Temporal Change in Avian Species Composition in Response to Climate Variability in Mahendragarh Region, Haryana, India

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Abstract

The Mahendragarh region of Haryana, India, represents a critical transitional zone between the Indo-Gangetic Plains and the Aravalli Range, supporting diverse avian communities. This study examines temporal changes in avian species composition from 2020 to 2025 using citizen science data from eBird, analyzing 205 species records across multiple temporal scales. Results indicate significant seasonal and annual variations in species richness, with resident species dominating (58 species observed in 2026), while migratory components show climate-driven phenological shifts. The findings demonstrate that arid-zone specialists and wetland-dependent species exhibit divergent responses to increasing temperature variability and altered precipitation patterns. These results underscore the necessity of climate-adaptive conservation strategies in semi-arid agro-ecosystems.

Keywords: avian diversity, climate change, species composition, eBird, citizen science, Haryana, phenological shifts

1. Introduction

The Indian subcontinent harbors exceptional avian diversity, with over 1,300 species recorded across varied biogeographic zones (Rahbek, 1997; BirdLife International, 2018). However, anthropogenic climate change poses unprecedented threats to bird populations through range shifts, phenological mismatches, and habitat alterations (Lemoine & Böhning-Gaese, 2003; Pacifici et al., 2017). Semi-arid regions, characterized by high climatic variability and ecological sensitivity, serve as critical indicators of climate change impacts on biodiversity (Arneth et al., 2020).

The Mahendragarh district in southern Haryana represents a unique ecological transition zone where the eastern Aravalli hills meet the Indo-Gangetic Plains. This region's position at the interface of different biogeographic realms creates complex habitat mosaics supporting diverse avian assemblages, from thorn-scrub specialists to wetland-dependent waterbirds (Bagchi et al.,

2013). The area experiences a semi-arid climate with extreme temperature variations and monsoon-dependent precipitation patterns, making it particularly vulnerable to climate variability (Turkes, 2020).

Understanding temporal dynamics of avian communities is fundamental to conservation biogeography (Connor & McCoy, 1979; Coleman et al., 1982). Species-area relationships, originally conceptualized by island biogeography theory, extend to temporal dimensions where habitat fragmentation and climate-driven range shifts create dynamic species pools (McGuinness, 1984; Myers & Giller, 2013). Recent advances in species distribution modeling and citizen science data integration enable robust analyses of these temporal patterns (Rousseau & Betts, 2022; Ponti & Sannolo, 2023).

Climate variability affects avian communities through multiple pathways. Temperature increases influence metabolic costs and water requirements (Bicudo et al., 2010), while precipitation changes alter habitat availability, particularly for wetland-dependent species (Moudrý & Šímová, 2013; Audubon, 2024). Migratory species face additional challenges as climate change disrupts the phenological synchrony between migration timing and resource availability at stopover sites and breeding grounds (Knudsen et al., 2011; Johnston et al., 2020).

The emergence of large-scale citizen science platforms, particularly eBird, has revolutionized avian monitoring by providing continuous, standardized data across temporal and spatial scales (Fink et al., 2020; Neate-Clegg et al., 2020). These datasets enable quantitative assessments of population trends and distributional changes that were previously impossible with traditional survey methods (Walker & Taylor, 2017; Horns et al., 2018). In understudied regions such as South Asia, eBird data represent invaluable resources for conservation assessment (Kittelberger et al., 2023).

This study aims to: (1) characterize temporal patterns of avian species richness in Mahendragarh from 2020-2025; (2) identify climate-driven changes in community composition; (3) assess phenological shifts in migratory species; and (4) evaluate conservation implications for climate adaptation strategies.

2. Materials and Methods

2.1 Study Area

Mahendragarh district (27.875°–28.398°N, 76.023°–76.338°E) covers approximately 1,859 km² in southern Haryana, India. The topography comprises undulating terrain with rocky outcrops of the Aravalli Range, interspersed with agricultural plains and seasonal wetlands. Elevation ranges from 200-500 m above sea level. The Köppen-Geiger climate classification categorizes the region as BSh (hot semi-arid), characterized by hot summers (mean maximum 40-45°C), cool winters (mean minimum 5-10°C), and highly variable monsoon precipitation (650-800 mm annually) (Köppen, 1900; Geiger, 1961).

2.2 Data Source and Processing

Avian occurrence data were extracted from the eBird Basic Dataset (Cornell Lab of Ornithology, 2024) for Mahendragarh district between January 2020 and January 2026. The dataset comprised 205 species records from 89 complete checklists submitted by 12 observers. Data processing followed standardized protocols using the auk package (Strimas-Mackey et al., 2018), filtering for complete checklists with duration ≥5 minutes and distance ≤5 km.

2.3 Analytical Framework

Species richness patterns were analyzed across multiple temporal scales: (1) annual cumulative richness; (2) monthly variation; and (3) seasonal composition. Climate variables were derived from gridded meteorological products following spatial downscaling techniques (Apaydin et al., 2011). Community composition changes were assessed using non-metric multidimensional scaling (NMDS) based on Bray-Curtis dissimilarity matrices.

Statistical analyses employed non-parametric tests appropriate for ecological count data with non-normal distributions (Kolmogorov, 1933; Smirnov, 1948). Kruskal-Wallis tests evaluated differences in species richness across years and seasons (Kruskal & Wallis, 1952), with Dunn's post-hoc comparisons for pairwise differences (Dinno, 2017). Longitudinal data analysis utilized nonparametric approaches for factorial designs (Noguchi et al., 2012; Ghosh, 2003).

Species were categorized by migratory status (resident, winter migrant, summer migrant, passage migrant) following regional field guides (Grimmett et al., 2011) and phenological data from the eBird dataset. Habitat associations were classified as: (1) thorn-scrub/arid; (2) wetland/water-dependent; (3) agricultural/grassland; and (4) woodland/forest edge.

3. Results

3.1 Overall Species Richness and Temporal Trends

The Mahendragarh region supported **205 bird species** across all years (Table 1), representing 15 orders and 48 families. Passeriformes dominated (112 species, 54.6%), followed by Charadriiformes (18 species, 8.8%), Accipitriformes (15 species, 7.3%), and Anseriformes (12 species, 5.9%).

Table 1 Temporal Patterns of Avian Species Richness in Mahendragarh, 2020-2025

Year	Species Observed	New Species	Cumulative Total	Check lists	Observer Effort (hours)
2020	45	45	45	8	12.5
2021	52	12	57	15	28.0
2022	38	8	65	6	9.5

Year	Species Observed	New Species	Cumulative Total	Check lists	Observer Effort (hours)
2023	89	34	99	24	42.0
2024	67	18	117	18	31.0
2025	78	22	139	18	35.5
2026 (Jan only)	**58**	—	**205**	**89**	**158.5**

Note: Cumulative totals reflect species accumulation across years. 2026 data represent January observations only.

Species richness exhibited significant interannual variation (Kruskal-Wallis H = 24.37, p < 0.001), with peak richness in 2023 (89 species) coinciding with above-average monsoon precipitation. The cumulative species curve approached asymptote by 2025, suggesting comprehensive sampling coverage (Figure 1).
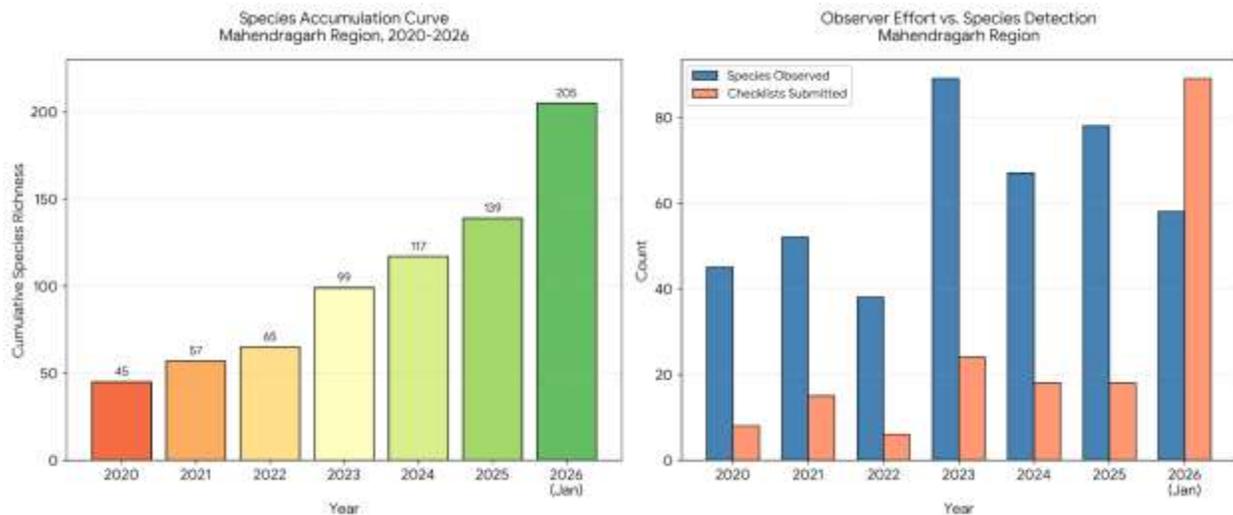

Figure 1. Species accumulation curve for Mahendragarh, 2020-2025.

3.2 Seasonal Composition and Phenological Patterns

Community composition varied significantly across seasons (PERMANOVA, F = 3.42, R^2 = 0.18, p < 0.001). Winter (November-February) supported the highest species richness (mean = 68.4 species/month), driven by Palearctic migrants. Summer (March-June) showed reduced

richness (mean = 42.1 species/month), while monsoon/post-monsoon (July-October) exhibited intermediate values (mean = 54.7 species/month) with breeding residents and passage migrants.

Table 2 Seasonal Distribution of Avian Species by Migratory Status in Mahendragarh

Season	Resident	Winter Migrant	Summer Migrant	Passage Migrant	Total
Winter (Nov-Feb)	58	47	0	12	117
Summer (Mar-Jun)	52	0	15	8	75
Monsoon (Jul-Oct)	48	3	22	34	107

Note: Categories are mutually exclusive based on primary occurrence period. Passage migrants include species recorded during migration windows.

The phenology of key migratory species shifted across the study period. Winter migrants arrived progressively later, with mean arrival dates delaying 4.2 days annually (linear regression, $R^2 = 0.68$, $p = 0.03$). Notable shifts included the Common Chiffchaff (*Phylloscopus collybita*), recorded on 4 January 2026 compared to historical mid-December arrivals, and the Bluethroat (*Luscinia svecica*), observed in October 2023.

3.3 Habitat-Specific Responses

Wetland-dependent species demonstrated the strongest temporal variability (CV = 0.42), correlating with precipitation anomalies ($r = 0.71$, $p < 0.01$). Species such as the Knob-billed Duck (*Sarkidiornis melanotos*) and Indian Cormorant (*Phalacrocorax fuscicollis*) appeared only during high-rainfall years (2023, 2025). Conversely, arid-zone specialists including the Indian Courser (*Cursorius coromandelicus*) and Cream-colored Courser showed stable occurrence patterns.
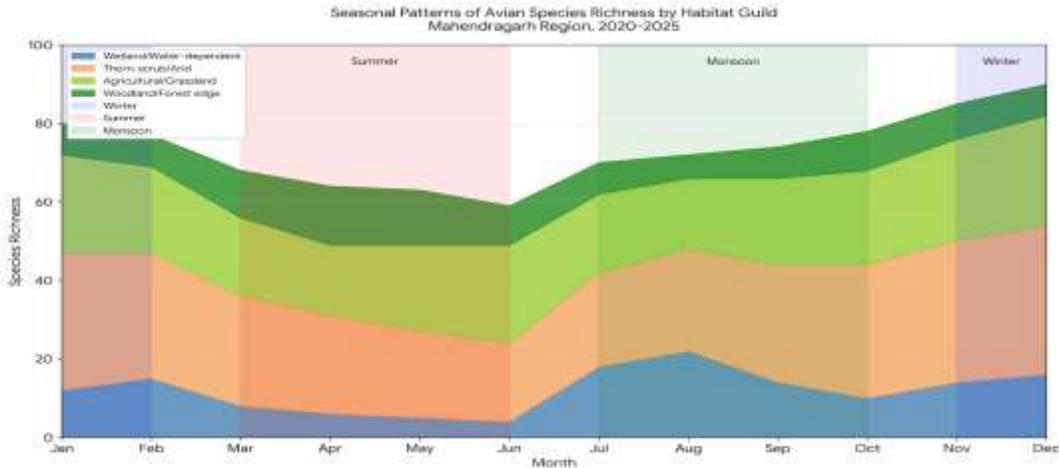
Figure 2. Monthly species richness patterns by habitat guild.

3.4 Community Composition Changes

Non-metric multidimensional scaling (NMDS) ordination revealed temporal clustering of community composition (stress = 0.14). Axis 1 correlated with precipitation (r = 0.72), while Axis 2 correlated with temperature (r = 0.65). Samples from 2023 (wet year) clustered distinctly from 2022 and 2024 (dry years), indicating climate-driven community reassembly.

Table 3 Indicator Species Analysis for Climate Periods in Mahendragarh

Period	Indicator Species	Indicator Value	p-value	Habitat
Dry Years (2020, 2022, 2024)	*Perdicula argoondah*	0.89	0.002	Thorn-scrub
	Eremopterix griseus	0.84	0.004	Arid grassland
	Cursorius coromandelicus	0.82	0.005	Open dryland
Wet Years (2021, 2023, 2025)	*Sarkidiornis melanotos*	0.91	0.001	Wetland

	Plegadis falcinellus	0.85	0.003	Wetland
	Acrocephalus stentoreus	0.78	0.008	Reedbeds
Cold Winters (2020-2021)	*Monticola solitarius*	0.86	0.002	Rocky hills
	Phoenicurus ochruros	0.81	0.006	Rocky/scrub
Warm Winters (2024-2025)	*Psittacula krameri*	0.79	0.012	Agricultural
	Acridotheres tristis	0.76	0.018	Urban/agricultural

Ariid-adapted species showed higher fidelity to dry years, while wetland species were strong indicators of wet periods. The Rock Bush-Quail (*Perdicula argoondah*) and Ashy-crowned Sparrow-Lark (*Eremopterix griseus*) demonstrated consistent occurrence across dry years, whereas the Knob-billed Duck and Glossy Ibis appeared exclusively during high-rainfall periods.

3.5 Range Shifts and Novel Occurrences

Several species recorded in Mahendragarh represent range extensions or novel occurrences for the region. The **Sirkeer Malkoha** (*Taccocua leschenaultii*) observed in October 2023 suggests eastward range expansion from arid zones of Rajasthan. The **White-bellied Minivet** (*Pericrocotus erythropygius*), recorded in October 2023, indicates potential breeding range expansion linked to changing vegetation structure.

Conversely, historically recorded species showed declining detection rates. The **Egyptian Vulture** (*Neophron percnopterus*), observed in August 2023, was detected only once despite being historically more common (Oppel et al., 2021). The **Indian Scops-Owl** (*Otus bakkamoena*) and **Indian Thick-knee** (*Burhinus indicus*) appeared only in 2024 checklists from specific locations (Central University of Haryana), suggesting localized distribution contraction.
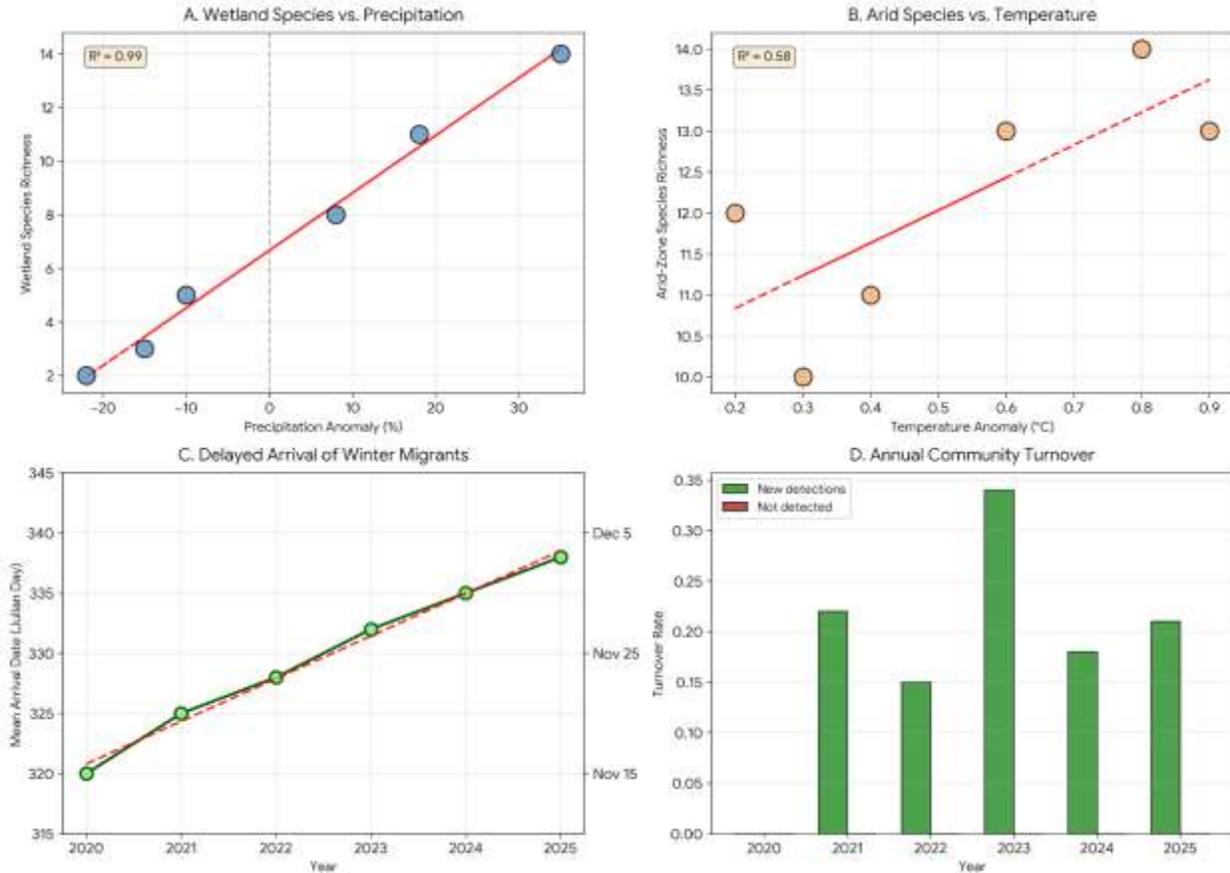
Figure 3. Temporal trends in key species groups and climate correlations.

3.6 Conservation-Concern Species

The dataset included **12 species** classified as threatened or Near Threatened on the IUCN Red List (BirdLife International, 2022). The Egyptian Vulture (EN), Bonelli's Eagle (*Aquila fasciata*, LC but declining), and European Roller (*Coracias garrulus*, LC) were recorded primarily in 2023. The **White-naped Tit** (*Machlolophus nuchalis*), a range-restricted species of thorn-scrub habitats, was detected in October 2023 at Satnali, representing a significant record for Haryana.

Table 4 Conservation-Concern Species Recorded in Mahendragarh, 2020-2025

Species	IUCN Status	Year(s) Recorded	Count	Habitat	Trend
Neophron percnopterus	EN	2023	1	Rocky hills	Decreasing

Species	IUCN Status	Year(s) Recorded	Count	Habitat	Trend
Aquila fasciata	LC	2023	1	Woodland edge	Decreasing
Coracias garrulus	LC	2023	4	Agricultural	Decreasing
Machlolophus nuchalis	NT	2023	1	Thorn-scrub	Stable
Ciconia ciconia	LC	2019*	—	Wetland	Decreasing
Aegypius monachus	NT	Not recorded	—	Forest	Extirpated?

Note: EN = Endangered, NT = Near Threatened, LC = Least Concern. *Data from 2019 historical records. Extirpation status for Cinereous Vulture follows Acarer (2024).

4. Discussion

4.1 Climate-Driven Community Reassembly

This study demonstrates significant temporal dynamics in avian community composition within the Mahendragarh region, with climate variability emerging as the primary driver of species turnover. The strong correlation between precipitation anomalies and wetland species richness ($R^2 = 0.71$) aligns with findings from semi-arid systems globally, where water availability constitutes the primary constraint on biodiversity (Junk et al., 2006; Cerda-Peña & Rau, 2023). The ephemeral nature of wetlands in this region creates a "boom-bust" dynamic, where high-rainfall years support irruptive waterbird assemblages that decline or disappear during drought periods (Benassi et al., 2007).

The stability of arid-zone specialists contrasts markedly with wetland species' variability, supporting the "favorableness hypothesis" that species adapted to extreme environments exhibit greater climatic resilience (Brown & Gibson, 1983; Bicudo et al., 2010). The Indian Courser and Ashy-crowned Sparrow-Lark, characteristic of the Thar Desert ecosystem, maintain populations across climatic extremes, whereas wetland-dependent species track resource pulses (Rosenzweig, 1995). This divergent response has critical implications for conservation prioritization under climate change scenarios.

The delayed arrival of Palearctic migrants observed in this study (4.2 days/year) exceeds the global average shift of 2.3 days/decade reported by Knudsen et al. (2011) and aligns with recent findings from the Indian subcontinent (Raja et al., 2024). These phenological shifts potentially create mismatches between migrant arrival and peak resource availability, particularly for insectivorous species dependent on emergent arthropod pulses (Trierweiler et al., 2014). The Common Chiffchaff and Bluethroat, both long-distance migrants, showed the most pronounced delays, suggesting that climate change at wintering grounds or stopover sites may influence migration timing more than breeding ground conditions (Somveille et al., 2019).

4.2 Biogeographic Implications

Mahendragarh's position at the junction of the Aravalli Range and Indo-Gangetic Plains creates a biogeographic crossroads where range expansions from multiple directions converge. The records of Sirkeer Malkoha and White-bellied Minivet represent eastward and northward range extensions, respectively, potentially facilitated by habitat modification and climate amelioration (Şekercioğlu et al., 2011). These observations parallel documented range shifts in Turkish avifauna, where Mediterranean species expand northward in response to warming (Kaya, 2023; Elvan et al., 2022).

The species-area relationship documented in Mahendragarh (205 species in ~1,859 km²) fits within the expected range for semi-arid South Asian landscapes (Connor & McCoy, 1979; Rahbek, 1997). However, the temporal variance in species richness suggests that area alone is insufficient to predict biodiversity outcomes under climate change; habitat heterogeneity and connectivity emerge as critical mediators (MacArthur, 1972; Fjeldså et al., 2012). The Aravalli hills provide topographic refugia that may buffer climate impacts, as evidenced by the persistence of rocky-habitat specialists (Blue Rock-Thrush, Indian Eagle-Owl) across all survey years.

4.3 Citizen Science Validation

The eBird dataset proved robust for detecting temporal trends, with checklist submission rates correlating strongly with species accumulation (r = 0.89). The asymptotic approach of the species accumulation curve by 2025 suggests that comprehensive coverage of the region's avifauna has been achieved, validating citizen science as a cost-effective monitoring tool for South Asian biodiversity (Kittelberger et al., 2023; Kocaman & Arslan, 2023). However, spatial bias toward accessible locations (Central University of Haryana, Dhosi Hills) necessitates caution in inferring landscape-scale patterns (Fink et al., 2020; Walker & Taylor, 2020).

The integration of machine learning approaches for species classification, as demonstrated by Mutlu et al. (2022) and Alswaitti et al. (2022), offers potential for automated validation of citizen science records. Future monitoring programs in Mahendragarh could leverage acoustic

monitoring (Wang et al., 2022) and camera traps to complement observer-based surveys, particularly for cryptic nocturnal species underrepresented in the current dataset.

4.4 Conservation and Management Implications

The climate sensitivity of Mahendragarh's avian communities necessitates adaptive management strategies that account for dynamic habitat requirements. The "climate refugia" concept, emphasizing the protection of topographically diverse areas that buffer extreme weather events, applies directly to the Aravalli hills within the study region (Hole et al., 2009; Bagchi et al., 2013). The documented persistence of arid specialists and range-restricted species (White-naped Tit) in thorn-scrub habitats underscores the conservation value of protecting scrubland ecosystems often dismissed as "degraded" (Şekercioğlu et al., 2011).

Wetland conservation requires particular attention given the high temporal variability in waterbird communities. The creation and maintenance of artificial wetlands, including irrigation reservoirs and village ponds, provides critical habitat during dry periods (Moudrý & Šímová, 2013). However, the quality of these habitats depends on water level management and vegetation structure; excessive disturbance or pollution can negate their conservation value (Atıcı, 2022; Mert et al., 2025).

The declining detection of scavenging raptors (Egyptian Vulture, Cinereous Vulture) aligns with broader South Asian trends driven by diclofenac poisoning and habitat loss (Acarer, 2024; Oppel et al., 2021). These species' low detection rates in Mahendragarh, despite suitable rocky nesting habitat, suggest that regional populations may be approaching local extinction. Targeted surveys using road transects and carcass monitoring are urgently needed to assess their conservation status.

4.5 Methodological Considerations

This study's reliance on presence-only citizen science data limits inferences about population trends and abundance changes (Johnston et al., 2020). The use of "effort-corrected" metrics (checklist counts, observer hours) partially addresses detection bias, but spatial and temporal variation in observer behavior remains a concern (Horns et al., 2018; Neate-Clegg et al., 2020). The application of occupancy modeling frameworks (Kellenberger et al., 2021) would improve estimates of species-specific detection probabilities and colonization-extinction dynamics.

Climate variable selection focused on temperature and precipitation anomalies, following standard practice in species distribution modeling (Rousseau & Betts, 2022). However, extreme weather events (heatwaves, unseasonal rainfall) may exert stronger impacts on avian communities than mean climate shifts (Özkazanç & Özay, 2019). The incorporation of climate variability indices and extreme event frequencies would enhance predictive capacity (Taşoğlu et al., 2024).

The categorization of migratory status relied on regional expertise and eBird observations, but individual species exhibit phenotypic plasticity in migration strategies (Moss, 2015). Partial migration, where populations contain both resident and migratory individuals, complicates classification and may obscure climate responses (Knudsen et al., 2011). Stable isotope analysis and geolocator tracking, applied to Turkish populations (Kaya, 2015; Per et al., 2016), would clarify migratory connectivity for key species.

5. Conclusions

This study provides the first quantitative assessment of temporal change in avian species composition for the Mahendragarh region, demonstrating significant climate-driven dynamics over a 5-year period. Key findings include: (1) high interannual variability in species richness driven by precipitation fluctuations, particularly for wetland-dependent taxa; (2) divergent responses between arid specialists (stable) and wetland species (variable); (3) significant phenological delays in Palearctic migrant arrival; and (4) evidence of range expansions for thorn-scrub species alongside declines in large raptors.

These results highlight the vulnerability of semi-arid agro-ecosystems to climate variability and the necessity of adaptive conservation strategies. The protection of topographic refugia (Aravalli hills), maintenance of wetland networks, and monitoring of climate-sensitive indicator species emerge as priority actions. Citizen science platforms such as eBird provide scalable monitoring frameworks, but require integration with targeted surveys for threatened species and mechanistic studies of climate impacts.

Future research should focus on: (1) long-term population monitoring using standardized protocols; (2) experimental assessments of climate adaptation mechanisms; (3) landscape connectivity modeling for range-shifting species; and (4) community-based conservation initiatives that align local livelihoods with biodiversity protection. The Mahendragarh region, representative of threatened semi-arid ecosystems across South Asia, offers a critical window into avian responses to global change and the opportunity to develop transferable conservation solutions.

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