UNIVERSIDAD DE INVESTIGACIÓN DE TECNOLOGÍA EXPERIMENTAL YACHAY

Escuela de Ciencias Biológicas e Ingeniería

TÍTULO: Effect of humidity on basal metabolic rate, thermal conductance and the breadth of the thermoneutral zone in two species of *Stilpnia* tanagers (Family Thraupidae)

Trabajo de integración curricular presentado como requisito para la obtención del título de Biólogo

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Dedicatoria

A mi querida familia y amigos.

Jimmy Arias Borja

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Resumen

A pesar de que los efectos de diferentes factores ecológicos en el metabolismo de las aves han sido estudiados, aún no está claro cómo la humedad afecta la relación entre la tasa metabólica y la temperatura ambiental. El aumento en la humedad relativa hace más difícil para los animales el disipar calor. En respuesta, las especies pueden evolucionar para ajustar su 1) tasa metabólica basal (TMB), 2) conductancia térmica (*C*), y/o 3) la amplitud de la zona térmica neutral (TNZ). Por esta razón, el presente estudio se enfocó en comparar estas tres respuestas metabólicas en dos especies relacionadas de tangaras, *Stilpnia heinei* y *Stilpnia vitriolina*, que habitan bosques nublados húmedos y bosques secos respectivamente. Las tasas metabólicas fueron obtenidas con un sistema de respirometría. Además, analicé datos publicados para evaluar una correlación entre la humedad y la TMB, en aves tropicales. Los datos indicaron que *S. heinei* presentó una TMB mayor y una conductancia térmica menor que *S. vitriolina*. Adicional, *S. heinei* aparentemente mostró una ZTN más amplia que *S. vitriolina*. Esto probablemente indicó que *S. heinei* tiende a tolerar un rango más amplio de temperaturas ambientales, tanto bajas como altas — un mecanismo de termorregulación conocido en varias especies tropicales. A pesar de que interpretar resultados publicados de tasas metabólicas puede convertirse en un enigma científico, dadas las muchas variables que actúan sobre el metabolismo de las aves, el análisis de 478 especies de passerinos sugierió que las especies en áreas tropicales secas tienen una TMB más baja dada posiblemente por la escasez de recursos, como agua y comida. Estos resultados podrían representar un punto de inicio hacia el estudio de las respuestas ecofisiológicas de aves tropicales a diferentes retos impuestos por su ambiente.

Palabras Clave: tasa metabólica, conductancia térmica, zona térmica neutral, humedad relativa, termorregulación, *Stilpnia heinei*, *Stilpnia vitriolina*

Abstract

Although the effects of different ecological factors on avian metabolism have been studied, it is not clear how humidity affects the relationship between metabolic rate and ambient temperature. An increase in relative humidity arguably makes it more difficult for animals to dissipate heat. In response, species might evolve to adjust their 1) basal metabolic rate (BMR), 2) thermal conductance (*C*), and/or 3) breadth of the thermoneutral zone (TNZ). For this reason, the present study focused on comparing those three metabolic responses in two related tanager species, *Stilpnia heinei* and *Stilpnia vitriolina* (Family Thraupidae – Passeriformes), that inhabit humid cloud forests and dry forests, respectively. Metabolic rates were obtained with an open flow-through respirometry system. In addition, I analyzed published data to test for a correlation between humidity and BMR. in tropical birds. Data showed that *S. heinei* presented a greater BMR and a lower thermal conductance than *S. vitriolina*. Further, *S. heinei* apparently showed a broader TNZ than *S. vitriolina*. This probably indicated that *S. heinei* tends to tolerate a wider range of ambient temperatures, both low and high — a thermoregulatory mechanism known to be present in several tropical species. Although to interpret published results on metabolic rates can become a scientific conundrum, given the many variables acting on a bird metabolism, the analysis of over 478 species of passerines suggested that species in dry tropical areas have a lower BMR possibly due to scarcity of resources, such as water and food. These results could represent a starting point towards the study of ecophysiological responses of tropical birds to different challenges imposed by their environment.

Keywords: metabolic rate, thermal conductance, thermoneutral zone, relative humidity, thermoregulation, *Stilpnia heinei*, *Stilpnia vitriolina*

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Abbreviations

BMR: Basal metabolic rate

MR: Metabolic rate

TNZ: Thermoneutral zone

EWL: Evaporative water loss

CEWL: Cutaneous evaporative water loss

REWL: Respiratory evaporative water loss

LCL: Lower critical limit

UCL: Upper critical limit

1. Introduction

1.1. Birds of Ecuador: An incredible diversity

Birds are the most diverse group of land vertebrates, and part of this great diversity can be found in Ecuador. According to the most recent checklist of the birds of Ecuador, published by the Ecuadorian Ornithological Records Committee, the number of species in the country was 1736 by the year 2022 (Freile et al., 2023), making Ecuador one of the top 12 richest countries, in terms of bird diversity, of the planet (García-Moreno et al., 2007). This diversity results from the influence of geographical and geological factors that are uniquely present in the country, they include: the location of Ecuador in the equatorial zone, the presence of the Andean Mountain range, and the effect of two marine currents (one warm at north and one cold at south) on the country's climate. These three factors favor the formation of a wide variety of ecosystems and bioregions (Tirira, 2017; Vasquez Noboa & Cervantes Daza, 2017).

The presence of birds in each one of these bioregions is a result of the development of several evolutionary adaptations, one of them is their capacity to regulate internal heat production to maintain a stable body temperature (T_b), a characteristic known as endothermy. This method of thermoregulation, found also in mammals, gives birds an evolutionary advantage, as it allows them to cope better with ambient temperature (T_a) fluctuations. Moreover, endothermy provides birds with other advantages such as a greater physical capacity, nocturnal activity that does not depend on solar radiation, and an efficient digestion and assimilation of food (Eliosa & Silva, 2011). Unfortunately, despite the capacity of studies on energetic physiology to explain birds' evolutionary adaptations, most of the information about thermoregulation on birds corresponds either to short-term studies of tropical species or larger studies performed on temperate species. This is an indication of the lack of resident biologists in tropical areas that dedicate themselves to the study of physiological ecology of birds and other vertebrates (McNab, 2013).

1.2. Understanding avian thermoregulation

Thermoregulation is a necessary mechanism for survival because body temperature represents a significant constraint for all animals, as extreme changes could affect the stability of the biochemical reactions necessary to maintain normal cell function (homeostasis) (Hickman et al., 2020). When body temperature is too low, metabolic processes slow down, and the amount of energy produced for any vital activity is reduced. On the other hand, if body temperature is too high, proteins are denatured, enzymatic activity is hampered, and metabolic reactions are altered (Hickman et al., 2020). This is why each animal species has a body temperature range at which homeostasis is maintained, and thermoregulatory mechanisms allow them to maintain their body temperature within this range without increasing their BMR (Fristoe et al., 2015). In the case of passerine birds, body temperature ranges from 40°C to 42°C in the majority of cases, and thermoregulation occurs by physical and chemical pathways.

1.2.1. Physical thermoregulation

Physical thermoregulation is related to heat exchange with the environment through four pathways: radiation, conduction, convection and evaporation (Figure 3; Hickman et al., 2020). The importance of each of these pathways is dependent upon the animal and the conditions of the environment (McNab, 1980). For example, when most birds face high temperatures, the main mechanism used in order to dissipate heat is by evaporative water loss (EWL), which occurs mainly by a combination of cutaneous (CEWL) and respiratory (REWL) evaporative pathways (Gerson et al., 2014) and the reliance of each one also varies among taxa. As a matter of fact, doves and pigeons (Order Columbiformes) appear to rely mostly on CEWL rather than on REWL (Smith et al., 2015). On the other hand, the opposite happens for passerines (Order Passeriformes), with up to 80% of the total evaporative water loss occurring as REWL (Gerson et al., 2014). Furthermore, the use of REWL can also vary among groups as it can be improved by some behavioral adaptations such as panting, like in sociable weaver (*Philetairus socius*), or gular fluttering, like in pelicans (genus *Pelecanus*) (Gerson et al., 2014).

Nevertheless, some clades of birds are able to dissipate large amounts of heat by other mechanisms rather than evaporation. As a matter of fact, a study performed on the Anna's hummingbird (*Calypte anna*) showed that hummingbirds may dissipate heat by dry heat transfer (convection, conduction, and radiation) rather than by evaporation, with the last one only counting for 58.6% of the metabolic heat dissipated (Powers, 1992). Another example has been proposed on some tropical birds that could also rely mostly on dry heat transfer, as their large beaks could aid in the dissipation of heat via radiation, like toucans (Family Ramphastidae) (Gerson et al., 2014; Tattersall et al., 2009).

As a result of this diversity of pathways and animal’s properties, the simultaneous study of the physical factors involved in heat exchange is nearly impossible. To solve this issue, most animal physiologists use a parameter known as thermal conductance (*C*) that, in theory, takes into account all the set of pathways for heat exchange (Herreid & Kessel, 1967; McNab, 1980).

Thermal conductance of endothermic animals, like birds and mammals, represents the amount of heat lost by the body per unit of temperature, below a lower critical limit, and it is mostly dictated by the body's shape, size and surface characteristics (Herreid & Kessel, 1967), as indicated by the equation:

$$C \cong 4\varepsilon\sigma A_1 T_a^3 + kA_2 + h_c A_3 + \frac{LE}{(T_b - T_a)} \qquad \text{Equation (1)}$$

Where ε represents emissivity, σ Stefan-Boltzmann constant, A_1 surface area for radiative exchange, k thermal conductivity of the integument, A_2 surface area for conductive exchange, h_c convective exchange, A_3 surface area for convective exchange, L latent heat of vaporization, and E the amount of water evaporated (McNab, 1980).

In simpler terms, thermal conductance is an indicator of how easily heat is transferred between an animals body and its environment (Pollock et al., 2019). This facility to transfer heat could be dangerous at very low ambient temperature where an animal could reach a point of minimal thermal conductance, where it is impossible to retard more heat loss and reach hypothermia (McNab, 1980; Pollock et al., 2019). This value of minimal thermal conductance is very low in mammals and birds because their fur and feathers provide them a layer for thermal insulation (the reciprocal of conductance) (Fristoe et al., 2015). In the case of birds, feathers can function as regulators of heat loss as their status changes in dependance of the environmental conditions face (Porter & Gates, 1969). In warm environments they are loosely ruffled to increase convection (transfer of heat by the movement of air past a surface) near the body, while in cold environments they appear fluffed so that a thicker layer of warm air surrounds the body and preserves heat (Figure 4). Moreover, some species could also present layers of fat to protect their bodies against heat loss (Welty, 1982).

1.2.2. Chemical thermoregulation

Chemical thermoregulation is considered to be the capacity of an animal to regulate the rates of metabolic processes and is the defining characteristic of endothermy (McNab, 1980; Porter & Gates, 1969). These regulation results in fluctuations of metabolic heat production that keeps the temperature differential between the body and the environment (ΔT) at levels where heat exchange is suitable to maintain homeostasis (McNab, 2013). Ectotherms, like reptiles, on the other hand, do not possess this property, so they are not able to produce an excess of metabolic heat to warm their bodies, and their body temperature relies purely on physical mechanisms, environmental conditions and thermoregulation is behavioral (Hickman et al., 2020).

In general, the use of chemical thermoregulation occurs at the limits of a range of ambient temperatures known as the zone of thermoneutrality (TNZ). These limits represent the temperatures at which an animal will need to increase metabolic rates to produce energy in order to keep body temperature stable (Fristoe et al., 2015). At ambient temperatures below the lower critical limit (LCL), energy is required to increase heat production by means of the shivering of skeletal muscles (Wiersma et al., 2007). On the contrary, when ambient temperature reaches the upper critical limit (UCL), energy is needed in order to employ cooling mechanisms like REWL (Hickman et al., 2020; Welty, 1982). If temperatures get extreme, they can reach a lethal limit at which heat production could exceed heat loss, or vice versa, leading to hyperthermia or hypothermia, respectively (Figure 5). Moreover, the width of the TNZ may vary according to the species, so a critical limit of one species could either be within the TNZ, or reach a lethal limit of another (Bozinovic et al., 2014).

On the other hand, temperatures within the range of the TNZ would not require a chemical thermoregulatory response, so the metabolic rate is mostly constant. Furthermore, if the animal is also under conditions of post-absorption, and inactivity during the period of inactivity, the metabolic rate is considered to be basal (McNab, 2013; Ricklefs et al., 1996). The basal rate of metabolism (BMR) represents the minimum rate of energy production necessary to maintain homeostasis in endothermic animals and is different among species (Naya et al., 2018; White et al., 2007). Most of the variation is due to differences in body mass, which is a reflection of the size of metabolic active tissue from organs like heart, kidneys, brain and intestine (McNab, 2016; Tieleman & Williams, 2000).

1.3. The role of ecology on thermoregulation

Even though the impact of body mass on BMR can be seen in most comparative studies, like one performed by McNab (2009) on 533 species from different orders in which body mass accounted for 96% of the BMR variation, the remaining percentage of unexplained variation can be accounted by ecological and life-history factors. In fact, the inclusion of ecological factors, on the same study, like food habits, climate, habitat, use of torpor, altitude, flightless condition, continental/ island distribution, and the passerine/non-passerine dichotomy increased this percentage to 97.7% (McNab, 2009). These results are consistent with several authors that determine the importance of ecological factors on avian energy expenditure (McNab, 2015).

Other well-researched ecological factors that have been found to influence BMR include migratory tendencies and pace of life. In the case of migratory tendency, its effect on BMR is simply explained by the high maintenance costs of the metabolic machinery for long-distance migration, which results in a BMR much higher in migrant birds than in non-migrant (Bushuev et al., 2018). On the other hand, in the case of pace of life, it has been shown that birds living in tropical zones have a lower BMR in comparison to the ones living in the temperate zones (Bushuev et al., 2018), and this could be a result of live-history traits consistent with a slower pace of life (Wiersma et al., 2007). In other words, birds on the tropics that face intense competition and predation present adaptations that increase survival but reduce high energy requirements for high rates of offspring production, fast maturation, and parental care, which can explain a low BMR (Londoño et al., 2015; Wiersma et al., 2007).

Furthermore, the capacity to transfer energy in the form of heat depends, in part, on climatic factors. Even though climate has proven to be an ecological factor that affects metabolism (McNab, 2009), there are no studies that have tested the impact of climatic elements *per se*. most big studies have compared climate by dichotomous categorizations, such as tropics versus temperate or desert versus non-desert, and don’t focus on the climatic elements that characterize those habitats, like temperature, precipitation, relative humidity and wind (Tieleman et al., 2003). Temperature, for example is considered an important predictor to BMR (Naya et al., 2018), whilst animals in warmer temperatures require lower metabolic rates in order to avoid rapid production of excessive heat that will be difficult to dissipate, animals living in cold environments present higher metabolic rates in order to make up for heat loss in a place where heat transfer occurs fast, due a high ΔT (O’Connor et al., 2021).

As for the other climatic elements, little is known about their individual impact on BMR, obscuring important biological information about their effects on avian physiology, which should be a topic for more research (Tieleman et al., 2003). For example, it has been suggested that humidity has an effect on thermoregulation because it affects the conductivity of heat, especially its dissipation by evaporation, which is the principal mechanism used by birds to regulate their body temperature at high ambient temperatures (Gerson et al., 2014). However, there is very little information about the true impact of humidity or aridity on avian thermal physiology (van Dyk et al., 2019). Moreover, existing studies have led to doubts about the influence of humidity on energy expenditure, mostly because they didn’t separate it as an ecological agent that could potentially influence adaptation (McNab, 2015).

The importance of studying the effect of humidity as a climatic variable, as well as other environmental factors, on thermoregulatory mechanisms lies in the necessity to understand the physiological adaptations that animals have evolved in order to survive, so we can predict the effect of any ambient alterations on them (Fristoe et al., 2015). As a matter of fact, the adjustment of thermoregulatory mechanisms has evidenced to affect survival, and fitness (Swanson et al., 2023). For example, one study on snow buntings (*Plectrophenax nivalis*) showed that these birds show signs of early heat stress at temperatures well below their body temperature, which suggests that the evolution of their physiological adaptations could affect their capacity to adjust to warmer temperatures (O'Connor et al., 2021). These evolutionary limitations to adjust to changes in the environments might be subject to phylogenetic constraints, which means that an animal might not able to adjust to some condition if their evolved features present restrictions imposed by their historical lineage (Losos & Miles, 1994).

1.4. Research objectives

Due to the discussed lack of studies about the impact of climatic elements on thermoregulation of tropical birds, the aim of this study is to determine the effect of humidity as it relates to thermoregulation, in two species of tanagers (Family Thraupidae): *Stilpnia heinei*, native of subtropical forest (Figure 1), and *Stilpnia vitriolina*, native of dry inter-Andean valleys (Figure 2). Both species were selected given their close phylogenetic relationship, reducing problems relating to differences caused by phylogenetic history (Tieleman et al., 2003), and their exclusive distribution to environments with different levels of relative humidity, which is very high in the subtropical forest and low in the inter-Andean valleys. The characteristics to evaluate in this study are:

- Basal metabolic rate (BMR).
- The width of the thermoneutral zone (TNZ).
- Minimal thermal conductance (*C*).

As a second objective, the results of BMR will be incorporated into a bigger data base, obtained from bibliography, to analyze the possible effects of humidity on the metabolic adaptations for thermoregulation in passerines and tanagers (Family Thraupidae). Moreover, they will be used to discuss how these characteristics could play a role in the distribution of both tanager species, and other tanagers present in the bibliography, as well as their limitations to adjust to environmental changes imposed by climate change.

2. Methodology

2.1. Bird capture

Sample sites were selected taking into account similar altitude levels and a contrast in humidity conditions. *S. heinei* individuals were captured at a humid cloud forest in the Puyucunapi Reserve (altitude: ca. 1990 m; 0° 01′ 34.2″ N, 78° 41′ 48.4″ W), while individuals of *S. vitriolina* were captured at a dry inter-Andean forest in the Yachay Botanical Garden (altitude: ca. 2300 m; 0° 25′ 4.7″ N, 78° 11′ 15″ W). Wild birds were captured using mist nets during the afternoon (14:00 – 17:00 h local time).

For every individual, in addition to the standard data usually collected (beak size, tarsometatarsus size, tail size, and wing size), I measured body weight and body temperature (T_b) right before and after each metabolic measurement using a Digital Pocket Scale (Cen-Tech Systems) and a Type-T Thermocouple Meter (model TC-2000, Sable Systems), respectively. In addition, I registered the following variables to characterize the reproductive or health status: pectoral muscle condition, presence of brood patch, plumage molting status, cloaca size and, in the case of *S. heinei*, sex; these data may help to explain the metabolic data obtained.

2.2. In situ measurements of oxygen consumption rates

Basal metabolic rate was estimated as oxygen consumption rate (Londoño et al., 2015). Following the recommendations of McNab (2013), Pollock et al., (2019), and White et al. (2007), measurements were made during the inactive period, when birds were postabsorptive. Birds were freed the morning after. Rates of oxygen consumption were measured using an open flow-through Moxar Respirometry System (Bushuev et al., 2018; Pollock et al., 2019; Tieleman et al., 2003; van Dyk et al., 2019), developed by AEI Technologies, and composed by: two flow meters, an oxygen sensor (model N-37M), a flow controller (model R-2), an oxygen analyzer (model S-3A/II), and a computer interface box (Figure 6). Each bird was placed in a plastic chamber ("metabolic chamber") specially designed with a thermocouple to measure ambient temperature, a hose to connect to the respirometry system, and an opening to assure ambient air exchange (Figure 7). The respirometry system works as follows: (1) Air from the metabolic chamber, and from ambient air (control) is sucked by the system; (2) Tubes containing silica gel beads and soda lime granules filter out water and CO_2 from the air, respectively; (3) Small impurities in the air are filtered out using syringe filters; (4) Air flow rate is then measured by flow meters; (5) Flow rate is adjusted by a flow controller, taking into account chamber size (McNab, 2006); (6) Air flow finally reaches the oxygen concentration sensor; (7) Real-time changes in oxygen concentration are transduce to oxygen percentage by the oxygen analyzer; (8) Measurements are then transformed into digital data by the interface box, and exported to a computer by an USB connection; (9) Data acquisition by the computer is achieved with the use of the MOXAR software every 5 seconds.

In agreement with other studies, once a bird showed a state of inactivity, evidenced by constant levels of oxygen consumption for at least 10 minutes, it was removed from the metabolic chamber and measurements of weight and body temperature taken (Bushuev et al., 2018; Gerson et al., 2014). The software was left running for an extra period of time before and after each measurement in order to minimize measurement drift (O'Connor et al., 2021). The total experimental time for each bird varied from 2 to 4 hours depending mostly on its activity.

The estimation of the critical limits of the thermoneutral zone requires measurements at different ambient temperatures in the metabolic chamber (McNab, 2013). Ideally, these measurements should be independent, meaning they should be taking on different birds. However, due to the low availability of birds captured during the study period, multiple measurements at different random temperatures were made on the same individual. Temperatures were adjusted by placing the chamber close to cold (ice packs) or warm (heat from the flow controller) sources. Care was taken to ensure that the air temperature of the metabolic chamber does not exceed 30°C, to avoid hyperthermia and bird death.

2.3. Quantitative estimation of metabolic rates

To estimate metabolic rates, first the rate of oxygen consumption must be calculated using the formula:

$$R_{\mathrm{O}_2} = \frac{\mathrm{FR} \times ([\mathrm{O}_2]_{if} - [\mathrm{O}_2]_{ef})}{1 - [\mathrm{O}_2]_{ef}} \qquad \text{Equation (2)}$$

Where R_{O_2} is the rate of oxygen consumption, FR is flow rate (mL/min), $[\mathrm{O}_2]_{ef}$ is the excurrent fractional oxygen concentration, and $[\mathrm{O}_2]_{if}$ is the incurrent fractional oxygen concentration (Londoño et al., 2015; Pollock et al., 2019). $[\mathrm{O}_2]_{ef}$ was calculated as the mean value of % oxygen from the stable period of minor oxygen consumption (Figure 8), while $[\mathrm{O}_2]_{if}$, which serves as control, was calculated as the mean value of % oxygen in ambient air during the same stable period. To further calculate metabolic rate (MR), R_{O_2} (mL O_2/min) was transformed to Watts using a coefficient of 19.8 J/mL O_2, and then from Watts (J/s) to KJ/h.

Metabolic rates from this study were compared to those expected for a passerine bird, which are given by McNab's (2009) equation as a function of bird mass:

$$\mathrm{BMR} = 0.130\ \mathrm{m}^{0.713\pm0.013} \qquad \text{Equation (3)}$$

Where BMR (KJ/h) is the basal metabolic rate and m is the bird mass (g).

2.4. Estimation of basal metabolic rate, thermoneutral zone and thermal conductance

The basal metabolic rate (BMR), the thermoneutral zone (TNZ), and thermal conductance are variables calculated at the species level by plotting metabolic rates (*y* axis) against ambient temperatures (*x* axis). Note that all birds have at least two metabolic rates measured.

2.4.1. Estimation of mean BMR and the TNZ

For each species, the critical limits of the TNZ are represented by the inflection points of the metabolic rate vs. ambient temperature plot. Inflection points were identified using a piecewise linear regression (O'Connor et al., 2021; Pollock et al., 2019, 2021). The metabolic rate values between the critical limits represent estimates of the BMR; these values were averaged to obtain a mean estimate of BMR for a given species (McNab, 2013) (Figure 5).

2.4.2. Estimation of thermal conductance

To estimate thermal conductance for a species, a linear regression plot must be obtained using the values below the lower critical limit of the TNZ, with the regression line also crossing the x-axis at the point at which ambient temperature (T_a) equals body temperature (T_b) (McNab, 1980; Pollock et al., 2019). The slope of the regression line estimates the wet thermal conductance, i.e., not corrected for evaporative heat loss (McNab, 1980; Zhao et al., 2014). Alternatively, mean thermal conductance (MT*C*) for a species can also be calculated by averaging the conductances (*C*) of *i* measurements:

$$MTC = \frac{\sum_i^n (C)_i}{n} = \frac{\sum_i^n \left(\frac{MR}{(T_\mathrm{b}\text{-}T_\mathrm{a})}\right)_i}{n} \qquad \text{Equation (4)}$$

Where MR is the metabolic rate for a given measurement (KJ/h), T_a is ambient temperature (°C), T_b is body temperature (°C), *C* is the thermal conductance of a given measurement (KJ/h°C), and n is the number of measurements taken for a species. The MTC value should be similar to the one estimated from the slope calculation explained above (McNab, 1980).

Furthermore, the thermal conductance values were also compared to the ones expected from a passerine bird, calculated form McNab's (2012) equation as a function of bird mass:

$$C\left(\frac{\mathrm{KJ}}{\mathrm{h°C}}\right)=0.012\ \mathrm{m}^{0.539} \qquad \text{Equation (5)}$$

Where C is thermal conductance, and m is the bird mass (g).

2.5. Statistical analyses

2.5.1. Comparison of thermal conductance between the two *Stilpnia* species from this study

To look for a significant difference between the minimal conductance of both *Stilpnia* tanagers, slopes of the linear regression below the lower critical limit of the TNZ were compared using a bootstrap approach, with 10,000 resamples (with replacement) and a 95% confidence interval. Bootstrapping is one of the most useful non-parametrical tests when sample size is insufficient to get a statistical inference (Estévez-Pérez et al., 2016).

2.5.2. Evaluation of the effect of humidity on basal metabolic rate of birds across different studies

Quantitative data of BMR and mass from both *Stilpnia* sample of this study was incorporated to a combined database of passerine birds from Londoño et al. (2015) and McNab (2009) (Annex 1). Values were converted to logarithmic data in order to linearize the relationship between BMR and mass, i.e, $\log_{10}$ BMR vs. $\log_{10}$ Mass (McNab, 1992). The effect of mass on BMR was evaluated using an ANCOVA (McNab, 2009).

To incorporate the effect of humidity, the level of relative humidity of each bird experiment was categorized. Categories were assigned considering the relative humidity percentages of the places where birds were captured, or from places near them. Relative humidity data was acquired from the online website http://www.timeanddate.com/, and codes were given in accordance with Ku-Mahamud & Khor (2009) (Table 1).

To analyze the effect of humidity, a new ANCOVA was performed with relative humidity as a fixed categorical factor with three levels (L, H, V). Furthermore, in order to test if BMR is significantly different across humidity levels (Londoño et al., 2015; Scholer et al., 2019), one ANOVA was conducted for temperate species, and another ANOVA, for tropical species.

Moreover, to search for other factors affecting BMR, other models were evaluated. On these models, the added fixed factors included family (as a way to account for phylogenetic effects) and ecological factors previously studied by McNab (2009) like food habits, climate (tropical vs temperate), and habitat. Other ecological factors like torpor or flightless condition were not considered because all passerine birds can fly, and only a few enter torpor (McNab & Weston, 2018).

2.5.3. Comparison of BMR between *Stilpnia* tanagers across different studies

To visually compare the BMR of both tanager species from this study, *S. heinei* and *S. vitriolina*, with other BMR published from other *Stilpnia* species, a simple graph of mass-independent BMR vs. humidity level was prepared. Mass-independent BMR information is presented as the residuals from the only-mass ANCOVA model (see section 2.5.2), or as mass-corrected BMR (Tieleman et al., 2003). Statistical analyses with these data were not possible to conduct because of limited sample size available for every species (Bennett & Harvey, 1987). However, at the family or genus levels, statistical analyses can indeed be properly done, as explained in the sections above.

3. Results

3.1. Estimations of basal metabolic rate, thermal conductance and the thermoneutral zone

3.1.1. Estimations of *Stilpnia heinei*

Out of 5 captured individuals of *Stilpnia heinei*, 16 total measurements were obtained at ambient temperatures ranging from 11.04°C to 30.38°C. The obtained data is summarized in Table 2, and the graph of metabolic rate as a function of environmental temperature is shown in figure 9.

Overall, the piecewise linear regression indicated a change in the slope at an ambient temperature of 20.68°C, which is considered the lower critical limit of the thermoneutral zone (TNZ). The metabolic rate values of the points above this limit show a mean value of 1.55 ± 0.05 KJ/h, which is an estimation of the basal metabolic rate (BMR). This value of BMR is 41.30% greater than the one expected for a passerine bird with a mass of 19.91 g, which is 1.09 KJ/h according to equation (3). On the other hand, the mean thermal conductance value, obtained from equation (4), equals 0.072 KJ/h°C, which is the same value as the slope of the regression line below the critical limit. This value of thermal conductance is 19.91% greater than the one expected for a passerine bird with a mass of 19.91 g, which is 0.060 KJ/h°C according to equation (5).

3.1.2. Estimations of *Stilpnia vitriolina*

For *Stilpnia vitriolina*, 3 individuals were captured, with one recapture, and 15 total measurements were obtained at ambient temperatures ranging from 9.2°C to 30.1°C. The obtained data is summarized in Table 3, and the graph of metabolic rate as a function of environmental temperature is shown in figure 10.

The piecewise linear regression showed that the lower critical limit of the TNZ is at an ambient temperature of 21.66°C. The mean BMR, obtained from metabolic rates above the lower TNZ limit, is 1.61 ± 0.05 Kj/h, which is slightly greater than the one of *S. heinei*. Also, this value is 38.49% greater than expected for a mass of 21.6 g, which is 1.16 Kj/h according to equation (3). Regarding thermal conductance, the mean value from equation (4) equals 0.084 Kj/h°C ± 0.03, which is similar to the value estimated from the slope (0.0806 Kj/h°C). The thermal conductance value is also greater than the one of *S. heinei*, and is 35.03% greater than the one expected for a mass of 21.6 g, which is 0.063 Kj/h°C according to equation (5).

3.2. Bootstrap comparison of thermal conductance between the *Stilpnia* tanagers from this study

The bootstrap analysis showed that the difference in slopes of the regression line below the thermoneutral zone between both species of this study, *S. heinei* and *S. vitriolina,* is not significant. This means that there is not a significant difference on thermal conductance between both tanagers. A histogram of the differences between resampled slopes is shown in figure 11.

3.3. Effect of humidity and other fixed factors on the basal metabolic rate of birds across different studies

ANCOVA analysis performed on the combined dataset of passerines showed that $\log_{10}$ BMR correlates significantly to $\log_{10}$ mass ($F_{1,476}$=2799.5, P< 2.2e-16), and it explains 85% of the variation, r^2=0.854 (Figure 12). This r^2 value is lower than the one obtained from McNab's data only, in which the correlation ($F_{1,280}$=3209.6, P< 2.2e-16) explains almost 92% of the variation, r^2=0.919. On the contrary, our r^2 is greater than the one of Londoño's data, in which the correlation ($F_{1,194}$=418.91, P< 2.2e-16) explains barely 68% of the variation, r^2=0.683.

When relative humidity was introduced into the model as a fixed factor, ANCOVA analysis indicated a correlation to $\log_{10}$ BMR ($F_{2,474}$=4.08, P=0.017). However, the explained variation increased very little, in relation to the only-mass model, from r^2=0.854 to r^2=0.857. The separate ANOVA analysis performed on tropical and temperate species showed that mass-independent BMR of tropical species don't differ significantly between humid or arid places ($F_{2,324}$=0.99, P=0.371) as seen in Figure 13a. The opposite occurred in the case of temperate species, with mass-independent BMR differing significantly between humid and arid species ($F_{2,138}$=8.28, P<0.05) as seen in Figure 13b. However, interpretation of these results should be made with caution, as the data for tropical species contains a lot of outliers, and there is not enough data of individuals living in very arid places.

For the phylogenetic model the ANCOVA results showed that $\log_{10}$ BMR correlates with family affiliation ($F_{54,422}$=1.75, P=0.001), and the model appears to explain a big part of the unexplained variation of the only-mass model with an increase of 2.7%, r^2=0.881. However, further analysis of the model could be complex or lead to less solid conclusions given the large number of degrees of freedom (74 families).

On the model including more ecological factors, the explained variation increased to 87.4%, r^2=0.874. Correlations occurred between $\log_{10}$ BMR with relative humidity ($F_{2,443}$=4.32, P=0.013) and climate ($F_{3,443}$=9.75, P=3.02e-06), but not between $\log_{10}$ BMR and food ($F_{18,443}$=1.14, P=0.304), nor habitat ($F_{10,443}$=0.95, P=0.485). All the ANCOVA models with their respective F, P, r^2 are shown in Table 4.

The effect of humidity on BMR can be seen in Figure 14, in which the mass-independent BMR values (residuals of the only-mass model) of birds from low humidity places are much lower than the ones expected. On the other hand, as humidity levels rise, so do the values of BMR, with values from humid places being slightly lower than the ones expected, and values from very humid places being greater than expected.

Regarding climate zones, Figure 15 shows that temperate species appear to have mass-independent values greater than the ones expected, while tropical ones have values lower than expected for their mass. This agrees with several studies like Bennett & Harvey (1987) and Wiersma et al. (2007).

3.4. BMR differences between *Stilpnia* tanagers across different studies

The plot of mass-independent BMR, i.e., residuals from the only-mass ANCOVA model, as function of relative humidity levels between *Stilpnia* tanagers is shown in Figure 16. At first glance, it seems like there is not a big difference between the BMR values of *S. vitriolina*, *S. heinei*, and *S. cyanicollis*, which all have BMR above the ones expected. However, it isn't the case for the BMR value of *S. larvata* which, apart from being lower than expected, appears to be very different from the ones of the other three species. Mass-corrected BMR values, shown in Table 5, better indicate the difference between BMR of *S. larvata* and the other *Stilpnia* tanagers. Moreover, it can be seen that even though measured BMR of *S. vitriolina* is greater than the one of *S. heinei*, this changes when we control the factor of mass and use mass-corrected values of BMR.

4. Discussion

4.1. Humidity levels correlate with an increase in the basal metabolic rate

In this study, humidity was proven to have an effect on avian metabolism, with species from arid environments having lower mass-independent BMR than species from humid places (Figure 14). Even though this pattern on metabolic rates is seen and somehow addressed in other studies (Fristoe et al., 2015; Tieleman & Williams, 2000; Vleck & Vleck, 1979), this is the first one, to my knowledge, where a quantitative analysis was performed and a statistically significant correlation between relative humidity and BMR has been demonstrated. In general, this correlation can be attributable to two main reasons: (1) BMR is a representation of the energetic demand to environments with different resource availability, (2) BMR represents a thermoregulatory response to different humidity conditions.

Supporting evidence exists for both ideas. First, humid places tend to be characterized by an abundance of water and food sources, leading animals to be able to maintain a high cost of energetic demands, and exhibit greater BMR values. These is not possible if environment conditions, specially obtention of food, are poor (Burton et al., 2011). In fact, Tielman & Williams (2000) have stated that a reduction in rates of energy expenditure in desert species is the result of an adjustment to low primary productivity and scarcity of surface water, a conclusion supported by other authors (Lindstrom & Kvist, 1995; Londoño et al., 2015; McNab, 2009). Data from this study also lead to similar conclusions, with *S. vitriolina*, that inhabits less productive dry valleys, showing lower mass-independent BMR than *S. heinei*, which inhabits highly productive humid forests.

A conclusion leading to the second idea is more debatable because the use of BMR as a thermoregulatory mechanism is different for temperate and tropical species. This is suggested by studies analyzing BMR at increasing elevations, which should be greater as ambient temperatures decrease. Even though temperate birds would exhibit the expected pattern (Scholer et al., 2019), this is not the case for tropical birds, as the increase in elevation showed no significant differences on their BMR, indicating that these species may not rely on BMR as their primal mechanism for thermoregulation (Londoño et al., 2015). In this study, a similar result is suggested for the case of humidity by the ANOVA analyses observed in figure 13, where temperate birds show a significant difference of mass-independent BMR among humidity categories, while tropical birds don't. The reason behind this incompatibility could be the explained by a less climate seasonality present across environments in tropical regions (Londoño et al., 2015).

Understanding the effects of humidity on thermoregulation and BMR is further complicated when, in theory, low levels of BMR can be beneficial for thermoregulation on both arid and humid species. For instance, BMR is correlated to high expenditures of water for evaporative cooling as ambient temperature increases (Gavrilov, 2017). Therefore, low BMR could benefit arid species as it decreases their need for water evaporation, which is restricted by water scarcity (Tieleman & Williams, 2000; White et al., 2007). On the other hand, humid species could also benefit from a low need of evaporative cooling because its efficiency decreases with humidity. In fact, humidity alters the water vapor gradient between the body and the surrounding air (van Dyk et al., 2019; Weathers, 1997).

4.2. Thermoregulation on tropical birds appears to be more reliant on thermal conductance and the width of the thermoneutral zone

Due to the benefits, stated above, of having a low BMR on both types of environments, and the non-significant difference on BMR between humidity categories on tropical species, the effect of humidity on BMR appears to be unrelated to thermoregulation on tropical birds. Instead, these species could mostly rely on other mechanisms, rather than BMR adjustments, to respond to ambient temperature fluctuations. In fact, some studies have suggested that tropical birds under humid conditions could cope to elevated ambient temperatures by increasing their tolerance to high body temperatures, which means an increase in the upper critical limit of their TNZ, even recuring to facultative hyperthermia (Tieleman & Williams, 2000; van Dyk et al., 2019; Weathers, 1997).

Toleration to high ambient temperatures is a great way to counter heat exchange limitations present in humid environments. One example is presented by van Dyk et al.(2019), whom measured evaporative heat dissipation of variable seed-eaters (*Sporophila corvina*) at increasing temperatures under humidity conditions below the ones experienced in their environment, the results showed that *S. corvina* could tolerate body temperatures as high as 47°C in order to cope with an ambient temperature of 45°C, something they don’t even have face on their natural habitat. Likewise, other birds from humid environments could also be expected to have a wider TNZ. Indeed, *S. heinei* in this study presented a lower critical limit than *S. vitriolina*, which could indicate a wider TNZ. However, the total width of the TNZ of both species remains to be established as the upper critical limit was not reached, even at temperatures of 30°C.

Another way to cope with heat stress in a humid environment is through changes in thermal conductance, which could be another main thermoregulatory mechanism used by tropical birds. In fact, those studies performed along an elevation gradient, which resulted in not-significant differences on BMR, indicated significant differences on thermal conductance (Scholer et al., 2019). However, it doesn't appear to be the case for the *Stilpnia* tanagers in this study. Even though *S. heinei* could benefit from releasing heat quickly at a place where heat exchange is restricted, its thermal conductance is lower than *S. vitriolina*.

The overall high BMR and low thermal conductance in a humid environment could suggest that the main thermoregulatory mechanism used by *S. heinei*, to cope with increases in ambient temperature, is having a greater tolerance to high body temperatures, which can be possible due to an increase in their TNZ (figure 9). On the other hand, for *S. vitriolina*, its low BMR, together with its greater conductance, could indicate a lower capacity to tolerate high body temperatures (figure 10), something not very necessary given the ease of releasing heat in more arid environments.

4.2. Phylogeny vs. ecology: Elucidating the observed patterns

In this study, family association showed a significant correlation with BMR, according to the ANCOVA analysis, and increased the explained variation of the only-mass model. That variation could be caused by large species of Passerine families like Thrushes from the genus *Turdus*, and Corvids, which present significant higher basal metabolic rates (McNab, 1988). However, the issue of including family affiliation in this study is that it can mistakenly overdrive the influence of humidity and other ecological factors on BMR (McKechnie & Wolf, 2004; Westoby et al., 1995).

When performing a comparative study between closely related species, variations of a trait are restricted by a shared common ancestry that produces similar phenotypes (Møller, 2009). However, when those species are facing completely different ecological conditions, such as humidity levels, they can exhibit significant differences on their features, which is the reflection of adaptation to a selective environment (McNab, 2009). On these cases, ecological factors could be better indicators to explain a trait's variability. In fact, even though characters are derived from a common ancestor, their maintenance is a reflection of their good performance to the conditions faced on the environment (McNab, 2016). Therefore, variation of a given feature should tried to be explained by the environmental factors that might be responsible for their maintenance (McNab, 2009). Indeed, in most studies, conventional analyses arrive to similar conclusions as phylogenetic analyses about the effects of environmental factors on a trait's variability (Tieleman & Williams, 2000; White et al., 2007; Wiersma et al., 2007).

In this study, besides humidity, three ecological factors —climate, food, and habitat— were suspected to significantly affect BMR. The ANCOVA results showed that only climate has a significant correlation with BMR, with temperate birds having a greater mass-independent BMR values than tropical species (Figure 15). This correlation could be the result of temperate birds being susceptible to more climate seasonality (as stated in section 4.1). On the contrary, habitat and food were not significantly correlated with BMR, contrasting with the results found by McNab (2009). In regards to habitat, a non-significant correlation could be explained by the lack of marine species on the database, which were the ones responsible for significant BMR differences in McNab's (2009) study. Concerning food, a disparity between the classification of diet used by McNab (2009) and the one applied to Londoño's (2015) database could have misled a non-significant influence on BMR by diet habits.

4.3. The effect of humidity on BMR is not appreciable on comparisons between *Stilpnia* species

When performing a comparative study at lower taxonomic levels, i.e., genus or species, difficulties appear when trying to obtain enough data. For example, in this study BMR data from only two *Stilpnia* tanagers could be obtained from literature despite the fact that there are, currently, 13 species belonging to that genus (Figure 17).

Comparison of BMR data on those four species showed that three of them —*S. heinei*, *S. vitriolina*, and *S. cyanicollis*— have similar values, but differ considerably with mass-independent BMR of *S. larvata*. This huge variation between *S. larvata* and the other three tanagers is hardly explained by differences in their biology because, apart from having different distributions in Ecuador (Figure 18), they all share similar traits (Burns et al., 2016). On the contrary, this difference in BMR values appear to be derived from experimental challenges when obtaining data.

4.3. Challenges when comparing metabolic rates

Even though research on energetics and BMR has been carried out over many years, there are still some complications that make it difficult to identify evident patterns on the measurements obtained, just as seen with the four tanagers on this study. A lot of those problems arise from the lack of a common methodology that could be applicable for any species. In regards to the two *Stilpnia* data obtained from literature, the BMR value of *S. cyanicollis* was measured at very similar conditions as *S. heinei* and *S. vitriolina* in this study. However, BMR of *S. larvata* was measured using a chamber with an added layer of mineral oil. The function of the layer was to trap excrement and exclude it as a source of water vapor that could increase humidity inside the chamber. This reduction of inner humidity could have affected the measurement of BMR as stated by van Dyk et al.(2019), which could explain the contrasting difference of *S. larvata*'s BMR value with the other three species. Nevertheless, it would be imprecise to argue that such a distinction in BMR values could be the result of just one methodological difference.

In fact, several factors, across studies, are not taking into account when measuring metabolic rates, like humidity inside the chamber, capture stress, and the seasonality at which measurements are made. The lack of regulation of those variables is due to the fact that their effects are, mistakenly, considered insignificant. As an example, some studies considered that metabolic data of birds kept in captivity didn't differ from the data of recently caught birds. However, nowadays it is suggested that the true effect of captivity in birds could be species specific (McNab, 2009). Moreover, variation on stress response during measurements could come from a personality component. Indeed, it has been suggested that behavioral responses to stress among individuals during measurements can cause an overestimation of BMR values (Burton et al., 2011; Careau et al., 2008; McNab, 2009). The way each individual elicits a stress response during metabolic experiments depends on their personality, with proactive or aggressive birds expending energy to evacuate stress at a higher rate than the reactive ones (Careau et al., 2008). The result of such contrast would cause proactive individuals to notably reach the period of inactivity rapidly, whereas reactive individuals would present a long-lasting stress response that could generate imperceptible stress-inflated values (Careau et al., 2008). The management of individual stress responses associated with experimental conditions are not always discussed in literature, which adds to the problem of comparing data from different studies (McKechnie & Wolf, 2004).

Another problem, especially when comparing metabolic rates, is given by the difficulty to obtain a significantly large sample size in order to reach reliable conclusions. Indeed, if we want to perform a strong statistical analysis, the data must be —ideally— independent, which is not achieved in this type of studies because repeated measurements are common due to the difficulty of capturing new individuals (McNab, 2009; Nakagawa et al., 2024). In the case of this study, BMR data of *S. heinei* and *S. vitriolina* was obtained from 3-5 individuals; on the other hand, BMR data of *S. cyanicollis* was obtained from measurements on just one individual, and for *S. larvata* the information about the number of individuals is not even given. The small sample size of *S. cyanicollis* and *S. larvata* could be adding to the BMR variation observed between species. In fact, the use of small samples could lead to wrong estimations of metabolic rates, a problem that has been recognized by scientists such as McKechnie & Wolf (2004), whom suggest a sample size of $n \geq 3$ individuals for metabolic measurements.

On the other side of the coin, although it is recommended to perform measurements on as many individuals as possible, it is important to take into account that a small sample size is not always synonymous with a small effect (Nakagawa et al., 2024). In fact, even though studies that work with small sample sizes would predict imprecise results, all of them collectively can exhibit patterns capable of providing an accurate estimate of a true effect (Nakagawa et al., 2024). Therefore, when the obtention of a large number of independent samples gets difficult, non-significant results and qualitative patterns, as the ones presented in this study, could also represent an important source of information.

4.4. What’s left to do?

Leaving aside the methodological problems, presented in the previous section, the main obstacle that scientists face when analyzing animal energetics is found in the complexity of thermoregulatory processes of endotherm organisms, which involve both physiological and behavioral mechanisms (Fristoe et al., 2015). Even though the majority of avian energetic studies focus on comparing BMRs, most of them don’t present data of thermal conductance nor the critical limits of the TNZ, something necessary to understand the true effect of factors like climatic elements, energy and water budget in the thermoregulation of birds in different environments (Vleck & Vleck, 1979). Furthermore, in order to further add weight to the argument that differences in BMR at humid and arid environments occur due to resource availability, metabolic studies under field conditions must be carried out, as they will help us to understand the real energy expenditure during activity. Those field experiments should then be compared with laboratory studies in order to dissect the real components of avian energy expenditure (McNab, 1989).

Finally, given the little implication of BMR on thermoregulation in tropical birds, contrary to what is observed in temperate zones, it is important to carry out more studies on tropical species, especially the ones found in South America, as only data of Peruvian birds is found in literature (McNab, 2009). Moreover, as seen in Figure 13, not enough data of tropical birds living in very arid places is available, which makes it difficult to evaluate the true effect of humidity. Specially, when birds from arid places are the ones causing a significant BMR difference on temperate birds.

Expanding data of tropical species across a broader geographic extent would be useful to study their capacity to adjust thermoregulatory mechanisms at different ambient temperatures and humidity levels (Pollock et al., 2021), Moreover, the data would allow scientists to explain and predict changes in the species distribution, as well as to evaluate the impact of challenges faced by a warming world (Smith et al., 2015). Regarding the later, a study performed by Pollock et al.(2021) concluded that tropical birds from Panama do not present a higher susceptibility to global warming than the birds found in temperate zones, despite giving the impression of being more sensitive to climate changes on their environment. Indeed, it is actually predicted that even a global temperature increase of 3-4°C by 2050 would not exceed the thermal safety margins of tropical birds. However, we must consider that those increases are referring to the mean ambient temperatures of the planet, but the real impact of global warming occurs when extreme heat waves become more frequent and intense, which can cause a catastrophic mortality in tropical birds (Pollock et al., 2021). Therefore, the constant study and understanding of avian energetics and thermoregulation is a key tool to comprehend and protect the great diversity of the unique species present in the tropics.

5. Conclusions

- Humidity has a significant effect on the metabolism of passerine birds, with those living in drier environments having a lower BMR. This effect appears to be mainly explained by the difficulty of obtaining water and food in environments at drier conditions. Moreover, the correlation between relative humidity and BMR doesn’t appear to be restricted by phylogeny.
- Species from tropical environments do not seem to rely on BMR as a primal mechanism for thermoregulation. Instead, thermoregulation in these species appears to be achieved through a coordination of other physiological responses that include modifications in the thermal conductance and the limits of the thermoneutral zone.
- The data obtained from *S. heinei*, in comparisson to *S. vitriolina*, includes a high basal metabolic rate and low conductance. This suggests that the main thermoregulatory mechanism for *S. heinei* in response to increasing ambient temperatures is the enlargement of the TNZ, which implies a greater tolerance to elevated body temperatures.
- In addition to phylogeny and ecological factors, it is important to consider the effects of inter-individual variation when performing inter-specific comparisons. In fact, the exclusion of factors such as individual personality, stress levels, and data collection methods could lead to miscalculations of metabolic data.
- More metabolic measurements are needed in tropical species from different environmental contexts. This would be useful to understand the true role of metabolic processes as mechanisms of thermoregulation.

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Tables

Table 1. Categorization of relative humidity percentages based on the study of Ku-Mahamud & Khor (2009)

Relative humidity (RH) (%)	Description	Code
RH<50%	Low RH	L
50%≤RH<80%	High RH	H
RH≥80%	Very High RH	V

Table 2. Experimental data obtained from measurements on *Stilpnia heinei*.

Individual code[a]	**Weight (g)**	**Body temperature (°C)**	**Ambient temperature (°C)**	**Delta O_2 (%)**
STIHEI-001-R1	19.9	38.47	21.6	0.7
STIHEI-001-R2	19.55	41.27	11.2	1.13
STIHEI-001-R3	19.35	40.45	27.2	0.88
STIHEI-002-R1	19.9	40.17	23.04	0.93
STIHEI-002-R2	19.5	40.97	12.19	1.06
STIHEI-002-R3	19	41.59	28.7	0.82
STIHEI-003-R1	19.3	40.05	20.68	0.72
STIHEI-003-R2	19.05	39.87	11.04	1.03
STIHEI-004-R1	21.85	40.02	11.86	0.95
STIHEI-004-R2	21.3	40.81	30.38	0.72
STIHEI-004-R3	20.8	39.97	21.15	0.77
STIHEI-004-R4	20.35	39.82	11.68	1.12
STIHEI-005-R1	20.95	40.56	28.7	0.78
STIHEI-005-R2	20.5	40.43	28.89	0.75
STIHEI-005-R3	20.1	40.27	14.8	0.96
STIHEI-005-R4	19.8	40.06	11.74	1

[a] Individual codes include the three initial letters of the genus (*Stilpnia*), the three initial letters of the epithet (*heinei*), a number for each captured individual, and the run carried out at a different temperature.

Table 3. Experimental data obtained from measurements on *Stilpnia vitriolina*.

Individual code[a]	Weight (g)	Body temperature (°C)	Ambient temperature (°C)	Delta O_2 (%)
STIVIT-001-R1	21.2	40.9	23.67	0.8
STIVIT-001-R2	20.6	39.76	16.06	0.97
STIVIT-001-R3	20.2	40.02	28.82	0.73
STIVIT-002-R1	23.1	40.73	30.1	0.8
STIVIT-002-R2	22.5	39.42	11.06	1.15
STIVIT-002-R3	22.1	39.72	12.32	1.3
STIVIT-002-R4	21.9	41.37	21.23	0.93
STIVIT-002-R5[b]	22.7	40.3	11.98	1.13
STIVIT-002-R6[b]	22.0	39.48	12.31	1.03
STIVIT-002-R7[b]	21.8	40.18	29.5	0.7
STIVIT-002-R8[b]	21.6	38.46	9.2	1.09
STIVIT-003-R1	22.3	39.4	16.65	0.98
STIVIT-003-R2	22	38.88	22.08	0.75
STIVIT-003-R3	21.5	39.6	21.66	0.75
STIVIT-003-R4	21.1	39.77	26.52	0.78

[a] Individual codes include the three initial letters of the genus (*Stilpnia*), the three initial letters of the epithet (*vitriolina*), a number for each captured individual, and the run carried out at a different temperature.

[b] Measurements of the individual at the day of recapture.

Table 4. ANCOVA results of several models testing for significant correlations between basal metabolic rate (BMR) and different fixed factors.

Model	**Covariate**	**Fixed factor**	***F* value**	***p* value**	$\mathbf{r^2}$
Only mass	Log_{10} Mass	- None	$F_{1,476}=2799$	$< 2.2\text{e-}16$	0.854
Only RH	Log_{10} Mass	- Relative humidity	$F_{2,474}=4.08$	=0.017	0.857
Inclusion of other ecological factors	Log_{10} Mass	- Relative humidity	$F_{2,443}=4.32$	=0.013	0.874
		- Climate	$F_{3,443}=9.75$	=3e-06	
		- Food	$F_{18,443}=1.14$	=0.304	
		- Habitat	$F_{10,443}=0.95$	=0.485	
Family affiliation	Log_{10} Mass	- Family	$F_{54,422}=1.75$	=0.001	0.881

Table 5. Experimental data, from different studies, of four *Stilpnia* species.

Species	Mass (g)	BMR (Kj/h)	Mass-independent BMR (Kj/h)	Source
Stilpnia heinei	16.3	1.55	0.15	This study
Stilpnia vitriolina	21.6	1.61	0.14	This study
Stilpnia cyanicollis	16.2	1.26	0.12	Londoño et al. (2015)
Stilpnia larvata	19.91	0.85	-0.04	McNab (2009)

Figures

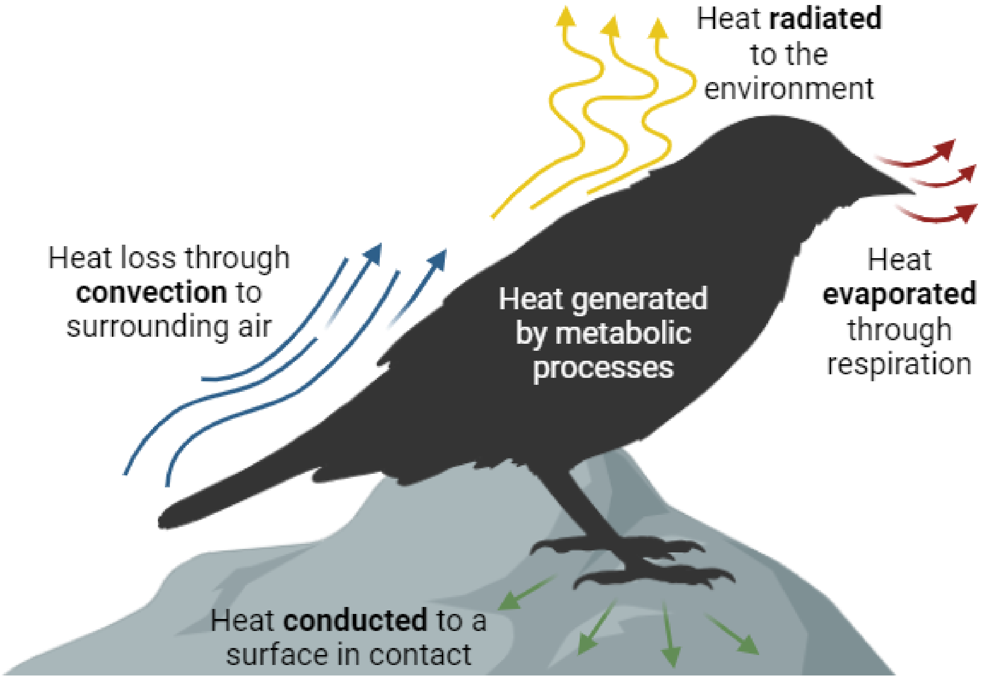

Figure 1. Physical pathways for heat loss in birds. For the majority of Passeriformes, most of the heat is lost through evaporation of water in the respiratory track. Illustration by Jimmy Arias.

Figure 2. Wild individual of American kestrel (*Falco sparverius*) fluffing its feathers as a mechanism to preserve heat at cold ambient temperatures. Photo credits: ©Jimmy Arias Borja.

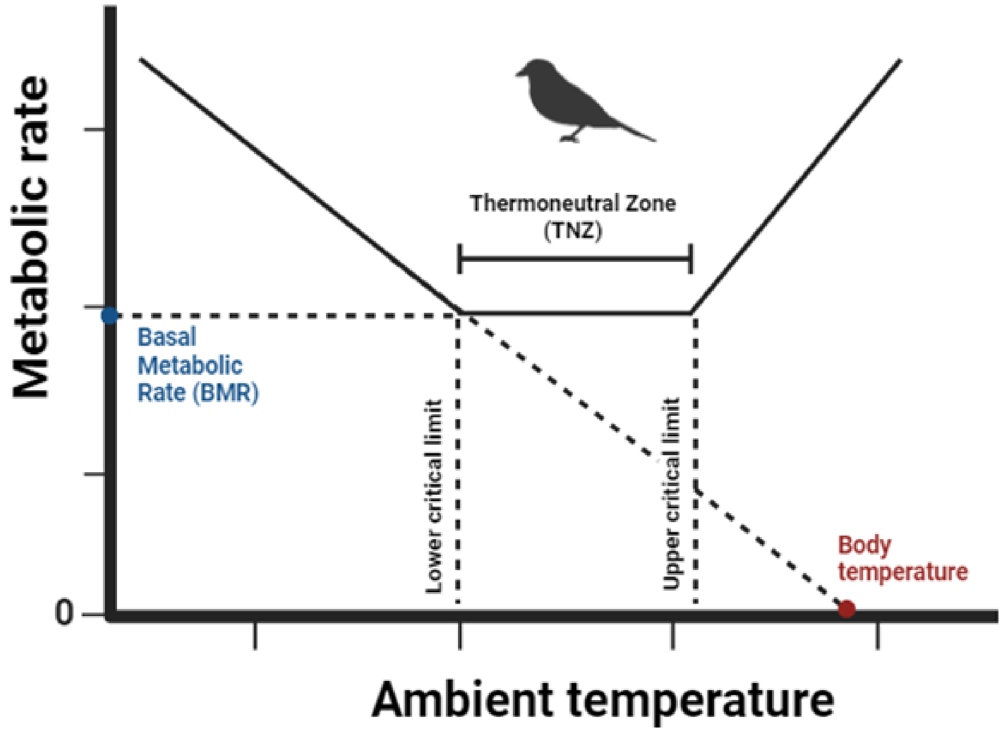

Figure 3. Metabolic graph (metabolic rate vs. ambient temperature) of an endotherm. The thermoneutral zone (TNZ) is marked as the range of ambient temperatures at which the animal maintains a constant metabolic rate, which is defined as the basal metabolic rate (BMR). Critical limits of the thermoneutral zone indicate the ambient temperatures at which the animal increases its metabolic rate for thermoregulation. Note that the extrapolation of the curve below the lower critical limit, which represents the thermal conductance (*C*), reaches the *x* axis at a value equal to the mean body temperature. Illustration by Jimmy Arias Borja.

Figure 4. Wild individuals of *Stilpnia heinei*, female on the left and male on the right, found at Puyucunapi Reserve, Pichincha, Ecuador. Photo credits: ©Jimmy Arias Borja.

Figure 5. Wild individuals of *Stilpnia vitriolina* found at the Yachay Botanical Garden, Imbabura, Ecuador. Photo credits: ©Jimmy Arias Borja.

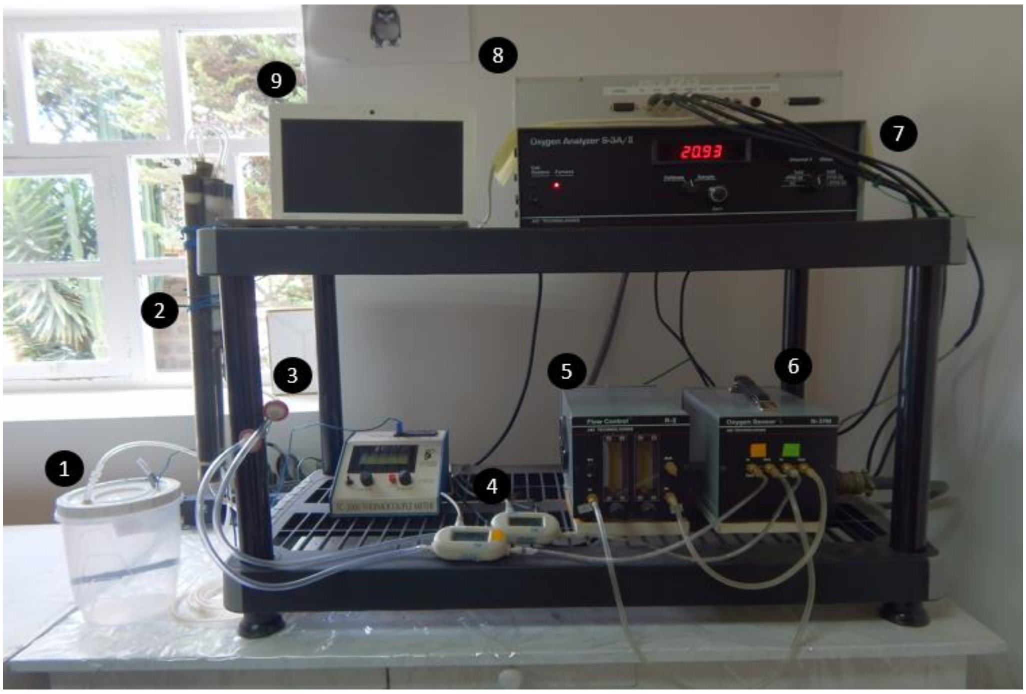

Figure 6. Open flow-through Respirometry System used for measurements. 1) Handmade metabolic chamber; notice the blue probe connected to the thermocouple meter. 2) Tubes containing silica gel beads and soda lime granules. 3) Syringe filters. 4) Flow-meters. 5) Flow controller. 6) Oxygen sensor. 7) Oxygen analyzer, notice a manual switch at the right side for the monitoring of oxygen percentage on the sample and control intake. 8) Interface Box. 9) Computer. For more details on how the respirometry system works, refer to the text. Photo credits: ©Jimmy Arias Borja.

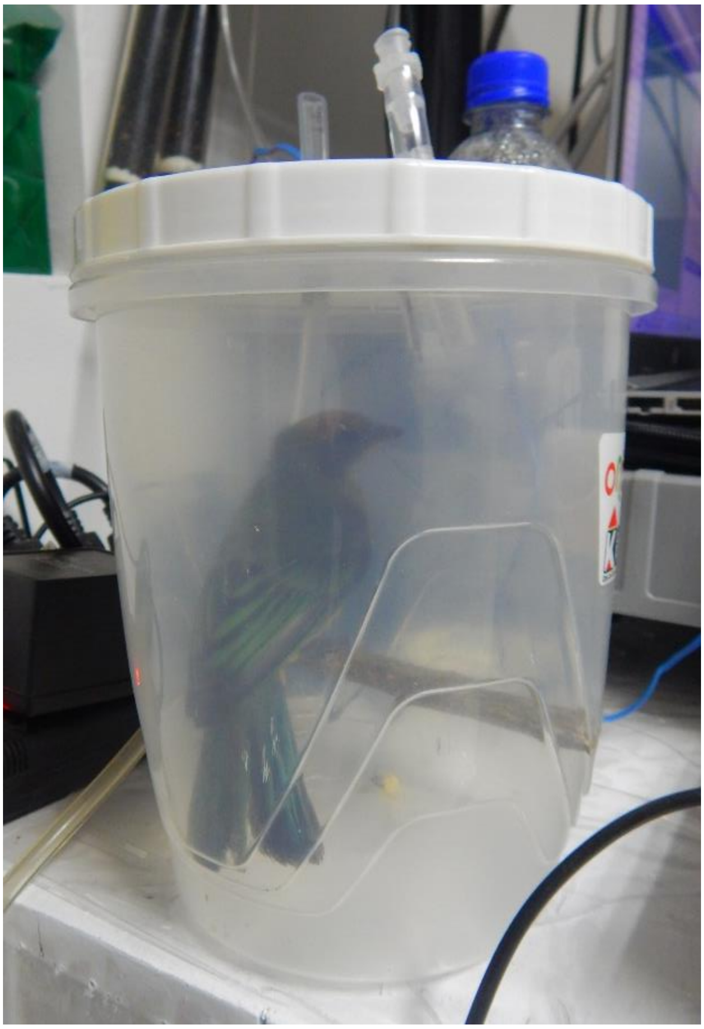

Figure 7. Individual of *Stilpnia vitriolina* inside the metabolic chamber. Notice the 2 small hoses protruding from the chamber, one of them for air intake and the other for connection to the respiratory system. A third tube, not noticeable in the picture, is used for the entry of a temperature probe. Before each measurement, the chamber was covered with a cloth bag or larger container to keep the bird under conditions of complete darkness. Photo credits: ©Jimmy Arias Borja.

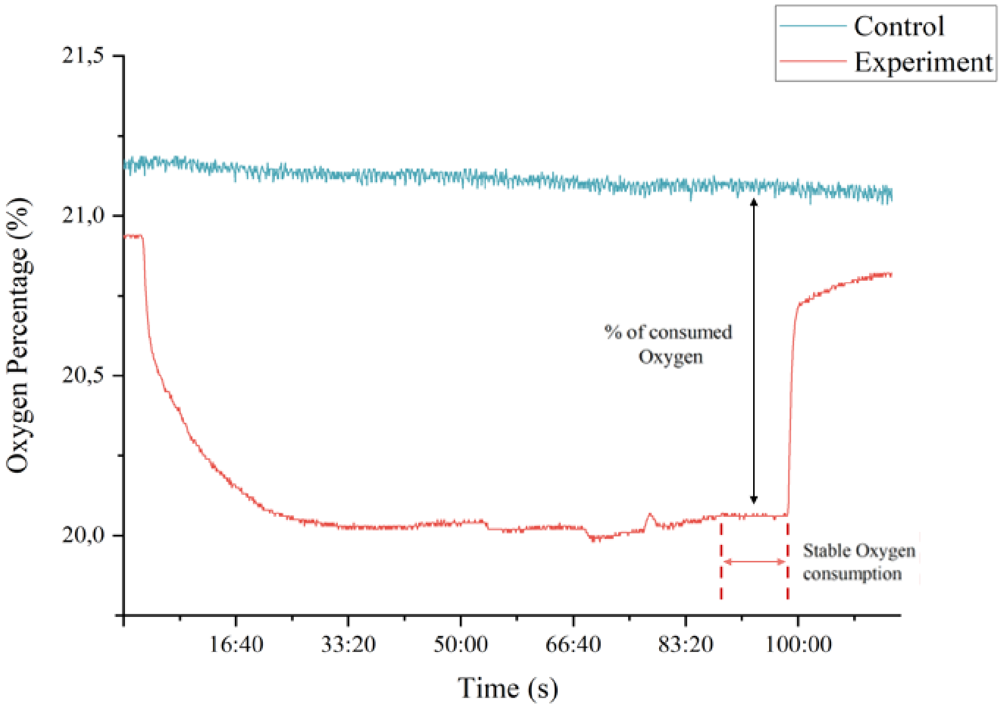

Figure 8. Plot of oxygen percentage (%) vs. time (s) obtained from one measurement of *Stilpnia vitriolina*. Excurrent fractional oxygen concentration $[O_2]_{ef}$, which is used for calculation of rate of oxygen consumption (R_{O_2}), was estimated as the mean value of % oxygen from the stable period of minor oxygen consumption (red arrow). Notice the small periods left for equipment stability before and after the run.

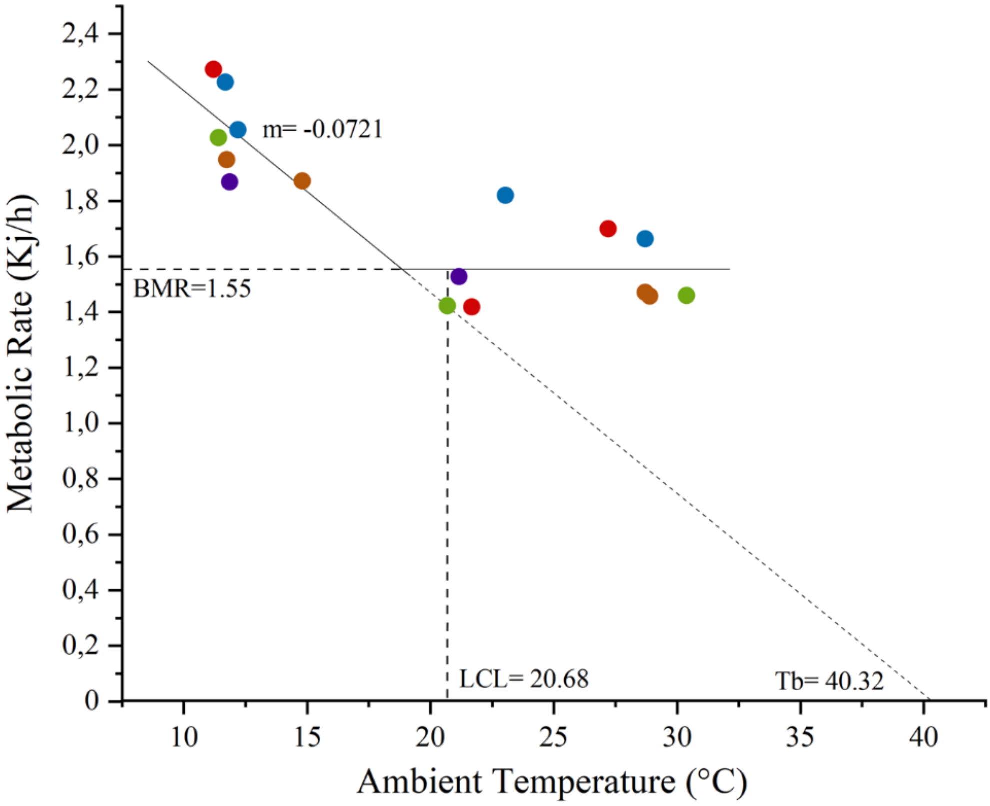

Figure 9. Graph of metabolic rate in relation to ambient temperature of *Stilpnia heinei*. Different colors for each point represent a different individual. The horizontal dashed line extrapolates to the *y* axis at a value equal to the mean basal metabolic rate (BMR = 1.55 Kj/h). The vertical dashed line extrapolates to the *x* axis at the lower critical limit (LCL = 20.68°C) of the thermoneutral zone (TNZ). Finally, the diagonal dashed line extrapolates to the *x* axis at the ambient temperature value that equals the mean body temperature (T_b = 40.32°C), the slope of the line is equal to the bird's thermal conductance (*C* = 0.072 Kj/h°C).

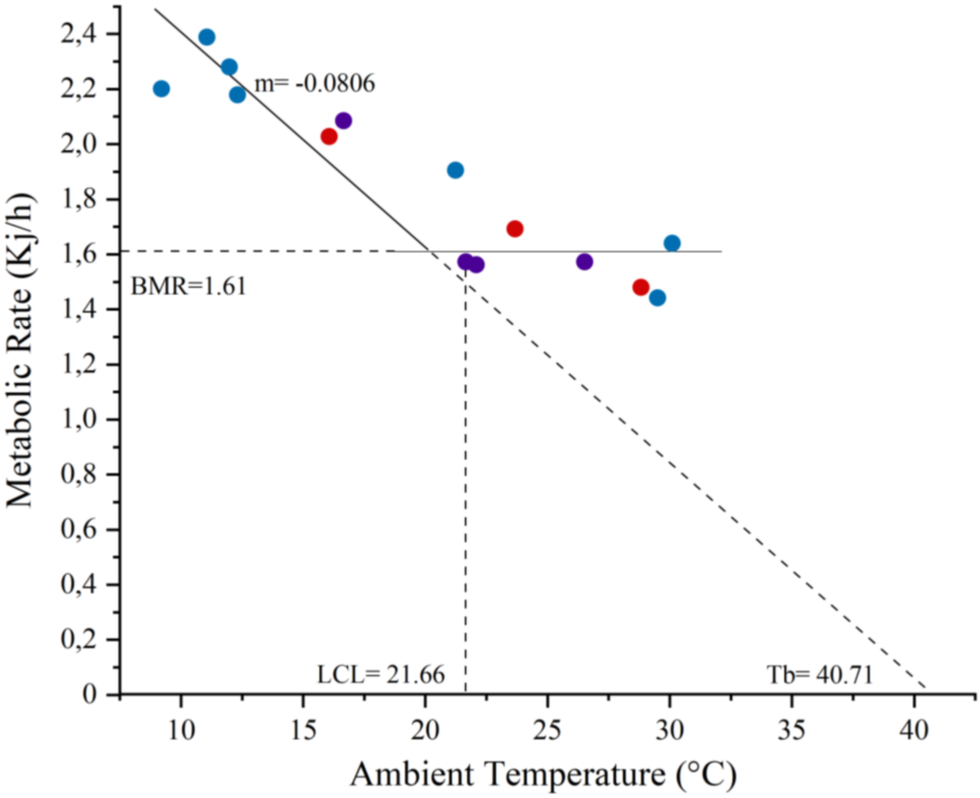

Figure 10. Graph of metabolic rate in relation to ambient temperature of *Stilpnia vitriolina*. Different point colors represent a different individual. The horizontal dashed line extrapolates to the *y* axis at the value equal to the mean basal metabolic rate (BMR = 1.61 Kj/h). The vertical dashed line extrapolates to the *x* axis at the lower critical limit (LCL = 21.66°C) of the thermoneutral zone (TNZ). Finally, the diagonal dashed line extrapolates to the *x* axis at the ambient temperature value that equals the mean body temperature (*Tb* = 40.71°C), the slope of the line is equal to the bird's minimal conductance (*C* = 0.081 Kj/h°C).

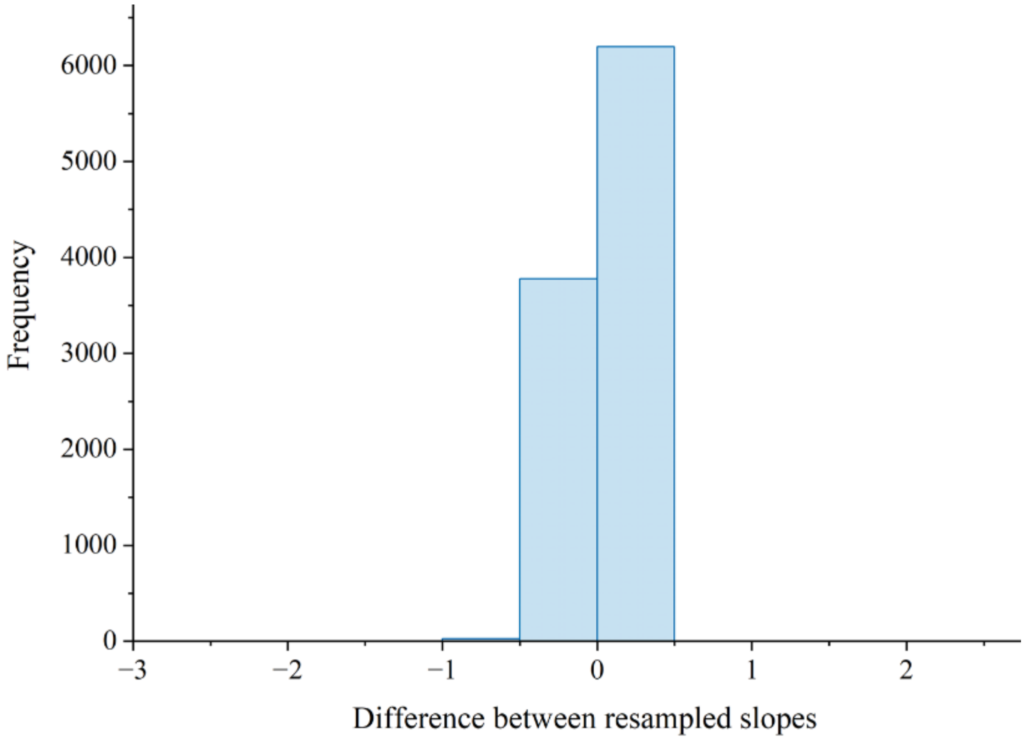

Figure 11. Histogram of differences between resampled slopes of the regression line below the thermoneutral zone of *S. heinei* and *S. vitriolina*. Most of the values are equal or near zero, which indicates a non-significant difference between the slopes, and therefore, a not-significant difference between thermal conductance of both species.

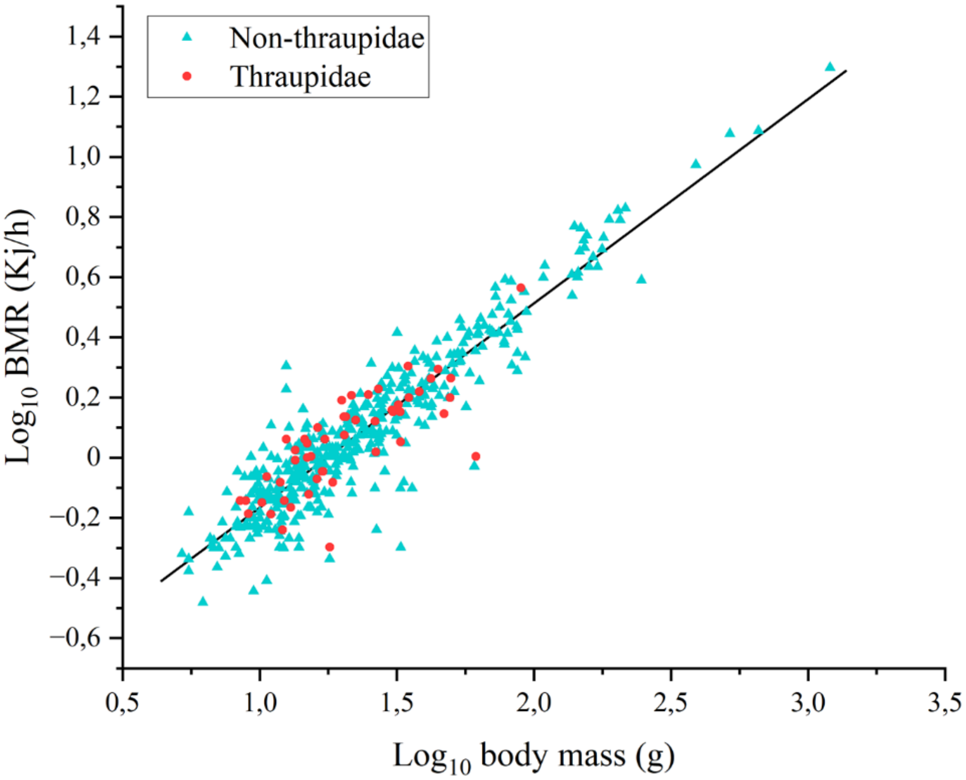

Figure 12. Log_{10} basal rate of metabolism as a function of $\log_{10}$ body mass in 478 species of passerine birds. Variation in basal metabolic rate (BMR) mostly stems from birds with lower body masses, including some from the Thraupidae family, which are represented by red circles.

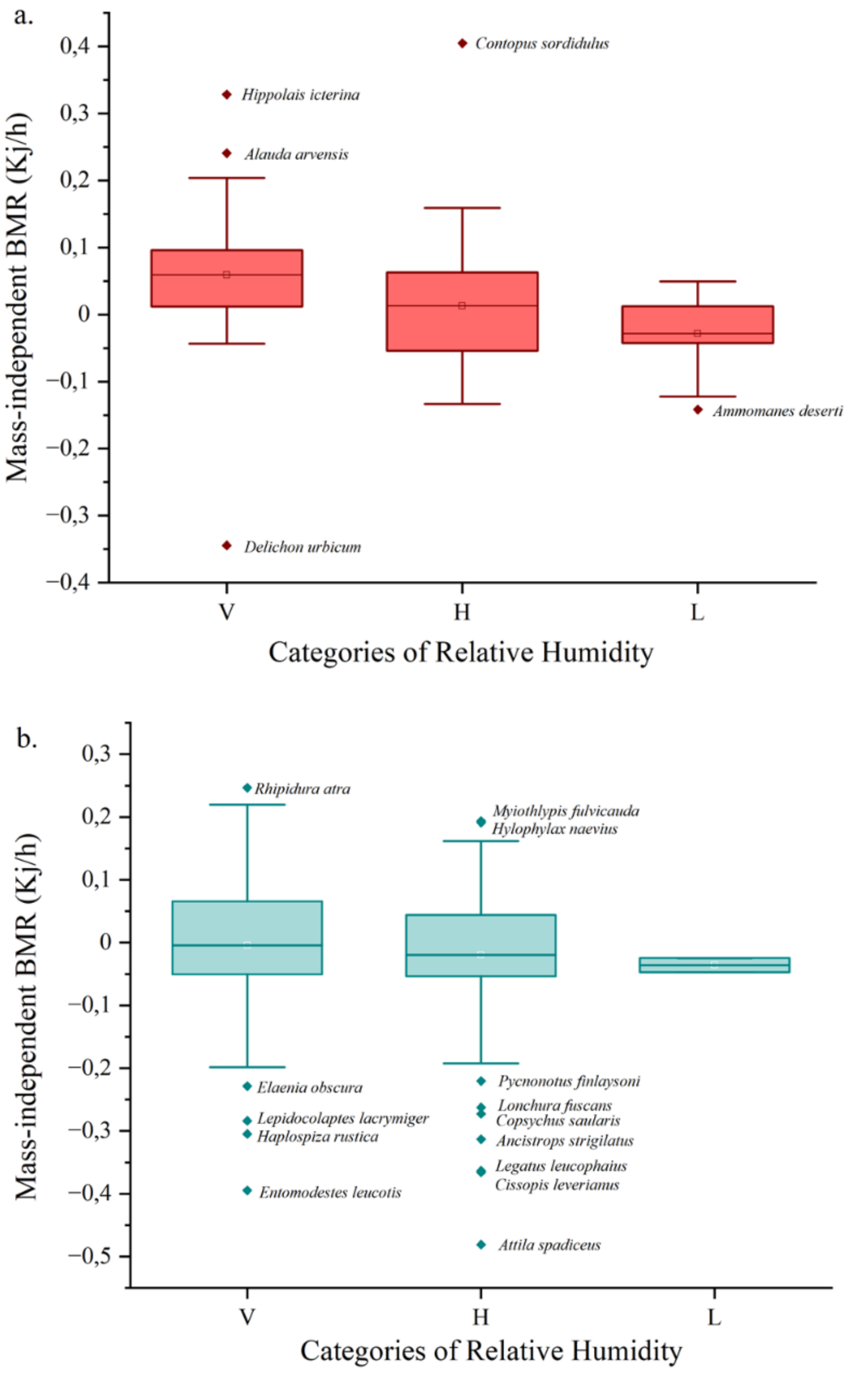

Figure 13. Boxplots of mass-independent BMR of 468 passerine species as a function of different categories of relative humidity in the environment. a) For 141 temperate species a significant difference can be seen for birds inhabiting places with low humidity. b) For the 327 tropical species, the means are not different for any of the groups. Notice that there are not enough data for species living in places with low humidity. Outliers are indicated on the graph.

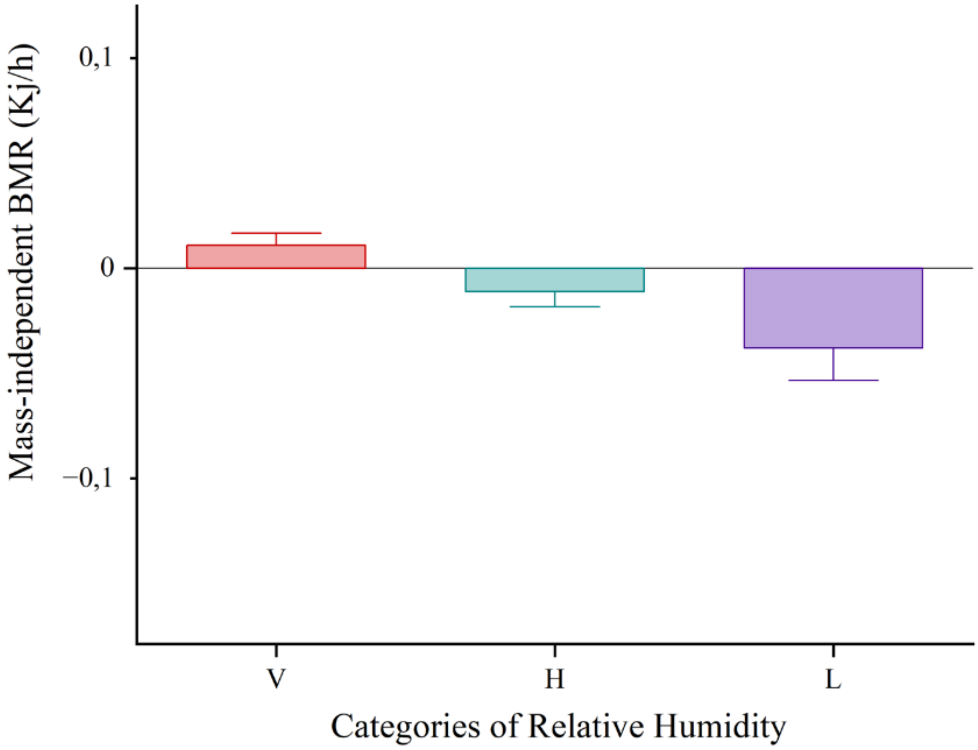

Figure 14. Bar chart of mass-independent BMR of 478 passerine species as a function of different levels of relative humidity in the environment. Notice a decreased BMR in environments with lower humidity.

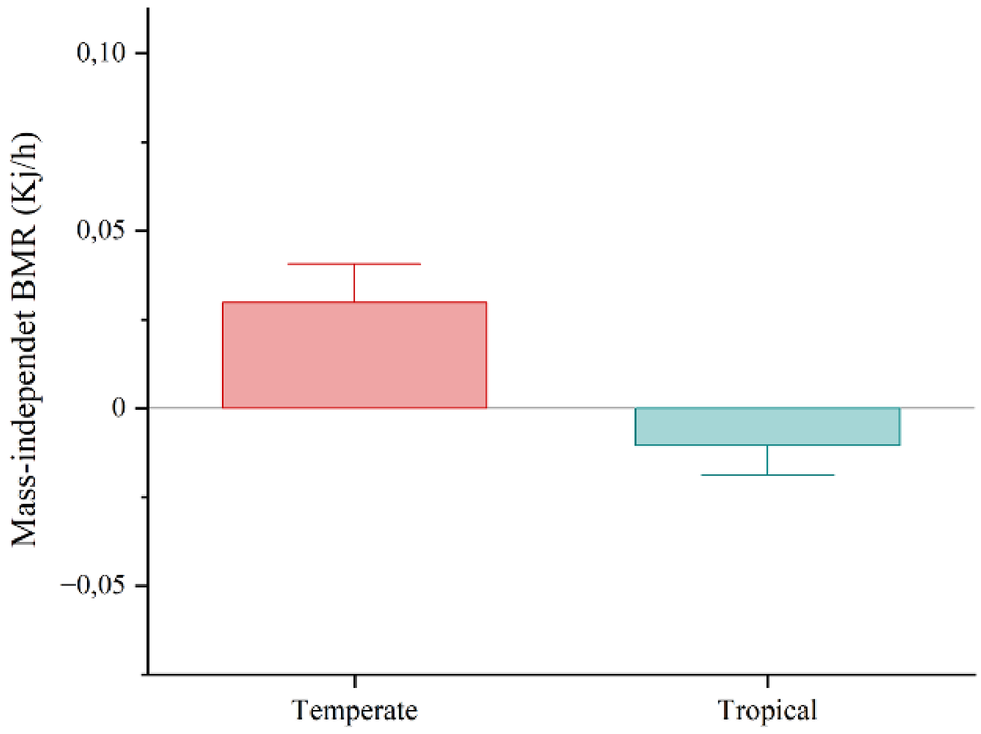

Figure 15. Bar chart of mass-independent BMR of 468 passerine species as a function of their climatic zone. Notice how the mean mass-independent BMR of temperate birds is greater than expected, while the opposite occurs for tropical species.

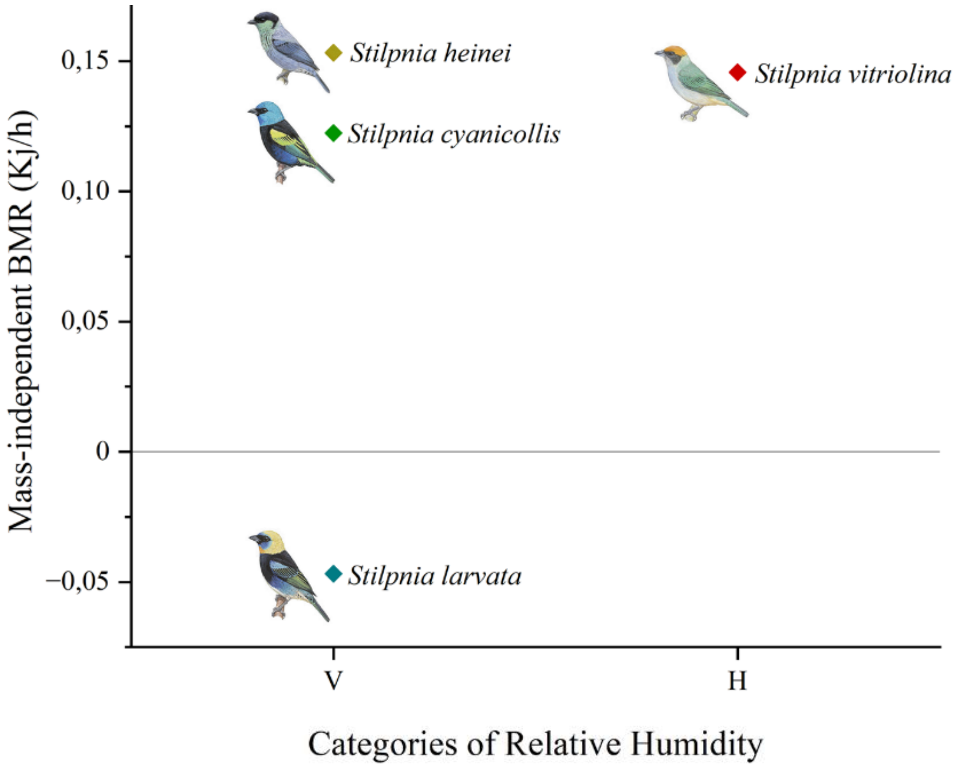

Figure 16. Mass-independent BMR of four *Stilpnia* tanagers as a function of the relative humidity category. Notice how the value of *S. larvata* is much lower than expected. Illustrations by Hilary Burn.

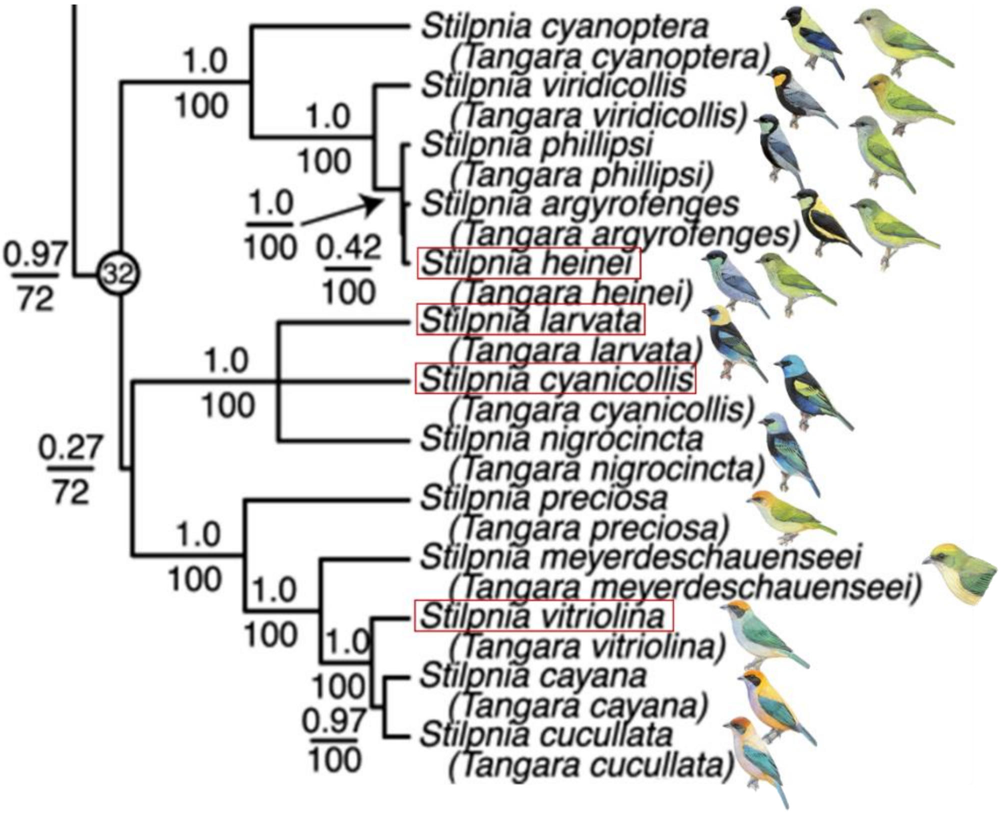

Figure 17. Phylogenetic tree of the *Stilpnia* genus. The four species with BMR data are enclosed in rectangles. Notice the close relationship between *S. larvata* and *S. cyanicollis*, and the more distant relationship with *S. vitriolina* and *S. heinei*. This figure is a segment of the phylogenetic tree of Thraupidae presented by Burns et al. (2016). Illustrations by Hilary Burn.

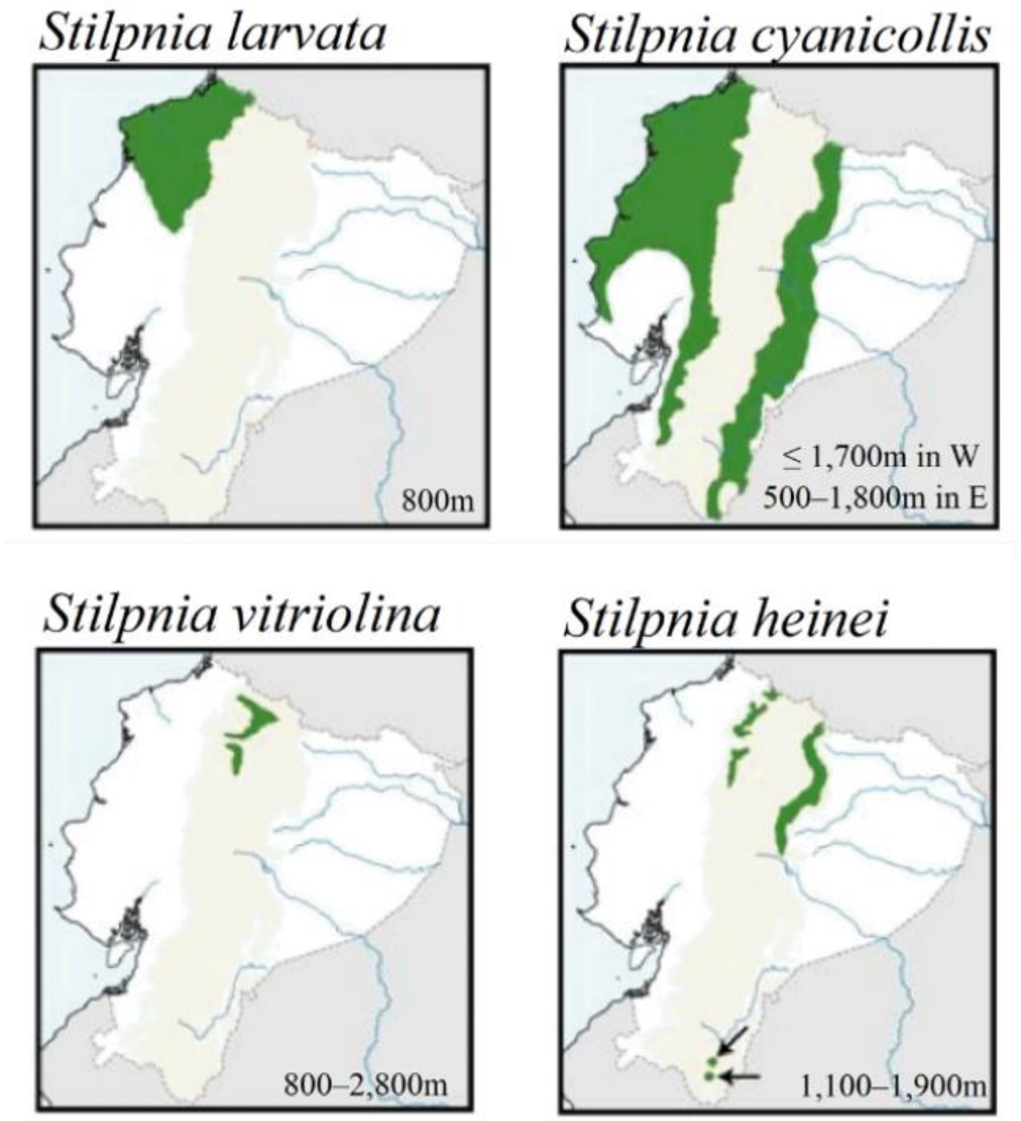

Figure 18. Distribution maps of the four *Stilpnia* tanagers from this study in Ecuador. Each map also contains the altitude distribution. Notice how only *S. cyanicollis* shares part of its distribution with *S. heinei* and *S. larvata*. The maps and altitude information are retrieved from Freile & Restall (2018).

Appendix

Annex 1. Table of compiled data from passerine birds.

Family	Species	Mass (g)	BMR (Kj/h)	RH category[a]	Climate[b]	Food[c]	Habitat[d]	Reference[e]
Acanthizidae	*Aethomyias papuensis*	9,8	0,59	V	TR	I	F	McNab (2009)
	Aethomyias perspicillatus	8,5	0,59	V	TR	I	F	McNab (2009)
	Crateroscelis robusta	17,3	0,95	V	TR	I	F	McNab (2009)
	Sericornis frontalis	11	0,66	H	T/TR	I	B	McNab (2009)
	Sericornis nouhuysi	16,1	0,93	V	TR	I	F	McNab (2009)
Acrocephalidae	*Acrocephalus arundinaceus*	21,9	0,936	H	T	I	G/W	Londoño et al. (2015)
	Acrocephalus palustris	10,8	0,73	V	T	I	B	McNab (2009)
	Acrocephalus schoenobaenus	11,5	0,78	V	T	I	B	McNab (2009)
	Hippolais icterina	12,5	1,69	V	T	I	F	McNab (2009)
Aegithalidae	*Aegithalos caudatus*	8,9	0,72	H	T	I	F	McNab (2009)
	Psaltriparus minimus	5,5	0,46	H	T	I/S	F/O	McNab (2009)
Alaudidae	*Alaudala rufescens*	23,6	1,332	H	T	I/S	B/G	Londoño et al. (2015)
	Ammomanes deserti	21,5	0,828	L	T	I/S	D	Londoño et al. (2015)
	Calandrella brachydactyla	24	1,476	H	T	I/S	B	Londoño et al. (2015)
	Chersomanes albofasciata	25,7	1,224	L	TR	I/S	D	Londoño et al. (2015)
	Eremopterix nigriceps	15,2	0,684	L	T	I/S	D	Londoño et al. (2015)
	Galerida cristata	31,2	1,332	L	T	I/S	B	Londoño et al. (2015)
	Melanocorypha calandra	50,6	2,052	L	T	I/S	B	Londoño et al. (2015)
	Mirafra erythroptera	27,3	1,512	H	TR	I/S	O	Londoño et al. (2015)
	Alaemon alaudipes	37,7	1,54	L	T	I	D	McNab (2009)
	Alauda arvensis	31,7	2,6	V	T	I/S	G	McNab (2009)
	Calendulauda erythrochlamys	27,3	1,5	H	T	I	D	McNab (2009)
	Eremalauda dunni	20,6	1	L	TR	I/S	B	McNab (2009)
	Eremophila alpestris	26	1,19	L	T	I	B/G	McNab (2009)
	Lullula arborea	25,5	2,06	V	T	I	B	McNab (2009)
Artamidae	*Artamus maximus*	61,2	2,26	V	TR	FI	O	McNab (2009)
Bombycillidae	*Bombycilla garrulus*	72,5	3,43	V	T	F/I	F	McNab (2009)
Cardinalidae	*Habia rubica*	36,7	2,088	H	TR	F/I	F	Londoño et al. (2015)
	Cardinalis cardinalis	41	1,81	L	T	I/S	B	McNab (2009)
	Cardinalis sinuatus	32	1,41	L	T	I/S	B	McNab (2009)
	Cyanoloxia cyanoides	27,9	1,35	V	TR	F/S	F	McNab (2009)
	Habia fuscicauda	40	1,28	V	TR	F/I	F	McNab (2009)
Cinclosomatidae	*Ifrita kowaldi*	28,9	1,23	V	TR	I	F	McNab (2009)
Cnemophilidae	*Cnemophilus macgregorii*	87,1	2,67	V	TR	F	F	McNab (2009)
Coerebidae	*Coereba flaveola*	10	0,77	H	TR	P	F	McNab (2009)

Family	Species	Mass (g)	BMR (Kj/h)	RH category[a]	Climate[b]	Food[c]	Habitat[d]	Reference[e]
Conopophagidae	*Conopophaga ardesiaca*	27,5	1,404	V	TR	I	F	Londoño et al. (2015)
	Conopophaga peruviana	24,5	1,224	H	TR	I	F	Londoño et al. (2015)
Corvidae	*Cyanolyca viridicyanus*	82,6	3,852	V	TR	O	F	Londoño et al. (2015)
	Corvus corax	1203	19,8	V	T	O	O	McNab (2009)
	Corvus corone	518	11,93	V	T	O	O	McNab (2009)
	Corvus frugilegus	390	9,42	V	T	O	F/O	McNab (2009)
	Corvus monedula	188	6,19	V	T	O	O	McNab (2009)
	Corvus ruficollis	660	12,23	L	T	V/I	D	McNab (2009)
	Cyanocitta cristata	80,8	3	H	T	O	O	McNab (2009)
	Garrulus glandarius	153	4,99	V	T	O	F	McNab (2009)
	Nucifraga caryocatactes	147	4,85	V	T	O	F	McNab (2009)
	Pica nuttalli	151,9	5,28	H	T	O	O	McNab (2009)
	Pica pica	158,9	4,31	H	T	O	O	McNab (2009)
	Pyrrhocorax graculus	206,4	6,17	V	T	O	O	McNab (2009)
Cotingidae	*Lipaugus vociferans*	86,6	2,736	H	TR	F	F	Londoño et al. (2015)
	Pipreola arcuata	93	2,16	V	TR	F	F	Londoño et al. (2015)
	Pipreola intermedia	49,6	2,196	V	TR	F	F	Londoño et al. (2015)
	Rupicola peruvianus	246,5	3,888	V	TR	F/I	F	Londoño et al. (2015)
	Phytotoma rara	41,6	2,06	H	T	L/G	G	McNab (2009)
	Pipreola riefferii	48,7	1,58	V	TR	F	F	Unpublished data
Dendrocolaptidae	*Dendrocincla fuliginosa*	39	1,77	V	TR	I	F	McNab (2009)
Emberizidae	*Ammodramus savannarum*	13,8	0,64	H	T	I/S	G	McNab (2009)
	Amphispiza bilineata	11,6	0,71	L	T	I/S	D	McNab (2009)
	Arremonops conirostris	39,7	1,63	V	TR	S	F	McNab (2009)
	Emberiza citrinella	26,8	1,57	H	T	S	O	McNab (2009)
	Emberiza hortulana	24,3	1,5	H	T	I	O	McNab (2009)
	Emberiza schoeniclus	17,6	1,08	V	T	S	O	McNab (2009)
	Passerculus sandwichensis	15,9	0,8	H	T	I/S	G	McNab (2009)
	Pooecetes gramineus	21,5	0,98	H	T	I/S	G	McNab (2009)
	Spizella passerina	11,9	0,7	H	T	I/S	F	McNab (2009)
	Zonotrichia albicollis	20,2	1	H	T	F/S	B	McNab (2009)
	Zonotrichia leucophrys	26,1	1,21	H	T	F/S	B	McNab (2009)
Estrildidae	*Lonchura maja*	12,8	0,54	H	TR	S	B/G	Londoño et al. (2015)
	Lonchura malacca	11,8	0,504	H	TR	S	G	Londoño et al. (2015)
	Amadina erythrocephala	21,7	0,76	L	T/TR	S/I	G	McNab (2009)
	Amadina fasciata	17,2	0,77	H	T/TR	S/I	O	McNab (2009)
	Anthus campestris	21,8	1,38	H	T	I	O	McNab (2009)
	Anthus pratensis	18,9	1,08	V	T	I	O	McNab (2009)

Family	**Species**	**Mass (g)**	**BMR (Kj/h)**	**RH category^a**	**Climate^b**	**Food^c**	**Habitat^d**	**Reference^e**
	Anthus trivialis	19,7	1,22	V	T	I	O	McNab (2009)
	Chloebia gouldiae	15,5	0,78	H	T	S	G	McNab (2009)
	Erythrura trichroa	15,1	1,1	V	TR	F/S	B	McNab (2009)
	Estrilda melpoda	7,5	0,47	H	TR	I/S	O	McNab (2009)
	Estrilda troglodytes	7,5	0,54	H	TR	S	O	McNab (2009)
	Lonchura fuscans	9,5	0,36	H	TR	S	O	McNab (2009)
	Lonchura striata	10,3	0,77	H	TR	S	B	McNab (2009)
	Motacilla alba	18	1,08	H	T	I	O	McNab (2009)
	Motacilla flava	14,7	0,93	V	T	I	G	McNab (2009)
	Oreostruthus fuliginosus	16,2	0,66	V	TR	F/S	B	McNab (2009)
	Padda oryzivora	25,4	1,11	H	T	O	F/G	McNab (2009)
	Prunella modularis	16,8	1,17	V	T	I	B	McNab (2009)
	Spermestes cucullata	10,6	0,39	H	T/TR	S	O	McNab (2009)
	Taeniopygia guttata	11,7	0,74	L	T/TR	I/L	O	McNab (2009)
	Uraeginthus bengalus	9,2	0,59	H	TR	S	F/O	McNab (2009)
Formicariidae	*Formicarius analis*	54,9	2,232	H	TR	I	F	Londoño et al. (2015)
	Formicarius rufipectus	70,3	2,628	V	TR	I	F	Londoño et al. (2015)
Fringillidae	*Acanthis flammea*	14,7	1,25	V	P	S	O	McNab (2009)
	Carduelis carduelis	16,5	1,25	V	T	S	O	McNab (2009)
	Carpodacus erythrinus	21,2	1,33	V	T	S/L	B	McNab (2009)
	Chloris chloris	28,2	1,71	V	T	S	F	McNab (2009)
	Coccothraustes coccothraustes	48,3	2,51	V	T	O	F	McNab (2009)
	Coccothraustes vespertinus	54,5	2,71	H	T	S/N	F	McNab (2009)
	Euphonia xanthogaster	12,9	0,792	V	TR	F/I	F/O	Londoño et al. (2015)
	Euphonia laniirostris	13,5	1,06	V	TR	F	B	McNab (2009)
	Fringilla coelebs	21	1,34	H	T	S	F	McNab (2009)
	Fringilla montifringilla	21	1,38	V	T	O	F	McNab (2009)
	Haemorhous cassinii	27,4	1,22	H	T	S	F	McNab (2009)
	Haemorhous mexicanus	20,4	1,12	H	T	S	O	McNab (2009)
	Himatione sanguinea	13,5	1,08	H	TR	P	F	McNab (2009)
	Linaria cannabina	16,9	1,22	V	T	S	B	McNab (2009)
	Loxia curvirostra	39,4	2,16	V	T	S	F	McNab (2009)
	Loxia leucoptera	29,8	1,67	H	T	S	F	McNab (2009)
	Loxia pytyopsittacus	53,7	2,87	V	T	S	F	McNab (2009)
	Loxioides bailleui	34,8	1,61	H	TR	S	F	McNab (2009)
	Pinicola enucleator	78,4	3,91	H	T	L	F	McNab (2009)
	Pyrrhula pyrrhula	30,4	1,99	V	T	L	F	McNab (2009)
	Spinus magellanicus	11,6	0,72	H	TR	S	B/G	Londoño et al. (2015)
	Spinus spinus	14	1,05	V	T	S	F	McNab (2009)

Family	Species	Mass (g)	BMR (Kj/h)	RH category[a]	Climate[b]	Food[c]	Habitat[d]	Reference[e]
	Spinus tristis	12,8	1,09	H	T	S	F/O	McNab (2009)
	Telespiza cantans	31,6	1,53	H	TR	O	G	McNab (2009)
Furnariidae	*Anabacerthia striaticollis*	24,2	1,26	V	TR	I	F	Londoño et al. (2015)
	Anabazenops dorsalis	39,2	1,62	H	TR	I	F	Londoño et al. (2015)
	Ancistrops strigilatus	36	0,792	H	TR	I	F	Londoño et al. (2015)
	Asthenes helleri	15	0,684	V	TR	I	F/B	Londoño et al. (2015)
	Automolus melanopezus	31,6	1,368	H	TR	I	F	Londoño et al. (2015)
	Automolus ochrolaemus	36,7	2,268	H	TR	I	F	Londoño et al. (2015)
	Automolus rufipileatus	36,2	1,656	H	TR	I	F	Londoño et al. (2015)
	Automolus subulatus	30,2	1,764	H	TR	I	F	Londoño et al. (2015)
	Cranioleuca marcapatae	19	1,008	V	TR	I	F	Londoño et al. (2015)
	Dendrocincla merula	52,8	2,232	H	TR	I	F	Londoño et al. (2015)
	Dendrocincla tyrannina	58,3	1,908	V	TR	I	F	Londoño et al. (2015)
	Dendrocolaptes picumnus	80,2	2,592	H	TR	I	F	Londoño et al. (2015)
	Glyphorynchus spirurus	13,5	0,72	V	TR	I	F	McNab (2009)
	Lepidocolaptes lacrymiger	32,6	0,792	V	TR	I	F	Londoño et al. (2015)
	Lochmias nematura	30,5	1,224	V	TR	I	F	Londoño et al. (2015)
	Margarornis squamiger	16,7	0,972	V	TR	I	F	Londoño et al. (2015)
	Philydor erythrocercum	38,2	1,512	H	TR	I	F	Londoño et al. (2015)
	Premnoplex brunnescens	15,7	1,152	V	TR	I	F	Londoño et al. (2015)
	Pseudocolaptes boissonneautii	42,9	1,98	V	TR	I	F	Londoño et al. (2015)
	Sclerurus caudacutus	36,2	1,656	H	TR	I	F	Londoño et al. (2015)
	Sclerurus mexicanus	28,8	1,584	H	TR	I	F	Londoño et al. (2015)
	Sittasomus griseicapillus	14,4	0,972	H	TR	I	F	Londoño et al. (2015)
	Synallaxis azarae	13,6	0,828	V	TR	I	F/B	Londoño et al. (2015)
	Synallaxis cabanisi	19,3	1,08	H	TR	I	F	Londoño et al. (2015)
	Syndactyla ucayalae	51,2	2,196	H	TR	I	F	Londoño et al. (2015)
	Thripadectes holostictus	42,5	1,368	V	TR	I	F	Londoño et al. (2015)
	Thripadectes melanorhynchus	47,5	1,944	V	TR	I	F	Londoño et al. (2015)
	Xiphorhynchus elegans	41,4	1,836	H	TR	I	F	Londoño et al. (2015)
	Xiphorhynchus guttatus	45,2	1,61	V	TR	I	F	McNab (2009)
	Xiphorhynchus triangularis	44,1	2,16	V	TR	I	F	Londoño et al. (2015)
	Cranioleuca erythrops	14,4	1,45	V	TR	I	F	Unpublished data
	Syndactyla subalaris	32,5	1,71	V	TR	I	F	Unpublished data
	Thripadectes virgaticeps	53,5	2,08	V	TR	I	F	Unpublished data
	Xenops minutus	9,9	0,82	V	TR	I	F	McNab (2009)
Grallariidae	*Grallaria guatimalensis*	87	2,232	V	TR	I	F	Londoño et al. (2015)

Family	**Species**	**Mass (g)**	**BMR (Kj/h)**	**RH category**[a]	**Climate**[b]	**Food**[c]	**Habitat**[d]	**Reference**[e]
	Grallaria rufula	33,8	1,872	V	TR	I	F	Londoño et al. (2015)
Hirundinidae	*Delichon urbicum*	18	0,46	V	T	FI	O	McNab (2009)
	Hirundo rustica	18,4	1,08	H	T	FI	O	McNab (2009)
	Hirundo tahitica	14,1	0,64	V	TR	FI	O	McNab (2009)
	Progne chalybea	34,9	1,68	V	TR	FI	O	McNab (2009)
	Riparia riparia	13,6	0,84	V	T	FI	O	McNab (2009)
	Stelgidopteryx ruficollis	11,9	0,57	V	TR	FI	O	McNab (2009)
	Tachycineta albilinea	11,7	0,9	V	TR	FI	O	McNab (2009)
	Tachycineta bicolor	16,4	1,03	H	TR	FI	O	McNab (2009)
Icteridae	*Amblycercus holosericeus*	50,4	2,052	V	TR	O	F/B	Londoño et al. (2015)
	Cacicus chrysonotus	94	3,06	V	TR	F/I	F	Londoño et al. (2015)
	Agelaius phoeniceus	43,1	1,74	H	T	I/S	W	McNab (2009)
	Icterus bullockii	34	1,81	H	T	F/I	F	McNab (2009)
	Icterus galbula	34	1,81	H	T	F/I	F	McNab (2009)
	Leistes militaris	38,2	1,59	V	TR	I	G	McNab (2009)
	Quiscalus mexicanus	137,3	4,06	V	TR	O	B	McNab (2009)
	Quiscalus quiscula	92,2	3,56	H	T	O	B	McNab (2009)
Laniidae	*Lanius collurio*	27	1,38	V	T	V/I	O	McNab (2009)
	Lanius excubitor	72,4	3,68	V	T	V/I	O	McNab (2009)
Melanocharitidae	*Melanocharis versteri*	14,3	0,94	V	TR	F/I	F	McNab (2009)
	Oreocharis arfaki	22,3	1,15	V	TR	F	F	McNab (2009)
	Paramythia montium	40,3	1,49	V	TR	F	F	McNab (2009)
	Toxorhamphus poliopterus	12,2	0,63	V	TR	P/I	F	McNab (2009)
Meliphagidae	*Acanthorhynchus tenuirostris*	9,7	0,9	H	T	P/I	B	Londoño et al. (2015)
	Phylidonyris novaehollandiae	17,3	1,152	H	T	P/I	B	Londoño et al. (2015)
	Gavicalis virescens	25	1,07	H	T/TR	P/I	D	McNab (2009)
	Gliciphila melanops	18,8	1,05	H	T	P/I	O	McNab (2009)
	Lichmera indistincta	10,1	0,76	H	T/TR	P/I	F	McNab (2009)
	Melidectes rufocrissalis	63,9	2,90	V	TR	P/I	B	McNab (2009)
	Melipotes fumigatus	57,1	2,53	V	TR	F	F	McNab (2009)
	Melithreptus lunatus	14,3	0,9	H	T	I	F	McNab (2009)
	Philemon buceroides	140,5	5,87	H	TR	O	F	McNab (2009)
	Prosthemadera novaeseelandiae	144,2	3,98	V	T	F/I	F	McNab (2009)
	Ptiloprora guisei	20,2	1,03	V	TR	F/I	F	McNab (2009)
Mimidae	*Mimus gilvus*	68,9	2,66	V	TR	O	B	McNab (2009)
	Mimus polyglottos	44,2	2,44	H	T	O	B	McNab (2009)
Muscicapidae	*Copsychus saularis*	33,5	0,828	H	TR	I	O	Londoño et al. (2015)
	Larvivora cyane	13,4	0,612	H	T	F/I	B	Londoño et al. (2015)

Family	**Species**	**Mass (g)**	**BMR (Kj/h)**	**RH category**[a]	**Climate**[b]	**Food**[c]	**Habitat**[d]	**Reference**[e]
	Erithacus rubecula	17,6	1,01	V	T	F/I	F	McNab (2009)
	Ficedula hypoleuca	11,7	0,84	V	T	I	F	McNab (2009)
	Luscinia svecica	20,8	1,29	V	T	I	F/O	McNab (2009)
	Muscicapa striata	14,4	0,89	V	T	I	O	McNab (2009)
	Phoenicurus ochruros	13,8	0,87	V	T	F/I	O	McNab (2009)
	Phoenicurus phoenicurus	13	0,84	V	T	F/I	F	McNab (2009)
	Saxicola rubetra	14,3	0,87	V	T	I	O	McNab (2009)
	Saxicola torquatus	16,5	0,92	H	TR	I	D	McNab (2009)
	Tarsiger cyanurus	14,8	0,85	H	T	I	F	McNab (2009)
Nectariniidae	*Aethopyga christinae*	5,2	0,48	H	TR	S	F	McNab (2009)
	Aethopyga siparaja	6,8	0,53	H	TR	P/I	F	McNab (2009)
	Anthreptes orientalis	11,8	0,55	H	TR	P/I	O	McNab (2009)
	Chalcomitra adelberti	9,5	0,63	H	TR	P/I	F	McNab (2009)
	Chalcomitra amethystina	10	0,63	H	TR	P/I	F	McNab (2009)
	Chalcomitra rubescens	10	0,66	H	TR	P/I	F	McNab (2009)
	Chalcomitra senegalensis	13,7	0,86	H	TR	P/I	F/O	McNab (2009)
	Cinnyris bifasciatus	6,2	0,33	H	TR	P/I	B	McNab (2009)
	Cinnyris chloropygius	6,8	0,5	H	TR	P/I	B	McNab (2009)
	Cinnyris cupreus	9	0,59	H	TR	P/I	F/O	McNab (2009)
	Cinnyris minimus	5,5	0,42	H	TR	P/I	F	McNab (2009)
	Cinnyris reichenowi	6,7	0,51	H	TR	P/I	F	McNab (2009)
	Cinnyris venustus	7,1	0,5	H	TR	P/I	F	McNab (2009)
	Cyanomitra cyanolaema	15,8	0,98	H	TR	P/I	F	McNab (2009)
	Cyanomitra olivacea	11,2	0,72	H	TR	P/I	F	McNab (2009)
	Cyanomitra veroxii	8,4	0,48	H	TR	I	F	McNab (2009)
	Cyanomitra verticalis	14,1	0,9	H	TR	P/I	F	McNab (2009)
	Hedydipna collaris	8,3	0,61	H	TR	I	F	McNab (2009)
	Nectarinia kilimensis	16,2	0,94	H	TR	P/I	F	McNab (2009)
	Nectarinia tacazze	13,5	0,88	H	TR	P/I	O	McNab (2009)
Oreoicidae	*Aleadryas rufinucha*	40	1,61	V	TR	F/I	F	McNab (2009)
Oriolidae	*Oriolus oriolus*	64,9	2,34	V	T	I	F	McNab (2009)
Oxyruncidae	*Myiobius villosus*	14,7	1,08	V	TR	I	F	Londoño et al. (2015)
	Onychorhynchus coronatus	14	1,08	H	TR	I	F	Londoño et al. (2015)
	Terenotriccus erythrurus	9,3	0,864	H	TR	I	F	Londoño et al. (2015)
Pachycephalidae	*Melanorectes nigrescens*	70,5	2,99	V	TR	F/I	F	McNab (2009)
	Pachycephala schlegelii	22	1,04	V	TR	F/I	F	McNab (2009)
	Pachycephala soror	23,4	1,30	V	TR	I	F	McNab (2009)
Paradisaeidae	*Astrapia stephaniae*	148,2	5,8	V	TR	F/I	F	McNab (2009)

Family	Species	Mass (g)	BMR (Kj/h)	RH category[a]	Climate[b]	Food[c]	Habitat[d]	Reference[e]
	Cicinnurus regius	54	2,1	V	TR	F/I	F	McNab (2009)
	Cnemophilus loriae	78,1	2,38	V	TR	F	F	McNab (2009)
	Diphyllodes magnificus	82,3	2,84	V	TR	F/I	F	McNab (2009)
	Epimachus meyeri	202,7	6,63	V	TR	F/I	F	McNab (2009)
	Lophorina superba	74,6	2,6	V	TR	F/I	F	McNab (2009)
	Manucodia chalybatus	177,2	4,94	V	TR	F	F	McNab (2009)
	Paradisaea raggiana	215,7	6,75	V	TR	F/I	F	McNab (2009)
	Paradisornis rudolphi	156,1	5,48	V	TR	F/I	F	McNab (2009)
	Parotia lawesii	144,9	4,13	V	TR	F	F	McNab (2009)
	Parotia wahnesi	164,2	4,64	V	TR	F	F	McNab (2009)
	Phonygammus keraudrenii	170,7	4,31	V	TR	F	F	McNab (2009)
	Ptiloris magnificus	179,4	5,4	V	TR	F/I	F	McNab (2009)
Paridae	*Cyanistes caeruleus*	9,6	0,6	V	T	I/S	F	McNab (2009)
	Parus major	16,5	1,26	V	T	I/S	F	McNab (2009)
	Periparus ater	10,8	0,85	V	T	I/S	F	McNab (2009)
	Poecile atricapillus	10,3	0,91	V	T	I/S	F/O	McNab (2009)
	Poecile montanus	11,6	0,99	V	T	I/S	F	McNab (2009)
Parulidae	*Basileuterus tristriatus*	12,6	0,9	V	TR	I	F	Londoño et al. (2015)
	Geothlypis trichas	10,6	0,612	H	T	I	G/W	Londoño et al. (2015)
	Myioborus melanocephalus	11,7	0,756	V	TR	I	F	Londoño et al. (2015)
	Myioborus miniatus	9,8	0,72	V	TR	I	F	Londoño et al. (2015)
	Myiothlypis bivittata	15,5	1,08	V	TR	I	F	Londoño et al. (2015)
	Myiothlypis chrysogaster	14,4	1,008	H	TR	I	F	Londoño et al. (2015)
	Myiothlypis coronata	15,1	1,16	V	TR	I	F	Unpublished data
	Myiothlypis fulvicauda	12,8	1,26	H	TR	I	F	Londoño et al. (2015)
	Myiothlypis luteoviridis	14,7	0,864	V	TR	I	F	Londoño et al. (2015)
	Myiothlypis signata	14,3	0,792	V	TR	I	F	Londoño et al. (2015)
	Parkesia noveboracensis	18,7	1,01	H	T	I	F	McNab (2009)
	Protonotaria citrea	12,8	0,72	H	T	I	F	McNab (2009)
	Seiurus aurocapilla	19	0,87	H	T	I	F	McNab (2009)
	Setophaga americana	7	0,432	H	T	I	F	Londoño et al. (2015)
	Setophaga citrina	12	0,792	H	T	I	F	Londoño et al. (2015)
	Setophaga coronata	11,5	0,68	H	T	F/I	F	McNab (2009)
	Setophaga dominica	9,8	0,58	H	T	I	F	McNab (2009)
	Setophaga palmarum	9,8	0,56	H	T	I	O	McNab (2009)
	Setophaga petechia	12,2	0,5	V	TR	I	F	McNab (2009)
	Setophaga pinus	12	0,64	H	T	I	F	McNab (2009)

Family	Species	Mass (g)	BMR (Kj/h)	RH category[a]	Climate[b]	Food[c]	Habitat[d]	Reference[e]
	Vermivora cyanoptera	7,8	0,54	H	T	I	F/O	McNab (2009)
Passerellidae	*Ammodramus aurifrons*	16,4	0,936	H	TR	I/S	B/G	Londoño et al. (2015)
	Arremon castaneiceps	35,7	1,908	V	TR	I/S	F	Londoño et al. (2015)
	Arremon taciturnus	27,7	1,512	H	TR	I/S	F	Londoño et al. (2015)
	Arremon torquatus	42,8	1,692	V	TR	I/S	F	Londoño et al. (2015)
	Atlapetes melanolaemus	25,5	1,224	V	TR	I/S	F	Londoño et al. (2015)
	Chlorospingus flavigularis	26,5	1,188	H	TR	F/I	F	Londoño et al. (2015)
	Chlorospingus parvirostris	23,1	1,188	V	TR	F/I	F	Londoño et al. (2015)
	Chlorospingus semifuscus	28,1	1,44	V	TR	F/I	F	Unpublished data
	Junco hyemalis	18	1,08	L	T	I/S	F/B	Londoño et al. (2015)
	Melospiza georgiana	14,9	0,76	H	T	I/S	B	McNab (2009)
	Melospiza melodia	19,1	0,9	H	T	I/S	B	McNab (2009)
	Zonotrichia capensis	22,2	1,116	H	TR	I/S	B	Londoño et al. (2015)
	Zonotrichia querula	33,3	1,77	H	T	I/S	B	McNab (2009)
Passeridae	*Passer domesticus*	23	1,32	V	T	S/L	O	McNab (2009)
	Passer montanus	22,3	1,46	V	T	I/S	O	McNab (2009)
Petroicidae	*Devioeca papuana*	12,9	0,75	V	TR	FI	F	McNab (2009)
	Melanodryas cyanus	23,8	1,25	V	TR	I	F	McNab (2009)
	Melanodryas sigillata	21,1	1,13	V	TR	I	F	McNab (2009)
Phylloscopidae	*Phylloscopus collybita*	8,2	0,59	V	T	I	F	McNab (2009)
	Phylloscopus sibilatrix	9,2	0,63	V	T	I	F	McNab (2009)
	Phylloscopus trochilus	10,7	0,75	V	T	I	B	McNab (2009)
Pipridae	*Ceratopipra chloromeros*	16,2	1,044	H	TR	F/I	F	Londoño et al. (2015)
	Chiroxiphia boliviana	17	1,08	H	TR	F	F	Londoño et al. (2015)
	Cryptopipo holochlora	16	0,756	H	TR	F	F	Londoño et al. (2015)
	Lepidothrix coeruleocapilla	9,6	0,864	V	TR	F/I	F	Londoño et al. (2015)
	Lepidothrix coronata	10,6	0,72	H	TR	F/I	F	Londoño et al. (2015)
	Machaeropterus pyrocephalus	10	0,864	H	TR	F/I	F	Londoño et al. (2015)
	Pipra fasciicauda	16,4	0,936	H	TR	F/I	F	Londoño et al. (2015)
	Ceratopipra mentalis	12,3	0,7	V	TR	F/I	F	McNab (2009)
	Chiroxiphia lanceolata	18,4	1,22	V	TR	F	F	McNab (2009)
	Lepidothrix velutina	9,2	0,54	V	TR	F/I	F	McNab (2009)
	Manacus vitellinus	15,5	0,84	V	TR	F/I	F	McNab (2009)
	Pitta versicolor	83,1	2,03	V	T/TR	I	F	McNab (2009)
Pycnonotidae	*Pycnonotus finlaysoni*	26,3	0,792	H	TR	F/I	B	Londoño et al. (2015)
	Pycnonotus goiavier	28,6	0,9	H	TR	O	B	Londoño et al. (2015)
	Eurillas curvirostris	23	1,06	H	TR	F	F	McNab (2009)

Family	Species	Mass (g)	BMR (Kj/h)	RH category[a]	Climate[b]	Food[c]	Habitat[d]	Reference[e]
	Eurillas latirostris	26,6	1,3	H	TR	F	F	McNab (2009)
	Eurillas virens	24,2	1,19	H	TR	F	F	McNab (2009)
	Phyllastrephus hypochloris	18,9	0,95	H	TR	I	F	McNab (2009)
	Pycnonotus barbatus	40,3	1,72	H	TR	F	F	McNab (2009)
Regulidae	*Regulus regulus*	5,5	0,66	V	T	I	F	McNab (2009)
Rhinocryptidae	*Scytalopus atratus*	21,5	1,368	V	TR	I	F	Londoño et al. (2015)
	Scytalopus parvirostris	17	1,296	V	TR	I	F	Londoño et al. (2015)
Rhipiduridae	*Rhipidura albolimbata*	10,3	1,08	V	TR	FI	F	McNab (2009)
	Rhipidura atra	11	1,28	V	TR	FI	F	McNab (2009)
Sittidae	*Sitta carolinensis*	18,3	1,04	H	T	I/S	F	McNab (2009)
Sturnidae	*Acridotheres cristatellus*	109,4	4,356	H	TR	F/I	B	Londoño et al. (2015)
	Sturnus vulgaris	75	3,16	V	T	O	O	McNab (2009)
Sylviidae	*Curruca curruca*	10,6	0,72	V	T	I	B	McNab (2009)
	Curruca nisoria	21,3	1,38	V	T	I	B	McNab (2009)
	Sylvia atricapilla	21,9	1,5	V	T	I	F	McNab (2009)
	Sylvia borin	24,8	1,5	V	T	I	F	McNab (2009)
Thamnophilidae	*Akletos goeldii*	42,4	1,512	H	TR	I	F/B	Londoño et al. (2015)
	Drymophila caudata	12,2	0,504	V	TR	I	F	Londoño et al. (2015)
	Epinecrophylla leucophthalma	9,4	0,684	H	TR	I	F	Londoño et al. (2015)
	Hylophylax naevius	12,8	1,26	H	TR	I	F	Londoño et al. (2015)
	Hypocnemis subflava	15,6	0,864	H	TR	I	F	Londoño et al. (2015)
	Isleria hauxwelli	10,8	0,756	H	TR	I	F	Londoño et al. (2015)
	Myrmelastes leucostigma	17,8	0,648	H	TR	I	F	Londoño et al. (2015)
	Myrmoborus leucophrys	19,8	1,188	H	TR	I	F	Londoño et al. (2015)
	Myrmoborus lophotes	31,6	1,188	H	TR	I	F	Londoño et al. (2015)
	Myrmoborus myotherinus	21,2	1,008	H	TR	I	F	Londoño et al. (2015)
	Myrmotherula longipennis	9,6	0,792	H	TR	I	F	Londoño et al. (2015)
	Myrmotherula menetriesii	9,3	1,008	H	TR	I	F	Londoño et al. (2015)
	Myrmotherula schisticolor	8,3	0,9	V	TR	I	F	Londoño et al. (2015)
	Oneillornis salvini	27,1	1,152	H	TR	I	F	Londoño et al. (2015)
	Phlegopsis nigromaculata	47,1	1,728	H	TR	I	F	Londoño et al. (2015)
	Pyriglena leuconota	32,1	1,98	V	TR	I	F	Londoño et al. (2015)
	Rhegmatorhina melanosticta	42,2	1,476	H	TR	I	F	Londoño et al. (2015)
	Sciaphylax hemimelaena	18	0,9	H	TR	I	F	Londoño et al. (2015)
	Thamnomanes ardesiacus	19,3	0,972	H	TR	I	F	Londoño et al. (2015)
	Thamnomanes schistogynus	19,7	1,224	H	TR	I	F	Londoño et al. (2015)
	Thamnophilus palliatus	27,8	1,764	V	TR	I	F/B	Londoño et al. (2015)
	Willisornis poecilinotus	22,3	1,404	H	TR	I	F	Londoño et al. (2015)

Family	Species	Mass (g)	BMR (Kj/h)	RH category[a]	Climate[b]	Food[c]	Habitat[d]	Reference[e]
	Cercomacroides tyrannina	15,4	0,68	V	TR	I	F	McNab (2009)
	Gymnopithys bicolor	27,7	1,2	V	TR	I	F	McNab (2009)
	Hylophylax naevioides	16,1	0,86	V	TR	I	F	McNab (2009)
	Myrmeciza longipes	27,4	1,17	V	TR	I	F	McNab (2009)
	Myrmotherula axillaris	9,6	0,78	V	TR	I	F	McNab (2009)
	Poliocrania exsul	28,3	1,04	V	TR	I	F	McNab (2009)
	Thamnophilus atrinucha	20,5	1,01	V	TR	I	F	McNab (2009)
	Thamnophilus doliatus	26,2	1,03	V	TR	I	F	McNab (2009)
	Thamnophilus punctatus	21	1,24	V	TR	I	F	McNab (2009)
Thraupidae	*Anisognathus igniventris*	35	1,584	V	TR	F/I	F	Londoño et al. (2015)
	Asemospiza obscura	12,1	0,576	H	TR	S	B	Londoño et al. (2015)
	Buthraupis montana	89,7	3,672	V	TR	F/I	F	Londoño et al. (2015)
	Catamblyrhynchus diadema	17	0,9	V	TR	F/I	F	Londoño et al. (2015)
	Chlorochrysa calliparaea	16,9	0,9	V	TR	F/I	F	Londoño et al. (2015)
	Chlorornis riefferii	49,8	1,836	V	TR	F/I	F	Londoño et al. (2015)
	Cissopis leverianus	61,4	1,008	H	TR	F/I	F	Londoño et al. (2015)
	Conirostrum sitticolor	11	0,648	V	TR	I	F	Londoño et al. (2015)
	Diglossa brunneiventris	10,6	0,864	V	TR	P/I	F/B	Londoño et al. (2015)
	Diglossa mystacalis	15,4	1,008	V	TR	P/I	F/B	Londoño et al. (2015)
	Haplospiza rustica	18	0,504	V	TR	S	F	Londoño et al. (2015)
	Iridosornis analis	27,1	1,692	V	TR	O	F	Londoño et al. (2015)
	Iridosornis jelskii	20,6	1,368	V	TR	O	F	Londoño et al. (2015)
	Ixothraupis xanthogastra	15,1	0,756	H	TR	F/I	F	Londoño et al. (2015)
	Kleinothraupis atropileus	20,4	1,368	V	TR	I	F	Londoño et al. (2015)
	Lanio versicolor	20,4	1,188	H	TR	F/I	F	Londoño et al. (2015)
	Loriotus luctuosus	12,5	1,152	H	TR	F/I	F	Londoño et al. (2015)
	Pipraeidea melanonota	20,3	1,368	H	TR	O	F/B	Londoño et al. (2015)
	Pseudospingus xanthophthalmus	13	0,684	V	TR	I	F	Londoño et al. (2015)
	Ramphocelus carbo	26,5	1,044	H	TR	F/I	F/B	Londoño et al. (2015)
	Ramphocelus dimidiatus	26,4	1,32	V	TR	F/I	B	McNab (2009)
	Ramphocelus flammigerus	32	1,5	V	TR	F/I	B	McNab (2009)
	Rauenia bonariensis	34,8	2,016	V	TR	F/I	B	Londoño et al. (2015)
	Sphenopsis melanotis	17,3	1,152	V	TR	I	F	Londoño et al. (2015)
	Sporathraupis cyanocephala	38,2	1,656	H	TR	F/I	F/B	Londoño et al. (2015)
	Sporophila castaneiventris	8,5	0,72	H	TR	F/S	O	Londoño et al. (2015)
	Sporophila nigricollis	8,9	0,72	H	TR	S	B/G	Londoño et al. (2015)

Family	**Species**	**Mass (g)**	**BMR (Kj/h)**	**RH category^a**	**Climate^b**	**Food^c**	**Habitat^d**	**Reference^e**
	Tangara arthus	22,4	1,332	V	TR	F/I	F/B	Londoño et al. (2015)
	Tangara vassorii	18,5	0,828	V	TR	F/I	F	Londoño et al. (2015)
	Thlypopsis ruficeps	11,9	0,828	V	TR	I	F/B	Londoño et al. (2015)
	Thlypopsis sordida	14,9	1,116	H	TR	F/I	F/G	Londoño et al. (2015)
	Thlypopsis superciliaris	14,6	1,152	V	TR	F/I	F	Londoño et al. (2015)
	Trichothraupis melanops	24,9	1,62	V	TR	O	F	Londoño et al. (2015)
	Cyanerpes cyaneus	13,5	0,98	V	TR	F/P	B	McNab (2009)
	Diglossa albilatera	9,09	0,65	V	TR	P	F	Unpublished data
	Diglossa cyanea	14,9	1	V	TR	P	F	Unpublished data
	Eucometis penicillata	30,7	1,42	V	TR	F/I	F	McNab (2009)
	Saltator grossus	49,5	1,584	V	TR	I/S	F	Londoño et al. (2015)
	Saltator maximus	44,8	1,97	V	TR	F/I	F	McNab (2009)
	Saltator striatipectus	42,1	1,83	V	TR	F/I	B	McNab (2009)
	Saltator coerulescens	47	1,4	H	TR	F/L	B	McNab (2009)
	Saltator orenocensis	32,7	1,13	H	TR	F/L	B	McNab (2009)
	Sporophila corvina	10,2	0,71	V	TR	S	O	McNab (2009)
	Sporophila funeria	12,3	0,72	V	TR	S	B	McNab (2009)
	Stilpnia cyanicollis	16,3	1,26	V	TR	F/I	F/B	Londoño et al. (2015)
	Stilpnia heinei	19,91	1,55	V	TR	F/I	F	This study
	Stilpnia larvata	16,2	0,85	V	TR	F/I	F	McNab (2009)
	Stilpnia vitriolina	21,6	1,61	H	TR	F/I	B	This study
	Thraupis episcopus	30,4	1,44	V	TR	F/I	B	McNab (2009)
	Thraupis palmarum	32,6	1,42	V	TR	F/I	B	McNab (2009)
Troglodytidae	*Cinnycerthia fulva*	16,3	0,72	V	TR	I	F	Londoño et al. (2015)
	Cyphorhinus thoracicus	34,4	1,512	V	TR	I	F	Londoño et al. (2015)
	Microcerculus marginatus	19,4	1,188	H	TR	I	F	Londoño et al. (2015)
	Cantorchilus leucotis	18	0,76	V	TR	I	F	McNab (2009)
	Henicorhina leucophrys	23,3	1,63	V	TR	I	F	Unpublished data
	Pheugopedius fasciatoventris	27,2	1,12	V	TR	I	F	McNab (2009)
	Thryophilus rufalbus	22,6	1,07	V	TR	I	F	McNab (2009)
	Thryothorus ludovicianus	14,9	1,29	H	T	I	F	McNab (2009)
	Troglodytes aedon	10,2	0,75	H	T	I	O	McNab (2009)
	Troglodytes musculus	13,3	0,76	V	TR	I	O	McNab (2009)
	Troglodytes troglodytes	8,9	0,6	V	T	I	F	McNab (2009)
	Troglodytes solstitialis	13	0,972	V	TR	I	F	Londoño et al. (2015)
Turdidae	*Catharus dryas*	35,9	1,656	H	TR	I	F	Londoño et al. (2015)
	Catharus ustulatus	28,2	1,548	H	T	F/I	F/B	Londoño et al. (2015)

Family	**Species**	**Mass (g)**	**BMR (Kj/h)**	**RH category[a]**	**Climate[b]**	**Food[c]**	**Habitat[d]**	**Reference[e]**
	Entomodestes leucotis	60,7	0,936	V	TR	F/I	F	Londoño et al. (2015)
	Myadestes ralloides	26,7	1,66	V	TR	F	F	Unpublished data
	Sialia mexicana	27,5	1,52	L	T	F/I	F	McNab (2009)
	Turdus albicollis	51,3	1,656	H	TR	O	F	Londoño et al. (2015)
	Turdus chiguanco	87	1,944	V	TR	F/I	B	Londoño et al. (2015)
	Turdus fuscater	138	3,456	V	TR	O	B	Londoño et al. (2015)
	Turdus hauxwelli	63,3	1,8	H	TR	F/I	F	Londoño et al. (2015)
	Turdus ignobilis	56,6	1,476	H	TR	F/I	F/O	Londoño et al. (2015)
	Turdus lawrencii	55,3	2,412	H	TR	O	F	Londoño et al. (2015)
	Turdus leucops	62,2	2,556	V	TR	O	F	Londoño et al. (2015)
	Turdus nigriceps	51,1	1,908	V	TR	F/I	F	Londoño et al. (2015)
	Turdus grayi	77,9	2,44	V	TR	F/I	F/O	McNab (2009)
	Turdus iliacus	58	2,6	V	T	F/I	F/O	McNab (2009)
	Turdus merula	82,6	3,34	V	T	I	F	McNab (2009)
	Turdus migratorius	62,4	2,74	H	T	F/I	F/B	McNab (2009)
	Turdus philomelos	62,8	2,61	H	T	F/I	F	McNab (2009)
	Turdus poliocephalus	66,1	2,75	V	TR	F/I	F/O	McNab (2009)
	Turdus serranus	71,3	2,58	V	TR	F/I	F	Unpublished data
	Turdus viscivorus	108,2	3,97	V	T	F/I	F	McNab (2009)
Tyrannidae	*Anairetes parulus*	6,6	0,54	V	TR	I	B	Londoño et al. (2015)
	Attila spadiceus	32,7	0,504	H	TR	V/I	F	Londoño et al. (2015)
	Contopus sordidulus	12,5	2,016	H	T	I	F	Londoño et al. (2015)
	Corythopis torquatus	18,7	1,008	H	TR	V/I	F	Londoño et al. (2015)
	Elaenia albiceps	16,8	0,684	V	TR	O	F/B	Londoño et al. (2015)
	Elaenia gigas	30,7	1,476	H	TR	O	O	Londoño et al. (2015)
	Elaenia obscura	13,9	0,504	V	TR	F/I	F	Londoño et al. (2015)
	Elaenia pallatangae	15,7	0,828	V	TR	F/I	F	Londoño et al. (2015)
	Hemitriccus granadensis	8,2	0,504	V	TR	I	F/B	Londoño et al. (2015)
	Knipolegus aterrimus	34	1,116	V	TR	I	B	Londoño et al. (2015)
	Lathrotriccus euleri	9,3	0,756	H	TR	I	F	Londoño et al. (2015)
	Legatus leucophaius	26,7	0,576	H	TR	O	B	Londoño et al. (2015)
	Leptopogon amaurocephalus	14,1	0,792	H	TR	I	F/O	Londoño et al. (2015)
	Leptopogon superciliaris	12,9	0,9	V	TR	I	F	Londoño et al. (2015)
	Lophotriccus pileatus	8,2	0,684	V	TR	I	F	Londoño et al. (2015)
	Mecocerculus leucophrys	13,9	0,54	V	TR	F/I	F/B	Londoño et al. (2015)
	Mecocerculus poecilocercus	7,6	0,77	V	TR	I	F	Unpublished data
	Mecocerculus stictopterus	10,9	0,792	V	TR	I	F	Londoño et al. (2015)

Family	Species	Mass (g)	BMR (Kj/h)	RH category[a]	Climate[b]	Food[c]	Habitat[d]	Reference[e]
	Mionectes macconnelli	11,4	0,576	H	TR	F/I	F	Londoño et al. (2015)
	Mionectes oleagineus	10,3	0,59	V	TR	F	F	McNab (2009)
	Mionectes olivaceus	15,7	1,008	H	TR	F/I	F	Londoño et al. (2015)
	Mionectes striaticollis	13,9	1,11	V	TR	F/I	F	Unpublished data
	Myiotheretes fuscorufus	29,2	1,872	V	TR	F/I	F	Londoño et al. (2015)
	Myiozetetes similis	27,1	1,044	V	TR	O	F/O	Londoño et al. (2015)
	Ochthoeca rufipectoralis	10,9	0,72	V	TR	I	F	Londoño et al. (2015)
	Platyrinchus coronatus	10,8	0,576	H	TR	I	F	Londoño et al. (2015)
	Platyrinchus platyrhynchos	14	1,08	H	TR	I	F	Londoño et al. (2015)
	Pogonotriccus ophthalmicus	8,8	0,864	V	TR	I	F	Londoño et al. (2015)
	Pyrrhomyias cinnamomeus	10,7	0,72	V	TR	I	F	Londoño et al. (2015)
	Ramphotrigon fuscicauda	17,4	1,008	H	TR	I	F	Londoño et al. (2015)
	Rhynchocyclus fulvipectus	26	1,404	V	TR	I	F	Londoño et al. (2015)
	Silvicultrix frontalis	10,7	0,612	V	TR	I	F	Londoño et al. (2015)
	Silvicultrix pulchella	12	0,612	V	TR	I	F	Londoño et al. (2015)
	Syrtidicola fluviatilis	13,6	0,936	H	TR	I	O	Londoño et al. (2015)
	Zimmerius bolivianus	11	1,008	V	TR	F/I	F/B	Londoño et al. (2015)
	Camptostoma obsoletum	12,5	0,95	V	TR	I	B	McNab (2009)
	Cnipodectes subbrunneus	20,5	0,99	V	TR	I	F	McNab (2009)
	Contopus virens	13,9	0,93	H	T	FI	F	McNab (2009)
	Empidonax virescens	12,3	0,64	H	T	FI	F	McNab (2009)
	Myiarchus crinitus	33,9	1,38	H	T	FI	F	McNab (2009)
	Myiodynastes maculatus	41	2,12	V	TR	FI	F	McNab (2009)
	Rhynchocyclus aequinoctialis	21	1,08	V	TR	I	F	McNab (2009)
	Sayornis phoebe	21,6	1,24	H	T	FI	F	McNab (2009)
	Todirostrum cinereum	7,3	0,61	V	TR	I	B	McNab (2009)
	Tyrannus melancholicus	38	1,31	V	TR	FI	G	McNab (2009)
	Tyrannus tyrannus	35,7	1,57	H	T	FI	G	McNab (2009)
Vireonidae	*Vireo flavoviridis*	15,9	1,01	V	TR	I	B	McNab (2009)
	Vireo olivaceus	16,2	0,86	V	T	I	B	McNab (2009)
Zosteropidae	*Zosterops lateralis*	11,8	0,58	H	T/TR	O	B	McNab (2009)

[a] Relative Humidity Category: V= Very high; H= High; L= Low.
[b] Climate: T= Temperate; TR= Tropical.
[c] Food: F= Fruits; I= Invertebrates; L= Leaves; P= Pollen and nectar; S= Seeds; FI= Flying insects; G= Grass; O= Omnivore; N= Nuts; V= Vertebrates.
[d] Habitat: B= Bare or disturbed grounds, brush; G= Grasslands and savannahs; D= Deserts; F= Forests, woodlands; O= Open areas; W= Wetlands.
[e] Values of mass and BMR represent a compilation of data from many academic works that were summarized in the studies of McNab (2009) and Londoño et al. (2015). To see the original source of information, please refer to the mentioned studies.