND WETLAND DEGRADATION

Habitat loss and wetland degradation were identified as significant threats in 25 of 41 included studies, making this the most broadly documented threat category after illegal hunting. Evidence spans multiple spatial scales and is sufficiently quantitative to support strong conclusions about the rate and direction of change.

The most comprehensive habitat assessment is provided by Suliman *et al.* (2026) whose 30-year geospatial analysis of Bannu and Lakki Marwat districts documented a 22.4% increase in built-up area, a 22.6% reduction in open barren foraging habitat, and a 4.2% decline in vegetation cover between 1994 and 2024. The Kurram River, Lora Nala, Baran Lake, Chashma Lake, and the Indus River were identified as critical corridors and stopover sites under increasing land-use pressure. At the regional scale, Batool *et al.* (2026) recorded a 99%

decline in waterbird abundance at Namal and Uchali Lakes between 2015 and 2025, driven primarily by vegetation loss rather than water availability, indicating structural wetland quality collapse at Indus Flyway stopover sites. [Meena *et al.* \(2021\)](#) recorded demoiselle crane numbers at Satlana Wetland, Rajasthan, confirming that shared wintering populations depend on a network of wetland sites across the subcontinent, where loss at any node carries wider flyway consequences. Together, these studies confirm that crane habitat is deteriorating simultaneously at multiple points along the migration corridor.

Habitat degradation and hunting pressure are not independent threats. Cranes displaced from primary wetland sites concentrate at fewer, more accessible locations, increasing their vulnerability to hunters. Cranes feeding in agricultural fields face additional risks from hunting and agrochemical exposure, with diet studies confirming heavy reliance on cereal grains and invertebrates at Pakistani stopover sites ([Sarwar *et al.*, 2013](#)). [Sundar and Subramanya \(2010\)](#) showed that cranes are frequent and dependent users of rice cultivation landscapes across South Asia, meaning agricultural transformation directly reduces foraging availability at Pakistani stopover sites.

The documented spatial overlap between active hunting sites along the Kurram, Kashu, Indus, and Gomul rivers ([Khan *et al.*, 2011](#); [Sarwar *et al.*, 2022](#); [Shah *et al.*, 2024](#)) and critical stopover habitats identified in geospatial analyses ([Suliman *et al.*, 2026](#)) indicates that these threats compound each other. Interventions addressing both simultaneously are therefore more likely to be effective than those targeting either in isolation.

Pakistan's obligations under the Ramsar Convention are not translating into effective wetland protection. [Qayum *et al.* \(2024\)](#) documented over 322,000 crane passages at Siranda Lake, Lasbela across two seasons and recommended it for Ramsar designation, yet the site remains unprotected. Anthropogenic pressure on crane migration sites extends across the Pakistan-Afghanistan border corridor. In District Zhob, Balochistan, environmental and anthropogenic factors affecting crane migration at Sabakzai Dam were documented, confirming that habitat pressure is not confined to KPK but operates across a geographically connected transboundary zone ([Nawaz *et al.*, 2025](#)). This gap between treaty commitment and on-the-ground governance represents a systemic failure with direct consequences for internationally significant crane populations. This implementation deficit reflects multiple compounding factors including inadequate enforcement capacity within provincial wildlife departments, competing land-use priorities in rapidly urbanizing and agriculturally intensifying districts, limited interagency coordination between wildlife, water, and land management authorities,

and the absence of dedicated wetland conservation funding at the district level. Addressing this gap therefore requires coordinated institutional reform and sustained political commitment rather than site-level conservation measures alone.

CLIMATE CHANGE

Climate change was identified as a significant and escalating threat in 10 of 41 included studies, with the most robust evidence derived from species distribution modelling and multi-decadal remote sensing analyses. Findings are consistent in direction: Crane habitat across Pakistan and the broader central asian flyway is being reduced and redistributed by climate warming, and this process is already measurable at the district level.

[Khan *et al.* \(2024\)](#) applied a maximum entropy model to four years of demoiselle crane survey data from KPK and Balochistan, projecting a 65% loss of currently suitable wintering habitat under moderate scenarios by 2050, rising to 85% under extreme scenarios by 2070, with residual suitable habitat shifting toward the Pakistan-Afghanistan border. Temperature seasonality, annual mean temperature, terrain ruggedness, and human population density together explained 81.3% of habitat suitability variation, identifying temperature as the dominant driver. [Suliman *et al.* \(2026\)](#) confirmed that warming is already occurring: A statistically significant increase of 0.022 degrees Celsius per year over 40 years in Bannu and Lakki Marwat corresponds to an observed total rise of approximately 0.9 °Celsius since 1984. At the flyway scale, [Ansari \(2023\)](#) projected complete loss of Siberian Crane breeding habitat in West Siberia by 2050 under both moderate and extreme scenarios, directly threatening source populations whose historical migration corridor transited Pakistan.

These projections become considerably more alarming when considered alongside concurrent hunting pressure and wetland degradation. A species facing an 85% wintering habitat reduction within 45 years, uncontrolled hunting at stopover sites, and progressive wetland loss across its range confronts a convergence of threats that may collectively exceed its resilience, even where individual threats might not. The kunming-montreal global biodiversity framework target 4 provides a direct international mandate for integrating crane conservation into Pakistan's climate adaptation planning. The NDVI recovery observed at KPK crane habitat sites following the Billion Tree Afforestation Project ([Suliman *et al.*, 2026](#)), suggests that large-scale restoration can produce measurable ecological improvement within existing policy frameworks, though whether this translates into improved

crane habitat quality requires dedicated field validation.

Infrastructure collision, pollution, and human disturbance

Infrastructure collision is a quantitatively documented and statistically consistent threat, with evidence now available from Pakistan, India, and Nepal for the same shared crane populations. [Zulfiqar *et al.* \(2025a\)](#) recorded power line collision as the fourth-ranked threat among 400 Indus flyway stakeholders, with a frequency score of 4.4 and severity score of 4.0 on a five-point scale. Notably, collision showed the strongest frequency-severity correlation of all five threat categories quantified ($r=0.930$, p less than 0.001), indicating near-perfect community consensus on both the regularity and consequence of collision events. The high absolute frequency score and exceptional correlation confirm that collision is perceived as a regular occurrence with severe consequences, not a rare or minor event.

Mortality data from adjacent range states strengthen this assessment. [Gehlot *et al.* \(2022\)](#) recorded 17 demoiselle cranes injured and 11 killed by power line electrocution over six years in Rajasthan, with insecticide poisoning responsible for an additional 138 crane casualties at a single site. [Sharma \(2006\)](#) established baseline data on sarus crane status, distribution, and habitat preferences in Nawalparasi District, providing the ecological foundation against which later threat assessments can be measured. [Sharma *et al.* \(2024\)](#) subsequently documented 47 Sarus Crane fatalities from power line collisions and electrocution in the same region between 2010 and 2023, approximately 3.6 fatalities per year from this single cause alone.

Although Nepalese sarus cranes are largely resident, the collision mechanisms documented are structurally identical to those faced by migratory cranes transiting Pakistan, and these findings constitute directly informative contextual evidence. The absence of systematic carcass-based mortality data from Pakistan reflects a research gap rather than evidence that the threat is absent. Power line marking or retrofitting at high-risk corridor locations represents a practically feasible intervention whose effectiveness in Pakistan remains untested.

Pollution was documented in eight included studies, encompassing agrochemical contamination, waterborne pathogens, and parasite loads. [Rehman *et al.* \(2021\)](#) detected *Escherichia coli* contamination in all 16 water samples across four Bannu district crane sites. [Ullah *et al.* \(2023\)](#) identified gastrointestinal parasites in 29% of crane fecal samples across three Pakistani habitat types, with the highest loads recorded at the most disturbed sites, suggesting a fitness cost from pollution that extends beyond direct foraging area loss and may affect survival and reproductive success in ways that mortality-focused studies do not capture. Human disturbance from livestock grazing, feral dogs, and recreational activity was documented in 15 studies, though its independent contribution to crane mortality remains unquantified in the Pakistani context ([Fig. 3](#)). [Xu *et al.* \(2021\)](#) demonstrate that such disturbance increases crane vigilance at the cost of foraging time, with direct implications for body condition before the trans-Himalayan crossing. A comparative summary of evidence density and quality across all documented threat categories is presented in ([Table I](#)).

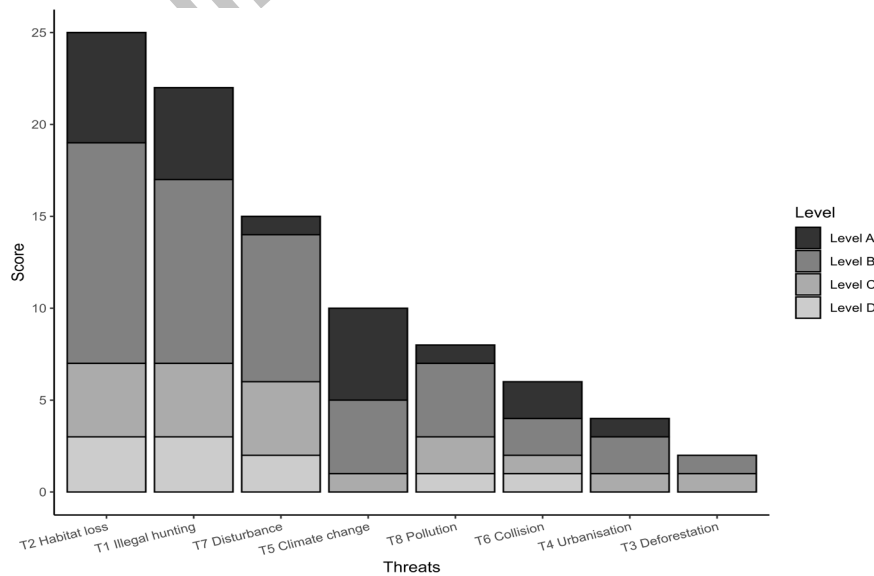


Fig. 3. Stacked bar chart showing the distribution of major threat categories affecting migratory crane populations along the Indus Flyway, categorized by evidence quality level (A to D) across eight threat categories identified in the systematic review.

CONSERVATION MEASURES AND THEIR EFFECTIVENESS

Conservation interventions were referenced in 28 of 41 included studies (Table II). The most consequential finding of this synthesis is the complete absence of evaluated conservation responses across 35 years of published research. No study in the included corpus, spanning 1991 to 2026, across five provinces, four species, and five conservation measure categories, reported a formal evaluation of any intervention using before-after, control-impact, or any comparable inferential design. Pakistan's crane fauna is therefore managed on the basis of assumed rather than demonstrated effectiveness, representing not merely an academic gap but an active conservation failure with direct consequences for species in rapid decline.

Legal protection through the Wildlife Protection Act, provincial legislation, and CMS treaty obligations is the most frequently referenced measure, cited in 18 studies, yet evidence for its effectiveness is uniformly negative. Hussain and Khan (2021) documented 100% illegal crane

trade across all 16 surveyed commercial wildlife markets in two KPK divisions, confirming that legal prohibition is not translating into enforcement at documented trading sites. Khan *et al.* (2011) noted a Section 144 hunting ban in Zhob District as a positive step, yet no monitoring data exist to confirm any subsequent change in crane numbers. The consistent pattern across studies of legal frameworks described alongside documented non-compliance indicates that Pakistan's conservation legislation is structurally adequate but operationally ineffective, with the primary deficit being enforcement capacity and political will rather than legislative coverage.

Community engagement was recommended as a priority action in 12 studies. Zulfiqar *et al.* (2025a) demonstrated that stakeholder threat perception varies significantly by threat type and hunting method but not by education or occupation, suggesting that community programs must be threat-specific and practically oriented rather than generic awareness campaigns. However, no included study reported outcomes from any implemented community conservation program in Pakistan, leaving

Table I. Threat categories affecting migratory cranes along the Indus flyway in Pakistan.

Threat category	No. of studies	Strongest quantitative evidence	Evidence quality range	Critical data gap
T1 (Illegal hunting and exploitation)	22	7,947 cranes captured at one camp cluster in a single season (Sarwar <i>et al.</i> , 2022), 3,700 birds held captive across two districts simultaneously (Suliman <i>et al.</i> , 2023), 100% illegal trade documented across all 16 surveyed commercial markets (Hussain and Khan, 2023).	A–D	National annual offtake never estimated; no quantitative data from Balochistan, Sindh, or southern Punjab
T2 (Habitat loss and wetland degradation)	25	99% waterbird abundance decline at Namal and Uchali Lakes, Punjab, 2015–2025 (Batoool <i>et al.</i> , 2026) 22.4% built-up area expansion equivalent to 171,108 ha in KPK crane districts 1994–2024 (Suliman <i>et al.</i> , 2026).	A–D	No province-wide wetland loss quantification; crane-specific habitat use not mapped nationally
T3 (Deforestation)	2	Documented qualitatively in Balochistan and KPK; no quantitative assessment available	C–D	No quantitative deforestation assessment at any crane habitat site in Pakistan
T4 (Urbanization and infrastructure development)	4	22.4% expansion of built-up land cover in KPK crane districts over 30 years, with direct encroachment on documented crane foraging and roosting habitat (Suliman <i>et al.</i> , 2026).	A–D	No crane-specific urban impact assessment conducted at any Pakistani site
T5 (Climate change)	10	65–85% loss of suitable Demoiselle Crane wintering habitat projected under moderate to extreme scenarios by 2050–2070 (Khan <i>et al.</i> , 2024); statistically significant temperature increase of 0.022°C per year over 40 years in key crane districts (Suliman <i>et al.</i> , 2026).	A–C	No crane migration phenology data from Pakistan; no crane-specific climate adaptation assessment conducted

T6 (Infrastructure collision)	6	Community-perceived collision frequency score 4.4 out of 5 with strongest frequency-severity correlation of all threat categories ($r = 0.930$, $p < 0.001$) (Zulfiqar <i>et al.</i> , 2025a) 47 Sarus Crane fatalities from power line collision and electrocution in Nepal 2010–2023 (Sharma <i>et al.</i> , 2024).	A–D	No carcass-based collision mortality data collected from any Pakistani crane migration corridor
T7 (Human disturbance)	15	Lowest ranked perceived threat among stakeholders, frequency score 2.3 out of 5 (Zulfiqar <i>et al.</i> , 2025a) gastrointestinal parasites in 29% of crane fecal samples from most disturbed habitat types (Ullah <i>et al.</i> , 2023).	A–D	No direct mortality quantification attributable to disturbance in Pakistan
T8 (Pollution)	8	<i>E. coli</i> contamination detected in 100% of water samples across four Bannu district crane study sites (Rehman <i>et al.</i> 2022), gastrointestinal parasites recorded in 29% of crane fecal samples with highest loads in most disturbed sites (Ullah <i>et al.</i> , 2023).	A–D	No agrochemical mortality or toxicological data from any Pakistani crane site

Evidence quality grades follow the four-level scale. Level A (High) = multi-year systematic surveys, GPS or satellite telemetry studies, or studies with sample sizes exceeding 50 individuals; Level B (Moderate) = single-season structured surveys or institutional datasets; Level C (Low) = opportunistic observations or studies with small samples or short duration; Level D (Very Low) = expert opinion, anecdotal reports, or grey literature without described methodology.

Table II. Conservation measures reported for migratory cranes in Pakistan across reviewed studies and their documented effectiveness evidence.

Conservation measure	Studies reporting it	Key examples from included literature	Effectiveness data available
C1 (Legal protection)	18	Pakistan Wildlife Protection Act; KPK Wildlife Act 2015; Pakistan Biological Diversity Act 2020; CITES Appendix listings; CMS Appendix II (Demoiselle and Eurasian Crane); Section 144 hunting ban in Zhob District (Khan <i>et al.</i> , 2011)	No, 100% illegal trade documented despite legal prohibition across all 16 surveyed markets (Hussain and Khan, 2021)
C2 (Protected areas)	6	Ramsar sites at Namal Lake and Uchali Lake; Siranda Lake Lasbela proposed for Ramsar designation based on 322,000+ crane passages across two seasons (Qayum <i>et al.</i> , 2024).	No, (no population monitoring data reported at any protected site in included literature)
C3 (Community engagement)	12	Anti-poaching awareness programs; alternative livelihood recommendations; cultural engagement with hunting communities recommended across multiple studies (Nawaz <i>et al.</i> , 2006; Zulfiqar <i>et al.</i> , 2025a).	No, (no program outcomes or participation data reported in any included study)
C4 (International collaboration)	10	CMS treaty obligations; Ramsar Convention; bilateral coordination with Afghanistan recommended (Mostafawi <i>et al.</i> , 2017) CAF Partnership documents; IUCN Crane Specialist Group assessments.	No, (treaty compliance and bilateral coordination outcomes not evaluated in any included study)
C5 (Research and monitoring)	28	District-level field surveys; species distribution models (Khan <i>et al.</i> , 2024) remote sensing analyses (Suliman <i>et al.</i> , 2026) GPS telemetry of shared populations (Ilyashenko <i>et al.</i> , 2022; Baraiya <i>et al.</i> , 2025) stakeholder surveys (Zulfiqar <i>et al.</i> , 2025a).	Partial, (research exists but no study uses standardized annually repeated methodology enabling population trend detection)

Conservation measure codes follow the classification applied in the systematic synthesis: C1 (Legal protection)= wildlife legislation, CITES listings, CMS treaty obligations; C2 (Protected areas)= Ramsar designations, national and provincial reserves; C3 (Community engagement)= anti-poaching awareness, alternative livelihoods, cultural engagement programs; C4 (International collaboration)= transboundary treaty frameworks, bilateral coordination, intergovernmental partnerships; C5 (Research and monitoring)= field surveys, species distribution modelling, remote sensing analyses, GPS telemetry, stakeholder surveys). The partial effectiveness rating for C5 reflects the existence of research activity without standardized annually repeated methodology enabling population trend detection.

no empirical basis for recommending one model over another. The designation of Siranda Lake as a Ramsar site, supported by counts exceeding 322,000 crane passages across two seasons (Qayum *et al.*, 2024), represents the most concrete and immediately actionable conservation

opportunity identified in this review and warrants urgent policy attention.

Critical knowledge gaps

This review identified eight critical knowledge gaps

that currently constrain evidence-based crane conservation in Pakistan. Their systematic documentation is among the primary contributions of this synthesis, as identifying where evidence is absent is as scientifically valuable as summarizing where it exists.

No standardized, multi-site population estimate exists for demoiselle or eurasian cranes wintering in Pakistan. Individual site counts confirm crane presence at specific localities, but no coordinated national or provincial census using standardized methodology has been conducted, making it impossible to determine whether populations are stable, declining, or recovering at any scale above the district level.

No GPS or satellite telemetry study has been initiated within Pakistan. All relevant tracking data derive from birds tagged in India, Ukraine, Russia, or Kazakhstan, none of which recorded Pakistani stopover sites at the spatial resolution required to prioritize specific localities for protection. Consequently, the sites most critical to crane survival during Pakistan transit cannot currently be identified from field evidence alone. [Ram et al. \(2023\)](#) partially address this gap, using satellite telemetry to identify key wintering areas in India with habitat use overlapping Pakistan's border regions, though systematic coverage of Pakistani sites remains absent. Initiating collaborative telemetry work through partnerships with research groups already tracking shared crane populations in India and Central Asia represents the most feasible and cost-effective pathway toward closing this gap, and should be treated as a primary research priority given that site-level protection and targeted enforcement cannot be evidence-based without it

No conservation intervention in Pakistan has been formally tested using before-after or control-impact designs. Several measures are documented in the literature: legal protection under the Pakistan Wildlife Protection Act and provincial laws including the KPK Wildlife Act 2015; seasonal hunting bans under Section 144 applied in districts such as Zhob; community awareness and anti-poaching campaigns across multiple KPK districts; and protected area designations at Ramsar sites including Namal and Uchali Lakes. However, none of these measures have been properly measured. No study has recorded how crane populations responded after a legal ban, whether hunting pressure dropped following awareness campaigns, or whether waterbirds recovered at any protected site. This means we simply do not know if any current conservation effort is working, and continuing to invest in approaches that have never been evaluated is itself a conservation problem, not just a research gap.

Cumulative annual crane hunting mortality across all Pakistani provinces has never been estimated. District-

level studies collectively document substantial local hunting pressure, but no study has aggregated these into a provincial or national total. A nationally coordinated hunter survey using the structured questionnaire methodology of [Zulfiqar et al. \(2025a\)](#) combined with systematic camp counts at known hotspots during peak migration windows, would enable a defensible national offtake estimate within two to three field seasons. Available district-level data conservatively suggest the national total may be an order of magnitude larger than any single study implies, underscoring the urgency of this estimate as a foundation for evidence-based anti-poaching policy.

The timing, rate, and proximate causes of sarus crane extirpation from Pakistan have not been systematically investigated. No study has reconstructed the population decline trajectory using museum records, historical hunter accounts, or interview-based recall data, leaving one of the most significant regional crane conservation failures without an evidence-based explanation that could inform prevention of similar losses for remaining species.

Climate change effects on crane migration phenology within Pakistan remain entirely unstudied. Whether migration timing, stopover duration, or route selection are already responding to the statistically significant temperature increase of 0.9 °C documented over 40 years in key crane districts ([Suliman et al., 2026](#)) is unknown, and this absence of phenological data prevents early detection of climate-driven range shifts. Retrospective analysis of existing eBird and Asian Waterbird Census records from Pakistan for temporal shifts in arrival dates, peak abundance timing, and departure windows represents a low-cost and immediately implementable first step toward closing this gap using open-access data already available

Systematic field assessment of power line collision mortality has not been conducted within Pakistan. Community-perceived collision frequency is now quantified for the Indus flyway ([Zulfiqar et al., 2025a](#)) and carcass-based mortality data exist for the same populations in India and Nepal ([Gehlot et al., 2022](#); [Sharma et al., 2024](#)), yet no study has directly recorded collision incidents or carcasses along Pakistani crane migration corridors. Systematic carcass surveys beneath power transmission lines at documented crane roosting and stopover sites during peak migration seasons, a methodology already validated for these populations in India and Nepal, combined with community recall interviews, represent the most feasible initial approach to quantifying this mortality source, with power line marking at identified high-risk locations as a logical second-phase intervention.

The sublethal and lethal impacts of agrochemical use on crane health in Pakistan have not been quantified. Insecticide poisoning is documented as a major mortality driver in

Indian wintering areas used by the same populations (Gehlot *et al.*, 2022), yet no equivalent toxicological or epidemiological assessment exists for Pakistani stopover and wintering sites. Pakistan's Punjab and Sindh agricultural landscapes are structurally comparable to the intensively cultivated areas of Rajasthan and Gujarat where this mortality has been formally documented, and the use of organophosphate and pyrethroid pesticides in Pakistani crane foraging areas is already established (Rehman *et al.*, 2021), making equivalent agrochemical risks a strongly plausible and immediately researchable conservation hypothesis amenable to biomonitoring approaches validated in the Indian literature.

CONCLUSIONS

Pakistan occupies a significant position on the Central Asian Flyway, yet this review demonstrates that its crane fauna is in active and accelerating decline. While demoiselle and eurasian crane populations remain numerically substantial globally (BirdLife International, 2024a, b), the compounding hunting pressure, wetland degradation, and projected climate impacts documented across this review are inconsistent with long-term population stability at the national level, and Pakistan's contribution to flyway-scale decline is likely larger than current data allow us to quantify. Two of the four crane species that historically occurred in Pakistan are now effectively extirpated. The two remaining species face hunting pressure that existing legal frameworks have demonstrably failed to control, concurrent wetland degradation that has driven near-total waterbird collapse at key stopover sites, and climate projections indicating 65% to 85% loss of suitable wintering habitat by mid-century. These threats compound each other spatially and temporally, making their combined impact substantially more severe than any individual assessment suggests. This review identifies eight critical knowledge gaps requiring urgent attention: national crane census, GPS telemetry within Pakistan, conservation intervention evaluation, national hunting offtake estimation, power line collision monitoring, sarus crane extirpation reconstruction, migration phenology monitoring, and agrochemical impact assessment. Of these, the national crane census is the most immediately tractable priority. A coordinated monitoring program built around existing frameworks such as the Asian waterbird census, using standardized point count protocols at the 10 to 15 key wetlands identified in this review, would generate population trend data sufficient for evidence-based conservation assessment within five survey seasons. Provincial wildlife departments, university zoology departments, and NGOs already active

in crane research across KPK, Punjab, and Balochistan provide a ready institutional network without requiring new infrastructure.

The most consequential finding of this review is not the scale of any single threat but the complete absence of evaluated conservation responses. Thirty-five years of research have documented what is being lost and why, yet not one conservation intervention has been formally assessed for effectiveness. The scientific foundation for action now exists: the threats are identified, the hotspots are mapped, and the policy frameworks are in place. What remains is the political will and institutional commitment to translate this evidence into coordinated, monitored, and evaluated conservation action before further irreversible losses occur.

DECLARATIONS

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Data availability

The data extraction spreadsheet supporting the findings of this review is available from the corresponding author upon reasonable request. The systematic review protocol is publicly available at the Open Science Framework (<https://doi.org/10.17605/OSF.IO/HTXU5>).

Supplementary material

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Generative AI and AI assisted technology statement

The authors declare that no generative AI and AI assisted technology was used in the creation of this manuscript.

Statement of conflict of interest

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Online First Article



Supplementary Material

Threats to Migratory Cranes Along the Indus Flyway in Pakistan: A Systematic Review

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Supplementary File S1. PRISMA 2020 checklist of reported items for the systematic review of migratory crane threat dynamics along the Indus Flyway.

Section and topic	Item No.	Checklist item	Location where item is reported
Title			
Title	1	Identify the report as a systematic review.	Title
Abstract			
Abstract	2	See the PRISMA 2020 for Abstracts checklist.	Abstract
Introduction			
Rationale	3	Describe the rationale for the review in the context of existing knowledge.	Introduction
Objectives	4	Provide an explicit statement of the objective(s) or question(s) the review addresses.	Introduction (last paragraph)
Methods			
Eligibility criteria	5	Specify the inclusion and exclusion criteria for the review and how studies were grouped for the syntheses.	Methods: Eligibility criteria
Information sources	6	Specify all databases, registers, websites, organisations, reference lists and other sources searched or consulted to identify studies. Specify the date when each source was last searched or consulted.	Methods: Information sources
Search strategy	7	Present the full search strategies for all databases, registers and websites, including any filters and limits used.	Methods: Search strategy; Supplementary Table

Table continues on next page.....

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0030-9923/2026/0001-0001 \$ 9.00/0



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Section and topic	Item No.	Checklist item	Location where item is reported
Selection process	8	Specify the methods used to decide whether a study met the inclusion criteria of the review, including how many reviewers screened each record and each report retrieved, whether they worked independently, and if applicable, details of automation tools used in the process.	Methods: Selection process
Data collection process	9	Specify the methods used to collect data from reports, including how many reviewers collected data from each report, whether they worked independently, any processes for obtaining or confirming data from study investigators, and if applicable, details of automation tools used in the process.	Methods: Data extraction
Data items	10a	List and define all outcomes for which data were sought. Specify whether all results that were compatible with each outcome domain in each study were sought (e.g. for all measures, time points, analyses), and if not, the methods used to decide which results to collect.	Methods: Data extraction
	10b	List and define all other variables for which data were sought (e.g. participant and intervention characteristics, funding sources). Describe any assumptions made about any missing or unclear information.	Methods: Data extraction
Study risk of bias assessment	11	Specify the methods used to assess risk of bias in the included studies, including details of the tool(s) used, how many reviewers assessed each study and whether they worked independently, and if applicable, details of automation tools used in the process.	Methods: Evidence quality assessment
Effect measures	12	Specify for each outcome the effect measure(s) (e.g. risk ratio, mean difference) used in the synthesis or presentation of results.	Methods: Synthesis; N/A (narrative synthesis)
Synthesis methods	13a	Describe the processes used to decide which studies were eligible for each synthesis (e.g. tabulating the study intervention characteristics and comparing against the planned groups for each synthesis (item #5)).	Methods: Synthesis
	13b	Describe any methods required to prepare the data for presentation or synthesis, such as handling of missing summary statistics, or data conversions.	Methods: Synthesis
	13c	Describe any methods used to tabulate or visually display results of individual studies and syntheses.	Methods: Synthesis; Table 1; Table 2
	13d	Describe any methods used to synthesize results and provide a rationale for the choice(s). If meta-analysis was performed, describe the model(s), method(s) to identify the presence and extent of statistical heterogeneity, and software package(s) used.	Methods: Synthesis,
	13e	Describe any methods used to explore possible causes of heterogeneity among study results (e.g. subgroup analysis, meta-regression).	N/A (narrative synthesis, no meta-analysis)
	13f	Describe any sensitivity analyses conducted to assess robustness of the synthesized results.	N/A (no sensitivity analyses conducted)
Reporting bias assessment	14	Describe any methods used to assess risk of bias due to missing results in a synthesis (arising from reporting biases).	N/A (no formal reporting bias assessment; discussed in limitations)
Certainty assessment	15	Describe any methods used to assess certainty (or confidence) in the body of evidence for an outcome.	Methods: Evidence quality assessment,
Results			
Study selection	16a	Describe the results of the search and selection process, from the number of records identified in the search to the number of studies included in the review, ideally using a flow diagram.	Results: Study selection; Figure 1
	16b	Cite studies that might appear to meet the inclusion criteria, but which were excluded, and explain why they were excluded.	Results: Study selection

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Section and topic	Item No.	Checklist item	Location where item is reported
Study characteristics	17	Cite each included study and present its characteristics.	Results: Characteristics of included studies; Supplementary Table S2
Risk of bias in studies	18	Present assessments of risk of bias for each included study.	Results: Characteristics of included studies
Results of individual studies	19	For all outcomes, present, for each study: (a) summary statistics for each group (where appropriate) and (b) an effect estimate and its precision (e.g. confidence/credible interval), ideally using structured tables or plots.	N/A (narrative synthesis; summary data in Table 1)
Results of syntheses	20a	For each synthesis, briefly summarise the characteristics and risk of bias among contributing studies.	Results: each threat category section
	20b	Present results of all statistical syntheses conducted. If meta-analysis was done, present for each the summary estimate and its precision (e.g. confidence/credible interval) and measures of statistical heterogeneity. If comparing groups, describe the direction of the effect.	N/A (no meta-analysis performed)
	20c	Present results of all investigations of possible causes of heterogeneity among study results.	N/A (no meta-analysis; heterogeneity addressed narratively)
	20d	Present results of all sensitivity analyses conducted to assess the robustness of the synthesized results.	N/A (no sensitivity analyses performed)
Reporting biases	21	Present assessments of risk of bias due to missing results (arising from reporting biases) for each synthesis assessed.	N/A (no formal reporting bias assessment conducted)
Certainty of evidence	22	Present assessments of certainty (or confidence) in the body of evidence for each outcome assessed.	Results: Characteristics of included studies
Discussion			
Discussion	23a	Provide a general interpretation of the results in the context of other evidence.	Discussion (integrated throughout Results and Discussion)
	23b	Discuss any limitations of the evidence included in the review.	Results: Critical knowledge gaps
	23c	Discuss any limitations of the review processes used.	Methods: Selection process and Synthesis sections
	23d	Discuss implications of the results for practice, policy, and future research.	Conclusion
Other information			
Registration and protocol	24a	Provide registration information for the review, including register name and registration number, or state that the review was not registered.	Methods: Protocol and registration; OSF: https://doi.org/10.17605/OSF.IO/HTXU5
	24b	Indicate where the review protocol can be accessed, or state that a protocol was not prepared.	Methods: Protocol and registration
	24c	Describe and explain any amendments to information provided at registration or in the protocol.	N/A (no amendments to the registered protocol)
Support	25	Describe sources of financial or non-financial support for the review, and the role of the funders or sponsors in the review.	Acknowledgements; no funding received
Competing interests	26	Declare any competing interests of review authors.	Declaration of competing interests
Availability of data, code and other materials	27	Report which of the following are publicly available and where they can be found: template data collection forms; data extracted from included studies; data used for all analyses; analytic code; any other materials used in the review.	Data availability statement

From: Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. *BMJ* 2021;372:n71. doi: 10.1136/bmj.n71. This work is licensed under CC BY 4.0. To view a copy of this license, visit <https://creativecommons.org/licenses/by/4.0/>

Supplementary Table S1. Full-text articles excluded from the systematic review of migratory crane conservation along the Indus Flyway, Pakistan, with reasons for exclusion. A total of 19 records were excluded following Stage 2 full-text assessment.

Authors (Year)	Title	Reason for exclusion
Gosai et al. (2016)	Population structure, behavior, and current threats to the sarus crane (<i>Grus antigone antigone</i>) in Nepal	Study geographically restricted to Rupandehi District, Nepal, which lies outside the defined spatial boundaries of the Indus Flyway corridor in Pakistan. The population investigated represents a largely resident, non-migratory segment of <i>Grus antigone antigone</i> , rendering its findings ecologically and biogeographically non-transferable to the migratory dynamics under review. Excluded on the basis of geographic ineligibility and population non-representativeness.
Sundar and Choudhury (2003)	The Indian Sarus Crane <i>Grus a. antigone</i> : a literature review	This narrative literature review is centered predominantly on Indian subpopulations of <i>Grus antigone antigone</i> and does not present primary empirical data pertaining to migratory behavior, flyway-specific conservation status, or habitat utilization within the Indus Flyway, Pakistan. As a non-systematic, geographically misaligned secondary source lacking site-specific data relevant to the review's defined scope, it does not satisfy the thematic or geographic inclusion criteria.
Li et al. (2024)	Comparative analysis of the gut bacteria and fungi in migratory demoiselle cranes (<i>Grus virgo</i>) and common cranes (<i>Grus grus</i>) in the Yellow River Wetland, China	Although this study investigates two crane species that are central to the present systematic review, it is geographically restricted to the Yellow River Wetland, China, which falls entirely outside the spatial boundaries of the Indus Flyway corridor in Pakistan. Furthermore, the study is exclusively focused on comparative gut microbiome composition
Gehlot et al. (2021)	Eternal Attachment of Demoiselle Crane (<i>Anthropoides virgo</i>) to the Thar Desert of Rajasthan, India	The investigation is predominantly descriptive, reporting population counts and habitat utilization percentages without addressing conservation interventions, threat assessments, migratory connectivity, or flyway-level population dynamics.
Malek et al. (2020)	Population Dynamics and Habitat Preference of Sarus Crane (<i>Grus antigone L.</i>) in Selected Pockets of Central Gujarat	The study investigates a resident, non-migratory population of <i>Grus antigone</i> in Central Gujarat, India, which is both geographically and ecologically disjointed from the migratory crane populations traversing the Indus Flyway corridor in Pakistan. The investigation is descriptive in nature, reporting basic demographic ratios and habitat associations across a limited three-month observational window, without engaging with conservation threat assessments, migratory connectivity, flyway dynamics, or population viability.
Gyawali (2015)	Population and Ecology of Sarus Crane (<i>Grus antigone</i> , Linnaeus 1758) in Northern Region of Rupandehi District	This doctoral dissertation investigates a resident breeding population of <i>Grus antigone antigone</i> in the Rupandehi District of Nepal, focusing exclusively on nest ecology, hatching success, and localized population estimation; none of which intersect with the migratory, conservation threat, or flyway connectivity themes central to the present systematic review.
Prange (2010)	Eurasian Crane: Reasons for Changes in Crane Migration Patterns along the West-European Flyway	This study exclusively examines migratory dynamics and population trends of <i>Grus grus</i> along the West-European Flyway (WEF), encompassing Germany, France, and Spain; a biogeographically and ecologically distinct flyway system entirely separate from the Central Asian/Indus Flyway corridor under review.
WWF Pakistan	WWF Pakistan: crane species / migratory birds web article	Record retrieved during grey literature screening of WWF Pakistan's online platform. The source constitutes a non-archival institutional webpage or press release lacking formal authorship attribution, pagination, peer review, and the bibliographic stability required for inclusion in a systematic review.
CMS/CAF Partnership Secretariat	CMS/CAF Partnership: Central Asian Flyway web document or policy brief	Record retrieved during grey literature screening of the CMS/CAF Partnership online repository. The source is a non-archival institutional web document or policy brief that does not constitute a peer-reviewed or formally published empirical study.
Author(s) as listed on research gate	ResearchGate preview page for a crane-related publication	Record retrieved as a ResearchGate platform preview page during database screening.

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Authors (Year)	Title	Reason for exclusion
Author(s) as indexed by Google Scholar	Google Scholar index preview for a crane-related record	Record surfaced as a Google Scholar index preview during systematic database searching. The retrieved record represents a search engine metadata entry rather than a directly accessible or citable publication.
Salvi (2013)	Eurasian crane <i>Grus grus</i> study in France over the last 30 years: a review	This review comprehensively documents three decades of <i>Grus grus</i> ecology, population trends, and conservation efforts exclusively within France, representing the West-European Flyway
Woutersen (2025)	How many common cranes (<i>Grus grus</i>) winter in Spain and Portugal?	This study examines wintering population enumeration and census methodology of <i>Grus grus</i> exclusively within the Iberian Peninsula
Nilsson et al. (2019)	Conservation success or increased crop damage risk? The Natura 2000 network for a thriving migratory and protected bird	it is exclusively focused on the Western European Flyway within the EU Natura 2000 network, a biogeographically and policy-contextually distinct system entirely separate from the Central Asian/Indus Flyway corridor in Pakistan.
Khan (1991)	The Antiquity of Crane-Catching in the Bannu Basin	This study is an archaeologically and ethnographically oriented investigation examining historical crane-catching practices in the Bannu Basin through analysis of prehistoric pottery motifs and contemporary folkloric traditions. It does not present any empirical ecological, ornithological, or conservation data pertaining to crane populations, habitat assessments, migratory connectivity, or threat evaluations.
Grimmett et al. (2026)	Birds of India: Pakistan, Nepal, Bangladesh, Bhutan, Sri Lanka, and the Maldives: Third Edition	This multi-author field guide constitutes a taxonomic and distributional reference work rather than an empirical research study. Although geographically inclusive of Pakistan and the broader South Asian region covered by the Indus Flyway corridor, the volume presents no primary data pertaining to crane population dynamics, migratory connectivity, conservation threat assessments, or habitat utilization derived from original fieldwork or systematic investigation.
Bairlein (2016)	Migratory birds under threat	The article does not engage with the Central Asian Flyway, demoiselle crane, common crane, or sarus crane in any substantive analytical capacity.
Parchizadeh and Belant (2020)	Mass mortality of migratory birds in Iran	The record does not address crane ecology, population status, migratory connectivity, or conservation interventions in any analytical depth.
Baraiya et al. (2023)	Fine-scale migratory movements of Common Cranes along desert route of Central Asian Flyway	Superseded record. This entry represents a preliminary abstract or preprint version of a study subsequently published as a full peer-reviewed article, which has been independently retrieved, assessed, and included in the present systematic review.

Supplementary Table S2. Complete search strings applied across all databases †‡ for the systematic review of migratory crane conservation along the Indus Flyway, Pakistan. All searches were conducted in May 2026.

Database	Search string	Records retained
Academic databases†		
Google Scholar	"Demoiselle crane" Pakistan	51
—	"Anthropoides virgo" Pakistan	—
—	"Eurasian crane" Pakistan	—
—	"Grus grus" Pakistan	—
—	crane hunting Pakistan	—
—	crane migration "Indus Flyway"	—
—	crane "Central Asian Flyway" Pakistan	—
—	migratory birds hunting Pakistan KPK	—
—	"Demoiselle crane" "Khyber Pakhtunkhwa"	—

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Database	Search string	Records retained
—	crane conservation Pakistan wetland	—
—	"Sarus crane" Pakistan	—
—	"Siberian crane" Pakistan	—
—	waterbird population Pakistan Punjab	—
—	crane population "South Asia" threat	—
—	illegal hunting migratory birds Pakistan	—
† Per-string counts not individually recorded; see footnote. Database total imported into Zotero after deduplication.		
Semantic Scholar	Demoiselle crane Pakistan	12
—	Anthropoides virgo Pakistan threat	—
—	crane hunting Khyber Pakhtunkhwa	—
—	migratory crane Indus Flyway conservation	—
—	Eurasian crane Pakistan population	—
—	Crane Central Asian Flyway Pakistan	—
† Per-string counts not individually recorded; see footnote. Database total imported into Zotero after deduplication.		
BASE	Demoiselle crane Pakistan	11
—	crane hunting Pakistan Khyber Pakhtunkhwa	—
—	migratory crane Central Asian Flyway	—
—	Anthropoides virgo threat conservation	—
—	waterbird wetland Pakistan conservation	—
† Per-string counts not individually recorded; see footnote. Database total imported into Zotero after deduplication.		
JSTOR	Demoiselle crane Pakistan	13
—	crane migration Pakistan	—
—	Grus Pakistan hunting	—
—	waterbird Pakistan wetland	—
—	migratory birds South Asia conservation	—
† Per-string counts not individually recorded; see footnote. Database total imported into Zotero after deduplication.		
ResearchGate	Demoiselle crane Pakistan	19
—	crane hunting Khyber Pakhtunkhwa	—
—	Anthropoides virgo Pakistan	—
—	migratory crane Indus Flyway	—
—	crane population Punjab Pakistan	—
—	Eurasian crane Pakistan threat	—
—	waterbird wetland conservation Pakistan	—
† Per-string counts not individually recorded; see footnote. Database total imported into Zotero after deduplication.		
Grey literature sources‡		
BirdLife Data Zone	Demoiselle Crane species factsheet	Grey literature
—	Eurasian Crane species factsheet	Grey literature
—	Siberian Crane species factsheet	Grey literature
—	Sarus Crane species factsheet	Grey literature

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Database	Search string	Records retained
IUCN Red List	Anthropoides virgo assessment	Grey literature
—	Grus grus assessment	Grey literature
—	Leucogeranus leucogeranus assessment	Grey literature
—	Antigone antigone assessment	Grey literature
WWF Pakistan	crane migratory birds	Grey literature
CMS	crane Pakistan Central Asian Flyway	Grey literature
Pakistan Journal of Zoology	crane Demoiselle Anthropoides	Grey literature
CAF Partnership	crane Pakistan Indus	Grey literature

† Records Retained reflect totals imported into Zotero reference library after initial deduplication for the first search string per database only. Searches were conducted up to 20 pages per database, sorted by relevance. Per-string hit counts were not individually recorded at the time of searching; “—” denotes strings executed within the same database session whose individual yield was not separately logged. Total records identified = 131 (academic databases n = 123; grey literature n = 8) prior to deduplication. See PRISMA 2020 flow diagram for full screening, eligibility assessment, and inclusion details. ‡ Grey literature sources were searched manually via official websites and institutional repositories. Numerical result counts are not applicable; records were assessed for relevance by direct inspection of available content.

Study ID	Authors (Year)	Study location	Species studied	Study design	Threat code	Conser- vation code	Evi- dence quality
ARCHIBA- LD 2003a	Archibald et al., 2003	Global review — Indian subcontinent, Southeast Asia, Australia; Pakistan referenced as part of former Indian Sarus range (Indus River lowlands)	Sarus Crane	Narrative literature review; field observations; museum specimen review	T1; T2; T6; T8	C1; C2; C3; C4; C5	D
SHARMA 2006a	Sharma, 2006	Western Nawalparasi District, Nepal (transboundary region adjacent to India and upstream of Indus Flyway range)	Sarus Crane	Road transect survey; questionnaire survey; nest measurements; habitat classification	T2; T7; T8	C3; C5	B
NAWAZ 2006a	Nawaz et al., 2006	Kurru Valley, North and South Waziristan, and Zhob District, (KPK and Balochistan)	Eurasian Crane; Demoiselle Crane; Siberian Crane	Field survey; hunter interviews; historical record review; questionnaire survey	T1; T7	C1; C4	C
HIGUCHI 2008a	Higuchi et al., 2008	Wintering ground: Gujarat, India (Bhuj district, Kutch); migration route: across Pakistan and Afghanistan skirting Hindu Kush; stopover sites in Turkmenistan and Kazakhstan; summer sites in Kazakhstan and Russia	Eurasian Crane (Grus grus)	Satellite telemetry (PTT); migration tracking	T1; T2; T7	C4; C5	A
PERVEEN 2010a	Parveen and Khan, 2010	District Bannu and Lakki Marwat, KPK	Common Crane; Demoiselle Crane	Field surveys; interviews; questionnaire surveys	T1; T2; T7	C1	B
SUNDA- R2010a	Sundar and Subraman- ya, 2010	India, Pakistan, Bangladesh, Nepal, Sri Lanka (Indian subcontinent review)	Broad review of 351 bird species including sarus crane and demoiselle crane	Narrative literature review; guild structure analysis	T2; T7; T8	C5	D
KHAN 2011a	Khan et al., 2011	District Zhob, Balochistan	Demoiselle Crane; Eurasian Crane; Siberian Crane	Point survey method; binocular counts	T1; T2; T7	C1; C2; C3; C5	B
SARWAR 2013a	Sarwar et al., 2013	District Lakki Marwat, KPK	Demoiselle Crane	Gizzard and fecal content analysis; botanical and zoological identification	T2; T7	C5	B

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Study ID	Authors (Year)	Study location	Species studied	Study design	Threat code	Conser- vation code	Evi- dence quality
MOSTAFA-WI 2017a	Mostafawai et al., 2017	Kapisa and Parwan provinces, Afghanistan	Demoiselle Crane; Eurasian Crane; Siberian Crane	Field assessment; hunting camp surveys; hunter interviews; direct observation	T1; T7	C1; C3; C4	B
GYAWALI 2018a	Gyawali, 2018	Upper Mustang, Kaligandaki Valley, Nepal	Demoiselle Crane	Direct visual count; flock photography; semi-structured questionnaire survey	T1; T2; T7	C2; C3; C5	B
UMAR 2018a	Umar et al., 2018	Pakistan-wide review, specific sites (Mangla Dam, Taunsa Barrage, Rasool Barrage, Uchalli Wetland Complex, Hingol National Park, Central Karakoram National Park, Jiواني Coastal Wetland, Muzaffarabad)	Migratory birds in Pakistan including cranes	Narrative literature review	T1; T2; T3; T4; T7; T8	C1; C2; C3; C5	D
AHMAD 2021a	Ahmad et al., 2021	District Bannu, Lakki Marwat and Karak, KPK	Demoiselle Crane; Common Crane	Field surveys; questionnaire surveys; interviews; fecal/ blood sample collection	T1; T8	C5	B
MEENA 2021a	Meena et al., 2021	District Jodhpur, Rajasthan, India	Demoiselle Crane	Random transect method; point count technique; community interviews	T2; T7	C2; C3; C5	C
XU 2021a	Xu et al., 2021	Balikun Lake, Xinjiang Province, Northwestern China, stopover site on Central Asian migration route	Demoiselle Crane	Group scan sampling; behavioural observation; ANCOVA	T7	C5	B
GEHLOT 2022a	Gehlot et al., 2022	Thar Desert, Rajasthan, India (border region sharing boundary with Pakistan)	Demoiselle Crane	Scan and focal sampling; questionnaire survey; rescue centre data; binocular survey	T2; T4; T6; T7; T8	C5	B
ILYAS-HENKO 2022a	Ilyashenko et al., 2022	Breeding grounds in Ukraine, Russia, and Kazakhstan; flyways across Central Asia; wintering grounds in Chad, Sudan, and northwestern India; trans-Himalayan and Central Asian corridors passing through or adjacent to Pakistan flyway	Demoiselle Crane	GPS-GSM satellite telemetry; multi-country collaborative tracking	T2; T5	C4; C5	A
REHMAN 2022a	Rehman et al., 2022	District Bannu, KPK	Demoiselle Crane	Line transect method; water quality tests (temperature, pH, E-coli contamination); questionnaire survey	T1; T2; T7; T8	C5	B
SARWAR 2022a	Sarwar et al., 2022	Wana, South Waziristan Agency, FATA (now merged district), KPK	Demoiselle Crane; Eurasian Crane	Questionnaire survey; hunter interviews; seasonal camp records	T1; T7	C1; C3	B
ANSARI 2023a	Ansari, 2023	Asia-wide — breeding range and wintering range	Siberian Crane	Ensemble species distribution modelling; AUC validation; future projections	T5; T2	C5	B

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Study ID	Authors (Year)	Study location	Species studied	Study design	Threat code	Conser- vation code	Evi- dence quality
HUSSAIN 2023a	Hussain and Khan, 2023	Bannu Division and Dera Ismail Khan Division, KPK	Demoiselle Crane; Eurasian Crane	Ethnozoological market survey; dealer interviews; market observation	T1; T7	C1	B
KON-DRAKOVA 2023a	Kondrakova, 2023	Agricultural fields during premigration period (Russia or Central Asia)	Eurasian Crane; Demoiselle Crane	Behavioural observation; time budget analysis; focal and scan sampling	T2; T7	C5	B
RAM 2023a	Ram et al., 2023	Wintering ground: Kaj wetland, Gir-Somnath district, Gujarat, India (IBA site); migration routes confirmed through Pakistan, Afghanistan, Iran, Turkmenistan, Uzbekistan, Kazakhstan, Russia	Demoiselle Crane; Eurasian Crane	GPS-GSM satellite telemetry; KDE home range estimation; GLM habitat analysis	T2; T6; T1	C4; C5	A
SULIMAN 2023a	Suliman et al., 2023	District Bannu and Lakki Marwat, KPK	Demoiselle Crane; Eurasian Crane	Field visits; Interviews; Questionnaire surveys; Captive population monitoring	T1	C3; C5	A
ULLAH 2023a	Ullah et al., 2023	River Indus, River Kurram, and Zara Daggar, KPK	Demoiselle Crane; Common Crane	Line transect survey; photographic counts; diversity indices; fecal sampling; questionnaire survey	T1; T2; T8	C5	A
BIRDLIFE_CC 2024a	BirdLife International, (2024)	Global range including Pakistan	Eurasian Crane	Official species factsheet	T1; T2; T5; T6	C1; C4; C5	B
BIRDLIFE_DV 2024a	BirdLife International, (2024)	Global range including Pakistan	Demoiselle Crane	Official species factsheet	T1; T2; T5	C1; C4; C5	B
BIRDLIFE_SA 2024a	BirdLife International, (2024)	Global range (Historically including Pakistan)	Sarus Crane	Official species factsheet	T1; T2; T8	C1; C2; C4; C5	B
BIRDLIFE_SC 2024a	BirdLife International, (2024)	Global range (Historically including Pakistan)	Siberian Crane	Official species factsheet	T1; T2; T5	C1; C2; C4; C5	B
IUCN 2024a	IUCN, (2024)	Global range including Pakistan	All four crane species	Official species assessment; expert panel review	T1; T2; T5; T6	C1; C4	B
KHAN 2024a	Khan et al., 2024	KPK and Balochistan	Demoiselle Crane (Anthropoides virgo)	Species distribution modelling (MaxEnt)	T5; T2	C5	A
QAYUM 2024a	Qayum et al., 2024	Lasbela Coast, Balochistan	Demoiselle Crane	Line transect method; visual observation; questionnaire-interview survey	T1; T7	C2; C5	B
SHAH 2024a	Shah et al., 2024	District Bannu, KPK	Demoiselle Crane	Questionnaire-based survey; direct observation; hunter interviews; field visits	T1; T7	C1	C

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Study ID	Authors (Year)	Study location	Species studied	Study design	Threat code	Conser- vation code	Evi- dence quality
SHARMA 2024a	Sharma et al., 2024	Chitwan to Kanchanpur districts, Nepal	Sarus Crane	Systematic road count survey; GLM; key informant inter-views	T2; T4; T6; T7	C2; C4; C5	A
BARAIYA 2025a	Baraiya et al., 2025	Wintering ground: Nal Sarovar Bird Sanctuary and Thol Lake Wildlife Sanctuary, Gujarat, India (both Ramsar sites); migration route confirmed through Pakistan (Kharan Desert), Afghanistan (Dasht-e-Margo), Iran, Turkmenistan, Uzbekistan, Kazakhstan; breeding grounds southwestern Siberia and northern Kazakhstan (55°N–58°N)	Eurasian Crane	GPS-GSM satellite telemetry; dBBMM movement model-ling; RSF habitat analysis	T1; T2; T7	C4; C5	A
DAI 2025a	Dai et al., 2025	East Asian-Australasian Flyway (EAAF) and Central Asian Flyway (CAF); (Flyway-scale review)	199 migratory water-bird species across EAAF and CAF including Siberian Crane, Sarus Crane.	Species-level anal-ysis; IUCN range maps; statistical modelling	T1; T2; T4; T5; T7; T8	C1; C2; C4; C5	B
KHAN 2025a	Khan et al., 2025	FR Bannu (Frontier Region Ban-nu), KPK	Demoiselle Crane	Questionnaire-based interview survey; descriptive analysis	T1; T2; T7	C3; C5	C
NAWAZ 2025a	Nawaz et al., 2025	District Zhob, Balochistan	Demoiselle Crane; Eurasian Crane; Houbara Bustard	Point survey method; structured interviews; questionnaire survey	T1; T2; T3; T4; T5; T7; T8	C1; C3	C
ZULFIQAR 2025a	Zulfiqar et al., 2025	Western Punjab Districts (Attock, Mianwali, Khushab, Bhakkar, Layyah, Muzzaffargarh, DG khan, Rajanpur)	Demoiselle Crane; Eurasian Crane	Questionnaire sur-vey; Spatial analysis; Cluster analysis	T1; T7; T6	C3; C5	A
ZULFIQAR 2025b	Zulfiqar et al., 2025	District Bhakkar, Punjab	Demoiselle Crane; Eurasian Crane	Field survey; diver-sity indices; PCA; habitat assessment; questionnaire survey	T1; T2; T7	C3; C4; C5	B
BATOOL 2026a	Batool et al., 2026	wetland sites (Namal Lake and Uchali Lake), Punjab	Northern Pintail primary species; migratory waterbird general context rele-vant to crane flyway	Boat-based and point-count surveys; Mann-Kendall trend test; GLMM	T2; T5; T8	C5	A
SULIMAN 2026a	Suliman et al., 2026	Bannu and Lakki Marwat Districts, KPK	Demoiselle Crane; Eurasian Crane	Remote sensing and GIS analysis; Landsat classifica-tion; Mann-Kendall trend test	T2; T4; T5; T7; T8	C2; C3; C5	A

Threat Codes	
Code	Meaning
T1	Illegal hunting/exploitation
T2	Agricultural habitat loss/wetland drainage
T3	Deforestation
T4	Urbanisation/infrastructure
T5	Climate change
T6	Power line/infrastructure collision
T7	Human disturbance
T8	Pollution
Conservation codes	
Code	Meaning
C1	Legal protection
C2	Protected areas
C3	Community engagement
C4	International collaboration
C5	Research and monitoring
Evidence quality	
Level	Criteria
A	Multi-year systematic survey, GPS telemetry, n>50
B	Single season structured survey, institutional dataset
C	Opportunistic observation, small sample, short term
D	Expert opinion, anecdotal, grey literature no methodology