EnergyBudget

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Using published and unpublished data from Dr. Don Powers' earlier work, we construct here a preliminary energy budget for a North American species, *Cynanthus latirostris*.

1. Basal Metabolic Rate (BMR)

This measurement is based on a regression model of metabolic rate measured under BMR conditions (in the dark, fasted, during the sleep phase), below the lower critical temperatures (measured during summer 2012). The assumptions of these measurements are:

- 35°C is the lower critical temperature (LCT) and represents the lowest temperature for measurement of BMR. This is consistent with measurements for other hummingbirds (Lasiewski 1963) and data on Costa's Hummingbirds (*Calypte costae*) and broad-tailed hummingbirds (*Selasphorus platycercus*; unpublished, Donald R. Powers).
- BMR is assumed a continuous cost for 24 hours except for birds that use torpor. If torpor is used then BMR is a continuous cost for 24 hours, excluding the hours spent in torpor. Hours for maximum torpor at the two sites studied were Harshaw Creek (HC) = 6 and at Sonoita Creek (SC) = 4.

Mean BMR_{BBLH} = 0.204 mL/min (4.1 J/min; 0.0683W)

2. Thermoregulation

A. Below the thermoneutral zone (TNZ; Operative temperature $T_e < 35$°C)

MR_L (mL O_2/min) = 0.9571 - 0.022*(T_e) ———- **Equation 1a**

Where MR_L is metabolic rate below the TNZ. This is calculated by subtracting BMR from the result of equation 1a when $T_e < 35$°C. For simplicity of calculation the result of equation 1a when $T_e < 35$°C included both the cost of BMR and of thermoregulation.

TRE_L (kJ) = $\Sigma(MR_L * 60)$ ——————— **Equation 1b**

Where TRE_L is the energy spent on thermoregulation below the TNZ. This is calculated for hourly averages for all hours where mean $T_e <$ LCT and there is no torpor use. Torpor was assumed to be zero because birds rarely entered torpor in Sonoita Creek.

B. Above the TNZ ($T_e > 35$°C)

Lasiewski's (1963) data suggests that the upper critical temperature for small hummingbirds is ~35-37 °C. This seems odd considering hummingbirds have a presumed body temperature of ~41 °C. Even so this appears consistent with all measures we are aware of. The TNZ of small hummingbirds appears so small that the LCT and upper critical temperature (UCT) are essentially identical Lasiewski (1963). The only data we know of for metabolic rate above the upper critical temperature in small hummingbirds is Powers' unpublished data on Costa's. The slope of this relationship was based on unpublished measurements of Costa's Hummingbird (*Calypte costae*), a similarly sized species.

MR_H (mL O_2/min) = 0.0144 (T_e) - 0.3623 ———- **Equation 2a**

Where MR_H is metabolic rate above upper critical temperatures. This is calculated by subtracting BMR from the result of equation 2a. Again, for simplicity of calculation the result of equation 2a is the combined cost of BMR and thermoregulation.

TRE_H (kJ) = $\Sigma(MR_H * 60)$ ———————— **Equation 2b**

Calculated for hourly averages for all hours where mean $T_e > UCT$ and again, assuming no torpor.

3. Activity Costs

A. Resting (perching)

Little data is available for how much resting metabolic rate (RMR) is elevated above BMR in hummingbirds. In the late 1980's Powers measured RMR for Costa's (3.66 mL O_2 $g^{-1}h^{-1}$; unpublished). Lasiewski (1963) measured BMR for Costa's (3.025 mL O_2 $g^{-1}h^{-1}$). Thus,

RMR_{Costa} = 1.21 x BMR

This is consistent with Aschoff & Pohl (1970) which reported data for several bird species suggesting RMR = 1.25 x BMR. The Aschoff & Pohl correction has often been used to estimate RMR but might underestimate true resting costs because the measurements upon which it is based were typically made on birds resting in the dark. This would eliminate any costs associated with response to light or surrounding events. Further, we believe that Aschoff & Pohl also fasted birds so the cost of specific dynamic action (i.e. the cost of digestion; SDA) is also not included. Two years ago Powers made RMR measurements on Calliope hummingbirds (*Selasphorus calliope*; ~2.4 g) while on a perch in an illuminated chamber. After subtracting thermoregulatory costs RMRCalliope = 0.2835 mL O_2/min. BMRCalliope = 0.1843 mL O_2/min (Lasiewski 1963). Thus,

$RMR_{Calliope}$ = 1.54 x BMR

In our opinion this more accurately reflects the metabolic rate of a perching hummingbird. Thus, we can estimate RMR as:

RMR = 1.5 x BMR ——————————————- **Equation 3**

B. Hovering

We have measured hovering metabolic rate (HMR) in broad-billed hummingbirds:

HMR = 2.1 mL O_2/min (42.21 J/min; 0.7035W)

This value is 10.3 x BMR, which is reasonable.

C. Forward flight

No measurements of been made on the metabolic cost of forward flight (FLMR) in broad-billed hummingbirds. If we assume that hummingbirds fly most often at their most efficient speed (6-8 m/s), FLMR can be estimated using data from other hummingbird species.

$FLMR_{Calliope}$ = 0.53 x HMR

$FLMR_{Rufous}$ = 0.49 x HMR

Thus, we can estimate FLMR to be:

FLMR = 0.5 x HMR —————————————— **Equation 4**

D. Total activity costs

ACT = (($Time_{RMR}$ * (RMR - BMR)) + ($Time_{HMR}$ * (HMR - BMR) + ($Time_{FLMR}$ * (FLMR - BMR) ———————— **Equation 5**

4. Nighttime Metabolic Rate

A. No torpor Nighttime metabolic rate (NMR) for normothermic hummingbirds can be calculated using equation 1a.

B. Torpor For the sake of modeling DEE we will assume that if torpor is used it is used to the full extent. By doing so we can create energetic boundaries based on whether or not torpor was used. For birds that used torpor maximally last summer:

Nighttime energy expenditure (NEE) = 2 kJ

Note: This value might change a bit as we refine the calculations. Even so this is such a small component of DEE that small changes to this value will have little impact on model results.

5. DEE Model

DEE = (TRE_L + TRE_H) + ACT + NEE

Where: DEE = Daily energy expenditure TRE_L = Cost of thermoregulation at lower critical temperatures TRE_H = Cost of thermoregulation at higher critical temperatures ACT = Activity costs (from above) NEE = Nighttime energy expenditure Note: If no torpor is used then NEE = 0, and NEE is included in TRE_L.

Model Test Using Sonoita Creek *C. latirostris* values

Here, assuming: 1. 70% of the daytime was spent perching and 30% flying. Flying was 50% hovering and 50% forward flight.

2. No torpor (this is realistic for SC).
3. Respiratory quotient (RQ) = 0.85 (for conversion of oxygen consumption to CO_2 production)
4. 14/10 photoperiod.

Results: Mean Measured DEE (DLW) = 51.3 mL CO_2/h Model Estimate = 43.2 mL CO_2/h

The model estimate is 16% lower than the measured value but is within the range of measured values (albeit at the low end). We are very encouraged by this considering that this model is likely biased low since costs of molt and reproduction are not specifically considered.