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Comparative Behavioral Thermoregulation in *Acridotheres tristis, Passer domesticus,* and *Corvus splendens* During Autumn to Early Winter in Swat, KPK, Pakistan

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ABSTRACT

Behavioral thermoregulation is important for avian energy conservation, yet field studies on urban birds in Pakistan remain limited. **Objectives:** To compare thermoregulatory behavior among *Acridotheres tristis*, *Passer domesticus*, and *Corvus splendens* from autumn to early winter in Swat Valley, Pakistan. **Methods:** This is an observational study. Seventy-five focal observations (25 per species) were conducted between September and December 2025 in urban and semi-urban habitats. Data were analyzed in R 4.5.1 using ANOVA, chi-square, Fisher's Exact, Kruskal–Wallis tests, multinomial logistic regression and correlation analysis. **Results:** Ambient temperature did not differ significantly among species (ANOVA: $F_{2,72}$ = 0.048, p=0.953), nor did behavioral composition (Fisher's Exact Test: p=1.000). Movement activity differed significantly across day periods (χ^2 = 31.35, p<0.001) and sunlight conditions (χ^2 = 38.01, p<0.001). Ambient temperature varied significantly among movement categories (Kruskal–Wallis: χ^2 = 8.70, p=0.013), with high movement occurring under warmer temperatures. Multinomial logistic regression showed that increasing temperature significantly raised the likelihood of high and moderate movement, while partial sunlight strongly reduced high movement behavior. Behavioral composition was strongly associated with day period (Fisher's Exact: p<0.001) and sun exposure (χ^2 = 54.67, p<0.001). **Conclusions:** Behavioral thermoregulation in urban birds of Swat Valley was strongly associated with environmental conditions rather than species identity, highlighting flexible behavioral responses to seasonal thermal variation.

INTRODUCTION

Species distributions are strongly influenced by environmental gradients interacting with physiological characteristics of organisms [1, 2], and as climate change intensifies environmental extremes and temperature variability including winter cold spells [3-7], small birds in temperate regions face substantial thermoregulatory challenges requiring continuous physiological and behavioral adjustments to maintain stable body temperatures and survival [8, 9]. Many bird species exhibit metabolic flexibility through phenotypic plasticity [10, 11], enabling seasonal shifts in basal metabolic rate and thermogenic capacity as adaptive survival strategies [7, 12]. Small passerines in cold temperate environments enhance winter thermogenesis through increased cold tolerance and elevated summit metabolism, while insulation changes reduce thermoregulatory costs below the lower critical temperature [13-15]. Annual late-summer moult provides greater plumage insulation and body mass in autumn and winter [10, 16], though gains are constrained by negative effects on flight performance and predator avoidance [17, 18]. Rising temperatures increase total evaporative water loss, posing combined thermal and hydric challenges expected to intensify under climate change [19, 20], while behavioral adjustments including

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plumage fluffing, body orientation changes and wing drooping modify heat exchange, enabling small passerines to maintain stable core body temperatures despite seasonal feather wear [15, 21]. Bird thermoregulatory behavior may also be influenced by additional environmental variables such as relative humidity, wind speed, cloud cover, and substrate surface temperature, which alter heat exchange with the surroundings; however, their relative importance in urban bird communities remains insufficiently documented locally.

Despite the ecological importance of behavioral thermoregulation, quantitative field studies on how urban birds adjust their behavior to seasonal thermal variation remain limited in Pakistan, particularly in Swat Valley. The present study aimed to compare behavioral thermoregulation in *Acridotheres tristis*, *Passer domesticus*, and *Corvus splendens* during autumn to early winter in Swat Valley, and to evaluate the influence of temperature, sunlight exposure, and day period on behavioral activity and movement patterns.

METHODS

The observational study was conducted from 15 September to 23 December 2025 across urban and semi-urban habitats of Swat Valley, Khyber Pakhtunkhwa, Pakistan. Three synanthropic species were studied: *Acridotheres tristis*, *Passer domesticus*, and *Corvus splendens*, selected for their abundance in human-modified habitats and observable behavioral responses to environmental change. Focal animal sampling was conducted daily between 07:00 and 18:00 across morning, midday, and afternoon periods, yielding 75 independent observations (25 per species). Each 10-minute observation recorded dominant behavioral activity, movement intensity, body condition, sun exposure, and ambient temperature, with humidity, wind speed, and surface temperature unmeasured. Observations were conducted at varied locations and times to minimize repeated sampling, with no birds captured, marked, or manipulated, in compliance with standard ethical guidelines for non-invasive wildlife research.

All analyses were performed in R version 4.5.1 using RStudio. Descriptive statistics were calculated for all variables, with temperature summarized as mean ± SD. Normality and variance homogeneity were assessed using Shapiro-Wilk and Levene's tests. Species-level temperature differences were analyzed using one-way ANOVA (η^2), body condition comparisons using independent samples t-tests (Cohen's d), and movement category comparisons using Kruskal-Wallis tests with Dunn's post-hoc comparisons, Bonferroni correction, and eta squared. Associations among species identity, behavioral category, movement intensity, day period, and sun exposure were examined using Pearson's chi-square and Fisher's exact tests with Cramér's V as an effect size measure. Multinomial logistic regression with movement category as the response variable and temperature, day period, and sun exposure as predictors reported odds ratios, Wald z statistics, and VIF diagnostics. Spearman correlation with heatmap visualization evaluated associations among environmental and behavioral variables. Statistical significance was accepted at p<0.050 throughout.

RESULTS

A total of 75 independent focal observations were recorded across three urban-adapted species — *Acridotheres tristis*, *Corvus splendens* and *Passer domesticus* — with 25 observations per species, conducted across urban and semi-urban habitats of Swat Valley during autumn to early winter under varying thermal and sunlight conditions. Ambient temperatures were similar among species: mean temperature was 14.4 ± 5.39 °C for both *A. tristis* and *C. splendens*, and 14.8 ± 4.97 °C for *P. domesticus*, with comparable median temperatures (14–15 °C) and ranges (5–25 °C for *A. tristis* and *C. splendens*; 5–24 °C for P. domesticus). One-way ANOVA confirmed no significant difference in ambient temperature among species ($F_{2, 72}$ = 0.048, p = 0.953; η^2 = 0.001), indicating that all three species were observed under broadly similar thermal conditions. Behavioural frequencies across species are presented (Figure 1).

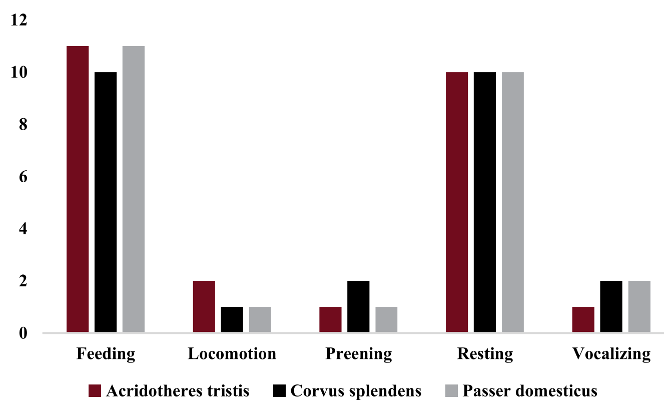

Figure 1: Behavioral Frequencies Across Species of *Acridotheres tristis, Corvus splendens*, and *Passer domesticus*

Feeding and resting were the most frequently observed behaviors across all species, while locomotion, preening and vocalizing occurred less frequently. Fisher's Exact Test showed no significant association between species identity and behavioral composition (p=1.000; Cramér's V = 0.00), suggesting broadly similar behavioral allocation among the three species. Movement activity varied significantly across daily periods, with high movement predominant in the morning and low movement strongly associated with the afternoon. Pearson's chi-square analysis confirmed a significant association between day

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period and movement activity (χ^2 = 31.35, df = 4, p<0.001; Cramér's V = 0.43), with standardized residuals showing overrepresentation of high movement in the morning and low movement in the afternoon. Sunlight conditions clearly shaped activity levels: high and moderate movement were far more common under full sunlight, while birds under partial sunlight tended toward low movement. This was confirmed by a strong, significant association between sun exposure and movement activity (χ^2 = 38.01, df = 2, p<0.001; Cramér's V = 0.70), with residual analysis identifying low movement as the behavior most strongly tied to partial sunlight. There were differences between movement categories in ambient temperature (Table 1).

Table 1: Ambient Temperature Across Movement Categories

Movement Category	Temperature (Mean ± SD)	χ^2	p-value
High	17.4 ± 1.62	8.70	0.013
Low	14.8 ± 5.98		
Moderate	12.8 ± 4.37		

High movement activity was observed in comparison with moderate movement activity under a comparatively lower temperature of (12.8 ± 4.37 °C). The data were not normally distributed, and therefore a Kruskal-Wallis test was used. The results of the analysis showed a significant difference between ambient temperature for the different categories of movement (χ^2 = 8.70, df. = 2, p=0.013, and the effect size (η^2 = 0.093). The Dunn's post hoc comparisons with Bonferroni correction indicated that the high movement activity occurred at significantly warmer temperatures than the moderate movement activity (adjusted p=0.010). There were no differences observed between the high and low movement categories or between the low and moderate movement categories (Table 2).

Table 2: Dunn's Post Hoc Comparisons for Ambient Temperature Across Movement Categories

Comparison	z-value	Adjusted p-value	Effect Size	Magnitude	Interpretation
High vs Low	-1.83	0.202	0.23	Small	Ambient temperature did not differ significantly between high and low movement categories
High vs Moderate	-2.92	0.010	0.48	Moderate	High movement activity occurred under significantly warmer temperatures than moderate movement
Low vs Moderate	-1.64	0.305	0.21	Small	Ambient temperature did not differ significantly between low and moderate movement categories

The temperatures of birds with fluffed plumage did not differ significantly from those with normal plumage. Independent samples t-test analysis showed no significant difference in ambient temperature between body-condition categories (t_{73} = 0.067, p=0.947), with a very small effect size (Cohen's d = 0.02), indicating little thermal differentiation between body-condition states. The ambient temperature related to body condition categories is reported (Table 3).

Table 3: Ambient Temperature Across Body Condition Categories

Body Conditions	Temperature (Mean ± SD)	Test statistic	p-value
Fluffed Plumage	14.60 ± 4.49	t=0.067	0.947
Normal Plumage	14.51 ± 5.45		

Behavioral composition varied strongly across daily periods, with most feeding observed in the morning and most resting in the afternoon. Fisher's Exact Test showed a highly significant association between day period and behavioral composition (p<0.001; Cramér's V = 0.52), with standardized residuals confirming strong representation of feeding in morning sessions and resting in afternoon sessions. Multinomial logistic regression analysis was performed to evaluate the effects of ambient temperature, day period, and sun exposure on movement activity. Variance inflation factor analysis showed no evidence of problematic multicollinearity among predictors. For high versus low movement activity, ambient temperature had a significant positive effect (Estimate = 1.37, OR = 3.94, p<0.001), while partial sunlight had a significant negative effect (Estimate = -13.16, OR = 0.000002, p<0.001), indicating that high activity was strongly associated with warmer temperatures and full sunlight conditions. For moderate versus low movement, ambient temperature also showed a significant positive association (Estimate = 0.64, OR = 1.90, p=0.008), while day period was not independently significant. Sun exposure distributions were identical across species, with no association detected between species identity and sun exposure (χ^2 = 0.00, df = 2, p=1.000; Cramér's V = 0.00) (Table 4).

Table 4: Multinomial Logistic Regression Predicting Movement Categories

Movement Comparison	Predictor	Estimate	Odds ratio	p-value	Interpretation
High vs Low	Temperature	1.37	3.94	<0.001	Higher temperatures increased the likelihood of high movement activity
High vs Low	Day period (Morning)	13.73	920622.00	0.726	Morning periods tended to favor high movement activity, but were not independently significant

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High vs Low	Sun exposure (Partial)	-13.16	0.000002	<0.001	Partial sunlight strongly reduced the likelihood of high movement activity
Moderate vs Low	Temperature	0.64	1.90	0.008	Warmer temperatures increased moderate movement activity
Moderate vs Low	Day period (Morning)	-5.14	0.006	0.865	No independent association detected
Moderate vs Low	Sun exposure (Partial)	-17.06	0.00000004	0.574	No statistically reliable independent effect detected

Behavioral categories differed markedly by sunlight condition, with feeding predominant under full sunlight and resting under partial sunlight. A very strong association was found between behavioral category and sun exposure (χ^2 = 54.67, df = 4, p<0.001; Cramér's V = 0.83), with standardized residuals confirming overrepresentation of feeding under full sunlight and resting under partial sunlight. Day-period distributions were similar among species, with no significant association detected (χ^2 = 0.74, df = 4, p=0.947; Cramér's V = 0.00). Spearman correlation analysis identified several strong associations among environmental and behavioral variables. Behavioral categories showed a strong positive association with sun exposure (r_s = 0.773), while movement intensity showed a strong negative association with sun exposure (r_s = –0.699). Day period was also strongly associated with both behavioral allocation (r_s = –0.717) and sunlight exposure (r_s = –0.762). In contrast, correlations involving species identity were consistently weak, indicating that environmental conditions influenced behavioral thermoregulation more strongly than species-specific differences (Figure 2).

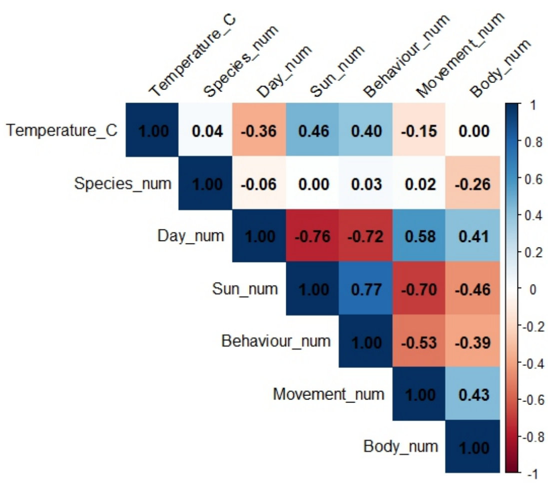

Figure 2: Spearman Correlation Heatmap Showing Relationships among Environmental and Behavioral Variables

DISCUSSION

Behavioral thermoregulation in *Acridotheres tristis, Passer domesticus*, and *Corvus splendens* was driven primarily by ambient temperature, sunlight exposure, and daily temporal variation rather than species identity, consistent with previous studies demonstrating that solar radiation reduces thermoregulatory costs and promotes locomotion and foraging while reduced solar exposure favors resting [5, 10]. The absence of significant interspecific differences reflects the ecological flexibility and broad thermal tolerance of these species and their shared exploitation of comparable urban microhabitats and anthropogenic resources, which tends to homogenize behavioral responses among co-occurring synanthropic species [5, 6]. The results also highlight the significance of microclimatic conditions on the thermoregulatory behavior of birds. In the present study, these environmental variables were not measured, but it is known that each of these factors can affect heat exchange, evaporative cooling, and behavioral responses in birds. New research shows that birds are not only influenced by ambient temperature but also by several climatic signals when making decisions about their movements, foraging, and rest during variable environmental conditions [19, 21]. Focusing on birds, McQueen *et al.* showed that both behavioral and morphological mechanisms contribute to regulating heat loss and hence can facilitate thermal stress in birds in response to different weather conditions [14]. Such a lack of behavioral differences between the three species observed in this study might be due to their common use of similar urban microhabitats and similarity in their behavioral plasticity in response to environmental variation. This flexibility is seen as an adaptive measure that contributes to being resilient to the climatic variations between the seasons and the rising temperatures in warmer urban climates. With the increased thermal extremes expected with climate change, more microclimatic variables should be included in behavioral studies to better understand species-specific thermoregulatory strategies and guide conservation and urban habitat management decisions.

Key limitations include the small sample size, single season, urban-only focus, and absence of microclimatic variables such as humidity, wind speed, and surface temperature. Future studies should expand species coverage, seasons and sample sizes, incorporate physiological and microclimatic data, and apply long-term monitoring with GLMMs to better capture spatial-temporal variability and climate-urbanization effects.

CONCLUSIONS

The findings highlight the importance of behavioral flexibility in urban birds facing seasonal environmental variation. Behavioral thermoregulation in *Acridotheres tristis, Passer domesticus*, and *Corvus splendens* from autumn to early winter was strongly associated with

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ambient temperature, sunlight exposure, and daily temporal variation. Species identity contributed relatively little to observed behavioral differences, whereas environmental conditions were consistently associated with movement intensity and behavioral allocation.

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Author's Contribution

Conceptualization: AA
Methodology: AA
Formal analysis: AA
Writing and Drafting: AA
Review and Editing: AA

The author approved the final manuscript and take responsibility for the integrity of the work.

Conflict of Interest

The author declare no conflict of interest.

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