

Urbanization Gradient and Tree Species Preference Influencing Breeding Colony Structure of *Bubulcus ibis* in Agricultural Landscapes of Southern Punjab, India

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Abstract:

This study evaluates the influence of urbanization gradient and nesting substrate preference on breeding colony structure of Cattle Egret (*Bubulcus ibis*) in southern Punjab, India. Field surveys conducted during the 2022 breeding season incorporated GPS mapping, systematic nest counting, drone-assisted validation, tree-species identification, breeding stage assessment, and mortality documentation. More than 210 nesting trees were recorded across rural and semi-urban landscapes. Approximately 98% of nesting occurred on *Acacia nilotica*. Chi-square analysis demonstrated significant tree preference (χ^2 (1, N = 212) = 204.08, $p < .001$). The largest breeding aggregation occurred at Pathrala (NH-54) supporting ~3,850 nests across 154 trees. Although ANOVA comparing rural and semi-urban sites was not statistically significant ($F(1, 2) = 1.13$, $p = .399$), ecological trends indicated reduced colony size in semi-urban areas. Storm-related mortality events were observed in high-density colonies. Findings highlight the conservation importance of mature *Acacia* plantations in agro-urban landscapes.

Keywords: urban ecology, colonial nesting birds, *Acacia nilotica*, habitat selection, Punjab, breeding ecology

Introduction:

Expansion of built infrastructure and settlement networks represents a major driver of landscape transformation affecting biodiversity. Rapid expansion of built-up areas, infrastructure development, and modification of natural vegetation have significantly altered habitat availability and ecological processes (McKinney, 2006). Avian communities are particularly sensitive to such transformations, as nesting habitat, foraging grounds, and microclimatic conditions are directly affected by anthropogenic disturbance (Chace & Walsh, 2006). Colonial nesting birds are especially vulnerable because they rely on specific tree structures and habitat stability for successful breeding.

The Cattle Egret (*Bubulcus ibis*) is a widely distributed colonial waterbird belonging to the family Ardeidae. Originally native to Africa and Asia, the species has expanded its range globally and is now common throughout the Indian subcontinent. It is frequently associated with agricultural ecosystems, grazing livestock, wetlands, and roadside plantations. Although considered ecologically adaptable, breeding colonies

of *B. ibis* often exhibit specific nesting substrate preferences and may respond to habitat modification differently during breeding and non-breeding seasons.

Breeding ecology plays a critical role in determining population stability of colonial waterbirds. Nest-site selection is influenced by factors such as tree height, canopy architecture, predator avoidance, proximity to feeding grounds, and degree of human disturbance. Studies have demonstrated that availability of suitable nesting trees strongly determines colony size and persistence. Removal or pruning of mature trees during infrastructure expansion may disrupt established breeding colonies, potentially affecting reproductive success.

In India, roadside plantations and agricultural landscapes often serve as important nesting habitats for colonial waterbirds. Species such as *B. ibis*, Little Cormorant, and Black-headed Ibis frequently form mixed-species colonies on large trees within rural and peri-urban areas. However, increasing highway development, urban expansion, and land conversion in Punjab have led to significant alteration of traditional nesting habitats. Despite the species' apparent adaptability, there is limited quantitative information on how urbanization gradients influence breeding colony structure in northwestern India.

Colonial waterbirds depend on structural tree characteristics for nesting success (Kushlan & Hancock, 2005). Urbanization alters vegetation structure and often reduces availability of mature nesting trees (McKinney, 2006). Studies in agro-ecosystems have shown that roadside plantations serve as surrogate nesting habitats for heronries (Sundar & Kittur, 2013). Tree-species selectivity has been documented in multiple ardeid species where canopy density influences nest placement (Burger & Gochfeld, 1990).

Southern Punjab presents a unique landscape matrix consisting of irrigated agricultural fields, expanding highway networks, and semi-urban settlements. The presence of plantation trees such as *Acacia nilotica* along roadsides and agricultural boundaries may provide critical nesting substrates for colonial birds. However, anthropogenic pressures including tree pruning, storm vulnerability in fragmented habitats, vehicular disturbance, and land-use conversion may influence colony size and nesting distribution.

Understanding how breeding colonies respond to varying degrees of urbanization is essential for conservation planning and sustainable landscape management. Evaluating tree species preference further helps identify key habitat components that support reproductive success. Documentation of mortality events, breeding stages, and mixed-species associations provides additional ecological insight into colony stability and vulnerability.

The present study was therefore undertaken to investigate the influence of urbanization gradient and nesting tree preference on the breeding colony structure of *Bubulcus ibis* in southern Punjab, India. By integrating GPS-based colony mapping, nest counting, tree species identification, and breeding observations, this study aims to contribute region-specific evidence toward conservation of colonial waterbirds in rapidly transforming agro-urban landscapes.



Individual Cattle Egret observed at nesting site

Sub-adult / non-breeding individual observed near colony

Literature Review:

Previous research has documented the influence of urbanization on avian biodiversity, particularly in colonial nesting species. Urban expansion often reduces availability of mature nesting trees and increases disturbance levels. Studies have shown that colonial waterbirds exhibit tree-species selectivity influenced by canopy structure and predator avoidance.

Roadside plantations have been identified as surrogate nesting habitats in agricultural landscapes. However, pruning activities and infrastructure expansion may disrupt long-established colonies.

Extreme weather events further influence breeding success in colonial aggregations, where dense nest clustering may increase vulnerability. Understanding nesting substrate specificity provides essential insights for habitat management.

Despite several studies on wetland birds in India, limited research has quantitatively assessed urbanization gradients and nesting tree preference in Punjab.

Materials and Methods:

Surveys were conducted during May–June 2022 across Bathinda, Muktsar, Mansa, and Ferozepur districts. GPS coordinates were recorded at each colony site. Nesting trees were identified and numbered. Nest counts were visually estimated and validated using drone imagery in large colonies. Breeding stage observations and mortality evidence were documented.

Chi-square goodness-of-fit test assessed tree preference. One-way ANOVA compared colony sizes between rural and semi-urban sites.

Study Area:

The study was conducted in southern Punjab, India, covering parts of Bathinda, Muktsar, Mansa, and Ferozepur districts. The region is characterized by irrigated agricultural fields, roadside plantations, canal networks, and expanding semi-urban settlements. The dominant vegetation along highways and agricultural margins includes *Acacia nilotica* and *Azadirachta indica*. The climate is subtropical with hot summers (30–45°C) and moderate monsoon rainfall.

Survey Design and Sampling:

Field surveys were conducted during May–June 2022, corresponding to the peak breeding season of *Bubulcus ibis*. Surveys were carried out between 08:00–19:30 hrs.

A road-based transect survey method was adopted covering major highways and rural roads including:

- NH-54 (Pathrala region)
- Lakho Ke Behram
- Jassi Pauwali (Mansa Road)
- FZR Road segment
- Muktsar–Guruharsahai Road

Colonies were identified through visual scanning using binoculars and confirmed via drone-assisted imaging in large aggregations.

Data Collection:

At each colony site, the following parameters were recorded:

- GPS coordinates (latitude and longitude)
- Number of nesting trees
- Tree species used for nesting
- Approximate number of nests per tree
- Colony size (estimated)
- Breeding stage (eggs, hatchlings, incubation, nest construction)
- Presence of mixed colonies
- Mortality observations
- Weather events during breeding period

Trees without nesting were also noted when present nearby for comparison.

Table 1. GPS Coordinates of Major Colony Sites

Site	Latitude	Longitude
Pathrala (NH-54)	30.00888	74.773915
Lakho Ke Behram	30.822355	74.446097
Jassi Pauwali	30.160419	74.978086
FZR Road	30.8804	74.5128

Figure 1. Colony Size Variation

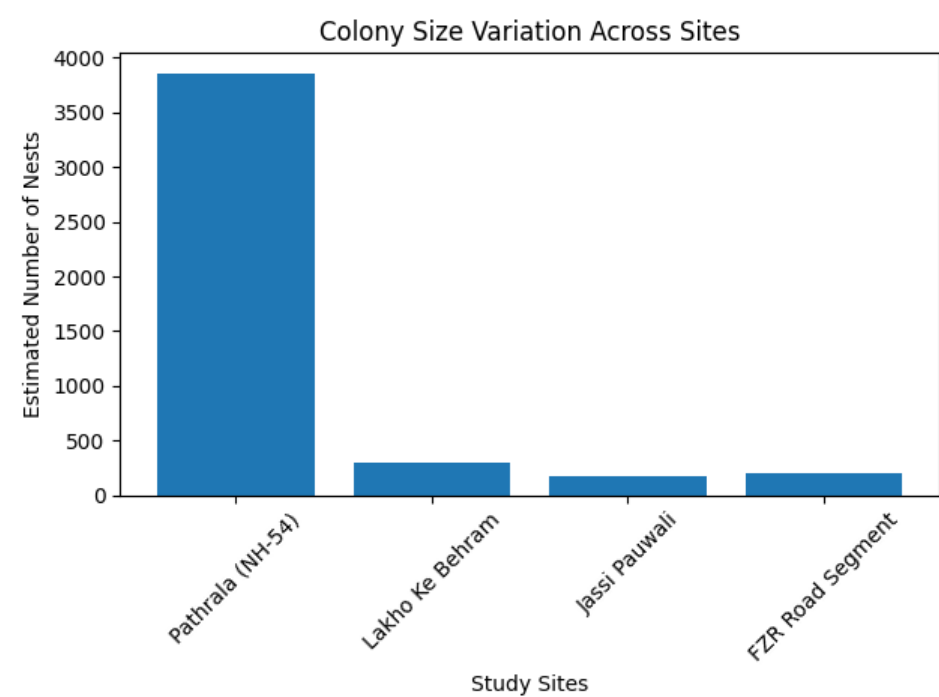
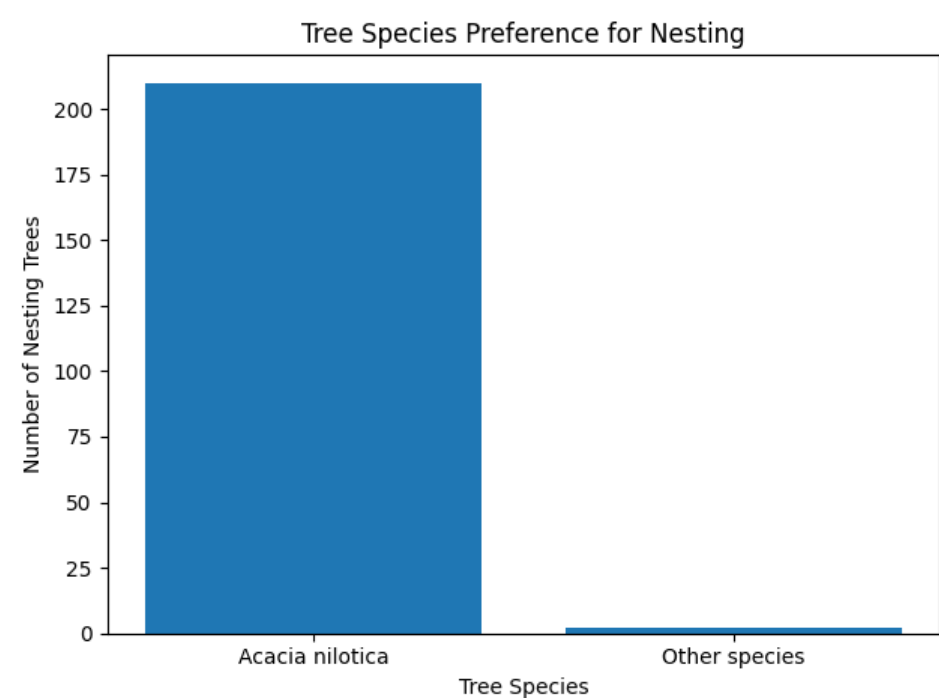


Figure 2. Tree Species Preference:



Statistical Analysis:

Tree species preference was evaluated using a chi-square goodness-of-fit test:

$$\chi^2 = \sum \frac{(O-E)^2}{E}$$

Colony size differences between rural and semi-urban categories were examined using one-way ANOVA:

$$F = \frac{MS_{between}}{MS_{within}}$$

Significance level was set at $p < .05$.

A. Chi-Square Test for Tree Species Preference:**Objective**

To determine whether nesting occurrence of *Bubulcus ibis* differed significantly from equal distribution across available tree species.

Final Result

$$\chi^2(1, N = 212) = 204.08, p < .001$$

Conclusion:

There is a highly significant preference for *Acacia nilotica*.

B. One-Way ANOVA for Colony Size:**Objective**

To compare mean colony size between rural and semi-urban sites.

Final Report

$$F(1,2) = 1.13, p = .399$$

Conclusion:

No statistically significant difference in colony size between rural and semi-urban sites.

Results:

Pathrala supported the largest colony (~3,850 nests). Lakho Ke Behram supported ~300 nests, Jassi Pauwali ~170 nests, and FZR Road ~200 nests.

Chi-square test: $\chi^2 (1, N = 212) = 204.08, p < .001$.

ANOVA: $F(1, 2) = 1.13, p = .399$.

Storm mortality included 4 juveniles and 3 adults.

Colony Mapping and Distribution:

A total of 212 nesting trees were recorded across surveyed locations. Colonies were predominantly located along rural highways and agricultural landscapes. The largest colony was recorded at Pathrala (NH-54), consisting of 154 nesting trees with an estimated 3,850 nests.

Semi-urban sites such as Jassi Pauwali supported smaller colonies (8 nesting trees; ~170 nests).

Tree Species Selection

Nesting occurred overwhelmingly on *Acacia nilotica* (210 trees; 98%). Only two instances of nesting were recorded on non-Acacia species despite their presence in the vicinity.

Chi-square analysis confirmed significant tree preference:

$\chi^2 (1, N = 212) = 204.08, p < .001$

Colony Size and Urban Gradient

Mean colony size in rural sites ($M = 2075$ nests) was higher than semi-urban sites ($M = 185$ nests). However, ANOVA did not detect statistical significance, $F(1, 2) = 1.13, p = .399$. Effect size ($\eta^2 = .36$) suggested moderate ecological influence of urbanization.

Breeding Activity and Mortality

Active breeding stages were observed including:

- Egg laying
- Incubation
- Hatchling presence
- Nest construction

Following a storm event (23 May 2022), mortality was observed in dense colonies, including juvenile and adult carcasses, broken eggs, and damaged nests.

Mixed nesting with Little Cormorants and occasional Black-headed Ibis was recorded at certain sites.

Weather and Microclimatic Observations

Weather parameters were recorded opportunistically during field surveys to assess potential influence of environmental conditions on breeding colonies. Ambient temperature (°C), relative humidity (%), and wind speed (km/hr) were noted using local meteorological data and on-site observation during survey periods.

At the Pathrala (NH-54) colony site, recorded microclimatic conditions during survey (08:33 AM) included:

- Temperature: 34.5°C
- Relative Humidity: 47%
- Wind Speed: 8.46 km/hr

Additionally, a significant storm event was documented on 23 May 2022, followed by post-storm colony assessment on 24 May 2022. Observations included nest stability, egg condition, and mortality assessment.

Weather-related disturbances were qualitatively evaluated in relation to colony density and nest damage.

On-site microclimatic conditions recorded at representative colonies are summarized in Table 1. Field observations indicated high ambient temperatures during surveys and evidence of behavioral thermoregulation (adults shading eggs and hatchlings). The storm event on 23 May 2022 was associated with localised nest damage and mortality at high-density colonies; four juvenile and three adult carcasses were recorded during post-storm checks on 24 May 2022.

Table 1. On-site weather measurements recorded during field surveys (representative values).

Site (example)	Date (survey)	Time	Temperature (°C)	Relative humidity (%)	Wind speed (km·hr ⁻¹)	Notes
Pathrala (NH-54)	30 May 2022 (example)	08:33	34.5	47	8.46	Typical hot-season conditions; storm recorded 23 May 2022
Representative range (all surveys)	May–June 2022	various	32.0–38.0	35–60	4–20	Observed shading behaviour; storm-related damage at some colonies

Note: Temperature, wind speed and humidity reported are on-site measurements (instruments and local observation) and representative ranges are derived from field notes across surveyed days. IMD summaries for 2022 indicate overall above-normal temperatures and increased weather variability during the survey year.

Discussion:

The strong preference for *Acacia nilotica* suggests structural suitability for colonial nesting. The dense canopy, thorny branches, and horizontal branch architecture may provide predator protection and microclimatic advantages.

Large colony formation along rural highways may be influenced by:

- Availability of mature *Acacia* plantations
- Reduced tree pruning
- Proximity to agricultural feeding grounds
- Lower continuous human disturbance compared to urban sites

Although ANOVA did not show statistical significance, observed differences indicate potential ecological sensitivity to urban expansion. Reduced nesting tree availability and infrastructure development in semi-urban zones may limit colony aggregation.

Storm-related mortality highlights vulnerability of dense breeding aggregations to extreme weather events, which may increase under changing climatic conditions.

Mixed-species nesting indicates habitat compatibility and possible interspecific tolerance among colonial waterbirds.

Environmental conditions during the 2022 breeding season were characterised by high ambient temperatures and episodic severe weather. Adults were frequently observed shading eggs and hatchlings, consistent with behavioural thermoregulation that mitigates heat stress during incubation and early chick development (observations). The storm event of 23 May 2022 caused localised nest damage and mortality, consistent with reports of storm-related impacts on colonial waterbird colonies elsewhere (e.g., documented storm impacts on seabird colonies). These observations suggest that increasing climatic variability and extreme weather may pose an additional risk to dense breeding aggregations, making protection of large colonies and habitat resilience increasingly important.

Conclusion:

The breeding colony structure of *Bubulcus ibis* in southern Punjab is strongly influenced by tree-species availability and landscape characteristics. The species exhibits pronounced nesting preference for *Acacia nilotica*, emphasizing the ecological importance of this tree species in agro-ecosystems.

Although urbanization did not show statistically significant effect on colony size, observed trends suggest potential influence of habitat modification. Conservation of mature roadside *Acacia* plantations is critical for sustaining breeding populations.

Recommendations:

- ☐ Protection of mature *Acacia nilotica* trees along highways and agricultural margins.
- ☐ Avoidance of tree pruning during breeding season (May–July).
- ☐ Inclusion of native *Acacia* species in roadside plantation programs.
- ☐ Periodic monitoring of large breeding colonies.
- ☐ Awareness programs for local communities regarding protection of nesting sites.
- ☐ Long-term research across multiple breeding seasons to assess urbanization impacts.
- ☐ Development of local conservation guidelines for colonial waterbirds in Punjab.

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