Postprint: Evolution of Phenotypic Environmental Adaptation in Tree Sparrows

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Abstract

Tree Sparrow (Passer montanus) exhibits a wide distribution range, spans large altitudinal gradients, and is a commensal species associated with human activities. Correlation analysis of 10 morphological traits from 837 samples in China with four major environmental factors—temperature, sunshine duration, altitude, and wind speed—demonstrated that body mass, gape width, wing length, tail length, tarsus length, cranial width, and interorbital distance were significantly correlated with sunshine duration ($P<0.05$); body mass, body length, wing length, tail length, and tarsus length were significantly correlated with altitude ($P<0.05$); and body mass, culmen length, wing length, and cranial length were significantly correlated with temperature ($P<0.05$). These results indicate that morphological indicators of Tree Sparrow readily vary with changes in environmental factors. Partial correlation analysis between morphological traits and latitude, controlling for longitude and altitude, revealed that body mass, wing length, cranial length, and cranial width were significantly positively correlated with latitude ($P<0.05$), whereas the protruding body parts culmen length and gape width were significantly negatively correlated with latitude ($P<0.05$). Specifically, as latitude increases, Tree Sparrows gradually increase in body size, conforming to Bergmann' s rule, while the protruding body parts culmen length and gape width decrease with increasing latitude, conforming to Allen' s rule. Flight capability was highly significantly positively correlated with altitude ($n=92$, $r=0.217$, $P=0.038$), indicating that Tree Sparrows possess stronger flight ability in high-altitude regions, which may represent an important factor contributing to their status as a widespread species.

Full Text

Preamble

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The Adaptive Evolution of the Tree Sparrow (*Passer montanus*) Phenotype to Environmental Factors

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Abstract

The tree sparrow (*Passer montanus*) is a widely distributed species commonly associated with human settlements, found across broad altitudinal and geographical gradients. This study analyzed the relationship between ten morphological characteristics of 837 tree sparrows and four environmental factors (air temperature, sunshine, altitude, and wind speed). Results indicated that morphological traits such as body weight, rictus, wing length, tail length, tarsus length, skull width, and interorbital distance were significantly correlated with sunshine factor ($P < 0.05$). Body weight, body size, wing length, tail length, and tarsus length were significantly correlated with altitude factor ($P < 0.05$). Additionally, body weight, culmen length, wing length, and skull length were significantly correlated with air temperature factor ($P < 0.05$), suggesting these morphological characteristics have adaptive potential in response to environmental variation.

Furthermore, we analyzed the relationship between morphological size and latitude while controlling for longitude and altitude. After controlling for these variables, body weight, wing length, and skull size showed significant positive correlations with latitude ($P < 0.05$), while culmen length and rictus showed significant negative correlations with latitude ($P < 0.05$). These findings suggest that body size increases with rising latitude while bill size decreases, consistent with Bergmann' s and Allen' s rules. A significant positive relationship was found between flight ability and altitude factor ($n = 92$, $r = 0.217$, $P = 0.038$), indicating that tree sparrows have greater flight ability at higher altitudes. This adaptive component of flight ability may explain why *P. montanus* is so widely distributed across the planet.

Keywords: *Passer montanus*; morphological traits; environmental factors; phenotypic evolution

Introduction

Global climate change has triggered a series of ecological responses that have attracted widespread scholarly attention [1-2]. Climate change affects the geographic distribution, phenology, and animal behavior of plant and animal populations. Species respond through three strategies: changing distribution ranges, adapting to new environments, and phenotypic plasticity determined by genes. Changes in species distribution and abundance have been validated as indicators of climate change in many populations [3-5], and numerous studies have examined relationships between climate warming and species phenological changes [1-2, 6-9]. Climate change-related body size variation has also received increasing attention [10-11].

Bergmann' s rule posits that endothermic animals living in cold regions have larger body sizes [17-18], with body size increasing with latitude [19]. Temperature decreases with increasing latitude [21-24], and this pattern has been documented in many bird species [27-30]. Allen' s rule states that with increasing latitude, the protruding parts of endothermic animals (such as bills or limbs) become shorter [25-27] because these animals reduce surface area to minimize heat loss [31]. Generally, for every 100 m increase in altitude, temperature drops by approximately 0.6°C. Many factors can alter species phenotypes, including food availability [32] and population density [33].

Numerous studies demonstrate that birds have responded to global climate change in terms of population dynamics, life history traits, and geographic distribution ranges [34-36]. Climate change not only directly affects bird behavior but also indirectly influences their lives by altering environmental conditions such as latitude and sunshine hours, thereby changing their lifestyles and distribution ranges [37-38].

The tree sparrow (*Passer montanus*), a resident bird of the Palearctic realm [39], belongs to Passeriformes, Passeridae. Its range extends from Europe to the Malay Peninsula and Indonesia [40], inhabiting altitudes from 300–2500 m, and can even reach 4500 m. As a human commensal species with a broad distribution and large altitudinal gradient, the tree sparrow provides excellent material for studying relationships between environmental change and morphological variation. Since tree sparrows are commonly found near human settlements, studying environmental impacts on them can indirectly reflect impacts on humans. Current domestic research on tree sparrows has focused primarily on reproductive biology [41], genetic structure [42], and physiology and biochemistry [43]. This study uses tree sparrows as a model to analyze relationships between morphological traits of different geographic populations and environmental variation, examining how body condition and flight ability are affected by environment, testing compliance with Bergmann' s and Allen' s rules, and exploring environmental adaptation in this species.

1. Materials and Methods

We collected morphological data from 837 adult tree sparrows from the Institute of Zoology (Chinese Academy of Sciences), Kunming Institute of Zoology (Chinese Academy of Sciences), South China Institute of Endangered Animals, and field collections. Since tree sparrows show no significant sexual dimorphism, sexes were not separated in our analysis.

Morphological measurements were taken using vernier calipers (precision 0.1 mm) and portable electronic balances (precision 0.1 g). The sample localities ranged from 76.17–129.17°E and 18.53–52.97°N, with altitudes from 2–4472 m. Ten morphological traits were measured: wing length (WL), tail length (TL), tarsus length (TAL), skull length (SL), skull width (SW), body length (BL), culmen length (CUL), rictus (RL), interorbital distance (ID), and body weight (BW).

To assess body condition and flight ability, we calculated: (1) body condition as the ratio of body weight to tarsus length [44], and (2) flight ability as the ratio of wing length to body weight [45]. Meteorological data for sampling localities were obtained from the China Meteorological Data Center for the sampling years, including extreme maximum temperature, extreme minimum temperature, sunshine hours, and wind speed.

Principal component analysis was used to extract major environmental factors. Pearson correlation analysis examined relationships between environmental factors and morphological traits. Partial correlation analysis tested Bergmann' s and Allen' s rules by controlling for longitude and altitude. All analyses were performed using SPSS 20.0, with $P < 0.05$ considered significant and $P < 0.01$ considered highly significant.

Sampling locations of *Passer montanus*

2. Results

2.1 Relationship Between Environmental Factors and Morphological Traits

Principal component analysis of four environmental factors yielded four major factors: temperature factor (-0.872), sunshine factor (-0.898), altitude factor (0.869), and wind speed factor (0.895), which together explained 83.20% of environmental variation.

Correlation analysis between these four major environmental factors and morphological traits revealed: body weight was significantly negatively correlated with temperature, sunshine, and altitude factors ($P < 0.05$); body length was significantly negatively correlated with altitude factor ($P < 0.05$); culmen length was significantly positively correlated with temperature factor ($P < 0.05$) but significantly negatively correlated with sunshine factor ($P < 0.05$); wing length was significantly negatively correlated with temperature, sunshine, and altitude factors ($P < 0.01$); tail length was significantly negatively correlated with sunshine and wind speed factors ($P < 0.05$); tarsus length was significantly negatively correlated with sunshine and altitude factors ($P < 0.05$); skull length was highly significantly negatively correlated with temperature factor ($P < 0.01$); skull width was highly significantly positively correlated with sunshine factor ($P < 0.01$); and interorbital distance was highly significantly negatively correlated with sunshine factor ($P < 0.01$).

Relationship between environmental factors and morphological traits

2.2 Bergmann' s Rule

Analysis of the correlation between altitude and mean temperature showed a highly significant negative relationship ($r = -0.774$, $P < 0.001$), with temperature decreasing significantly as altitude increased.

Partial correlation analysis controlling for longitude and altitude revealed that body weight was highly significantly positively correlated with latitude ($r = 0.311$, $P = 0.001$). Wing length was significantly positively correlated with latitude ($r = 0.320$, $P < 0.05$). Both skull length and skull width were significantly positively correlated with latitude ($r = 0.169$, $P < 0.05$; $r = 0.320$, $P < 0.05$, respectively). Body length showed no significant correlation with latitude ($r = 0.056$, $P = 0.560$), and interorbital distance was not significantly related to latitude ($r = 0.077$, $P > 0.05$). These results support Bergmann' s rule, as body size increased with latitude.

Birds typically use wing length to represent body size. With increasing latitude, tree sparrow body weight and wing length gradually increased.

[Figure 1: see original paper] Relationship between air temperature and altitude
[Figure 2: see original paper] Relationship between body weight and latitude of *P. montanus*
[Figure 3: see original paper] Relationship between skull length and latitude of *P. montanus*

2.3 Allen' s Rule

Partial correlation analysis controlling for longitude and altitude showed that culmen length was highly significantly negatively correlated with latitude ($r = -0.277$, $P = 0.003$), and rictus was significantly negatively correlated with latitude ($r = -0.225$, $P = 0.017$). This indicates that bill size gradually decreases with increasing latitude, consistent with Allen' s rule.

[Figure 4: see original paper] Relationship between culmen length and latitude of *P. montanus*

[Figure 5: see original paper] Relationship between rictus length and latitude of *P. montanus*

2.4 Relationship Between Physical Fitness and Environmental Factors

Correlation analysis between the four environmental factors (temperature, sunshine, altitude, and wind speed) and body condition/flight ability revealed that tree sparrow body condition was significantly negatively correlated with temperature, sunshine, and altitude factors ($P < 0.05$), but not significantly correlated with wind speed ($P > 0.05$). Flight ability was significantly positively correlated with altitude factor ($n = 92$, $r = 0.217$, $P = 0.038$).

Correlations between the ability of tree sparrow and environmental factors (Pearson)

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3. Discussion

Physiological plasticity is commonly referred to as adaptation to environmental change [46-47]. Our results indicate that morphological traits of tree sparrows are most strongly influenced by sunshine factor, followed by temperature factor, and least affected by wind speed. Body weight and wing length showed significant negative correlations with all three environmental factors (sunshine, temperature, and altitude), while skull length was significantly negatively correlated with temperature and sunshine factors ($P < 0.01$), and skull width was significantly positively correlated with sunshine factor ($P < 0.01$). This suggests that tree sparrows have larger skulls in regions with low temperature and less sunshine. Although high altitude regions have lower temperatures, altitude factor did not significantly affect skull size ($P > 0.05$), indicating relative stability of skull size across altitudinal gradients.

Bird body size is influenced by food availability and interspecific competition [31,48], with primary productivity being significantly positively correlated with individual body size in any environment [49]. In high altitude areas, lower primary productivity and hypoxia may lead to smaller body sizes in tree sparrows. The relationship between body size and latitude has been supported in 72% of relevant studies [52]. Birds often use wing length to represent body size, and this trend can be interpreted as adaptation to climate change [53]. When studying large regions or continents, the mechanisms underlying Bergmann' s rule remain controversial, and it is unclear whether Bergmann' s rule can be extended to predict impacts of climate change [52]. However, our results show that tree sparrow body weight, wing length, and skull size are significantly positively correlated with latitude ($P < 0.05$), indicating that changes in body size conform to Bergmann' s rule.

This study demonstrates that protruding body parts (bill size) of tree sparrows show significant decreasing trends with increasing latitude, consistent with

Allen' s rule. Bill shape variation is a classic example of evolutionary diversity and has been widely used to detect morphological changes in avian evolution [55]. For instance, studies have shown that bill size decreases with decreasing minimum temperature [27], and researchers in Hawaii found bill shortening with altitudinal gradients in *Chasiempis* [56]. Our results indicate that tree sparrow bills are sensitive to environmental changes, with smaller bills in cold high-latitude regions reducing heat loss and improving adaptation. Bird body size is related to food supply, which is typically affected by environmental primary productivity. High temperature and sufficient precipitation influence primary productivity, thereby affecting bill morphology to facilitate food acquisition [57]. Thus, plastic changes in tree sparrow bills indicate adaptive evolution to environment.

Tree sparrow body condition was significantly negatively correlated with temperature, sunshine, and altitude factors, indicating that body condition decreases with increasing environmental temperature, likely due to harsh conditions and excessive physiological costs in high altitude areas. As a human commensal species, this may indirectly reflect that humans living at high altitudes have poorer body condition due to various stresses including cold, hypoxia, drought, and intense radiation. Flight ability was significantly positively correlated with altitude factor ($n = 92$, $r = 0.217$, $P = 0.038$), suggesting stronger flight ability in high altitude populations. This may explain why *P. montanus* is so widely distributed. Additionally, most morphological traits (except tail length) were not significantly correlated with wind speed, consistent with the flight ability results.

Global warming may not affect tree sparrow distribution. Morphological traits such as body weight and tail length were significantly correlated with all environmental factors except wind speed, and bill shape was significantly correlated with temperature and latitude, indicating that tree sparrow morphological indicators readily change with environmental factors. This high degree of environmental adaptability may be an important reason for its status as a widely distributed species.

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