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RESEARCH ARTICLE

Small organ size contributes to the slow pace of life in tropical birds

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SUMMARY

Attributes of an animal's life history, such as reproductive rate or longevity, typically fall along a 'slow–fast' continuum. Animals at the fast end of this continuum, such as temperate birds, are thought to experience high rates of mortality and invest more resources in reproduction, whereas animals at the slow end, such as tropical birds, live longer, have fewer offspring and invest more resources in self-maintenance. We have previously shown that tropical birds, compared with temperate species, have a reduced basal (BMR) and peak metabolic rate (PMR), patterns consistent with a slow pace of life. Here, we elucidate a fundamental linkage between the smaller mass of central organs of tropical species and their reduced BMR, and between their smaller flight muscles and reduced PMR. Analyses of up to 408 species from the literature showed that the heart, flight muscles, liver, pancreas and kidneys were smaller in tropical species. Direct measurements on 49 species showed smaller heart, lungs, flight muscles, liver, kidneys, ovaries and testes in tropical species, as well as lower feather mass. In combination, our results indicate that the benign tropical environment imposes a relaxed selection pressure on high levels of sustained metabolic performance, permitting species to reduce the mass of organs that are energetically costly to maintain. Brain, gizzard and intestine were exceptions, even though energy turnover of brain and intestine are high. Feather mass was 37% lower in tropical species compared with similar-sized temperate birds, supporting the idea that temperate birds require more insulation for thermoregulation.

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Key words: body composition, organ mass, feather mass, tropical birds, pace of life, basal metabolic rate.

INTRODUCTION

Life-history theory postulates that many physiological traits and behaviour patterns may be understood in terms of key maturational and reproductive characteristics over an organism's life span (Roff, 1992; Stearns, 1992). Variation in these characteristics is thought to reflect different allocation patterns of resources, time and/or energy, to competing life functions, especially growth, body maintenance and reproduction (Charnov, 1993; Ghalambor and Martin, 2001; Williams, 1957). The costs of reproduction are viewed as energy diverted away from bodily maintenance or immunological competence in support of energy allocation for reproduction (Kirkwood, 1977; Sheldon and Verhulst, 1996; Wiersma et al., 2004). Although it is widely acknowledged that physiological processes are the basis of life-history trade-offs, the mechanisms underlying the diversification of life histories remain elusive (Else et al., 2004; Ricklefs and Wikelski, 2002; Speakman, 2008; Stearns, 1992).

Because the rate of metabolism of an organism integrates numerous aspects of its physiology and links those internal systems with its ecology and life history, investigations into functional linkages between metabolism, at the organ, cellular and molecular level, and key attributes of life history hold considerable promise in advancing our understanding of the connections between metabolic rate and life history (Ricklefs and Wikelski, 2002). Some recent studies challenge the idea of a direct causal link between the rate of metabolism and longevity – the rate of living theory (Pearl, 1928; Speakman, 2005; Rottenberg, 2007). However, linkages among metabolism, free radical production and longevity remain a fundamental assumption in the free radical theory of ageing, a commonly accepted theory amongst many gerontologists, although it is clear that these linkages operate in complex and yet unresolved ways (Rottenberg, 2007; Austad, 2010; Speakman, 2005; Speakman and Selman, 2011).

Across species, body size is the major determinant of the rate of whole-organism metabolism (McNab, 2008; McNab, 2009), often measured as basal metabolic rate (BMR) (McNab, 1997). Peak metabolic rate (PMR), the maximum rate of oxygen consumption, is measured by forcing the animal to exercise, run or fly (PMR_E) (Chappell et al., 1999), or by exposing them to cold (PMR_C) (Swanson and Liknes, 2006). PMR is assumed to be related to fitness because enhanced performance, as measured by locomotor speed, flying endurance or cold tolerance, should increase survival (Burns and Ydenberg, 2002; Husak et al., 2006; Jayne and Bennett, 1990). PMR_E usually exceeds PMR_C in birds (Hinds et al., 1993), suggesting that different physiological mechanisms may be involved when these two variables are measured.

Recently, we demonstrated that tropical birds have an 18% lower BMR, 34% lower PMR_C and 39% lower PMR_E compared with temperate species (Wiersma et al., 2007a; Wiersma et al., 2007b). Along with a reduced metabolism, tropical birds tend to have a smaller clutch size than their temperate counterparts (Cardillo, 2002; Kulesza, 1990), have protracted nestling and fledgling periods (Russell et al., 2004; Schaefer et al., 2004; Tarwater and Brawn, 2010), and tend to live longer than temperate species (Fogden, 1972;

Francis et al., 1999; Johnston et al., 1997; Ricklefs, 1997; Snow and Lill, 1974). This suite of physiological and life-history characteristics is often embodied in the phrase 'slow pace of life' (Promislow and Harvey, 1990; Ricklefs and Wikelski, 2002).

Progress in understanding the evolution of metabolic rates requires knowledge of the physiological mechanisms acted upon by natural selection that produce variation in metabolism (Williams et al., 2010). Metabolic intensity of tissues may vary because of differences in mitochondria (Else and Hulbert, 1985; Moyes, 2003; Porter, 2001; Suarez, 1996), concentrations of metabolic enzymes (Garrido et al., 1996; Marsh and Dawson, 1982; Vézina and Williams, 2005; Weber and Piersma, 1996), activity of the membrane sodium pump (Wu et al., 2001) and fatty acid composition of cell membranes (Brzek et al., 2007; Hulbert and Else, 2005). Variation in BMR between lowland tropical birds and their temperate counterparts could arise if the relative size of some or all of the central organs in tropical species were smaller (Piersma et al., 1996). In a study that employed data on human organ masses and organ-specific metabolism, about 60% of resting oxygen consumption could be attributed to the liver, brain, heart and kidneys, but these organs together accounted for only 5% of body mass (Gallagher et al., 1998). Mass-specific oxygen consumption, or metabolic intensity, of these tissues exceeds that of tissues from the gastro-intestinal tract, lungs and muscle by 2–5 times (Elia, 1992; Krebs, 1950). Studies within species have shown correlations between BMR and masses of central organs (Brzek et al., 2007; Chappell et al., 1999; Even et al., 2001; Piersma et al., 1996), but other studies have failed to find correlations between BMR and sizes of central organs within species (Geluso and Hayes, 1999; Russell and Chappell, 2007). In some interspecific comparisons, authors have elucidated positive correlations between BMR and sizes of some organs (Daan et al., 1990; Raichlen et al., 2010), but other studies have failed to find such an association (Tieleman et al., 2003).

During exercise, oxygen consumption of skeletal muscles increases to more than 90% of the total, requiring blood flow to be routed away from central organs to muscles (Taylor et al., 1981). Because cold- and exercise-induced PMR is lower in tropical compared with temperate birds (Wiersma et al., 2007a; Wiersma et al., 2007b), one might predict that skeletal muscles are smaller in tropical species.

In this paper, we identify a functional linkage between the low rate of basal metabolism in tropical birds and the small size of their central organs. Further, we offer compelling evidence that the low PMR of tropical birds can be explained, at least in part, by a reduction in skeletal muscle mass. Our approach included collation of a large data set on organ sizes of birds from the literature and direct measurement of organ sizes of lowland tropical species and species from Ohio. The results from literature data and our direct measurements offer unequivocal evidence that tropical birds have smaller heart, lungs, liver, pancreas, kidneys, ovaries and testes than do temperate species of the same body size, which accounts for, at least in part, their lower rate of basal metabolism. Moreover, we found that flight muscles of tropical birds were 18% smaller than those of temperate species. This suggests that natural selection has adjusted organ size to fit the ecological needs of a species, and this affects their overall rate of metabolism.

MATERIALS AND METHODS

We obtained organ masses for 408 species from the literature (supplementary material Table S1). Origins of birds collected by Hartman (Hartman, 1961) were corroborated using original data provided by J. Condit, Museum of Biological Diversity, Columbus, OH, USA, and by G. Ludwig, National Museum of Natural History, Washington, DC, USA. Data for organs from birds that were collected from the southern USA were excluded from analyses. Based on information on habitat and distribution, tropical birds collected by Hartman (N=295) (Hartman, 1955; Hartman, 1961) originated mainly from lowland Panama, but a few specimens apparently came from altitudes of 1000–2000 m. Crile and Quiring (Crile and Quiring, 1940) collected birds in eastern Africa, mainly Lake Manyara, Tanzania (N=16), and from lowland Guatemala (N=1), whereas Rensch and Rensch (Rensch and Rensch, 1956) gathered data on tropical birds near Mysore, India, elevation *ca*. 770 m (N=9). We assigned a species as temperate when they were collected at latitudes between 35°N and 67°N or S, and as tropical when they were collected between 23°N and 23°S. We excluded organ masses of long-distance migrants. Where individual or sex-specific values were given for the mass of organs, we calculated the mean. We used organ dry mass in our analyses. Because all authors reported wet organ mass, we estimated organ dry mass based on measurements of water content that we had made. Conclusions did not vary when we used wet or dry organ mass in our analyses. Body masses of all birds were obtained from original sources.

We directly measured organ sizes of 32 species of lowland tropical birds, captured with mist nets in and around Gamboa, Panama (9°7′N, 79°42′W) in March–June, 2006 and 2007, and of 17 species of temperate birds, collected with mist nets during the breeding season in Ohio in 2006 and 2007 (supplementary material Table S2). Birds were killed by cervical dislocation; all feathers were removed and the brain (including brainstem), gonads (including oviduct for females), stomach, intestines (excluding pancreas), liver, kidneys, heart, lungs, flight muscles (pectoralis and supracoracoideus), leg muscles, spleen and gallbladder excised. Intestines and gizzard were opened and the contents removed by washing. We removed visible fat from body components prior to weighing. We counted all remaining tissue including the skeleton and excluding skin in the category 'carcass'. Organs were placed in preweighed aluminium trays and feathers in previously dried paper bags. We dried both to constant mass for a minimum of 3 days in an oven at 70°C. Dried organs and feathers were weighed to the nearest 0.1 mg using a Mettler analytical balance.

All procedures were approved by the Institutional Animal Care and Use Committee of The Ohio State University (protocol IACUC2004A0093) and capture of birds in Panama was accomplished under permit from Panamanian Autoridad Nacional del Ambiente (No. SE/A-36-06) and Autoridad del Canal de Panamá.

Statistics

We used phylogenetic generalized least squares (PGLS) analyses to test for the effect of climate (tropical or temperate) on dry mass of tissues. For data from the literature, dry masses of organs were regressed against climate and fresh body mass, from which the mass of the focal organ had been subtracted to ensure independence of data (Christians, 1999). In addition, the source of data was added as an independent variable to control for methodological differences among investigators. In analyses of our direct measurements of organ size, we controlled for sex, diet and migratory behaviour (see supplementary material Table S2). To control for size we used dry carcass mass instead of body mass. Carcass mass, which included the skeleton, was the remainder of tissues after all major organs had been removed. Because body mass includes the mass of the focal organ, it is not an independent variable. Subtracting the mass of the focal organ from body mass would in most cases not solve the problem because the sizes of other organs often covary with the mass of the focal organ.

We used PGLS because this method is an improvement over previous methods of incorporating phylogeny into statistical models, such as phylogenetic independent contrasts (PIC), because it can test and modify assumptions within these earlier models, and provide information on how traits have evolved by selecting the most appropriate evolutionary model. PGLS is a regression model where the structure of the error term incorporates the phylogeny of the species by adjusting the variance–covariance matrix, thus taking into account the independence of data points as a result of phylogenetic history (Paradis, 2006; Rohlf, 2001). Covariances can be manipulated to conform to different models of trait evolution and to incorporate varying degrees of phylogenetic signal. Three models of trait evolution were evaluated and the best model was selected on the basis of corrected Akaike information criteria (AIC_C) (Burnham and Anderson, 2002). Pagel's model modifies covariances between species by multiplying with a constant, λ, as estimated by the model. When species traits are phylogenetically uncorrelated, λ=0, and when there is a strong phylogenetic signal within the data, λ=1. For the latter trait, evolution follows Brownian motion where differences in traits between species are proportional to the time since divergence (Felsenstein, 1985). The second model that was evaluated incorporated stabilizing selection, where trait covariances decrease exponentially with increasing time since divergence and where the strength of the directional selective force is controlled by parameter α (Martins and Hansen, 1997). The model allows trait evolution to vary between non-directional Brownian motion (α=0) and strong directional selection (α=1). Grafen's model first calculates branch lengths based on number of descendants, thereby discarding information on branch lengths (Grafen, 1989). The tree is scaled so that the root has depth 1, and branch lengths are raised to the power ρ. When ρ=1, a strong phylogenetic signal is implied.

PGLS statistics were performed in R v.2.12 (R Development Core Team, 2011) using the package ape v.2.6 (Paradis et al., 2004) to calculate phylogenetic correlation structures, package nlme v.3.1 (Pinheiro et al., 2011) for PGLS analyses and package AICcmodavg v.1.14 (Mazerolle, 2011) for calculating AIC_C.

Because potential errors in phylogeny could affect the outcome of statistical tests, we also compared organ masses within phylogenetically closely related pairs of tropical–temperate species (supplementary material Table S3). Differences between sister species from separate environments are not likely to be the result of phylogenetic distance. Pair-wise analysis uses less phylogenetic information but also restricts the number of data points to species with recent common ancestors. Analyses were performed using linear mixed models with species pair and intercept entered as random effects. We entered 'carcass mass', 'climate', 'sex', 'diet' and 'migratory behaviour' as independent variables. Mixed models were performed using SPSS v. 19 (SPSS Inc., Chicago, IL, USA).

Phylogenies

For the large number of species in our data set from the literature, we used a family-level tree and included species of the same family as polytomies. We used the family tree of Sibley and Ahlquist (Sibley and Ahlquist, 1990), which was obtained from the R-package 'ape'.

The phylogenetic relationships for species that we directly measured were based on information assembled by Boyd (Boyd, 2011) (supplementary material Fig. S1). Branch lengths were derived from Sibley and Ahlquist (Sibley and Ahlquist, 1990). When a species' phylogeny was not resolved, we introduced a polytomy. Individuals of one species were incorporated into the tree as polytomies at the tips with zero branch lengths. Trees were manipulated using TreeGraph 2 (Stöver and Müller, 2010) and Mesquite (Maddison and Maddison, 2010).

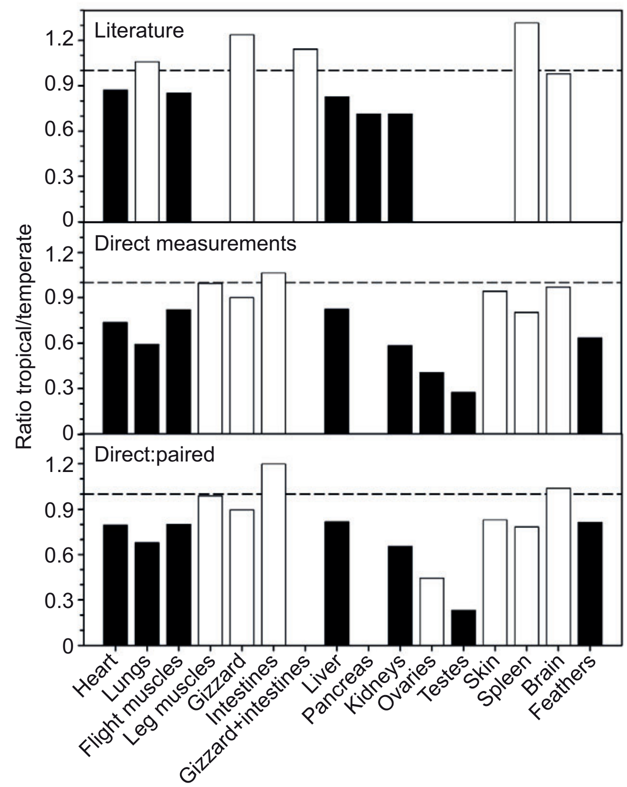

Fig. 1. Ratios of the difference in dry mass between organs of tropical and temperate species. Because models were linear and, except for feather mass, contained no interactions, the results are not affected by body size, sex, migratory strategy or diet. Filled bars represent a significant difference between tropical and temperate species.

RESULTS

Based on literature data, heart, flight muscles, liver, pancreas and kidneys were 13–29% smaller in tropical species (Fig. 1, Table 1). Direct measurement of organ masses showed that heart, lungs, flight muscles, liver, kidneys, ovaries, testes and feathers were significantly lighter in tropical species (Fig. 1, Table 2). These differences ranged from –18% for the flight muscles and liver to –72% in reproductive organs. Leg muscles, gizzard, intestines and skin did not statistically differ between climates. Fresh mass of all organs summed was 14.8% lower in tropical than in temperate birds with equal carcass mass. Masses of several organs were correlated with sex, migratory behaviour and diet (Table 2). Lungs were smaller in our direct measurements but not in data from the literature. Gizzard, intestine and brain were not significantly different in either data set. In our direct measurements, feather mass was significantly lower in tropical birds. The slope of the relationship between feather mass and body mass was shallower in temperate species, indicating that small temperate species had relatively more feathers (Fig. 2).

When we compared organs from phylogenetically paired comparisons, we found significantly reduced sizes of heart, lungs,

Table 1. Results of phylogenetic generalized least squares (PGLS) models describing dry tissue mass as a function of body mass minus fresh focal tissue mass, tropical or temperate climate

	Heart	Lungs	Flight muscles	Gizzard+ intestines	Gizzard	Liver	Pancreas	Kidneys	Spleen	Brain
Intercept	–1.718±0.067***	–1.554±0.126***	–0.603±0.068***	–0.835±0.226**	–1.808±0.350***	–1.096±0.083***	–2.837±0.339***	–1.715±0.086***	–2.870±0.646***	–0.952±0.080***
$\log_{10}$ body mass†	0.901±0.014***	0.911±0.044***	1.010±0.015***	0.933±0.086***	1.140±0.142***	0.850±0.029***	1.106±0.028***	0.914±0.030***	1.040±0.252***	0.607±0.018***
Climate (=tropical)	–0.0602±0.0135***	0.0244±0.0579	–0.0700±0.0334*	0.0580±0.1318	–0.154±0.113	–0.0831±0.0387*	–0.147±0.001***	–0.147±0.036***	0.119±0.354	–0.00877±0.0179
Source=1	0	0		0		0		0	0	0
Source=2										–0.0445±0.0202*
Source=3										–0.0881±0.0527
Source=4	–0.135±0.025***		0							
Source=5						–0.141±0.136			–0.233±0.737	
Source=6	–0.143±0.039***				0	–0.148±0.056*	0	–0.0175±0.0553	–0.0901±0.4345	
d.f. (residual, total)	403, 408	29, 32	285, 288	9, 12	9, 12	45, 50	5, 8	41, 45	15, 20	134, 139
AIC_C Pagel	–627.3 (λ=0.736)	–7.6 (λ=0.409)	–536.9 (λ=0.793)	13.7 (λ=0.007)	–58.5 (λ=1.000)	–31.7 (λ=0.000)	35.5 (λ=1.000)	–35.0 (λ=0.045)	59.1 (λ=–0.077)	–218.2 (λ=0.867)
AIC_C Grafen	–536.6 (ρ=0.169)	–6.1 (ρ=0.174)	–479.8 (ρ=0.287)	13.5 (ρ=0.063)	18.7 (ρ=0.000)	–29.0 (ρ=0.000)	32.6 (ρ=7.676)	–35.8 (ρ=0.108)	59.1 (ρ=0.000)	–189.2 (ρ=0.403)
AIC_C Martins	–490.3 (α=1.000)	–4.1 (α=1.000)	–452.4 (α=1.000)	19.9 (α=1.000)	19.4 (α=1.000)	–7.3 (α=1.000)	37.4 (α=1.000)	–16.6 (α=1.000)	68.4 (α=1.000)	–161.0 (α=1.000)

Data are $\log_{10}$ tissue or organ mass and were collected from literature sources.

The phylogeny was revolved down to family level. Shown are parameter estimates with standard errors and *P*-value categories, as well as degrees of freedom (total=number of species), evolutionary model parameter estimates and corrected Akaike information criteria (AIC_C) values of final model. Significant variables are shaded grey as is the model with the lowest AIC_C.

* $P<0.05$; ** $P<0.01$; *** $P<0.001$.

†Excluding mass of focal tissue.

Source=0 for reference category or indicating the single data source. Source 1 (Crile and Quiring, 1940), 2 (Garamszegi et al., 2002), 3 (Graber and Graber, 1965), 4 (Hartman, 1955; Hartman, 1961), 5 (Oakeson, 1956), 6 (Rensch and Rensch, 1956).

flight muscles, liver, kidneys, testes and feathers in tropical birds, in support of our previous findings (Table 3).

We examined scaling exponents for each organ to evaluate whether organs scaled differently between tropical and temperate birds and whether masses increased in proportion with body size. Most organs scaled in proportion to body size except for the heart, liver and kidneys, with lower slopes of around 0.88, and brain which had a slope of 0.555 (*t*-tests, $P<0.05$; Table 2). Slopes did not differ between tropical and temperate species for any organ (PGLS, testing for interaction between carcass mass and climate, all $P>0.05$). The slope for feather mass was higher in tropical species (Fig. 2).

DISCUSSION

We have demonstrated a strong link between a slow pace of life in tropical birds and smaller organ sizes. Our results indicate that the heart, liver, pancreas, lungs, flight muscles, kidneys, ovaries and testes were reduced in mass in tropical species, which will contribute significantly to the birds' reduced BMR. Moreover, we found that muscles that power flight are significantly reduced in tropical species, which would contribute to the reduced PMR (see Vézina et al., 2006). Feather mass was greater in temperate species, a likely requirement for their larger thermoregulatory demand. Despite its high energy turnover and diversification in size among bird taxa (Nealen and Ricklefs, 2001), brain size was similar in tropical and temperate birds.

Model estimates inform about phylogenetic signal and the evolutionary trajectory that best fits that data. The method of PIC (Felsenstein, 1985) depends on a model with maximum phylogenetic correlation as predicted by Brownian motion. Although the extent of the phylogenetic signal in literature data and our direct measurements varied considerably, in most cases controlling for phylogeny was warranted (Pagel's λ in Tables 1 and 2), but estimates of model parameters, in particular λ and ρ, showed that the optimal models for organ masses were, in general, intermediate between a star phylogeny and our structured phylogeny based on DNA hybridization.

BMR depends on the mass of organs and tissues and on the metabolic intensities of their cells. Krebs (Krebs, 1950) showed that tissue metabolism of mammals scaled allometrically with BMR as body size increased, findings later confirmed by more precise measurements (Savage et al., 2007). We showed earlier that the allometric slope for BMR of birds from the same areas and time of year, and often of the same species as analysed here for organ masses, is close to 0.67 (Wiersma et al., 2007a). Masses of most organs, except brain, spleen, ovaries and testes, varied with body mass, with slopes exceeding 0.67, and only brain, heart, liver and kidneys had slopes lower than 1 (*t*-tests, correcting for body mass for proper comparison with slopes for BMR; supplementary material Table S4). This evidence is consistent with the idea that the metabolic intensity of organ tissues decreases with increasing body mass. Allometric exponents for organ masses did not differ between tropical and temperate species.

We found that tropical birds have a smaller feather mass than temperate species. When birds live in conditions like the lowland tropics where the air temperature rarely falls below the lower critical temperature, and where high air temperatures may be more problematic, possessing a plumage with low insulation may be advantageous. It reduces energy expenditure at high temperatures and reduces costs of growth and maintenance of feathers. Indeed, feather mass was on average 37% lower in tropical species (Fig. 1). Scholander et al. (Scholander et al., 1950) showed that the insulative properties of arctic mammal fur were higher than those of tropical mammals, and speculated that birds showed the same pattern. Our results lend support to Scholander's idea. Moreover, we showed that slopes for feather mass were higher in tropical than in temperate species (1.10 *versus* 0.95; $P<0.01$): small tropical birds have lower

Table 2. Results of PGLS models describing dry tissue mass as a function of dry carcass mass, tropical or temperate climate, sex, migratory strategy and diet

	Heart	Lungs	Flight muscles	Leg muscles	Gizzard	Intestines	Liver
Intercept	–1.442±0.0574***	–1.460±0.055***	–0.312±0.0704***	–1.018±0.090***	–1.460±0.1290***	–1.543±0.126***	–1.015±0.084***
$\log_{10}$ dry carcass mass	0.872±0.0332***	0.956±0.038***	0.990±0.035***	1.105±0.041***	0.907±0.072***	1.063±0.076***	0.881±0.047***
Climate (=tropical)	–0.133±0.017***	–0.228±0.024***	–0.0855±0.0152***	–0.0022±0.0164	–0.0459±0.0473	0.0267±0.0402	–0.0841±0.0231**
Sex (=male)	0.0317±0.0118**	0.0254±0.0143*	0.00165±0.01036	–0.0167±0.0113	–0.0364±0.0216	–0.107±0.029**	–0.0326±0.0160*
Migrant (=yes)	–0.0666±0.0289*	0.0269±0.0388	0.0148±0.0264	–0.0125±0.0290	–0.215±0.074**	–0.0365±0.0690	–0.0312±0.0395
Diet (=granivorous)	–0.0453±0.0296	–0.0169±0.0379	–0.0268±0.0314	–0.0366±0.0380	0.321±0.078***	–0.189±0.089**	–0.171±0.042***
Diet (=insectivorous)	–0.0588±0.0350	–0.0727±0.0411	–0.0947±0.0395*	–0.0564±0.0482	0.330±0.090**	–0.194±0.0783*	–0.138±0.050**
Diet (=nectivorous)	0.129±0.104	0.0062±0.0874	0.0605±0.1354	–0.218±0.178	–0.298±0.164	–0.0385±0.2257	–0.0811±0.1550
Diet (=omnivorous)	–0.0933±0.0302**	–0.0635±0.0398	–0.0797±0.0338*	0.0469±0.0418	0.248±0.085**	–0.127±0.069	–0.152±0.043**
Diet (=frugivorous)	0	0	0	0	0	0	0
d.f. (residual, total)	175, 184	176, 185	178, 187	178, 187	174, 183	177, 186	177, 186
AIC_C Pagel	–335.5 (λ=0.629)	–269.0 (λ=0.509)	–367.2 (λ=0.858)	–324.4 (λ=0.923)	–72.3 (λ=0.837)	–25.7 (λ=0.520)	–225.6 (λ=0.690)
AIC_C Grafen	–333.5 (ρ=0.141)	–270.7 (ρ=0.127)	–364.8 (ρ=0.373)	–312.0 (ρ=0.336)	–99.8 (ρ=0.330)	–21.7 (ρ=0.096)	–221.8 (ρ=0.138)
AIC_C Martins	NA	–252.9 (α=0.724)	NA	–314.0 (α=0.075)	NA	–8.6 (α=0.589)	–217.7 (α=0.540)
	Kidneys	Ovaries	Testes	Skin	Spleen	Brain	Feathers
Intercept	–1.401±0.057***	–1.634±0.299***	–1.940±0.333***	–1.042±0.068***	–2.680±0.247***	–1.171±0.057***	–0.375±0.073***
$\log_{10}$ dry carcass mass	0.894±0.037***	0.845±0.318***	1.132±0.238***	1.056±0.061***	0.925±0.158***	0.599±0.029***	1.035±0.043***
Climate (=tropical)	–0.234±0.024***	–0.390±0.151***	–0.560±0.158***	–0.0256±0.0261	–0.0955±0.0972	–0.0126±0.0133	–0.198±0.021***
Sex (=male)	–0.0264±0.0128*			–0.0475±0.0160**	–0.0988±0.0726	0.0156±0.009	–0.0061±0.0145
Migrant (=yes)	–0.0923±0.0376*	–0.395±0.290	0.202±0.252	–0.0259±0.0420	–0.0749±0.1548	–0.0462±0.0231*	0.0515±0.0346
Diet (=granivorous)	–0.187±0.038***	–0.752±0.289***	–0.276±0.242	0.0095±0.0573	–0.0811±0.180	0.0145±0.0270	0.0569±0.0379
Diet (=insectivorous)	–0.0585±0.0418	–0.411±0.290	–0.215±0.257	0.0006±0.0680	–0.164±0.185	–0.0127±0.0333	–0.0095±0.0476
Diet (=nectivorous)	0.0511±0.0844	–0.239±0.608	–0.683±0.555	–0.0892±0.0623		–0.0751±0.1085	
Diet (=omnivorous)	–0.142±0.040**	–0.341±0.329	–0.0330±0.2479	–1.042±0.068	–0.0724±0.1652	0.0524±0.0284	0.0306±0.0390
Diet (=frugivorous)	0	0	0	0	0	0	0
d.f. (residual, total)	176, 185	50, 58	50, 58	101, 109	112, 120	175, 184	112, 120
AIC_C Pagel	–301.3 (λ=0.651)	117.5 (λ=1.000)	307.7 (λ=1.000)	–137.6 (λ=0.841)	152.1 (λ=0.257)	–412.3 (λ=0.816)	–164.2 (λ=0.686)
AIC_C Grafen	–302.1 (ρ=0.184)	106.0 (ρ=0.155)	205.7 (ρ=0.162)	–131.6 (ρ=0.233)	152.6 (ρ=0.031)	–401.5 (ρ=0.253)	–201.9 (ρ=0.134)
AIC_C Martins	–272.3 (α=0.709)	100.9 (α=0.260)	201.5 (α=0.156)	–139.1 (α=0.158)	152.4 (α=1.221)	–371.1 (α=0.071)	–200.8 (α=0.444)

Data are $\log_{10}$ tissue or organ mass.

Migratory strategy: long-distance migrants that breed in North America and migrate at least as far as Central America *vs* sedentary birds and short-distance migrants.

Parameter estimates for alternative variable values are used as reference and equal 0 and are not shown. For diet, frugivory is used as reference category. Shown are parameter estimates with standard errors and *P*-value categories, as well as degrees of freedom (total=number of specimens), evolutionary model parameter estimates and AIC_C values of final model. Significant variables are shaded grey as is the model with lowest AIC_C. When a model did not converge AIC_C=NA.

**P*<0.05; ***P*<0.01; ****P*<0.001.

feather mass but these differences diminish as body size increases (Fig. 2). Because the surface to volume ratio increases when body size decreases, we hypothesize that it is more advantageous for temperate birds that are small to have extra insulation than it is for larger birds as a result of the former's high thermoregulatory requirements at low ambient temperatures. In addition, because lower critical temperatures increase with body size, small birds are likely to have greater selection pressure to increase insulation.

Ultimately, evolutionary physiologists seek to identify selection pressures that fashion physiological phenotypes occuring within a given environment. In the tropics, it is plausible that individuals have lower energy needs than their temperate counterparts. Tropical birds have a shorter day length in which they can be active compared with temperate birds during the breeding season, live in an environment that is stable and warm, and are likely to have abundant food resources. Because in a benign environment birds may have lower energy demands, we suggest that selection has down-regulated organ systems responsible for digestion and heat production (Piersma et al., 1996). In colder environments, selection might be expected to favour individuals with a greater capacity for activity and thermoregulation, requiring more energy intake and larger organs to process food (Kersten et al., 1998). Contrary to our expectations, gizzard and intestines were not reduced in tropical species (Fig. 1), which is remarkable considering the presumed high metabolic costs of intestinal tissue (Aiello and Wheeler, 1995). However, the metabolic intensity of mammalian intestines varies considerably, so we do not know that intestinal tissues of birds have high rates of metabolism (Aiello and Wheeler, 1995). Moreover, the intestinal tract of mammals is considerably larger than that of birds (Isler and van Schaik, 2006). For example, intestines represent 2.1% of fresh body mass in our data and 9.1% in mice of 20 g (Konarzewski and Diamond, 1995). But even if the metabolic costs of the intestines are minimal, the question of why their size does not follow the general pattern of other central organs in tropical and temperate birds remains.

Our data are also consistent with the heat dissipation limit theory, which assumes that maximum rates of heat loss limit reproductive effort, causing the association between life-history variables and body mass (Speakman and Król, 2010). In this view, tropical birds are under selection to minimize energy expenditure and maximize heat loss, which can be achieved by having smaller organs and reduced insulation.

Only a small fraction of total body mass consists of internal organs, in tropical birds 9.5–15.5%, but because these organs have high metabolic intensities, they contribute towards a significant part of BMR (Elia, 1992). Rather than operating directly on BMR, we

Table 3. Results of pair-wise comparisons of dry tissue masses of 10 pairs of closely related temperate–tropical species, controlling for body size using log dry carcass mass, sex, migratory strategy and diet

	Heart	Lungs	Flight muscles	Leg muscles	Gizzard	Intestines	Liver
Intercept	–1.359±0.090***	–1.517±0.089***	–0.343±0.076***	–1.018±0.139***	–2.179±0.142***	–1.345±0.161***	–0.903±0.058***
$\log_{10}$ dry carcass mass	0.718±0.076***	0.813±0.087***	1.147±0.068***	1.166±0.080***	1.197±0.139***	1.024±0.161***	0.957±0.054***
Climate (=tropical)	–0.0997±0.0221***	–0.167±0.029***	–0.0970±0.0206***	–0.0044±0.0212	–0.0483±0.0469	0.0793±0.0607	–0.0876±0.0295*
Sex (=male)	0.0371±0.0146*	0.0343±0.0198	–0.0007±0.0135	–0.0361±0.0137*	–0.0336±0.0318	–0.136±0.042**	–0.0560±0.0211
Migrant (=yes)	–0.0287±0.0314	0.0633±0.0420	–0.0080±0.0290	–0.0126±0.0296	–0.115±0.068	–0.0577±0.0890	–0.0517±0.0414
Diet (=granivorous)	0.0133±0.0432	0.125±0.061*	–0.0155±0.0408	–0.110±0.0412**	0.711±0.098***	–0.324±0.126*	–0.301±0.064***
Diet (=insectivorous)	–0.112±0.0970	0.0031±0.0904	–0.141±0.081	0.0091±0.1619	0.974±0.145***	–0.167±0.160	–0.179±0.054**
Diet (=nectivorous)	–0.159±0.153	–0.0923±0.1506	0.183±0.129	–0.0545±0.2397	0.779±0.241**	–0.306±0.272	–0.137±0.097
Diet (=omnivorous)	0.0994±0.0981	–0.0366±0.0915	0.232±0.081*	–0.106±0.168	–0.710±0.146**	0.0958±0.1624	0.208±0.061**
Diet (=frugivorous)	0	0	0	0	0	0	0
N (temperate, tropical)	51, 48	50, 49	51, 49	51, 49	51, 46	51, 48	52, 48
	Kidneys	Ovaries	Testes	Skin	Spleen	Brain	Feathers
Intercept	–1.462±0.058***	–0.424±0.358*	–1.369±0.467*	–1.061±0.104***	–2.725±0.245***	–1.015±0.042***	–0.237±0.117
$\log_{10}$ dry carcass mass	0.833±0.058***	0.317±0.610	1.362±0.735	1.231±0.137***	1.190±0.267***	0.365±0.040***	0.675±0.104***
Climate (=tropical)	–0.185±0.024***	–0.352±0.209	–0.634±0.247*	–0.0810±0.0537	–0.106±0.116	0.0158±0.0179	–0.0907±0.0285**
Sex (=male)	–0.0417±0.0165*			–0.0399±0.0252	–0.145±0.084	0.0250±0.0127	–0.000±0.014
Migrant (=yes)	–0.0497±0.0344	–0.406±0.261	0.221±0.331	0.101±0.066	0.147±0.160	–0.0240±0.0260	0.172±0.037***
Diet (=granivorous)	–0.144±0.051**	–1.897±0.338***	–0.662±0.492	–0.0356±0.0759	–0.229±0.246	–0.0505±0.0402	0.189±0.042***
Diet (=insectivorous)	0.0547±0.0564	–1.480±0.352*	–0.874±0.460	0.0205±0.1001	–0.179±0.208	–0.0323±0.0410	–0.104±0.131
Diet (=nectivorous)	–0.102±0.097		–1.303±0.749			–0.369±0.069***	0.148±0.132
Diet (=omnivorous)	0.0106±0.0588	1.163±0.520*	–0.787±0.664	0.239±0.108*	–0.365±0.262	–0.147±0.043**	–0.148±0.132
Diet (=frugivorous)	0	0	0	0		0	0
N (temperate, tropical)	51, 49	18, 17	27, 31	52, 48	49, 29	51, 49	52, 49

Data are $\log_{10}$ dry tissue or organ mass.

Migratory strategy: long-distance migrants that breed in North America and migrate at least as far as Central America *vs* sedentary birds and short-distance migrants.

Parameter estimates for alternative variable values are used as reference and equal 0 and are not shown. For diet, frugivory is used as reference category. Data were collected in Panama and Ohio. Shown are parameter estimates with standard errors and *P*-value categories, as well as sample sizes. Significant variables are shaded grey.

P*<0.05; ***P*<0.01; * *P*<0.001.

argue that there is strong selection on organ systems that support levels of activity measured as sustained metabolic rates (Ksiazek et al., 2004) or as indexed by maximum metabolic performance in birds, measured by PMR_C and PMR_E. Recent insight into genes that regulate cell and organ growth through transcriptional regulation of protein and lipid synthesis may point to the specific targets for natural selection (Portsmann et al., 2009).

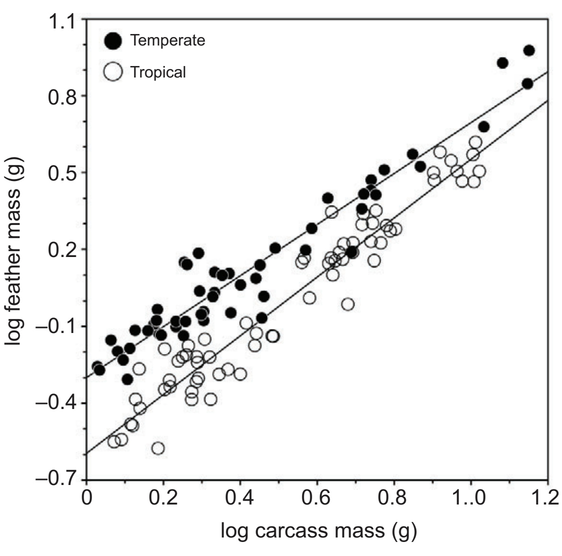

Fig. 2. Dry feather mass in relation to dry carcass mass of 123 specimens of 14 tropical and 13 temperate bird species. The interaction between feather mass and carcass mass was significant: phylogenetic generalized least squares (PGLS) with sex, diet and migratory behaviour as covariates, interaction log feather mass × log carcass mass: 0.150±0.054 (mean ± s.e.m.) for tropical species and 0 for temperate species, *t*=2.80, *P*<0.01; Pagel's λ=0.680.

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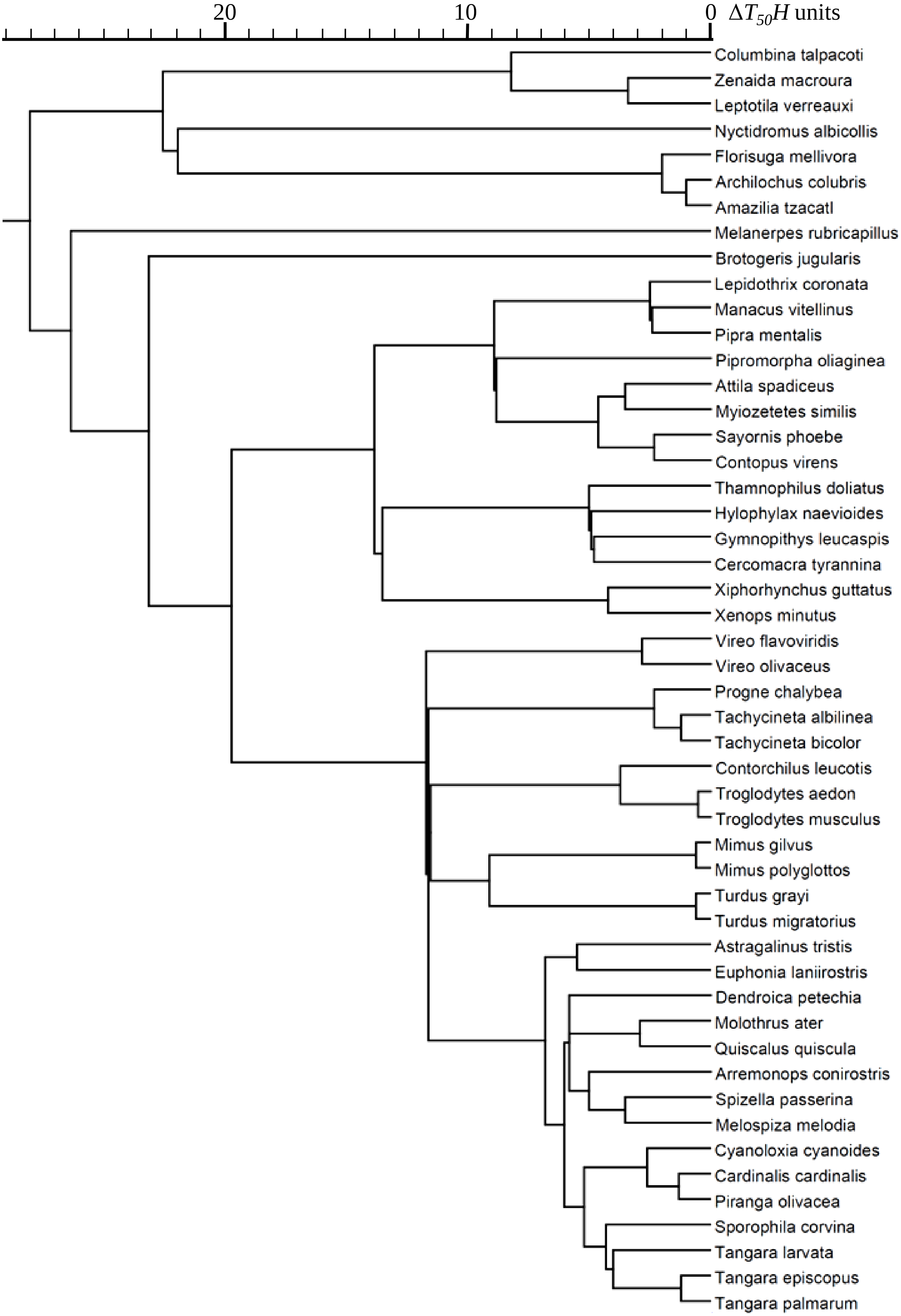
20
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$\Delta T_{50}H$ units
Columbina talpacoti
Zenaida macroura
Leptotila verreauxi
Nyctidromus albicollis
Florisuga mellivora
Archilochus colubris
Amazilia tzacatl
Melanerpes rubricapillus
Brotogeris jugularis
Lepidothrix coronata
Manacus vitellinus
Pipra mentalis
Pipromorpha oliaginea
Attila spadiceus
Myiozetetes similis
Sayornis phoebe
Contopus virens
Thamnophilus doliatus
Hylophylax naevioides
Gymnopithys leucaspis
Cercomacra tyrannina
Xiphorhynchus guttatus
Xenops minutus
Vireo flavoviridis
Vireo olivaceus
Progne chalybea
Tachycineta albilinea
Tachycineta bicolor
Contorchilus leucotis
Troglodytes aedon
Troglodytes musculus
Mimus gilvus
Mimus polyglottos
Turdus grayi
Turdus migratorius
Astragalinus tristis
Euphonia laniirostris
Dendroica petechia
Molothrus ater
Quiscalus quiscula
Arremonops conirostris
Spizella passerina
Melospiza melodia
Cyanoloxia cyanoides
Cardinalis cardinalis
Piranga olivacea
Sporophila corvina
Tangara larvata
Tangara episcopus
Tangara palmarum

Table S1. Species for which data on organ masses were collected from literature sources

Family	Species	Name	Climate	Literature source for data on									
				Hea	Lun	FlMu	Giz	GiIn	Liv	Kid	Pan	Spl	Bra
Accipitridae	*Accipiter bicolor*	Bicoloured hawk	tropical	H2		H2							
	Accipiter cooperii	Cooper's Hawk	temperate	H2		H2							
	Accipiter gentilis	Northern Goshawk	temperate										G
	Accipiter nisus	Eurasian Sparrowhawk	temperate										G
	Accipiter striatus	Sharp-Shinned Hawk	temperate	C	C								C
	Aquila rapax	Tawny Eagle	tropical	C	C				C	C			C
	Asturina nitida	Grey-Lined Hawk	tropical	H2		H2							
	Busarellus nigricollis	Black-Collared Hawk	tropical	H2		H2							
	Buteo lagopus	Rough-legged Hawk	temperate										G
	Buteo magnirostris	Roadside Hawk	tropical	H2		H2							
	Buteogallus anthracinus	Common Black-Hawk	tropical	H2		H2							
	Buteogallus meridionalis	Savanna Hawk	tropical	H2		H2							
	Buteogallus urubitinga	Great Black-Hawk	tropical	H1,2		H1,2							
	Chondrohierax uncinatus	Hook-Billed Kite	tropical	H2		H2							
	Circus aeruginosus	Western Marsh-Harrier	temperate										G
	Geranospiza caerulescens	Crane Hawk	tropical	H2		H2							
	Gyps africanus	White-Backed Vulture	tropical	C					C	C			C
	Haliaeetus vocifer	African Fish-Eagle	tropical	C	C			C	C	C			C
	Harpagus bidentatus	Double-Toothed Kite	tropical	H2		H2							
	Leptodon cayanensis	Grey-Headed Kite	tropical	H2		H2							
	Spizaetus ornatus	Ornate Hawk-Eagle	tropical	H2		H2							
	Spizastur melanoleucus	Black-And-White Hawk-Eagle	tropical	H2		H2							
Alaudidae	*Alauda arvensis*	Eurasian Skylark	temperate	R					R	R		R	G
	Eremophila bilopha	Temminck's Lark	tropical										G
	Galerida cristata	Crested Lark	temperate										G
	Lullula arborea	Wood Lark	temperate	R					R	R		R	
Alcedinidae	*Alcedo atthis*	Common Kingfisher	temperate										G
	Alcedo cristata	Malachite Kingfisher	tropical										G
Anatidae	*Alopochen aegyptiaca*	Egyptian Goose	tropical	C	C				C	C			C
	Anas acuta	Northern Pintail	temperate	C	C			C	C	C		C	C
	Anas carolinensis	Green-Winged Teal	temperate	C	C			C	C	C		C	C
	Anas penelope	Eurasian Wigeon	temperate	H2		H2							
	Anas platyrhynchos	Mallard	temperate										G
	Aythya affinis	Lesser Scaup	temperate	C	C				C	C			
	Aythya marila	Greater Scaup	temperate	C	C			C	C	C			C
	Clangula hyemalis	Long-tailed Duck	temperate										G
	Mergus merganser	Common Merganser	temperate										G
	Mergus serrator	Red-Breasted Merganser	temperate	C	C			C	C	C		C	G
	Nomonyx dominicus	Masked Duck	tropical	H2		H2							
	Somateria mollissima	Common Eider	temperate										G
Ardeidae	*Agamia agami*	Agami Heron	tropical	H2		H2							
	Ardea alba	Great Egret	tropical	H1									
	Ardea cinerea	Grey Heron	temperate										G
	Ardea herodias	Great Blue Heron	temperate	H1									
	Butorides virescens	Green Heron	tropical	H2		H2							
	Cochlearius cochlearius	Boat-Billed Heron	tropical	H2		H2							
	Egretta caerulea	Little Blue Heron	tropical	H2		H2							
	Egretta intermedia	Yellow-Billed Egret	tropical	C	C				C	C			C
	Ixobrychus exilis	Least Bittern	temperate	H1									
	Tigrisoma fasciatum	Fasciated Tiger-Heron	tropical	H1									
	Tigrisoma lineatum	Rufescent Tiger-Heron	tropical	H2		H2							
	Tigrisoma mexicanum	Bare-Throated Tiger-Heron	tropical	H2		H2							
Bombycillidae	*Bombycilla cedrorum*	Cedar Waxwing	temperate	H1									
	Bombycilla garrulus	Bohemian Waxwing	temperate										G
	Bombycilla japonica	Japanese Waxwing	temperate										G

				Literature source for data on									
Family	Species	Name	Climate	Hea	Lun	FlMu	Giz	Giln	Liv	Kid	Pan	Spl	Bra
	Ptilogonys caudatus	Long-Tailed Silky-Flycatcher	tropical	H2		H2							
Bucconidae	*Malacoptila panamensis*	White-Whiskered Puffbird	tropical	H2		H2							
	Nonnula frontalis	Grey-Cheeked Nunlet	tropical	H2		H2							
	Notharchus macrorhynchos	White-Necked Puffbird	tropical	H2		H2							
Bucorvidae	*Bucorvus leadbeateri*	Southern Ground-Hornbill	tropical	C	C			C	C	C			C
Caprimulgidae	*Chordeiles acutipennis*	Lesser Nighthawk	tropical	H2		H2							
(Caprimulgidae)	*Nyctidromus albicollis*	Pauraque	tropical	H2		H2							
Cathartidae	*Cathartes aura*	Turkey Vulture	tropical	H2		H2							
	Coragyps atratus	Black Vulture	tropical	H2		H2							
Centropidae	*Centropus sinensis*	Greater Coucal	tropical	R			R		R				
Certhiidae	*Certhia americana*	Brown Treecreeper	temperate	H2		H2							
	Certhia familiaris	Eurasian Treecreeper	temperate	H1									G
	Cistothorus palustris	Marsh Wren	temperate	H1									
	Cyphorhinus phaeocephalus	Song Wren	tropical	H2		H2							
	Henicorhina leucophrys	Grey-Breasted Wood-Wren	tropical	H2		H2							
	Henicorhina leucosticta	White-Breasted Wood-Wren	tropical	H2		H2							
	Polioptila caerulea	Blue-Grey Gnatcatcher	temperate	H1									
	Polioptila plumbea	Tropical Gnatcatcher	tropical	H2		H2							
	Ramphocaenus melanurus	Long-Billed Gnatwren	tropical	H2		H2							
	Thryothorus fasciatoventris	Black-Bellied Wren	tropical	H2		H2							
	Thryothorus modestus	Plain Wren	tropical	H2		H2							
	Thryothorus rutilus	Rufous-Breasted Wren	tropical	H2		H2							
	Troglodytes aedon aedon	Northern House-Wren	temperate	H1									G
	Troglodytes ochraceus	Ochraceous Wren	tropical	H2		H2							
	Troglodytes troglodytes	House Wren	temperate										G
Cerylidae	*Chloroceryle aenea*	American Pygmy Kingfisher	tropical	H2		H2							
	Chloroceryle amazona	Amazon Kingfisher	tropical	H2		H2							
	Chloroceryle americana	Green Kingfisher	tropical	H2		H2							
	Megaceryle alcyon	Belted Kingfisher	temperate	H1									
	Megaceryle torquata	Ringed Kingfisher	tropical	H2		H2							
Charadriidae	*Charadrius vociferus*	Killdeer	temperate	H1									
	Pluvialis apricaria	Eurasian/European Golden-Plover	temperate										G
	Vanellus vanellus	Northern Lapwing	temperate										G
Ciconiidae	*Ciconia abdimii*	Abdim's Stork	tropical	C	C				C	C			C
	Leptoptilos crumeniferus	Marabou Stork	tropical	C	C			C	C	C			C
	Sarcoramphus papa	King Vulture	tropical	H1									
Cinclidae	*Cinclus cinclus*	White-throated Dipper	temperate										G
Coccyzidae	*Coccycua minuta*	Little Cuckoo	tropical	H2		H2							
	Piaya cayana	Squirrel Cuckoo	tropical	H2		H2							
Columbidae	*Chalcophaps indica*	Emerald Dove	tropical										G
	Claravis mondetoura	Maroon-Chested Ground-Dove	tropical	H2		H2							
	Claravis pretiosa	Blue Ground-Dove	tropical	H2		H2							
	Columba albinucha	White-Naped Pigeon	tropical	H1									
	Columba palumbus	Common Wood-Pigeon	temperate										G
	Columbina minuta	Plain-Breasted Ground-Dove	tropical	H2		H2							
	Geotrygon chiriquensis	Rufous-Breasted Quail-Dove	tropical	H2		H2							
	Geotrygon costaricensis	Buff-Fronted Quail-Dove	tropical	H2		H2							
	Geotrygon montana	Ruddy Quail-Dove	tropical	H2		H2							
	Leptotila cassini	Grey-Chested Dove	tropical	H2		H2							
	Leptotila verreauxi	White-Tipped Dove	tropical	H2		H2							
	Patagioenas fasciata	Band-Tailed Pigeon	tropical	H2		H2							
	Patagioenas nigrirostris	Short-Billed Pigeon	tropical	H2		H2							
	Patagioenas subvinacea	Ruddy Pigeon	tropical	H2		H2							
	Streptopelia decaocto	Eurasian Collared-Dove	temperate										G
	Zenaida macroura	Mourning Dove	temperate	H1									
Corvidae	*Corvus brachyrhynchos*	American Crow	temperate	H1									

				Literature source for data on									
Family	Species	Name	Climate	Hea	Lun	FlMu	Giz	Giln	Liv	Kid	Pan	Spl	Bra
	Corvus corax	Common Raven	temperate										G
	Corvus cornix	Hooded Crow	temperate										G
	Corvus corone	Carrion Crow	temperate										G
	Corvus frugilegus	Rook	temperate										G
	Corvus monedula	Eurasian Jackdaw	temperate										G
	Cyanocitta cristata	Blue Jay	temperate	H2		H2							
	Cyanocorax affinis	Black-Chested Jay	tropical	H2		H2							
	Cyanolyca argentigula	Silvery-Throated Jay	tropical	H2		H2							
	Garrulus glandarius	Eurasian Jay	temperate										G
	Nucifraga caryocatactes	Spotted Nutcracker	temperate										G
	Pica pica	Black-billed Magpie	temperate										G
	Platysteira cyanea	Brown-throated Wattle-eye	tropical										G
	Tephrodornis pondicerianus	Common Woodshrike	tropical	R			R		R	R	R	R	
Cracidae	*Chamaepetes unicolor*	Black Guan	tropical	H2		H2							
	Ortalis garrula	Chestnut-Winged Chachalaca	tropical	H2		H2							
Crotophagidae	*Crotophaga ani*	Smooth-Billed Ani	tropical	H2		H2							
(Crotophagidae)	*Crotophaga major*	Greater Ani	tropical	H2		H2							
	Crotophaga sulcirostris	Groove-Billed Ani	tropical	H2		H2							
Falconidae	*Caracara cheriway*	Crested Caracara	tropical	H1									
	Falco rufigularis	Bat Falcon	tropical	H2		H2							
	Falco sparverius	American Kestrel	temperate	C	C			C	C	C			C
	Falco tinnunculus	Common Kestrel	temperate										G
	Herpetotheres cachinnans	Laughing Falcon	tropical	H2		H2							
	Micrastur ruficollis	Barred Forest-Falcon	tropical	H2		H2							
	Micrastur semitorquatus	Collared Forest-Falcon	tropical	H2		H2							
	Milvago chimachima	Yellow-Headed Caracara	tropical	H2		H2							
Formicariidae	*Formicarius analis*	Black-Faced Antthrush	tropical	H2		H2							
Fregatidae	*Fregata aquila*	Ascension Frigatebird	temperate	C					C				C
Fringillidae	*Agelaius phoeniceus*	Red-Winged Blackbird	temperate	H1									
	Amblycercus holosericeus	Yellow-Billed Cacique	tropical	H2		H2							
	Ammodramus henslowii	Henslow's Sparrow	temperate	H1									
	Ammodramus savannarum	Grasshopper Sparrow	temperate	H1									
	Atlapetes gutturalis	Yellow-Throated Brush-Finch	tropical	H2		H2							
	Basileuterus culicivorus	Golden-Crowned Warbler	tropical	H2		H2							
	Basileuterus fulvicauda	Buff-Rumped Warbler	tropical	H2		H2							
	Basileuterus melanogenys	Black-Cheeked Warbler	tropical	H2		H2							
	Buarremon brunneinucha	Chestnut-Capped Brush-Finch	tropical	H2		H2							
	Buarremon torquatus	Stripe-Headed Brush-Finch	tropical	H2		H2							
	Cacicus cela	Yellow-Rumped Cacique	tropical	H2		H2							
	Cacicus uropygialis	Scarlet-Rumped Cacique	tropical	H2		H2							
	Cardinalis cardinalis	Northern Cardinal	temperate	H1									
	Carduelis cannabina	Eurasian Linnet	temperate										G
	Carduelis carduelis	European Goldfinch	temperate										G
	Carduelis chloris	European Greenfinch	temperate										G
	Carduelis flammea	Common Redpoll	temperate										G
	Carduelis spinus	Eurasian Siskin	temperate										G
	Carduelis tristis	American Goldfinch	temperate	H2		H2							
	Carduelis xanthogastra	Yellow-Bellied Siskin	tropical	H2		H2							
	Carpodacus roseus	Pallas's Rosefinch	temperate										G
(Fringillidae)	*Chlorophanes spiza*	Green Honeycreeper	tropical	H2		H2							
	Chlorophonia callophrys	Golden-Browed Chlorophonia	tropical	H2		H2							
	Chlorospingus ophthalmicus	Common Bush-Tanager	tropical	H2		H2							
	Chlorospingus pileatus	Sooty-Capped Bush-Tanager	tropical	H2		H2							
	Cyanerpes cyaneus	Red-Legged Honeycreeper	tropical	H2		H2							
	Cyanerpes lucidus	Shining Honeycreeper	tropical	H2		H2							
	Dacnis cayana	Blue Dacnis	tropical	H1									

				Literature source for data on									
Family	Species	Name	Climate	Hea	Lun	FlMu	Giz	GiIn	Liv	Kid	Pan	Spl	Bra
	Dacnis venusta	Scarlet-Thighed Dacnis	tropical	H2		H2							
	Dendroica virens	Black-Throated Green Warbler	temperate	H1									
	Emberiza citrinella	Yellowhammer	temperate										G
	Emberiza schoeniclus	Reed Bunting	temperate										G
	Eucometis penicillata	Grey-Headed Tanager	tropical	H2		H2							
	Euphagus carolinus	Rusty Blackbird	temperate	H1									
	Euphonia elegantissima	Elegant(/Blue-Hooded) Euphonia	tropical	H2		H2							
	Euphonia fulvicrissa	Fulvous-Vented Euphonia	tropical	H2		H2							
	Euphonia hirundinacea	Yellow-Throated Euphonia	tropical	H2		H2							
	Euphonia imitans	Spot-Crowned Euphonia	tropical	H2		H2							
	Euphonia luteicapilla	Yellow-Crowned Euphonia	tropical	H2		H2							
	Euphonia minuta	White-Vented Euphonia	tropical	H2		H2							
	Fringilla coelebs	Chaffinch	temperate										G
	Fringilla montifringilla	Brambling	temperate										G
	Geothlypis chiriquensis	Chiriqui Yellowthroat	tropical	H2		H2							
	Geothlypis trichas	Common Yellowthroat	temperate	H1									
	Habia fuscicauda	Red-Throated Ant-Tanager	tropical	H2		H2							
	Habia rubica	Red-Crowned Ant-Tanager	tropical	H2		H2							
	Icterus mesomelas	Yellow-Tailed Oriole	tropical	H2		H2							
	Melospiza georgiana	Swamp Sparrow	temperate	H1									
	Melospiza melodia	Song Sparrow	temperate	H1									
	Mniotilta varia	Black-And-White Warbler	temperate	H1									
	Molothrus ater	Brown-Headed Cowbird	temperate	H1									
	Oryzoborus angolensis	Lesser Seed-Finch	tropical	H2		H2							
	Parula gutturalis	Flame-Throated Warbler	tropical	H2		H2							
	Parula pitiayumi	Tropical Parula	tropical	H2		H2							
(Fringillidae)	*Passerculus sandwichensis*	Savannah Sparrow	temperate	H1									
	Pezopetes capitalis	Large-Footed Finch	tropical	H2		H2							
	Pheucticus ludovicianus	Rose-Breasted Grosbeak	temperate	H1									GG
	Pheucticus tibialis	Black-Thighed Grosbeak	tropical	H2		H2							
	Pipilo erythrophthalmus	Eastern Towhee	temperate	H1									
	Piranga bidentata	Flame-Colored Tanager	tropical	H2		H2							
	Piranga leucoptera	White-Winged Tanager	tropical	H2		H2							
	Psarocolius decumanus	Crested Oropendola	tropical	H2		H2							
	Psarocolius wagleri	Chestnut-Headed Oropendola	tropical	H2		H2							
	Pselliophorus tibialis	Yellow-Thighed Finch	tropical	H2		H2							
	Quiscalus mexicanus	Great-Tailed Grackle	tropical	H2		H2							
	Quiscalus quiscula	Common Grackle	temperate	C	C			C	C	C		C	C
	Ramphocelus dimidiatus	Crimson-Backed Tanager	tropical	H2		H2							
	Ramphocelus flammigerus	Flame-Rumped Tanager	tropical	H2		H2							
	Ramphocelus passerinii	Passerini's/Scarlet-Rumped Tanager	tropical	H2		H2							
	Rhodinocichla rosea	Rosy Thrush-Tanager	tropical	H2		H2							
	Saltator albicollis	Lesser Antillean(/Streaked) Saltator	tropical	H2		H2							
	Saltator atriceps	Black-Headed Saltator	tropical	H2		H2							
	Saltator maximus	Buff-Throated Saltator	tropical	H2		H2							
	Saltator striatipectus	Streaked Saltator	tropical	H1									
	Scaphidura oryzivora	Giant Cowbird	tropical	H2		H2							
	Seiurus aurocapilla	Ovenbird	temperate	H1									GG
	Seiurus noveboracensis	Northern Waterthrush	temperate	H2		H2							
	Serinus burtoni	Thick-billed Seedeater	tropical										G
	Serinus canaria	Island Canary	temperate	C	C			C	C	C		C	C
	Spizella passerina	Chipping Sparrow	temperate	H1									
	Spizella pusilla	Field Sparrow	temperate	H1									
	Sturnella magna	Eastern Meadowlark	tropical	H2		H2							
	Sturnella militaris	Red-Breasted Blackbird	tropical	H2		H2							
	Tachyphonus luctuosus	White-Shouldered Tanager	tropical	H2		H2							

				Literature source for data on									
Family	Species	Name	Climate	Hea	Lun	FlMu	Giz	GiIn	Liv	Kid	Pan	Spl	Bra
	Tachyphonus rufus	White-Lined Tanager	tropical	H2		H2							
	Tangara guttata	Speckled Tanager	tropical	H2		H2							
	Tangara gyrola	Bay-Headed Tanager	tropical	H2		H2							
(Fringillidae)	*Tangara icterocephala*	Silver-Throated Tanager	tropical	H2		H2							
	Tangara inornata	Plain-Colored Tanager	tropical	H2		H2							
	Tangara larvata	Golden-Hooded Tanager	tropical	H2		H2							
	Thraupis palmarum	Palm Tanager	tropical	H2		H2							G
	Tiaris olivaceus	Yellow-Faced Grassquit	tropical	H2		H2							
	Volatinia jacarina	Blue-Black Grassquit	tropical	H2		H2							
	Zonotrichia albicollis	White-Throated Sparrow	temperate	H1									
	Zonotrichia capensis	Rufous-Collared Sparrow	tropical	H2		H2							G
	Zonotrichia leucophrys	White-Crowned Sparrow	temperate	O					O			O	
Furnariidae	*Anabacerthia striaticollis*	Montane Foliage-Gleaner	tropical	H2		H2							
	Anabacerthia variegaticeps	Scaly-Throated Foliage-Gleaner	tropical	H1									
	Automolus ochrolaemus	Buff-Throated Foliage-Gleaner	tropical	H2		H2							
	Campylorhamphus pusillus	Brown-Billed Scythebill	tropical	H2		H2							
	Cranioleuca erythrops	Red-Faced Spinetail	tropical	H2		H2							
	Dendrocincla fuliginosa	Plain-Brown Woodcreeper	tropical	H2		H2							
	Dendrocincla homochroa	Ruddy Woodcreeper	tropical	H2		H2							
	Dendrocolaptes certhia	Amazonian Barred-Woodcreeper	tropical	H2		H2							
	Glyphorynchus spirurus	Wedge-Billed Woodcreeper	tropical	H2		H2							
	Lepidocolaptes affinis	Spot-Crowned Woodcreeper	tropical	H2		H2							
	Margarornis rubiginosus	Ruddy Treerunner	tropical	H2		H2							
	Premnoplex brunnescens	Spotted Barbtail	tropical	H2		H2							
	Pseudocolaptes lawrencii	Buffy Tuftedcheek	tropical	H2		H2							
	Sclerurus guatemalensis	Scaly-Throated Leaftosser	tropical	H2		H2							
	Sittasomus griseicapillus	Olivaceous Woodcreeper	tropical	H2		H2							
	Synallaxis albescens	Pale-Breasted Spinetail	tropical	H2		H2							
	Synallaxis brachyura	Slaty Spinetail	tropical	H2		H2							
	Syndactyla subalaris	Lineated Foliage-Gleaner	tropical	H2		H2							
	Thripadectes rufobrunneus	Streak-Breasted Treehunter	tropical	H2		H2							
	Xenops rutilans	Streaked Xenops	tropical	H2		H2							
	Xiphorhynchus erythropygius	Spotted Woodcreeper	tropical	H2		H2							
	Xiphorhynchus guttatus	Buff-Throated Woodcreeper	tropical	H2		H2							
	Xiphorhynchus susurrans	Cocoa Woodcreeper	tropical	H1									
Gaviidae	*Gavia immer*	Common Loon	temperate	H1									
(Gaviidae)	*Gavia stellata*	Red-Throated Loon	temperate	C	C			C	C	C			C
Gruidae	*Balearica pavonina*	Black Crowned-Crane	tropical	C	C				C	C			C
	Grus canadensis	Sandhill Crane	temperate	C	C			C	C	C		C	C
Heliornithidae	*Heliornis fulica*	Sungrebe	tropical	H2		H2							
Hirundinidae	*Notiochelidon cyanoleuca*	Blue-And-White Swallow	tropical	H2		H2							
	Tachycineta bicolor	Tree Swallow	temperate	H1									
Irenidae	*Irena puella*	Asian Fairy-bluebird	tropical										G
Jacanidae	*Jacana spinosa*	Northern Jacana	tropical	H2		H2							
Laniidae	*Lanius excubitor*	Northern Shrike	temperate										G
Laridae	*Alle alle*	Dovekie	temperate	C	C			C	C	C			G
	Fratercula arctica	Atlantic Puffin	temperate										G
	Larus argentatus	Herring Gull	temperate	C					C				C
	Larus atricilla	Laughing Gull	temperate	H1									
	Larus canus	Mew Gull	temperate										G
	Larus delawarensis	Ring-Billed Gull	temperate	C	C			C	C	C			C
	Larus philadelphia	Boneparte's Gull	temperate	C	C			C	C	C			C
	Larus ridibundus	Black-headed Gull	temperate										G
	Uria aalge	Common Murre	temperate										G
Megalaimidae	*Megalaima asiatica*	Blue-throated Barbet	tropical										G
Momotidae	*Momotus momota*	Blue-Crowned Motmot	tropical	H2		H2							

Family	Species	Name	Climate	Literature source for data on									
				Hea	Lun	FlMu	Giz	Giln	Liv	Kid	Pan	Spl	Bra
Muscicapidae	*Catharus aurantiirostris*	Orange-Billed Nightingale-Thrush	tropical	H2		H2							
	Catharus frantzii	Ruddy-Capped Nightingale-Thrush	tropical	H2		H2							
	Catharus guttatus	Hermit Thrush	temperate	H1									
	Erithacus rubecula	European Robin	temperate										G
	Myadestes melanops	Black-Faced Solitaire	tropical	H2		H2							
	Oenanthe oenanthe	Northern Wheatear	temperate										G
	Sialia sialis	Eastern Bluebird	temperate	H1									
	Turdus assimilis	White-Throated Thrush	tropical	H2		H2							
	Turdus merula	Eurasian Blackbird	temperate										G
	Turdus migratorius	American Robin	temperate	H1									
	Turdus philomelos	Song Thrush	temperate										G
	Turdus pilaris	Fieldfare	temperate										G
	Turdus plebejus	American Mountain Thrush	tropical	H2		H2							
Nectariniidae	*Nectarinia minima*	Crimson-Backed Sunbird	tropical	R			R		R	R			
	Nectarinia venusta	Variable Sunbird	tropical										G
Neomorphidae	*Dromococcyx phasianellus*	Pheasant Cuckoo	tropical	H2		H2							
	Tapera naevia	Striped Cuckoo	tropical	H2		H2							
Numididae	*Numida meleagris*	Helmeted Guineafowl	tropical	C	C				C	C			C
Nyctibiidae	*Nyctibius griseus*	Common(/Grey) Potoo	tropical	H2		H2							
Odontophoridae	*Callipepla gambelii*	Gambel's Quail	temperate										G
Otididae	*Ardeotis kori*	Kori Bustard	tropical	C	C			C	C	C			C
	Lissotis melanogaster	Black-Bellied Bustard	tropical	C	C			C	C	C			C
Paridae	*Baeolophus bicolor*	Tufted Titmouse	temperate	H1									
	Cyanistes caeruleus	Blue Tit	temperate										G
	Cyanistes cyanus	Azure Tit	temperate										G
	Parus major	Great Tit	temperate	R			R		R	R	R	R	G
	Parus xanthogenys	Black-Lored Tit	tropical	R			R		R	R		R	
	Periparus ater	Coal Tit	temperate										G
	Periparus venustulus	Yellow-bellied Tit	temperate										G
	Poecile atricapillus	Black-Capped Chickadee	temperate	H1									
	Poecile carolinensis	Carolina Chickadee	temperate	H1									
Parulidae	*Myioborus miniatus*	Slate-Throated Redstart	tropical	H2		H2							
	Myioborus torquatus	Collared Redstart	tropical	H2		H2							
Passeridae	*Anthus lutescens*	Yellowish Pipit	tropical	H2		H2							
	Anthus rufulus	Paddyfield Pipit	tropical	R			R		R	R	R	R	
	Anthus spinoletta	Water Pipit	temperate	H1									
	Lonchura molucca	Black-faced Munia	tropical										G
	Motacilla alba	White Wagtail	temperate	R			R		R	R	R	R	G
	Passer domesticus	House Sparrow	temperate										G
	Passer montanus	Eurasian Tree Sparrow	temperate										G
	Passer rutilans	Russet Sparrow	temperate										G
	Prunella modularis	Hedge Accentor	temperate										G
	Pyrenestes sanguineus	Crimson Seedcracker	tropical										G
Pelecanidae	*Pelecanus occidentalis*	Brown Pelican	temperate	C	C			C	C				C
Phalacrocoracidae	*Phalacrocorax brasilianus*	Neotropic/Olivaceous Cormorant	tropical	H2		H2							
	Phalacrocorax carbo	Great Cormorant	temperate										G
Phasianidae	*Dendroperdix sephaena*	Crested Francolin	tropical	C					C	C			C
	Gallus sonneratii	Grey Junglefowl	tropical	R			R		R	R	R	R	G
	Lagopus lagopus	Willow Ptarmigan	temperate	C	C				C	C			C
	Lagopus muta	Rock Ptarmigan	temperate										G
	Odontophorus guttatus	Spotted Wood-Quail	tropical	H2		H2							
	Perdix perdix	Grey Partridge	temperate										G
	Phasianus colchicus	Common Pheasant	temperate	C	C			C	C	C			G
	Tetrao urogallus	Western Capercaillie	temperate										G
Phoenicopteridae	*Phoeniconaias minor*	Lesser Flamingo	tropical	C	C				C	C			C
Picidae	*Campephilus guatemalensis*	Pale-Billed Woodpecker	tropical	H2		H2							

				Literature source for data on									
Family	Species	Name	Climate	Hea	Lun	FlMu	Giz	Giln	Liv	Kid	Pan	Spl	Bra
	Campephilus melanoleucos	Crimson-Crested Woodpecker	tropical	H2		H2							
	Dendrocopos major	Great Spotted Woodpecker	temperate										G
	Dryocopus lineatus	Lineated Woodpecker	tropical	H2		H2							
	Dryocopus pileatus	Pileated Woodpecker	temperate	H1									
	Melanerpes carolinus	Red-Bellied Woodpecker	temperate	H1									
	Melanerpes chrysauchen	Golden-Naped Woodpecker	tropical	H2		H2							
	Melanerpes formicivorus	Acorn Woodpecker	tropical	H2		H2							
	Melanerpes pucherani	Black-Cheeked Woodpecker	tropical	H2		H2							
	Melanerpes rubricapillus	Red-Crowned Woodpecker	tropical	H2		H2							
	Picoides pubescens	Downy Woodpecker	temperate	H1									
	Picoides villosus	Hairy Woodpecker	temperate	H1									
	Piculus rubiginosus	Golden-Olive Woodpecker	tropical	H2		H2							
	Picumnus olivaceus	Olivaceous Piculet	tropical	H2		H2							
	Picus canus	Grey-Faced Woodpecker	temperate	R			R		R	R	R	R	
	Picus viridis	Eurasian Green Woodpecker	temperate										G
	Sphyrapicus varius	Yellow-Bellied Sapsucker	temperate	H1									
	Veniliornis fumigatus	Smoky-Brown Woodpecker	tropical	H2		H2							
Pittidae	*Pitta brachyura*	Indian Pitta	tropical	R			R		R	R	R	R	
	Pitta sordida	Hooded Pitta	tropical										G
Podicipedidae	*Podiceps cristatus*	Great Crested Grebe	temperate										G
	Tachybaptus dominicus	Least Grebe	tropical	H2		H2							
Procellariidae	*Puffinus griseus*	Sooty Shearwater	temperate	C	C			C	C	C			C
Psittacidae	*Amazona aestiva*	Blue-fronted Parrot	tropical										G
(Psittacidae)	*Amazona amazonica*	Orange-winged Parrot	tropical										G
	Amazona autumnalis	Red-Lored Parrot	tropical	H2		H2							
	Ara ararauna	Blue-and-yellow Macaw	tropical										G
	Bolborhynchus lineola	Barred Parakeet	tropical	H2		H2							
	Brotogeris jugularis	Orange-Chinned Parakeet	tropical	H2		H2							
	Orthopsittaca manilata	Red-bellied Macaw	tropical										G
	Pionopsitta haematotis	Brown-Hooded Parrot	tropical	H2		H2							
	Pionus senilis	White-Crowned Parrot	tropical	H2		H2							
	Platycercus caledonicus	Green Rosella	temperate										G
	Poicephalus meyeri	Meyer's Parrot	tropical										G
	Pyrrhura hoffmanni	Sulphur-Winged Parakeet	tropical	H2		H2							
Rallidae	*Aramides cajanea*	Grey-Necked Wood-Rail	tropical	H2		H2							
	Fulica americana	American Coot	temperate	H1									
	Fulica atra	Common Coot	temperate										G
	Gallinula chloropus	Common Moorhen	temperate										G
	Laterallus albigularis	White-Throated Crake	tropical	H2		H2							
Ramphastidae	*Aulacorhynchus prasinus*	Guatemalan Emerald-Toucanet	tropical	H2		H2							
	Eubucco bourcierii	Red-Headed Barbet	tropical	H2		H2							
	Pteroglossus frantzii	Fiery-Billed Aracari	tropical	H2		H2							
	Pteroglossus torquatus	Collared Aracari	tropical	H2		H2							
	Ramphastos swainsonii	Chestnut-Mandibled Toucan	tropical	H2		H2							
Regulidae	*Regulus calendula*	Ruby-Crowned Kinglet	temperate	H1									
	Regulus regulus	Goldcrest	temperate										G
	Regulus satrapa	Golden-Crowned Kinglet	temperate	H1									
Scolopacidae	*Calidris maritima*	Purple Sandpiper	temperate										G
	Scolopax rusticola	Eurasian Woodcock	temperate										G
Scopidae	*Scopus umbretta*	Hamerkop	tropical	C	C								C
Sittidae	*Sitta canadensis*	Red-Breasted Nuthatch	temperate	H1									
	Sitta carolinensis	White-Breasted Nuthatch	temperate	H2		H2							
	Sitta europaea	Wood Nuthatch	temperate	R					R	R		R	G
	Sitta frontalis	Velvet-Fronted Nuthatch	tropical	R			R		R	R		R	
Strigidae	*Asio flammeus*	Short-eared Owl	temperate										G
	Asio otus	Long-eared Owl	temperate										G

Family	Species	Name	Climate	Literature source for data on									
				Hea	Lun	FlMu	Giz	Giln	Liv	Kid	Pan	Spl	Bra
(Strigidae)	*Bubo virginianus*	Great Horned Owl	temperate	H1									
	Megascops choliba	Tropical Screech-Owl	tropical	H2		H2							
	Pseudoscops clamator	Striped Owl	tropical	H2		H2							
	Pulsatrix perspicillata	Spectacled Owl	tropical	H2		H2							
	Strix aluco	Tawny Owl	temperate										G
	Strix nigrolineata	Black-And-White Owl	tropical	H2		H2							
	Strix varia	Barred Owl	temperate	H1									
	Strix virgata	Mottled Owl	tropical	H2		H2							
Sturnidae	*Dumetella carolinensis*	Grey Catbird	temperate	H1									
	Sturnus vulgaris	Common Starling	temperate	H1									G
	Toxostoma rufum	Brown Thrasher	temperate	H1									
Sylviidae	*Panurus biarmicus*	Bearded Parrotbill	temperate										G
Tamaliidae	*Sylvia atricapilla*	Blackcap	temperate										G
Thamnophilidae	*Cercomacra nigricans*	Jet Antbird	tropical	H2		H2							
	Cymbilaimus lineatus	Fasciated Antshrike	tropical	H2		H2							
	Dysithamnus mentalis	Plain Antvireo	tropical	H2		H2							
	Gymnopithys leucaspis	Bicolored Antbird	tropical	H2		H2							
	Hylophylax naevioides	Spotted Antbird	tropical	H2		H2							
	Myrmeciza exsul	Chestnut-Backed Antbird	tropical	H2		H2							
	Myrmeciza longipes	White-Bellied Antbird	tropical	H2		H2							
	Myrmotherula schisticolor	Slaty Antwren	tropical	H2		H2							
	Myrmotherula surinamensis	Guianan Streaked-Antwren	tropical	H2		H2							
	Taraba major	Great Antshrike	tropical	H2		H2							
	Thamnistes anabatinus	Russet Antshrike	tropical	H2		H2							
	Thamnophilus doliatus	Barred Antshrike	tropical	H2		H2							
	Thamnophilus punctatus	Eastern Slaty-Antshrike	tropical	H2		H2							
Tinamidae	*Crypturellus soui*	Little Tinamou	tropical	H2		H2							
	Nothocercus bonapartei	Highland Tinamou	tropical	H2		H2							
	Tinamus major	Great Tinamou	tropical	H2		H2							
Trochilidae	*Amazilia tzacatl*	Rufous-Tailed Hummingbird	tropical	C	C				C	C			C
	Campylopterus hemileucurus	Violet Sabrewing	tropical	H1									
	Glaucis hirsutus	Rufous-Breasted Hermit	tropical	H2		H2							
	Selasphorus scintilla	Scintillant Hummingbird	tropical	H1									
Trogonidae	*Harpactes fasciatus*	Malabar Trogon	tropical	R			R		R	R	R	R	
	Pharomachrus mocinno	Resplendent Quetzal	tropical	H2		H2							
	Trogon collaris	Collared Trogon	tropical	H2		H2							
	Trogon curucui	Blue-Crowned Trogon	tropical	H2		H2							
	Trogon massena	Slaty-Tailed Trogon	tropical	H2		H2							
	Trogon melanurus	Black-Tailed Trogon	tropical	H2		H2							
	Trogon violaceus	Violaceous Trogon	tropical	H2		H2							
	Trogon viridis	White-Tailed Trogon	tropical	H2		H2							
Tyrannidae	*Attila spadiceus*	Bright-Rumped Attila	tropical	H2		H2							
	Camptostoma obsoletum	Southern Beardless-Tyrannulet	tropical	H2		H2							
	Capsiempis flaveola	Yellow Tyrannulet	tropical	H2		H2							
	Chiroxiphia lanceolata	Lance-Tailed Manakin	tropical	H2		H2							
	Cnipodectes subbrunneus	Twistwing	tropical	H2		H2							
	Contopus lugubris	Dark Pewee	tropical	H2		H2							
	Corapipo leucorrhoa	White-Bibbed Manakin	tropical	H2		H2							
	Cotinga ridgwayi	Turquoise Cotinga	tropical	H2		H2							
	Elaenia chiriquensis	Lesser Elaenia	tropical	H2		H2							
	Elaenia flavogaster	Yellow-Bellied Elaenia	tropical	H2		H2							
	Elaenia frantzii	Mountain Elaenia	tropical	H2		H2							
	Empidonax flavescens	Yellowish Flycatcher	tropical	H2		H2							
	Empidonax minimus	Least Flycatcher	temperate	H1									
	Empidonax traillii	Willow Flycatcher	temperate	H1									
	Fluvicola pica	Pied Water-Tyrant	tropical	H2		H2							

				Literature source for data on									
Family	Species	Name	Climate	Hea	Lun	FlMu	Giz	Giln	Liv	Kid	Pan	Spl	Bra
	Laniocera rufescens	Speckled Mourner	tropical	H1									
	Legatus leucophaius	Piratic Flycatcher	tropical	H2		H2							
	Leptopogon superciliaris	Slaty-Capped Flycatcher	tropical	H2		H2							
	Lipaugus unirufus	Rufous Piha	tropical	H2		H2							
	Lophotriccus pileatus	Scale-Crested Pygmy-Tyrant	tropical	H2		H2							
	Manacus vitellinus	Golden-Collared Manakin	tropical	H2		H2							
	Megarynchus pitangua	Boat-Billed Flycatcher	tropical	H2		H2							
	Mionectes olivaceus	Olive-Striped Flycatcher	tropical	H2		H2							
	Mitrephanes phaeocercus	Tufted Flycatcher	tropical	H2		H2							
	Myiarchus ferox	Short-Crested Flycatcher	tropical	H2		H2							
(Tyrannidae)	*Myiarchus tuberculifer*	Dusky-Capped Flycatcher	tropical	H2		H2							
	Myiobius atricaudus	Black-Tailed Flycatcher	tropical	H2		H2							
	Myiobius barbatus	Sulphur-Rumped Flycatcher	tropical	H2		H2							
	Myiodynastes hemichrysus	Golden-Bellied Flycatcher	tropical	H2		H2							
	Myiodynastes maculatus	Streaked Flycatcher	tropical	H2		H2							
	Myiopagis viridicata	Greenish Elaenia	tropical	H2		H2							
	Myiophobus fasciatus	Bran-Colored Flycatcher	tropical	H2		H2							
	Myiozetetes cayanensis	Rusty-Margined Flycatcher	tropical	H2		H2							
	Myiozetetes granadensis	Grey-Capped Flycatcher	tropical	H2		H2							
	Myiozetetes similis	Social Flycatcher	tropical	H2		H2							
	Oncostoma olivaceum	Southern Bentbill	tropical	H2		H2							
	Onychorhynchus coronatus	Royal Flycatcher	tropical	H2		H2							
	Pachyramphus cinnamomeus	Cinnamon Becard	tropical	H2		H2							
	Pachyramphus polychopterus	White-Winged Becard	tropical	H2		H2							
	Pachyramphus versicolor	Barred Becard	tropical	H2		H2							
	Pipra mentalis	Red-Capped Manakin	tropical	H2		H2							
	Platyrinchus mystaceus	White-Throated Spadebill	tropical	H2		H2							
	Poecilotriccus sylvia	Slate-Headed Tody-Tyrant	tropical	H2		H2							
	Querula purpurata	Purple-Throated Fruitcrow	tropical	H2		H2							
	Rhynchocyclus brevirostris	Eye-Ringed Flatbill	tropical	H2		H2							
	Rhynchocyclus olivaceus	Olivaceous Flatbill	tropical	H2		H2							
	Rhytipterna holerythra	Rufous Mourner	tropical	H2		H2							
	Sayornis phoebe	Eastern Phoebe	temperate	H1									
	Schiffornis turdina	Thrush-Like Schiffornis	tropical	H2		H2							
	Serpophaga cinerea	Torrent Tyrannulet	tropical	H2		H2							
	Terenotriccus erythurus	Ruddy-Tailed Flycatcher	tropical	H2		H2							
	Tityra inquisitor	Black-Crowned Tityra	tropical	H2		H2							
	Tityra semifasciata	Masked Tityra	tropical	H2		H2							
	Todirostrum cinereum	Common Tody-Flycatcher	tropical	H2		H2							
	Tolmomyias sulphurescens	Yellow-Olive Flycatcher	tropical	H2		H2							
	Tyranniscus zeledoni	White-Fronted Tyrannulet	tropical	H2		H2							
	Tyrannulus elatus	Yellow-Crowned Tyrannulet	tropical	H2		H2							
	Tyrannus melancholicus	Tropical Kingbird	tropical	H2		H2							
(Tyrannidae)	*Tyrannus savana*	Fork-Tailed Flycatcher	tropical	H2		H2							
	Zimmerius vilissimus	Paltry Tyrannulet	tropical	H2		H2							
Tytonidae	*Tyto alba*	Barn Owl	temperate										G
Vireonidae	*Cyclarhis gujanensis*	Rufous-Browed Peppershrike	tropical	H2		H2							
	Hylophilus aurantiifrons	Golden-Fronted Greenlet	tropical	H2		H2							
	Hylophilus decurtatus	Lesser Greenlet	tropical	H2		H2							
	Hylophilus flavipes	Scrub Greenlet	tropical	H2		H2							
	Hylophilus ochraceiceps	Tawny-Crowned Greenlet	tropical	H2		H2							
	Vireo carmioli	Yellow-Winged Vireo	tropical	H2		H2							
	Vireo leucophrys	Brown-Capped Vireo	tropical	H2		H2							
	Vireo solitarius	Blue-Headed Vireo	temperate	H1									

Species are ordered alphabetically on family and species name. Literature sources are abbreviated as follows: C: (Crile and Quiring, 1940), G: (Garamszegi et al., 2002), GG: (Graber and Graber, 1965), H1: (Hartman, 1955), H2: (Hartman, 1961), O: (Oakeson, 1956), R: (Rensch and Rensch, 1956). References are presented below. Organs names are indicated by Hea: heart, Lun: lungs, FlMu: flight muscles, Giz: gizzard, GiIn: gizzard+intestines, Liv: liver, Kid: kidneys, Pan: pancreas, Spl: spleen, Bra: brain.

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Table S2. Climate of breeding area, diet, migratory behaviour (long-distance or not), mean (±s.e.m. where available) body mass (g) and dry mass of organs (mg) of birds collected for this study (sample sizes in parentheses)

	Amazilia tzacatl	*Archilochus colubris*	*Arremonops conirostris*	*Astragalinus tristis*	*Attila spadiceus*	*Brotogeris jugularis*	*Cardinalis cardinalis*
Climate	Tropical	Temperate	Tropical	Temperate	Tropical	Tropical	Temperate
Diet	Nectivorous	Nectivorous	Omnivorous	Granivorous	Insectivorous	Granivorous	Granivorous
Migratory	No	Yes	No	No	No	No	No
Body mass (n)	6.5 (1)	2.7 (1)	39.9 (5)	11.4 (7)	36.2 (1)	57.2 (1)	38.8 (6)
Brain	0.070 (1)	0.016 (1)	0.295±0.004 (5)	0.114±0.004 (7)	0.191 (1)	0.479 (1)	0.301±0.007 (6)
Carcass	0.865 (1)	0.298 (1)	5.731±0.245 (5)	1.708±0.086 (7)	4.931 (1)	7.942 (1)	4.920±0.323 (6)
Fat	0.001 (1)	0.001 (1)	0.014±0.007 (5)	0.028±0.010 (7)	0.001 (1)	0.001 (1)	0.060±0.032 (6)
Gallbladder	0.000 (1)	(0)	0.005 (1)	(0)	0.000 (1)	0.000 (1)	0.005±0.003 (3)
Gizzard	0.057 (1)	0.003 (1)	0.332±0.008 (5)	0.051±0.004 (6)	0.265 (1)	0.130 (1)	0.354±0.032 (6)
Heart	0.017 (1)	0.018 (1)	0.093±0.006 (4)	0.051±0.001 (7)	0.097 (1)	0.239 (1)	0.121±0.011 (6)
Intestines	0.006 (1)	0.013 (1)	0.191±0.015 (5)	0.032±0.004 (7)	0.122 (1)	0.168 (1)	0.163±0.021 (6)
Kidneys	0.016 (1)	0.007 (1)	0.079±0.006 (5)	0.037±0.002 (6)	0.107 (1)	0.085 (1)	0.127±0.013 (5)
Leg muscles	0.086 (.1)	0.014 (1)	1.177±0.054 (5)	0.144±0.008 (7)	0.585 (1)	0.811 (1)	0.600±0.033 (6)
Liver	0.034 (1)	0.037 (1)	0.350±0.042 (5)	0.092±0.011 (7)	0.29 (1)	0.381 (1)	0.291±0.022 (6)
Lungs	0.010 (1)	0.018 (1)	0.076±0.007 (5)	0.057±0.003 (6)	0.111 (1)	0.193 (1)	0.116±0.007 (5)
Ovaries	(0)	(0)	(0)	0.006±0.002 (3)	0.581 (1)	(0)	0.018±0.006 (2)
Oviduct	(0)	(0)	(0)	0.002±0 (0)	(0)	(0)	0.018±0.018 (2)
Flight muscles	0.358 (1)	0.221 (1)	1.450±0.08 (5)	0.682±0.022 (7)	1.524 (1)	3.349 (1)	1.891±0.123 (6)
Skin	(0)	(0)	0.352±0.027 (5)	0.141±0.017 (6)	(0)	(0)	0.328±0.038 (5)
Spleen	0.001 (1)	(0)	0.014±0.005 (4)	0.002±0.001 (7)	0.001 (1)	0.001 (1)	0.008±0.001 (6)
Testes	0.001 (1)	0.000 (1)	0.037±0.009 (4)	0.023±0.006 (4)	(0)	0.009 (1)	0.051±0.006 (4)

	Columbina talpacoti	*Contopus virens*	*Contorchilus leucotis*	*Cyanoloxia cyanoides*	*Dendroica petechia*	*Euphonia laniirostris*	*Florisuga mellivora*
Climate	Tropical	Temperate	Tropical	Tropical	Temperate	Tropical	Tropical
Diet	Granivorous	Insectivorous	Insectivorous	Omnivorous	Insectivorous	Frugivorous	Nectivorous
Migratory	No	Yes	No	No	Yes	No	No
Body mass (n)	37.9 (8)	11.6 (1)	20.3 (5)	26.8 (5)	7.2 (1)	12.8 (5)	7.0 (1)
Brain	0.119±0.004 (7)	0.090 (1)	0.192±0.006 (5)	0.250±0.011 (5)	0.088 (1)	0.133±0.007 (4)	0.034 (1)
Carcass	4.577±0.196 (8)	1.530 (1)	2.801±0.072 (5)	4.175±0.239 (5)	1.154 (1)	1.859±0.054 (5)	0.923 (1)
Fat	0.001±0.000 (8)	0.001 (1)	0.028±0.014 (5)	0.001±0.000 (5)	0.001 (1)	0.015±0.007 (5)	0.001 (1)
Gallbladder	0.004±0.002 (4)	(0)	0.002±0.001 (3)	0.004 (1)	(0)	0.002±0.000 (3)	0.000 (1)
Gizzard	0.407±0.013 (8)	0.079 (1)	0.177±0.009 (5)	0.210±0.027 (5)	0.045 (1)	0.010±0.000 (5)	0.017 (1)
Heart	0.095±0.006 (8)	0.039 (1)	0.053±0.008 (5)	0.067±0.006 (5)	0.028 (1)	0.043±0.002 (5)	0.049 (1)
Intestines	0.101±0.012 (8)	0.011 (1)	0.099±0.005 (5)	0.082±0.010 (5)	0.017 (1)	0.086±0.007 (5)	0.026 (1)
Kidneys	0.044±0.002 (8)	0.038 (1)	0.058±0.006 (5)	0.044±0.003 (5)	0.028 (1)	0.036±0.002 (5)	0.019 (1)
Leg muscles	0.506±0.021 (8)	0.101 (1)	0.621±0.018 (5)	0.448±0.032 (5)	0.151 (1)	0.202±0.011 (5)	0.027 (1)
Liver	0.210±0.024 (8)	0.073 (1)	0.188±0.018 (5)	0.174±0.035 (5)	0.057 (1)	0.171±0.019 (5)	0.048 (1)
Lungs	0.077±0.005 (8)	0.036 (1)	0.042±0.004 (5)	0.059±0.009 (5)	0.034 (1)	0.032±0.003 (5)	0.017 (1)
Ovaries	0.005±0.002 (5)	(0)	0.014 (1)	0.006±0.003 (3)	(0)	0.205±0.010 (2)	0.005 (1)
Oviduct	0.000±0.000 (3)	(0)	0.000 (1)	0.000±0.000 (3)	(0)	0.000±0.000 (2)	(0)
Flight muscles	2.605±0.146 (8)	0.643 (1)	0.580±0.044 (5)	1.282±0.087 (5)	0.346 (1)	0.636±0.030 (5)	0.470 (1)
Skin	0.497±0.074 (5)	0.092 (1)	0.237±0.013 (4)	0.187±0.016 (5)	(0)	0.145±0.013 (5)	(0)
Spleen	0.001±0.000 (4)	(0)	0.003±0.001 (5)	0.013±0.005 (5)	0.001 (1)	0.004±0.001 (4)	0.001 (1)
Testes	0.013±0.003 (2)	0.008 (1)	0.007±0.002 (4)	0.019±0.013 (2)	0.020 (1)	0.024±0.006 (3)	(0)

	Gymnopithys leucaspis	*Hylophylax naevioides*	*Lepidothrix coronata*	*Leptotila verreauxi*	*Manacus vitellinus*	*Melanerpes rubricapillus*	*Melospiza melodia*
Climate	Tropical	Tropical	Tropical	Tropical	Tropical	Tropical	Temperate
Diet	Insectivorous	Insectivorous	Frugivorous	Granivorous	Frugivorous	Insectivorous	Omnivorous
Migratory	No	No	No	No	No	No	No
Body mass (n)	30.2 (1)	16.1 (2)	8.6 (2)	132.1 (1)	15.0 (2)	43.5 (1)	19.3 (5)
Brain	0.160 (1)	0.124±0.020 (2)	0.079±0.013 (2)	0.247 (1)	0.111±0.002 (2)	0.300 (1)	0.187±0.009 (5)
Carcass	4.386 (1)	2.037±0.046 (2)	1.149±0.041 (2)	19.964 (1)	1.993±0.118 (2)	6.314 (1)	2.619±0.145 (5)
Fat	0.001 (1)	0.001±0.000 (2)	0.001±0.000 (2)	5.193 (1)	0.122±0.121 (2)	0.001 (1)	0.042±0.018 (5)
Gallbladder	0.000 (1)	0.000±0.000 (2)	0.000±0.000 (2)	0.000 (1)	0.001±0.001 (2)	0.002 (1)	(0)
Gizzard	0.200 (1)	0.151±0.001 (2)	0.102±0.018 (2)	2.042 (1)	0.200±0.029 (2)	0.324 (1)	0.145±0.023 (5)
Heart	0.102 (1)	0.044±0.000 (2)	0.028±0.004 (2)	0.477 (1)	0.046±0.001 (2)	0.110 (1)	0.055±0.003 (5)
Intestines	0.064 (1)	0.055±0.009 (2)	0.023±0.000 (2)	0.354 (1)	0.068±0.011 (2)	0.119 (1)	0.084±0.031 (5)
Kidneys	0.114 (1)	0.049±0.003 (2)	0.033±0.000 (2)	0.149 (1)	0.048±0.002 (2)	0.091 (1)	0.063±0.008 (5)
Leg muscles	1.059 (1)	0.375±0.026 (2)	0.102±0.010 (2)	2.003 (1)	0.212±0.028 (2)	0.598 (1)	0.454±0.029 (5)
Liver	0.298 (1)	0.167±0.007 (2)	0.064±0.012 (2)	0.960 (1)	0.138±0.012 (2)	0.330 (1)	0.165±0.015 (5)
Lungs	0.108 (1)	0.033±0.000 (2)	0.023±0.001 (2)	0.320 (1)	0.040±0.008 (2)	0.108 (1)	0.059±0.005 (5)
Ovaries	(0)	0.003 (1)	0.003 (1)	(0)	0.003±0.001 (2)	0.012 (1)	0.059±0.059 (5)
Oviduct	(0)	(0)	(0)	(0)	(0)	(0)	0.066±0.066 (5)
Flight muscles	0.961 (1)	0.436±0.045 (2)	0.386±0.011 (2)	11.395 (1)	0.681±0.113 (2)	1.654 (1)	0.728±0.091 (5)
Skin	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Spleen	0.001 (1)	0.001±0.000 (2)	0.001±0.000 (2)	0.001 (1)	0.001±0.000 (2)	0.001 (1)	0.003±0.001 (4)
Testes	0.004 (1)	0 (1)	0.002 (1)	(0)	(0)	(0)	0.037±0.003 (3)

	Mimus gilvus	*Mimus polyglottos*	*Molothrus ater*	*Myiozetetes similis*	*Nyctidromus albicollis*	*Pipra mentalis*	*Pipromorpha oliaginea*
Climate	Tropical	Temperate	Temperate	Tropical	Tropical	Tropical	Tropical
Diet	Omnivorous	Omnivorous	Omnivorous	Insectivorous	Insectivorous	Frugivorous	Omnivorous
Migratory	No	No	No	No	No	No	No
Body mass (n)	59.8 (5)	46.6 (5)	39.0 (2)	22.8 (2)	49.5 (3)	12.2 (3)	9.5 (6)
Brain	0.338±0.012 (5)	0.269±0.011 (5)	0.251±0.001 (2)	0.127±0.004 (2)	0.146±0.014 (3)	0.091±0.004 (3)	0.089±0.006 (6)
Carcass	8.781±0.271 (5)	6.636±0.382 (5)	4.644±0.202 (2)	3.144±0.084 (2)	7.755±0.794 (3)	1.576±0.053 (3)	1.278±0.029 (6)
Fat	0.038±0.020 (5)	0.082±0.061 (5)	0.079±0.040 (2)	0.001±0.000 (2)	0.162±0.161 (3)	0.001±0.000 (3)	0.010±0.009 (6)
Gallbladder	(0)	0.008±0.001 (5)	0.003 (1)	0.001±0.001 (2)	0.001±0.001 (3)	0.003±0.001 (3)	0.001 (1)
Gizzard	0.397±0.022 (5)	0.365±0.022 (5)	0.256±0.013 (2)	0.193±0.025 (2)	0.727±0.028 (3)	0.134±0.034 (3)	0.083±0.008 (6)
Heart	0.128±0.005 (5)	0.166±0.008 (5)	0.114±0.011 (2)	0.073±0.013 (2)	0.114±0.013 (3)	0.036±0.003 (3)	0.033±0.001 (6)
Intestines	0.368±0.044 (5)	0.235±0.039 (5)	0.222±0.111 (2)	0.083±0.046 (2)	0.100±0.016 (3)	0.035±0.009 (3)	0.035±0.007 (6)
Kidneys	0.151±0.008 (5)	0.162±0.014 (5)	0.111±0.003 (2)	0.051±0.009 (2)	0.080±0.004 (3)	0.042±0.002 (3)	0.027±0.002 (6)
Leg muscles	1.624±0.051 (5)	1.051±0.055 (5)	0.638±0.066 (2)	0.263±0.050 (2)	0.635±0.076 (3)	0.171±0.012 (3)	0.122±0.007 (6)
Liver	0.462±0.026 (5)	0.450±0.033 (5)	0.329±0.008 (2)	0.155±0.037 (2)	0.246±0.045 (3)	0.081±0.006 (3)	0.067±0.008 (6)
Lungs	0.150±0.023 (5)	0.182±0.016 (5)	0.162±0.011 (2)	0.059±0.001 (2)	0.103±0.013 (3)	0.040±0.002 (3)	0.024±0.002 (6)
Ovaries	0.020±0.008 (2)	0.027 (1)	0.088±0.066 (2)	0.008 (1)	0.007±0.002 (2)	(0)	0.000 (1)
Oviduct	0.000±0.000 (2)	0.085 (1)	0.545±0.123 (2)	(0)	(0)	(0)	0.035 (1)
Flight muscles	2.289±0.110 (5)	2.142±0.141 (5)	2.062±0.157 (2)	1.197±0.026 (2)	2.306±0.121 (3)	0.643±0.060 (3)	0.556±0.042 (6)
Skin	0.644±0.027 (5)	0.464±0.013 (2)	(0)	(0)	(0)	(0)	0.098±0.006 (5)
Spleen	0.005±0.000 (5)	0.008±0.002 (5)	0.01±0.004 (2)	0.001±0.000 (2)	0.001±0.000 (3)	0.001±0.000 (3)	0.003±0.002 (6)
Testes	0.013±0.010 (3)	0.034±0.003 (4)	(0)	0.003 (1)	0.009 (1)	0.002±0.000 (3)	0.005±0.001 (5)

	Piranga olivacea	*Progne chalybea*	*Quiscalus quiscula*	*Sayornis phoebe*	*Spizella passerina*	*Sporophila corvina*	*Tachycineta albilinea*
Climate	Temperate	Tropical	Temperate	Temperate	Temperate	Tropical	Tropical
Diet	Insectivorous	Insectivorous	Omnivorous	Insectivorous	Granivorous	Granivorous	Insectivorous
Migratory	Yes	No	No	Yes	No	No	No
Body mass (n)	27.3 (4)	35.7 (5)	108.2 (1)	16.6 (5)	11.0 (5)	10.1 (1)0)	13.4 (5)
Brain	0.196±0.005 (4)	0.206±0.005 (5)	0.596 (1)	0.121±0.005 (4)	0.102±0.004 (5)	0.121±0.003 (1)0	0.102±0.006 (5)
Carcass	3.891±0.373 (4)	5.393±0.301 (5)	16.205 (1)	2.127±0.059 (4)	1.357±0.066 (5)	1.535±0.042 (1)0	1.811±0.064 (5)
Fat	0.011±0.008 (4)	0.182±0.167 (5)	0.078 (1)	0.010±0.009 (4)	0.003±0.002 (5)	0.003±0.002 (1)0	0.010±0.009 (5)
Gallbladder	(0)	(0)	0.008 (1)	0.003 (1)	(0)	0.000±0.000 (5)	0.000 (1)
Gizzard	0.158±0.005 (4)	0.343±0.033 (5)	0.763 (1)	0.134±0.008 (4)	0.097±0.004 (5)	0.070±0.004 (1)0	0.124±0.006 (5)
Heart	0.088±0.004 (4)	0.155±0.009 (4)	0.325 (1)	0.050±0.005 (4)	0.036±0.002 (5)	0.034±0.002 (1)0	0.046±0.002 (5)
Intestines	0.094±0.010 (4)	0.184±0.034 (5)	0.574 (1)	0.035±0.005 (4)	0.031±0.003 (5)	0.035±0.005 (1)0	0.106±0.018 (5)
Kidneys	0.095±0.006 (4)	0.103±0.010 (5)	0.297 (1)	0.065±0.002 (4)	0.033±0.003 (5)	0.017±0.001 (1)0	0.046±0.003 (5)
Leg muscles	0.353±0.014 (4)	0.407±0.035 (5)	2.553 (1)	0.170±0.013 (4)	0.146±0.007 (5)	0.165±0.008 (1)0	0.108±0.012 (5)
Liver	0.220±0.015 (4)	0.246±0.030 (5)	0.928 (1)	0.149±0.018 (4)	0.089±0.006 (5)	0.095±0.009 (1)0	0.132±0.009 (5)
Lungs	0.104±0.008 (4)	0.123±0.012 (5)	0.610 (1)	0.057±0.005 (4)	0.037±0.004 (5)	0.029±0.002 (1)0	0.041±0.002 (5)
Ovaries	(0)	0.005±0.005 (2)	(0)	0.005±0.002 (3)	0.005 (1)	0.001±0.001 (5)	0.002 (1)
Oviduct	(0)	0.000±0.000 (2)	(0)	0.006±0.002 (3)	0 (1)	0.000±0.000 (3)	0.000 (1)
Flight muscles	1.614±0.084 (4)	1.833±0.164 (5)	5.396 (1)	0.870±0.063 (4)	0.613±0.077 (5)	0.420±0.017 (1)0	0.607±0.057 (5)
Skin	0.224±0.025 (4)	0.600±0.126 (5)	(0)	0.163±0.017 (4)	0.073±0.005 (4)	0.112±0.010 (5)	0.183±0.008 (4)
Spleen	0.006±0.001 (4)	0.004±0.001 (5)	0.015 (1)	0.002±0.000 (3)	0.003±0.001 (5)	0.002±0.001 (8)	0.003±0.001 (5)
Testes	0.103±0.013 (4)	0.117±0.024 (3)	0.245 (1)	0.017 (1)	0.030±0.006 (4)	0.002±0.001 (5)	0.001±0.001 (4)

	Tachycineta bicolor	*Tangara episcopus*	*Tangara larvata*	*Tangara palmarum*	*Thamnophilus doliatus*	*Troglodytes aedon*	*Troglodytes musculus*
Climate	Temperate	Tropical	Tropical	Tropical	Tropical	Temperate	Tropical
Diet	Insectivorous	Frugivorous	Frugivorous	Frugivorous	Insectivorous	Insectivorous	Insectivorous
Migratory	Yes	No	No	No	No	No	No
Body mass (n)	16.3 (5)	31.2 (8)	32.3 (1)	34.5 (1)	29.9 (1)	9.4 (6)	12.8 (9)
Brain	0.106±0.004 (5)	0.213±0.007 (8)	0.176 (1)	0.235 (1)	0.201 (1)	0.112±0.002 (5)	0.127±0.003 (9)
Carcass	2.017±0.104 (5)	4.701±0.136 (8)	4.715 (1)	4.648 (1)	4.138 (1)	1.176±0.043 (5)	1.780±0.061 (9)
Fat	0.051±0.033 (5)	0.047±0.037 (8)	0.001 (1)	0.001 (1)	0.001 (1)	0.011±0.005 (5)	0.014±0.010 (9)
Gallbladder	0.004 (1)	0.005±0.001 (4)	0.000 (1)	0.004 (1)	0.000 (1)	(0)	0.000±0.000 (4)
Gizzard	0.156±0.010 (5)	0.087±0.009 (8)	0.243 (1)	0.119 (1)	0.384 (1)	0.082±0.006 (5)	0.095±0.003 (8)
Heart	0.052±0.002 (5)	0.110±0.005 (8)	0.121 (1)	0.108 (1)	0.090 (1)	0.033±0.001 (5)	0.041±0.002 (9)
Intestines	0.090±0.018 (5)	0.178±0.015 (8)	0.091 (1)	0.183 (1)	0.140 (1)	0.030±0.007 (5)	0.054±0.008 (9)
Kidneys	0.066±0.002 (5)	0.070±0.006 (8)	0.101 (1)	0.070 (1)	0.100 (1)	0.038±0.004 (5)	0.036±0.003 (9)
Leg muscles	0.150±0.012 (5)	0.576±0.028 (8)	0.485 (1)	0.590 (1)	0.683 (1)	0.232±0.012 (5)	0.369±0.014 (9)
Liver	0.148±0.013 (5)	0.321±0.022 (8)	0.307 (1)	0.303 (1)	0.408 (1)	0.093±0.010 (5)	0.109±0.009 (9)
Lungs	0.077±0.004 (5)	0.088±0.006 (8)	0.079 (1)	0.122 (1)	0.065 (1)	0.033±0.003 (5)	0.033±0.003 (9)
Ovaries	0.006±0.001 (3)	0.018±0.007 (4)	(0)	(0)	(0)	0.013±0.003 (2)	0.005 (1)
Oviduct	0.009±0.000 (3)	0.020±0.020 (2)	(0)	(0)	(0)	0.088±0.057 (2)	0.000 (1)
Flight muscles	0.709±0.060 (5)	1.682±0.089 (8)	1.308 (1)	1.853 (1)	0.730 (1)	0.302±0.015 (5)	0.411±0.026 (9)
Skin	0.247±0.045 (5)	0.321±0.024 (5)	(0)	(0)	(0)	0.104±0.007 (4)	0.163±0.010 (5)
Spleen	0.002±0.001 (5)	0.004±0.001 (8)	0.001 (1)	0.001 (1)	0.001 (1)	0.001±0.000 (5)	0.003±0.002 (7)
Testes	0.056±0.027 (2)	0.049±0.016 (4)	0.003 (1)	0.012 (1)	0.004 (1)	0.031±0.001 (3)	0.006±0.002 (8)

	Turdus grayi	*Turdus migratorius*	*Vireo flavoviridis*	*Vireo olivaceus*	*Xenops minutus*	*Xiphorhynchus guttatus*	*Zenaida macroura*
Climate	Tropical	Temperate	Tropical	Temperate	Tropical	Tropical	Temperate
Diet	Omnivorous	Omnivorous	Insectivorous	Insectivorous	Insectivorous	Insectivorous	Granivorous
Migratory	No	No	No	Yes	No	No	No
Body mass (n)	65 9 (11)	73.7 (5)	17.1 (5)	15.1 (7)	11.0 (1)	43.6 (1)	122.8 (6)
Brain	0.328±0.016 (11	0.332±0.012 (4)	0.136±0.008 (5)	0.125±0.005 (6)	0.084 (1)	0.316 (1)	0.226±0.008 (6)
Carcass	9.546±0.510 (11)	9.383±0.624 (4)	2.443±0.17 (5)	2.134±0.139 (7)	1.536 (1)	7.299 (1)	14.154±0.781 (6)
Fat	0.042±0.016 (11	0.026±0.017 (4)	0.342±0.336 (5)	0.016±0.009 (7)	0.001 (1)	0.001 (1)	0.359 (0).1 (6)
Gallbladder	0.006±0.001 (7)	0.010±0.003 (2)	0.009 (1)	(0)	0.000 (1)	0.002 (1)	(0)
Gizzard	0.345±0.052 (10)	0.300±0.053 (4)	0.107±0.004 (4)	0.079±0.005 (7)	0.077 (1)	0.319 (1)	0.863±0.019 (6)
Heart	0.169±0.009 (11)	0.245±0.018 (4)	0.060±0.004 (4)	0.072±0.005 (7)	0.049 (1)	0.108 (1)	0.427±0.010 (6)
Intestines	0.421±0.049 (11)	0.374±0.041 (4)	0.080±0.004 (4)	0.038±0.005 (7)	0.011 (1)	0.049 (1)	0.280±0.043 (6)
Kidneys	0.135±0.007 (11)	0.230±0.024 (4)	0.055±0.006 (5)	0.061±0.005 (7)	0.020 (1)	0.126 (1)	0.211±0.008 (6)
Leg muscles	1.144±0.082 (11)	1.242±0.053 (4)	0.271±0.015 (5)	0.205±0.008 (7)	0.205 (1)	0.787 (1)	1.434±0.069 (6)
Liver	0.488±0.036 (10)	0.661±0.025 (4)	0.148±0.012 (5)	0.119±0.007 (7)	0.065 (1)	0.264 (1)	0.778±0.033 (6)
Lungs	0.183±0.013 (11)	0.251±0.012 (4)	0.052±0.008 (5)	0.071±0.006 (7)	0.025 (1)	0.073 (1)	0.448±0.020 (6)
Ovaries	0.030±0.013 (7)	0.025 (1)	0.018±0.018 (2)	0.009 (1)	(0)	(0)	0.026±0.026 (2)
Oviduct	0.000±0.000 (2)	0.031 (1)	0.092±0.092 (2)	0.018 (1)	(0)	(0)	0.139±0.139 (2)
Flight muscles	3.474±0.268 (11)	4.392±0.136 (4)	0.740±0.078 (5)	0.819±0.061 (7)	0.512 (1)	2.244 (1)	10.897±0.258 (6)
Skin	0.555±0.059 (5)	(0)	0.168±0.007 (4)	0.137±0.021 (6)	(0)	(0)	2.019 (1)
Spleen	0.005±0.002 (1)0	0.031±0.011 (4)	0.003±0.001 (5)	0.004±0.001 (7)	0.001 (1)	0.001 (1)	0.025±0.005 (6)
Testes	0.215±0.082 (4)	0.102±0.037 (3)	0.030±0.015 (3)	0.032±0.004 (6)	0.009 (1)	0.003 (1)	0.107±0.008 (4)

Table S3. Species pairs used in temperate–tropical pair-wise comparison of tissue masses

Temperate species	Tropical species
Mourning dove *Zenaida macroura*	White-tipped dove *Leptotila verreauxi*
Ruby-throated hummingbird *Archilochus colubris*	Rufous-tailed hummingbird *Amazilia tzacatl*
Eastern phoebe *Sayornis phoebe*	Social flycatcher *Myiozetetes similis*
Red-eyed vireo *Vireo olivaceus*	Yellow-green vireo *Vireo flavoviridis*
Tree swallow *Tachycineta bicolor*	Mangrove swallow *Tachycineta albilinea*
Northern house wren *Troglodytes aedon*	Southern house wren *Troglodytes musculus*
Northern mockingbird *Mimus polyglottos*	Tropical mockingbird *Mimus gilvus*
American robin *Turdus migratorius*	Clay-colored thrush *Turdus grayi*
American goldfinch *Astragalinus tristis*	Thick-billed euphonia *Euphonia laniirostris*
Song sparrow *Melospiza melodia*	Black-striped sparrow *Arremonops conirostris*

Table S4. Results of phylogenetic generalized least squares models describing dry organ mass as a function of body mass, tropical or temperate climate, sex, migratory strategy (long-distance migrants that breed in North America and migrate at least as far as Central America *vs* sedentary birds and short-distance migrants) and diet

	Heart	Lungs	Flight muscles	Leg muscles	Gizzard	Intestines	Liver
Intercept	-2.284±0.077***	-2.382±0.084***	-1.308±0.087***	-2.133±0.108***	-2.420±0.169***	-2.587±0.160***	-1.903±0.099***
log_{10}(dry carcass mass)	0.897±0.034***	0.984±0.041***	1.050±0.037***	1.159±0.0414***	0.977±0.075***	1.109±0.074***	0.927±0.044***
Climate(=tropical)	-0.0937±0.0167***	-0.192±0.026***	-0.0477±0.0237*	0.0432±0.0157**	-0.0046±0.0471	0.0748±0.0394	-0.0427±0.0223
Sex(=male)	0.0281±0.0116*	0.0268±0.0139	0.0088±0.0100	-0.0225±0.0109*	-0.0351±0.0212	-0.110±0.028***	-0.0355±0.0156*
Migrant(=yes)	-0.0525±0.0287	0.0391±0.0404	0.0674±0.0364	0.0007±0.0281	-0.203±0.073**	-0.0179±0.0670	-0.0135±0.0379
Diet(=granivorous)	-0.0281±0.0297	0.0447±0.0405	0.0204±0.0395	-0.00465±0.0372	0.356±0.078***	-0.167±0.066*	-0.144±0.039***
Diet(=insectivorous)	-0.0283±0.0352	-0.0283±0.0448	-0.106±0.046*	0.0101±0.047	0.391±0.090***	-0.160±0.073*	-0.101±0.045*
Diet(=nectivorous)	0.140±0.106	-0.0290±0.0913	0.0530±0.0811	-0.169±0.174	-0.231±0.164	-0.0208±0.2081	-0.0536±0.1345
Diet(=omnivorous)	-0.0742±0.0302*	-0.0294.0428	-0.0221±0.0429	0.0864±0.0406*	0.286±0.084***	-0.107±0.065	-0.129±0.039**
Diet(=frugivorous)	0	0	0	0	0	0	0
df (residual, total)	175, 184	176, 185	178, 187	178, 187	174, 183	177, 186	177, 186
AIC_C Pagel	-339.6 (λ=0.654)	-268.3 (λ=0.527)	-354.9 (λ=0.819)	-335.7 (λ=0.926)	-80.0 (λ=0.828)	-34.1 (λ=0.462)	-239.0 (λ=0.601)
AIC_C Grafen	-348.9 (ρ=0.186)	-275.6 (ρ=0.180)	-366.5 (ρ=0.392)	-327.2 (ρ=0.371)	-105.1 (ρ=0.339)	-29.4 (ρ=0.097)	-236.2 (ρ=0.137)
AIC_C Martins	-325.7 (α=0.393)	-250.6 (α=0.926)	-328.6 (α=0.160)	-327.0 (α=0.070)	-42.6 (α=0.180)	-8.1 (α=0.588)	-221.0 (α=0.495)

	Kidneys	Ovaries	Testes	Skin	Spleen	Brain	Feathers
Intercept	-2.365±0.080***	-2.602±0.552***	-2.963±0.479***	-1.990±0.094***	-3.541±0.346***	-1.769±0.074***	-1.387±0.089***
log_{10}(dry carcass mass)	0.943±0.036***	0.979±0.335**	1.138±0.245***	1.037±0.060***	0.936±0.165***	0.628±0.030***	1.0693±0.0405***
Climate(=tropical)	-0.196±0.018***	-0.310±0.140*	-0.542±0.159**	0.0296±0.0279	-0.0543±0.0977	0.0127±0.0127	-0.150±0.019***
Sex(=male)	-0.0258±0.0125*			-0.0614±0.0186**	-0.101±0.722	0.0134±0.0088	-0.0184±0.0128*
Migrant(=yes)	-0.0765±0.0303*	-0.325±0.286	0.186±0.252	-0.0154±0.0453	-0.061±0.157	-0.0386±0.0222	0.0693±0.0128
Diet(=granivorous)	-0.154±0.032***	-0.828±0.311*	-0.275±0.242	0.0229±0.0580	-0.090±0.181	0.0305±0.0269	0.0794±0.0345*
Diet(=insectivorous)	-0.0147±0.0366	-0.451±0.332	-0.167±0.258	0.0294±0.0662	-0.158±0.189	0.0151±0.0333	0.0107±0.0439
Diet(=nectivorous)	0.0459±0.1090	-0.208±0.682	-0.710±0.558			-0.0531±0.1114	
Diet(=omnivorous)	-0.124±0.032***	-0.402±0.352	-0.001±0.248	-0.079±0.061	-0.068±0.167	0.0703±0.0284*	0.0490±0.0357
Diet(=frugivorous)	0	0	0	0	0	0	0
df (residual, total)	176, 185	50, 58	105, 113	101, 109	112, 120	175, 184	112, 120
AIC_C Pagel	-316.6 (λ=0.613)	106.5 (λ=0.812)	207.0 (λ=0.171)	-123.0 (λ=0.843)	151.8 (λ=0.304)	-424.3 (λ=0.848)	-228.8 (λ=0.745)
AIC_C Grafen	-314.0 (ρ=0.186)	105.6 (ρ=0.162)	202.5 (ρ=0.152)	-119.8 (ρ=0.228)	152.2 (ρ=0.049)	-410.8 (ρ=0.295)	-226.8 (ρ=0.213)
AIC_C Martins	-282.2 (α=0.860)	101.1 (α=0.160)	210.6 (α=19.5)	-124.9 (α=0.233)	153.3 (α=0.978)	-387.7 (α=0.052)	-205.8 (α=0.371)

Data are log_{10} tissue or organ mass.

Parameter estimates for alternative variable values are used as reference and equal 0 and are not shown. For diet, frugivory is used as reference category. Shown are parameter estimates with standard errors and p-value categories, as well as degrees of freedom (total=number of specimens), evolutionary model parameter estimates and AIC_C values of final model. Significant variables are emphasized with grey as is the model with lowest AIC_C. When a model did not converge AIC_C=NA.

P*<0.05; ***P*<0.01; * *P*<0.001.