

Long-Term Assessment of Wetland Health through Avifaunal Responses to Climate Variability in Selected Wetlands of Tamil Nadu (2013–2020): Implications for Sustainable Development Goals (SDGs) 6, 13, 14 and 15

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Abstract

Wetlands are critical habitats for resident and migratory birds and are sensitive to changes in water availability, habitat condition and climatic variability, making avifaunal responses a valuable proxy for assessing overall wetland health. This study used long-term (2013–2020) avifaunal diversity and abundance as indicators of wetland health across four ecologically contrasting Tamil Nadu wetlands which are Pallikaranai Marshland (urban), Vedanthangal Bird Sanctuary (freshwater breeding colony), Karaivetti Bird Sanctuary (inland freshwater) and Point Calimere Wildlife and Bird Sanctuary (coastal) in relation to temperature and rainfall. All four sites showed positive long-term trends, but abundance patterns and climatic sensitivity were markedly site-specific: Vedanthangal sustained consistently high counts, Point Calimere showed pronounced migration-driven inter-annual fluctuation, Karaivetti increased gradually, and Pallikaranai remained persistently low. Temperature showed limited variation and weak predictive value for bird abundance at all sites, while rainfall showed complex, often lagged, site-specific relationships. The results indicate that wetland habitat characteristics and hydrology, together with climatic variability, jointly govern avifaunal abundance and, by extension, wetland health, and that long-term multi-site monitoring is essential for effective wetland bird conservation in Tamil Nadu. These findings carry direct implications for the Sustainable Development Goals, informing water-related ecosystem protection under SDG 6, climate-responsive monitoring under SDG 13, coastal and marine-linked habitat conservation under SDG 14, and terrestrial and freshwater biodiversity protection under SDG 15.

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INTRODUCTION

Wetlands remain permanently or seasonally saturated with water and provide essential feeding, breeding, nesting and wintering habitats for resident and migratory [1]. Bird abundance and diversity are shaped by water availability, vegetation structure, food resources and hydrological conditions, and are increasingly affected by anthropogenic pressures such as urbanisation, pollution and habitat fragmentation

as well as by climatic variability in rainfall and temperature [2]. Because changes in avian distribution and abundance reflect changes in habitat quality, birds are widely used as bioindicators of wetland ecological health, and appropriate restoration and management can improve conditions for waterbirds [3]. Wetland degradation and loss have become major global biodiversity concerns, with changes in hydrology, land use and habitat condition directly affecting freshwater and wetland-dependent species [4].

Tamil Nadu supports several ecologically important wetlands; however, this study assesses Pallikaranai Marshland, Vedanthangal Bird Sanctuary, Karaivetti Bird Sanctuary and Point Calimere Wildlife and Bird Sanctuary that differ in habitat type, geographical setting and anthropogenic influence [5]. While individual wetlands have been studied, comparative long-term assessments across contrasting Tamil Nadu wetlands remain limited. Recent studies from Tamil Nadu have also documented relationships between urbanisation, land-use change, water quality and avian fauna, particularly in Pallikaranai Marshland [6]. This study addresses that gap by evaluating long-term (2013–2020) trends in avifaunal diversity and abundance across the four wetlands in relation to temperature and rainfall, to identify key species groups, migratory patterns and site-specific climatic responses relevant to wetland biodiversity monitoring and conservation [7].

Long-term avifaunal monitoring of this kind also carries direct relevance for global sustainability commitments. Because bird abundance is closely tied to water availability and quality, hydrological condition and habitat integrity, avifaunal trends serve as an accessible proxy for wetland health that peaks to SDG 6 (Clean Water and Sanitation), particularly its targets on protecting and restoring water-related ecosystems [8]. Because rainfall and temperature variability directly influence habitat suitability and species movement, the same data inform SDG 13 (Climate Action) by documenting biological responses to climatic variability [2]. The inclusion of a coastal wetland (Point Calimere), where mudflat exposure and nearshore productivity govern bird abundance, links the assessment to SDG 14 (Life Below Water), while the freshwater and terrestrial wetlands (Vedanthangal, Karaivetti and Pallikaranai) connect it to SDG 15 (Life on Land) through habitat and biodiversity protection [2, 4]. This study accordingly frames its long-term assessment of avifaunal diversity and abundance as a contribution to both wetland biodiversity monitoring and the achievement of these interconnected SDGs [9].

MATERIALS AND METHODS

The study was conducted across four ecologically distinct wetlands of Tamil Nadu. Pallikaranai Marshland (Chennai district) is a degraded urban wetland under considerable anthropogenic pressure [10]. Vedanthangal Bird Sanctuary (Chengalpattu district) is a shallow freshwater tank and one of South Asia's major waterbird breeding colonies. Karaivetti Bird Sanctuary (Ariyalur district) is an inland, monsoon-fed freshwater wetland on the Central Asian Flyway. Point Calimere Wildlife and Bird Sanctuary (Kodikkarai, Nagapattinam district) is a coastal wetland complex important for migratory waterbirds [11].

Monthly bird census data (2013–2020) were obtained from the Tamil Nadu Forest Department, supplemented with published literature and field observations, and compared with concurrent mean monthly temperature and total monthly rainfall from associated meteorological stations [12]. Annual averages were derived from monthly records for each site and variable, and bird abundance was examined against temperature and rainfall to identify temporal and site-specific patterns [13].

RESULTS

Pallikaranai Marsh, Chennai District

Pallikaranai recorded the lowest bird counts of the four sites, rising from 8.7 individuals in 2013 to a peak of 15.3 in 2019, a trend plausibly linked to conservation measures following the site's 2002 Ramsar designation. Moderate-rainfall years (2018–2019) coincided with the highest counts, whereas the wettest year (2014, 86.6 mm) showed little change from baseline, suggesting temporary flooding

of feeding grounds suppresses counts (Table-1). Temperatures were marginally higher than at other sites (29.5–30.5°C), consistent with an urban heat-island effect (Figure-1).

Vedanthangal Bird Sanctuary, Chengalpattu District

Vedanthangal showed the most consistently high counts of all sites, rising from 238.9 individuals in 2013 to a peak of 764.8 in 2018 before stabilising near 475–483 in 2019–2020 (Table 2). Peak counts were not associated with high rainfall (2018: 41.6 mm), indicating that colony fidelity and nesting-habitat availability, rather than annual rainfall, primarily drive abundance at this breeding colony (Figure-2).

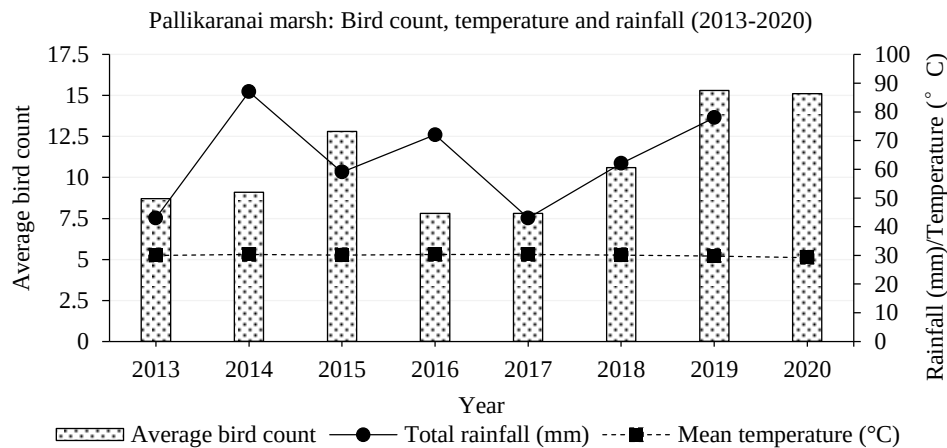


Figure 1. Bird Count, Mean Temperature and Total Rainfall — Pallikaranai Marsh, 2013–2020.

Table 1. Annual Average Bird Count, Mean Temperature and Total Rainfall — Pallikaranai Marsh, 2013–2020.

Year	Avg. Bird Count	Mean Temp. (°C)	Total Rainfall (mm)
2013	8.7	30.2	43.5
2014	9.1	30.5	86.6
2015	12.8	30.3	58.6
2016	7.8	30.5	72.1
2017	7.8	30.5	43.8
2018	10.6	30.3	62.4
2019	15.3	30	77.9
2020	15.1	29.5	—

Source: Pallikaranai Marsh Bird Census Records; IMD Station Data. 2020 rainfall incomplete.

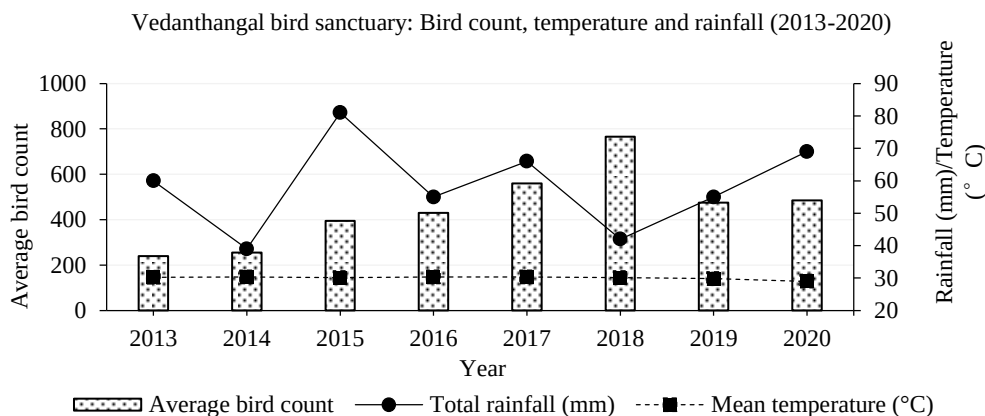


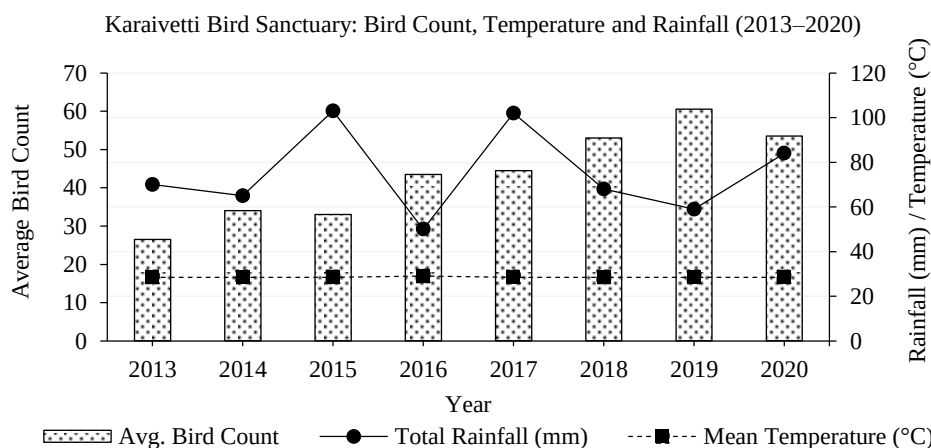
Figure 2. Bird Count, Mean Temperature and Total Rainfall — Vedanthangal Bird Sanctuary, 2013–2020**Karaivetti Bird Sanctuary, Ariyalur District**

Karaivetti displayed a gradual, near-monotonic increase from 26.5 individuals in 2013 to 60.8 in 2019, followed by a slight decline to 53.6 in 2020, consistent with progressive habitat improvement rather than migratory flux (Table-3). High-rainfall years (2015, 2017; >104 mm) coincided with stagnating counts, while lower-rainfall years supported continued increases consistent with reduced water depth improving shallow-water foraging conditions for wading species (Figure-3).

Table 2. Annual Average Bird Count, Mean Temperature and Total Rainfall — Vedanthangal Bird Sanctuary, 2013–2020.

Year	Avg. Bird Count	Mean Temp. (°C)	Total Rainfall (mm)
2013	238.9	30.5	59.6
2014	256.6	30.6	38.6
2015	396.8	30.4	80.8
2016	434.1	30.6	54.8
2017	558.8	30.6	66.1
2018	764.8	30.4	41.6
2019	474.1	30.2	54.4
2020	483	29.6	69.3

Source: Vedanthangal Bird Sanctuary Census Records; IMD Station Data.

**Figure 3.** Bird Count, Mean Temperature and Total Rainfall — Karaivetti Bird Sanctuary, 2013–2020**Table 3.** Annual Average Bird Count, Mean Temperature and Total Rainfall — Karaivetti Bird Sanctuary, 2013–2020.

Year	Avg. Bird Count	Mean Temp. (°C)	Total Rainfall (mm)
2013	26.5	29.3	69.4
2014	34.08	29.1	64.1
2015	32.83	29.4	104.7
2016	43.5	29.5	49.3
2017	44.25	29.3	104.1
2018	52.92	29.1	67.8
2019	60.75	29.1	59.2

2020	53.58	29	84
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Source: Karaivetti Bird Sanctuary Census Records; IMD Station Data.

Point Calimere Wildlife Sanctuary (Kodikkarai), Nagapattinam District

Point Calimere showed the greatest inter-annual variability of all sites, ranging from 28.6 individuals in 2017 to 2,514.8 in 2019 an approximately 88-fold range reflecting dependence on long-distance migratory species whose visitation is governed by remote breeding success and flyway conditions as well as local factors (Table 4). Mean temperature remained stable (29.0–29.5°C), reflecting coastal moderation, while the two highest-count years (2018–2019) followed average-to-below-average rainfall, suggesting reduced rainfall increases mudflat exposure and prey availability for foraging birds (Figure-4).

Cross-Site Comparison

All four sites showed net positive trends over 2013–2020, from a marginal increase at Pallikaranai to multi-fold increases at Point Calimere and Vedanthangal, suggesting a shared regional influence of conservation and management effort (Table-5). Temperature had low predictive power at all sites owing to its narrow variation (mostly <1°C), well within birds' thermal tolerance. Rainfall showed more complex, often lagged, site-specific relationships generally negative at Point Calimere and Pallikaranai, and linked to prior-year hydrology at Karaivetti and Vedanthangal. Absolute abundance differences among sites reflected habitat area, quality and protection status rather than climate; Pallikaranai's persistently low numbers, despite ecological potential, point to anthropogenic habitat degradation as the dominant constraint (Figure-5).

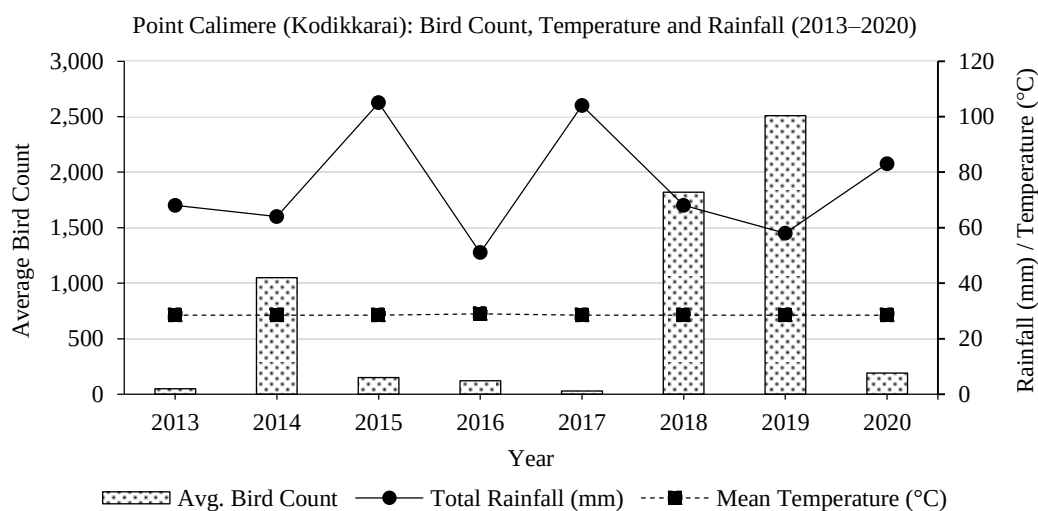


Figure 4. Bird Count, Mean Temperature and Total Rainfall — Point Calimere (Kodikkarai), 2013–2020.

Table 4. Annual Average Bird Count, Mean Temperature and Total Rainfall — Point Calimere (Kodikkarai), 2013–2020.

Year	Avg. Bird Count	Mean Temp. (°C)	Total Rainfall (mm)
2013	53.3	29.43	67.15
2014	1055.4	29.09	64.13
2015	148.4	29.4	104.7
2016	122.3	29.52	49.31
2017	28.6	29.33	104.1
2018	1825.6	29.12	67.81

2019	2514.8	29.13	59.2
2020	196.1	29	83.95

Source: Point Calimere Bird Census Records; IMD Station Data.

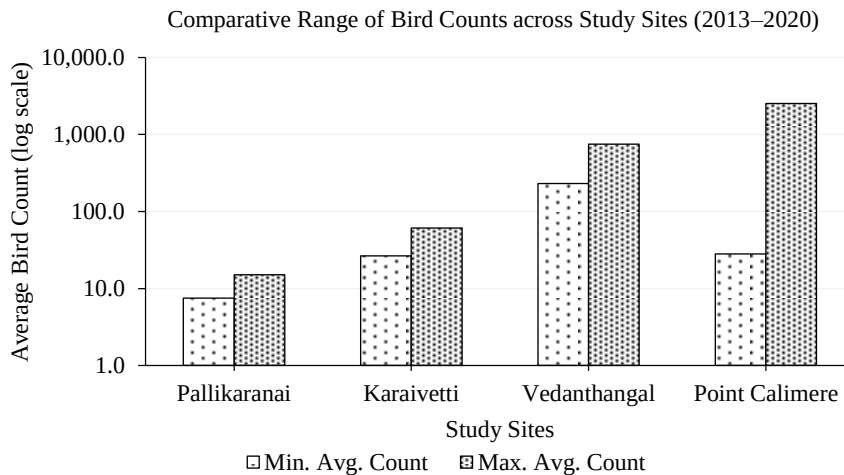


Figure 5. Comparative Range of Bird Counts across the Four Study Sites, 2013–2020

Table 5. Comparative Summary of Bird Count Trends across the Four Study Sites, 2013–2020.

Study Region	Min. Avg. Count	Max. Avg. Count	Peak Year	Overall Trend
Point Calimere	28.6	2,514.8	2019	Strongly positive
Karaivetti	26.5	60.8	2019	Gradually positive
Vedanthangal	238.9	764.8	2018	Strongly positive
Pallikaranai	7.8	15.3	2019	Marginally positive

Trend classifications based on linear regression slope, 2013–2020; counts are annual averages of monthly census records.

DISCUSSION

Avian responses to climatic variability were strongly site- and habitat-type dependent. Stable breeding conditions sustained high abundance at Vedanthangal; migratory dynamics drove volatility at Point Calimere; gradual habitat recovery explains the Karaivetti trend; and anthropogenic pressure constrained Pallikaranai despite its ecological potential [14]. Temperature's limited variability gave it little explanatory power at any site, whereas rainfall's influence appeared mediated by wetland hydrology, water depth, mudflat exposure and food availability rather than acting through a uniform direct effect [15]. These findings support interpreting climatic variables alongside local habitat and hydrological conditions, and underline the value of combining long-term, multi-site avifaunal monitoring with climatic and hydrological data to guide wetland conservation priorities [16].

Implications for Sustainable Development Goals (SDGs 6, 13, 14 and 15)

The site-specific patterns documented here map onto several Sustainable Development Goals. Wetland hydrology and water availability the strongest drivers of bird abundance at Karaivetti, Vedanthangal and Point Calimere are central to SDG 6 (Clean Water and Sanitation), underscoring the value of avifaunal monitoring as a low-cost indicator of water-related ecosystem condition [17]. The muted influence of temperature and the pronounced, often lagged rainfall effects observed across sites illustrate how climatic variability propagates through wetland systems to affect biodiversity, supporting the case for incorporating long-term avifaunal datasets into climate vulnerability assessments under SDG 13 (Climate Action) [18]. At Point Calimere, migration-driven fluctuations tied to mudflat exposure and coastal productivity connect wetland bird monitoring to the health of adjoining nearshore and coastal habitats, relevant to SDG 14 (Life Below Water). Finally, the persistently low abundance at Pallikaranai despite its 2002 Ramsar designation, contrasted with the

recovery trajectories at Karaivetti and Vedanthangal, highlights the role of habitat protection and restoration in sustaining terrestrial and freshwater biodiversity under SDG 15 (Life on Land) [19]. Taken together, these findings suggest that long-term, multi-site avifaunal monitoring can serve as a practical tool for tracking progress on interlinked water, climate and biodiversity targets in Tamil Nadu's wetlands [20-25].

CONCLUSION

This study demonstrates substantial spatial and temporal variation in avifaunal abundance across four contrasting Tamil Nadu wetlands over 2013–2020. Vedanthangal sustained high, stable abundance; Point Calimere showed strong migration-driven fluctuation; Karaivetti increased gradually; and Pallikaranai remained consistently low. Temperature exerted limited influence on abundance, while rainfall effects were site-specific and often lagged. Continued long-term monitoring, together with habitat protection and restoration particularly at Pallikaranai is essential to sustain wetland bird diversity in Tamil Nadu. By linking avifaunal trends to wetland hydrology and climatic variability, these findings also contribute evidence relevant to SDG 6, SDG 13, SDG 14 and SDG 15, supporting integrated water, climate and biodiversity management in Tamil Nadu's wetlands.

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