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Supplementary material

Appendix 1

Hummingbird torpor in context: duration, more than temperature, is the key to nighttime energy savings

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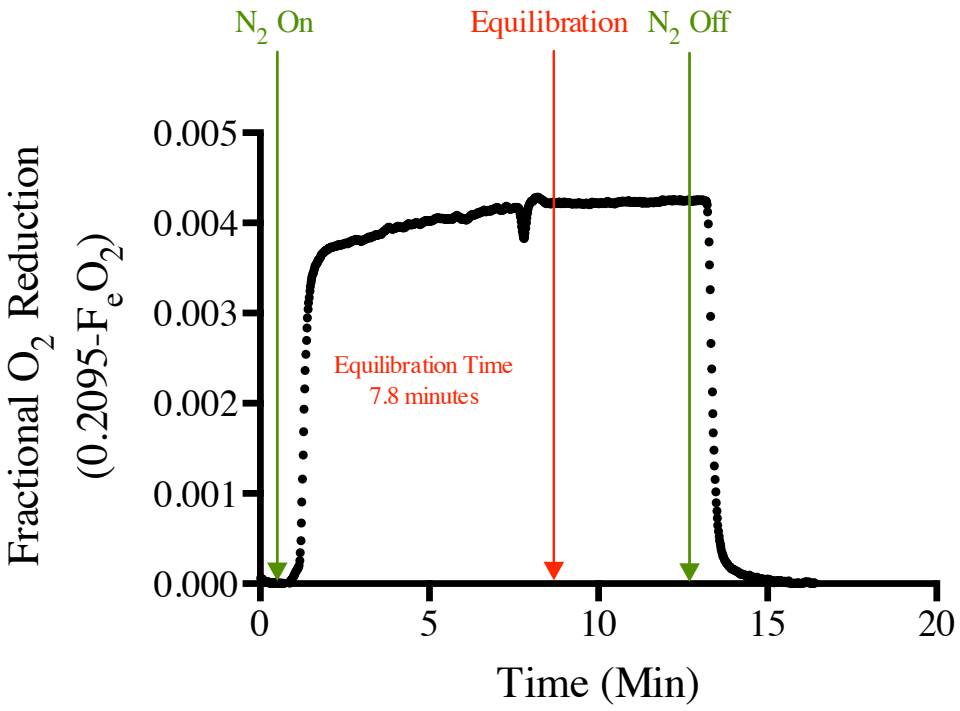

Figure A1: Equilibration time for the respirometry chamber, representing change in fractional oxygen values (baseline oxygen (.2095) – excurrent oxygen values (F_eO_2)). To approximate the equilibration time of our metabolic chambers using the negative pressure, "mask" design, we first baselined with atmospheric air, then added a constant flow of 99.99% nitrogen gas near the perch sufficient to generate an oxygen depression similar to that observed during hummingbird metabolic measurements. Air flow rate through the chambers was the same as that used during our metabolic trials. This figure shows an equilibration measurement for the system used in Ecuador (6L torpor chamber, flowrate = 1000 mL/min). We found that the flow rates we used were sufficient to equilibrate within ~8 minutes from start of nitrogen flow in the chamber.

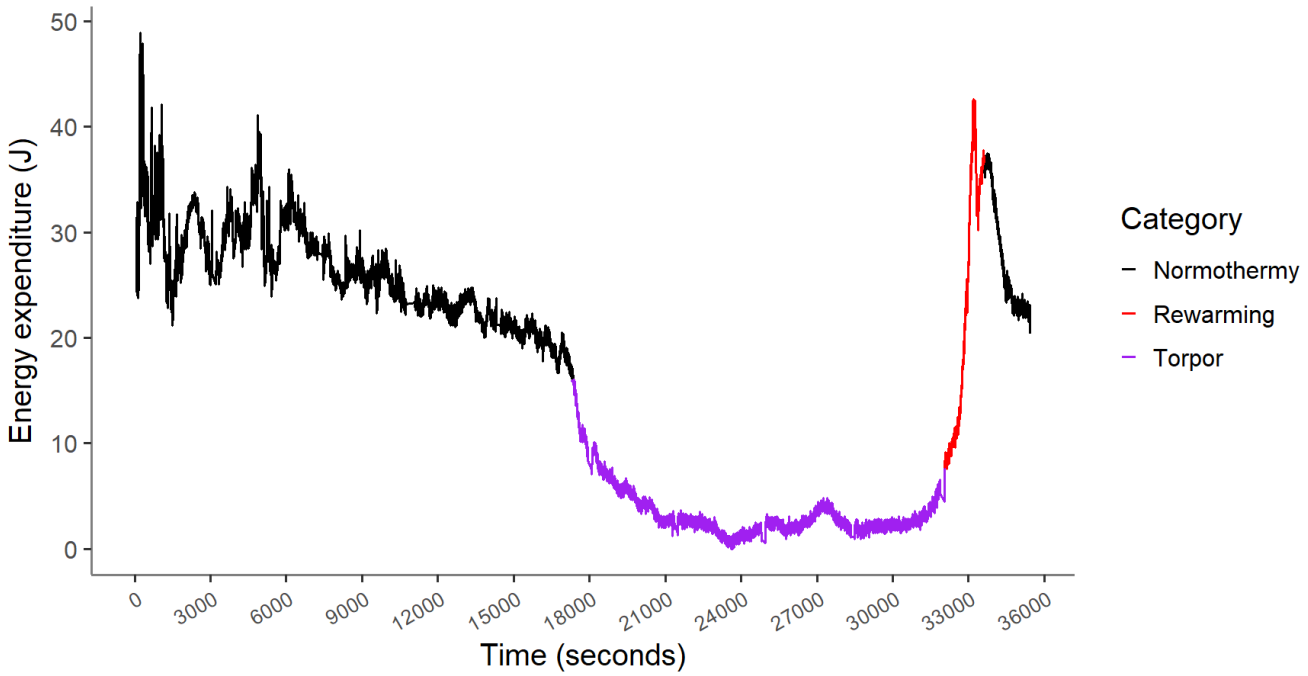

Figure A2: Sample graph of energy expenditure (Joules) of a green-crowned brilliant over the course of a night (1930h – 0530h), colored by its metabolic state. This graph excludes baseline periods. At the beginning, the individual was active and perhaps flew around the chamber initially before settling down. Individuals were considered torpid (purple) when metabolic rate fell below resting normothermic values (a minimum of 0.4 O_2 mL/min change, and an average of 1.1 mL O_2/min in 30-90 minutes; Hiebert 1990, Powers et al. 2003). 'Rewarming' or arousal from torpor (red) began when VO_2 started to steadily increase and ended when VO_2 values peaked as the birds stopped actively increasing their metabolism (Bartholomew and Lighton 1986).

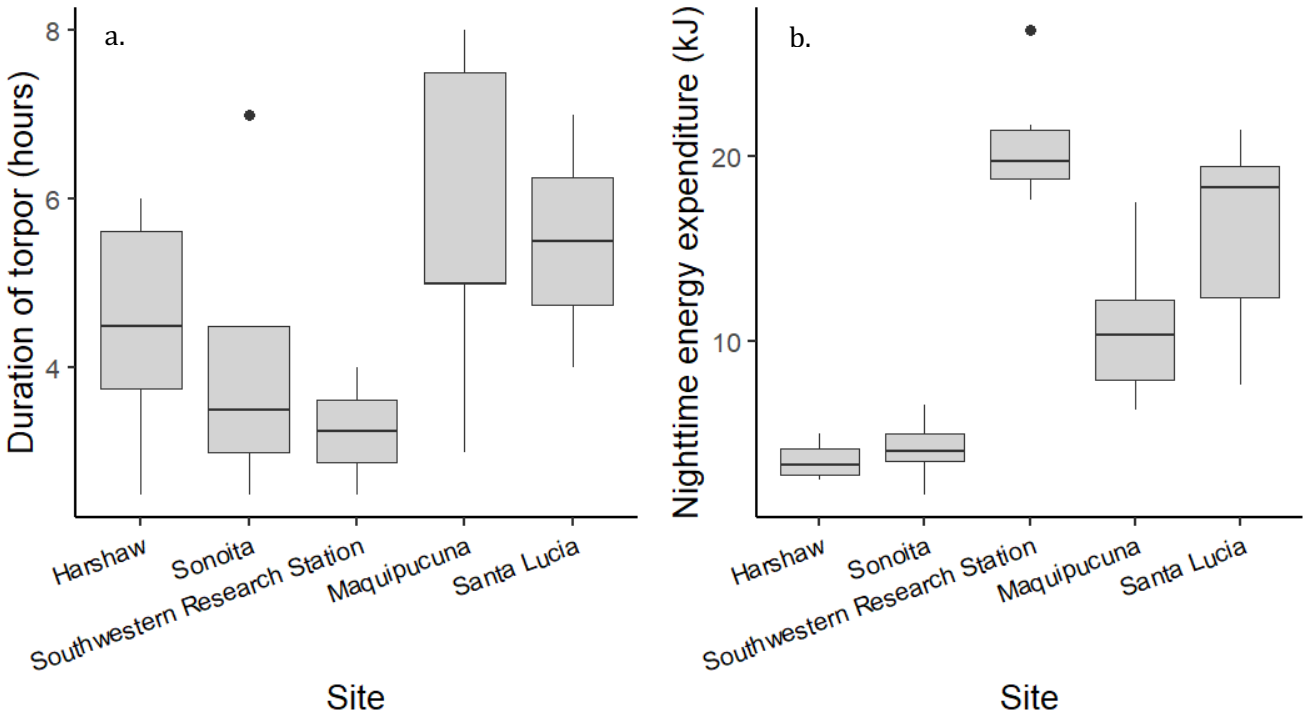

Figure A3: Site-wise measures of a. duration (hours) of torpor and b. nighttime energy expenditure (kJ). Boxplots show median (horizontal black central line), first and third quartiles (25^{th} and 75^{th} percentiles, at the ends of the box), and whiskers extending up to 1.5*(inter-quartile range). Duration of torpor was positively related to night length and nighttime energy expenditure was strongly correlated with duration.

Table A1: Stepwise model DIC values for parameter combinations in the nighttime energy expenditure MCMCglmm models. All the independent variables in this model were modelled as continuous variables except for energy savings, which had a bimodal distribution and was transformed into an ordinal variable (in 25th quantiles) for this model. The best model was $Nighttime\ energy\ expenditure \sim Duration$. Other models, such as the 'duration + T_c min', had similar DIC scores but were less parsimonious.

Model	DIC	α	G-structure	β, pMCMC Mass	β, pMCMC Duration	β, pMCMC T_c_min	β, pMCMC Savings	β, pMCMC Rewarming
1. Mass	213.24	-2.95 (-15.40, 11.96)	40.32 (3.49, 100.7)	2.40 (0.60, 4.11), 0.014	-	-	-	-
2. Duration	**192.85**	**15.75 (8.79, 22.26)**	**44.46 (7.64, 109.4)**	-	**-1.01 (-1.39, -0.63), <2e-04**	**-**	**-**	**-**
3. T_c min	216.22	13.01 (2.85, 23.81)	88.7 (16.19, 209.2)	-	-	0.004 (-0.26, 0.24), 0.96	-	-
4. Savings	207.54	16.27 (7.40, 24.07)	62.54 (10.62, 148.1)	-	-	-	-1.94 (-3.18, -0.66), 0.0036	-
5. Duration + T_c min	192.00	18.73 (11.22, 26.59)	41.53 (7.99, 100.4)	-	-1.09 (-1.46, -0.71), <2e-04	-0.16 (-0.36, 0.03), 0.10	-	-
6. Mass + Duration + T_c min	193.31	6.23 (-1.58, 14.33)	8.93 (0, 25.66)	1.92 (0.95, 2.89), 0.0052	-1.09 (-1.43, -0.72), <2e-04	-0.21 (-0.39, -0.02), 0.03	-	-
7. Duration + T_c min + savings	193.96	18.61 (10.99, 26.45)	41.76 (8.15, 99.78)	-	-1.17 (-1.73, -0.64), <2e-04	-0.17 (-0.36, 0.03), 0.093	0.27 (-1.21, 1.69), 0.69	-
8. Mass + Duration + T_c min + savings	195.43	6.00 (-2.07, 14.35)	9.09 (0.0003, 27.03)	1.94 (0.95, 2.91), 0.0036	-1.14 (-1.63, -0.63), <2e-04	-0.21 (-0.40, -0.04), 0.025	0.22 (-1.17, 1.70), 0.76	-

9. Mass + Duration + T_c min + savings + rewarming	194.78	4.33 (-4.02, 13.06)	8.78 (0.0002, 25.88)	2.15 (1.07, 3.07), 0.002	-0.95 (-1.50, -0.39), 0.0008	-0.21 (-0.40, -0.04), 0.03	-0.36 (-1.07, 1.78), 0.62	-1.70 (-4.04, 0.59), 0.15

Table A2: Comparing MCMCglmm stepwise model results for the rewarming models Rewarming (kJ) ~ Mass (g) and Rewarming (kJ) ~ Mass (g) + chamber temperature (T_c in °C).

Model	DIC	α, pMCMC	G-structure	β, pMCMC mass	β, pMCMC Tc
1. Mass	30.18	-0.63 (-2.48, 0.73), 0.24	0.29 (0.0001, 1.06)	0.20 (-0.003, 0.48), 0.012	-
2. Mass + T_c during rewarming	29.73	-0.55 (-3.60, 1.05), 0.63	0.59 (0.0002, 2.45)	0.25 (0.01, 0.75), 0.004	-0.02 (-0.06, 0.01), 0.19

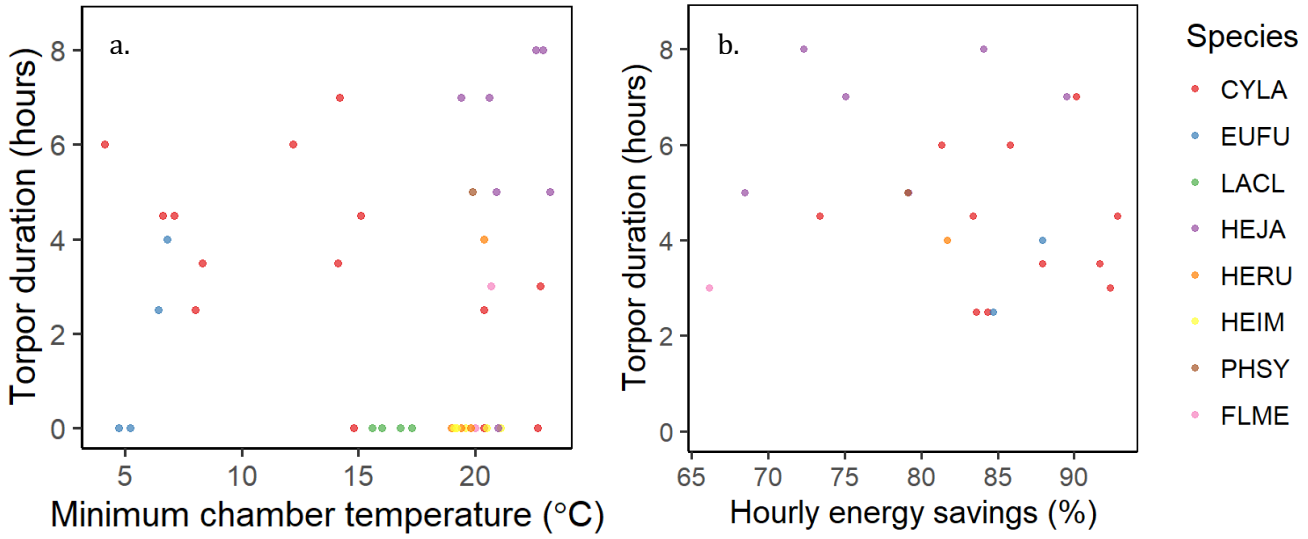

Figure A4: a. Torpor duration vs. minimum chamber temperature (T_c min) for the night. b. Torpor duration vs. average hourly energy savings in torpor relative to normothermy. Both T_c min and hourly energy savings were uncorrelated with torpor duration. *CYLA* (*Cynanthus latirostris*), *EUFU* (*Eugenes fulgens*), and *LACL* (*Lampornis clemenciae*) were in Arizona; *HEJA* (*Heliodoxa jacula*), *HERU* (*H. rubinoides*), *HEIM* (*H. imperatrix*), *PHSY* (*Phaethornis syrmatophorus*), and *FLME* (*Florisuga mellivora*) were Ecuadorian birds.

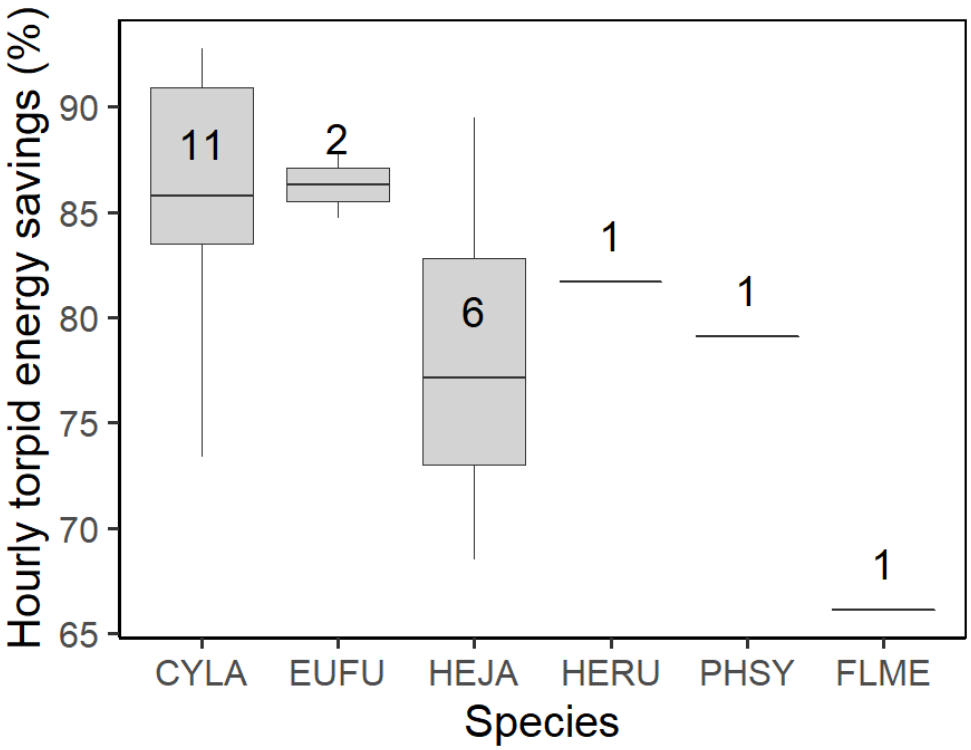

Figure A5: Average hourly torpid energy savings relative to normothermy for all individuals that used torpor across all sites. *CYLA* (*Cynanthus latirostris*) and *EUFU* (*Eugenes fulgens*) were in Arizona; *HEJA* (*Heliodoxa jacula*), *HERU* (*H. rubinoides*), *PHSY* (*Phaethornis syrmatophorus*), and *FLME* (*Florisuga mellivora*) were Ecuadorian birds. Numbers refer to the sample sizes of torpid individuals. *LACL* (*Lampornis clemenciae*) and *HEIM* (*H. imperatrix*) are not shown, as they did not enter torpor.

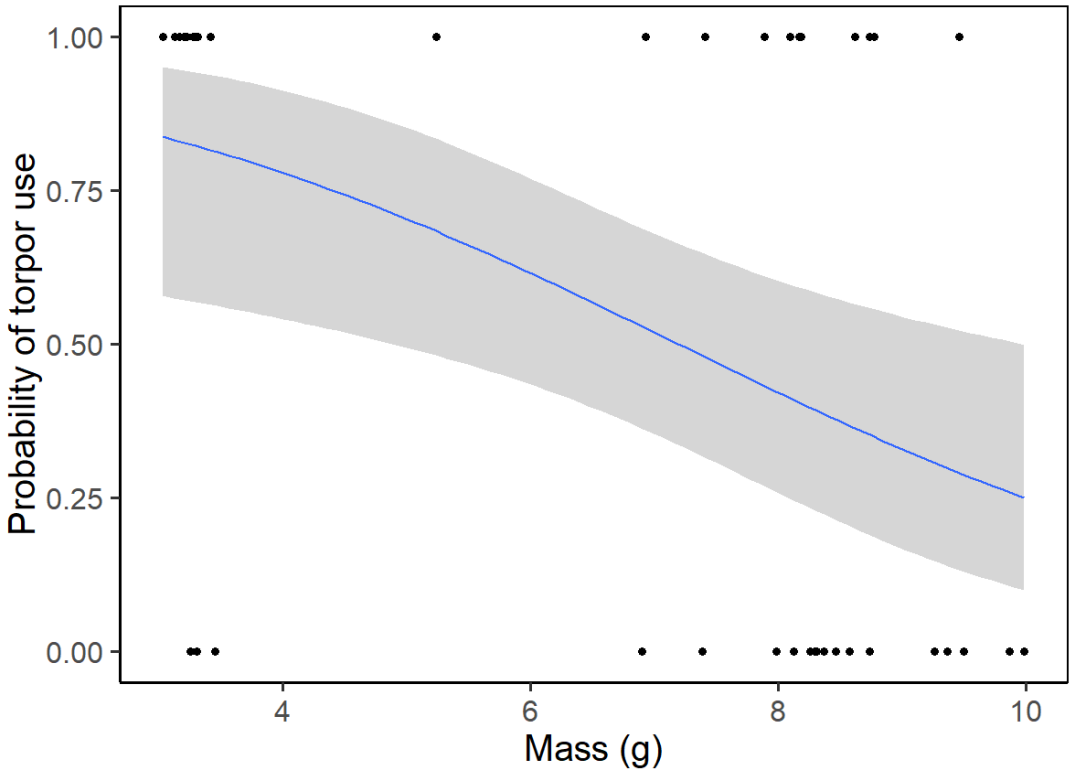

Figure A6: The probability of entering torpor is a negative binomial function of the mass of the individual. This is a graphical depiction of model 1 in Table 3 of the main paper.

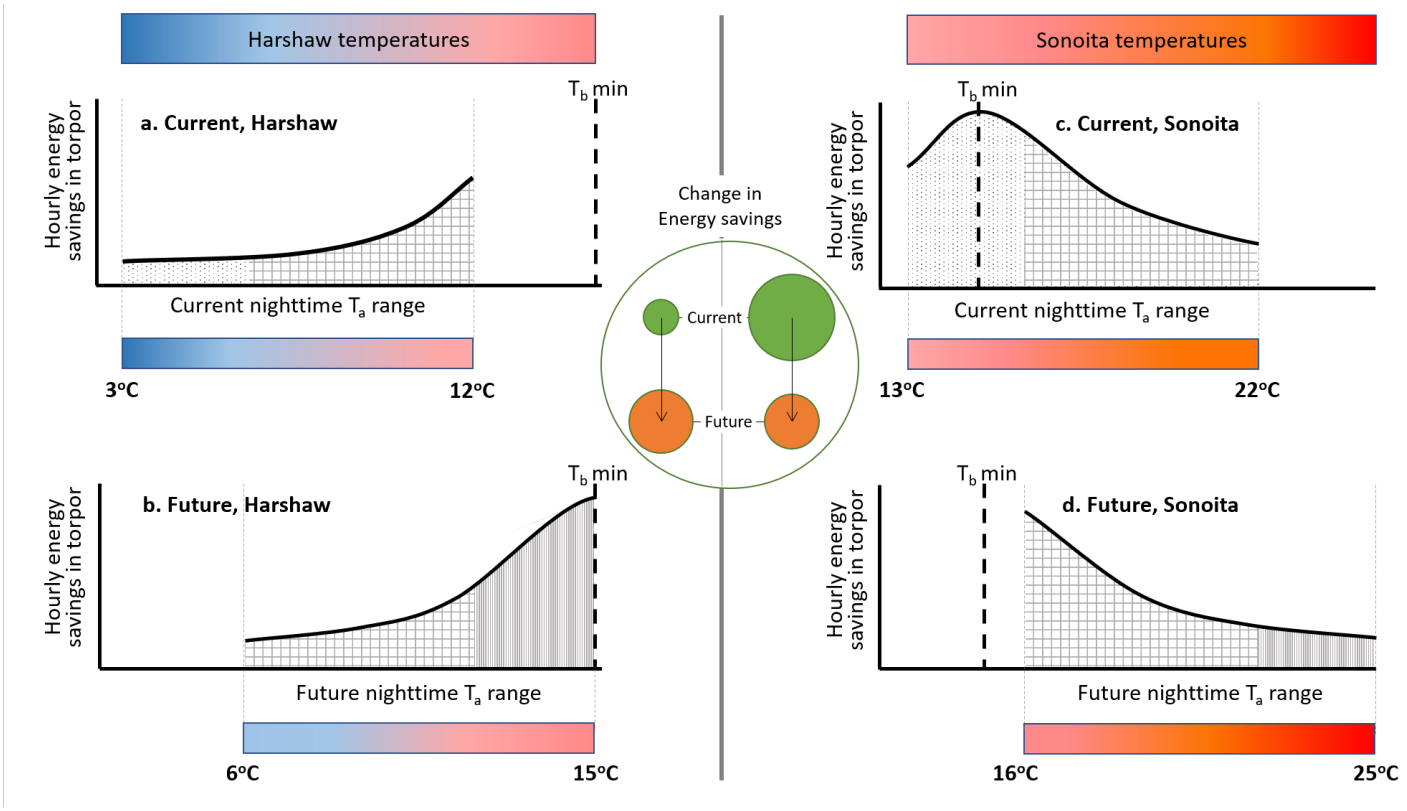

Figure A7: Schematic diagram depicting the relationship between hourly energy savings (calculated as % energy saved/hour of torpor relative to normothermy), minimum T_b, and T_a for the broad-billed hummingbird under current and future temperatures at two Arizona sites (Harshaw and Sonoita). Overall, energy savings depend on how close T_a is to minimum T_b. Assuming a future increase of 3°C in nighttime temperatures, energy savings could decrease in Sonoita and increase in Harshaw under warming conditions. As per our calculations, these changes in hourly energy savings do not significantly impact nighttime energy expenditure but may have longer-term physiological relevance. Colour bars and temperature scales at the base of each plot represent temperature ranges at that time period and site. Minimum T_b for broad-billed hummingbirds (~15°C) is depicted by the bold vertical dashed lines. Lighter vertical dashed lines represent the range of ambient temperatures for that time period. The 'current' plots have light dotted shading; future portions of the plots have dense vertical shading; portions of the plots that overlap have chequered shading. The circle in the middle represents overall nighttime energy savings under that scenario- green is current and orange is future.

References

Bartholomew, G. A., and J. R. B. Lighton. 1986. Oxygen consumption during hover-feeding in free-ranging Anna hummingbirds. The Journal of Experimental Biology 123:191–199.

Hiebert, S. M. 1990. Energy costs and temporal organization of torpor in the rufous hummingbird (*Selasphorus rufus*). Physiological Zoology 63:1082–1097.

Powers, D. R., A. R. Brown, and J. A. Van Hook. 2003. Influence of normal daytime fat deposition on laboratory measurements of torpor use in territorial versus nonterritorial hummingbirds. Physiological and Biochemical Zoology 76:389–97.

Metadata for

Hummingbird torpor in context: duration, more than temperature, is key to nighttime energy savings

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Introduction

This metadata describes and explains the data and methods that accompany the hummingbird torpor and nighttime energy expenditure study conducted June 2013 – August 2014. The objectives of the study were to measure the parameters of torpor use across either hummingbird species. This study was performed at three sites in the Patagonia and Chiricahua Mountains in south-eastern Arizona, as well as at two sites in the mid-elevation cloud forests of the Ecuadorian Andes.

Site table

These site codes are used in all other data tables.

Site code	Site	Latitude, Longitude	Altitude (m)	Dates sampled
HC	Harshaw Creek	31.50, -110.68	1370 – 1635	Jun – Jul 2013
SC	Sonoita Creek	31.50, -110.86	1100 – 1180	Jun – Jul 2013
SWRS	Southwest Research Station	31.88, -109.21	1650 – 1720	May – Jul 2014
MQ	Maquipucuna ('Maqui')	0.12, -78.64	1275 – 1370	Jul – Aug 2014
SL	Santa Lucia	0.12, -78.61	1800 – 2100	Jul – Aug 2014

Species table

These species codes are used in some of the data tables below

Species code	Species scientific name	Species common name	Site(s) studied
CYLA	*Cynanthus latirostris*	broad-billed hummingbird	HC, SC
EUFU	*Eugenes fulgens*	Rivoli's hummingbird	SWRS
LACL	*Lampornis clemenciae*	blue-throated hummingbird	SWRS
HEIM	*Heliodoxa imperatrix*	empress brilliant	SL
FLME	*Florisuga mellivora*	white-necked jacobin	MQ, SL
HEJA	*Heliodoxa jacula*	green-crowned brilliant	MQ, SL
PHSY	*Phaethornis syrmatophorus*	tawny-bellied hermit	MQ
HERU	*Heliodoxa rubinoides*	fawn-breasted brilliant	SL

Summary of respirometry data

Dataset file

Identity: Torpor_individual_summaries.csv
Size: 41 records, not including header row, 12 kilobytes.
Format and storage mode: comma delimited
Header information: The first row of the file contains the variable names. See below for detailed descriptions of the column contents
Alphanumeric attributes: Mixed
Special characters/fields: If no information is available for a given record, or if a value is not appropriate, this is indicated by NA. 0's indicate true zero.

Variables

Variable name	*Variable definition*	*Storage type*	*Variable definitions*
Site	Abbreviated site code where experiment was performed	Character	See Site table above
Temptrop	Code for whether the site is temperate or tropical	Character	Temperate = Arizona sites; Tropical = Ecuadorian sites
Species	Abbreviated species name	Character	See Species table above
Sp_indiv_no	Number of the individual within the species	Integer	NA
ID_AZ_BBLH	Individual identifier	Float	NA
Day	Day the experiment started	Integer	NA
Month	Month the experiment was performed	Integer	NA
Year	Year the experiment was performed	Integer	NA
Mass	Capture mass of the individual	Float	NA
Nectar_ consumption	Fed mass before start of experiment – end mass at the end of the night	Float	NA
Torpid_not	Binary character code indicating whether the individual used torpor or not	Character	T = torpid; N = normothermic
Tornor	Binary numeric code indicating whether the individual used torpor or not	Integer	1 = Used torpor; 0 = Did not use torpor
Time_of_entry	Hour in military time at which the bird entered torpor; NA if bird did not use torpor	Integer	NA
EntryTime_ numeric	Hour relative to start of night at which bird entered torpor;	Integer	NA

	beginning of 1st hour of night is 0, end of first hour is 1, and so on.		
Hours_torpid	Number of hours spent torpid, rounded to the nearest half hour	Float	NA
Hours_normo	Number of hours spent normothermic, rounded to the nearest half hour	Float	NA
Rewarming_ start_time	Military hour at which the bird started to rewarm after torpor, to the nearest minute	Integer	NA
Rewarming_start_VO2	VO_2 at time when rewarming started.	Float	NA
Rewarmingbefore_ overshoot_time	Military time at which rewarming was ending, but before oxygen consumption overshot stable normothermic values.	Integer	NA
Rewarming_ overshoot_ max_time	Military hour at which the bird's oxygen consumption peaked during rewarming	Integer	NA
Rewarming_overshoot _max_VO2	Value of oxygen consumption at its peak during rewarming	Float	NA
Rewarming_overshoot _end_time	Military hour at which the bird's oxygen consumption stopped increasing and started to stabilize after rewarming	Integer	NA
Rewarming_ duration_min	Duration in minutes of the total rewarming bout, from start to peak overshoot	Integer	NA
Rewarming_stable_ end_VO2	VO2 after rewarming, at stable value	Float	NA
Rewarming_O2_change	Total difference in O2 consumption after rewarming minus before rewarming had started	Float	NA
Rewarming_O2_rate	Rate of change of O2 consumption over the rewarming bout	Float	NA
Reliable_rewarming _mmt	Binary character variable indicating whether the rewarming measurements were complete or not. Details in comments. Though some were missing the very end of rewarming, the overall values are mostly reliable for comparison	Character	Y = Complete rewarming bout captured; N = Incomplete rewarming bout
AOC_duration_minutes_ mintopeak	Duration of the area under the curve measured from minimal end O2 in torpor to peak O2 consumption during rewarming	Float	NA

AOC_mintopeak_O2ml_Min	Area under the curve of oxygen consumption in mL O2 consumed per minute, from minimum end torpor O2 consumption to peak O2 during rewarming	Float	NA
Rewarming_Tc	The average temperature of chamber during the rewarming period	Float	NA
kJ_rewarming_BeforeOvershoot	The area under the oxygen consumption curve through the duration of rewarming after torpor, converted to kiloJoules	Float	NA
kJ_RER071_rewarming_BeforeOvershoot	The area under the oxygen consumption curve through the duration of rewarming after torpor, converted to kiloJoules. We used this value in the paper (with a lower RER of 0.71 than the previous column), because the birds were likely burning fat at this point	Float	NA
Rate_kJ	Rate of change of energy expenditure in kJ from the beginning to end of rewarming	Float	NA
Total_hours	Night length in hours at that site	Integer	NA
Prop_hours	Proportion of the night spent torpid. Calculated as Hours_torpid/Total_hours	Float	NA
NEE_kJ_with_constRER	Total nighttime energy expenditure, in kiloJoules. These calculations were made assuming a constant RER through the night of 0.85.	Float	NA
NEE_constRER_minus_rewarming_kJ	Total nighttime energy expenditure, minus rewarming costs, in kiloJoules. These calculations were made assuming a constant RER through the night of 0.85.	Float	NA
NEE_kJ_variableRER	Total nighttime energy expenditure, in kiloJoules. These calculations were made allowing RER to change through the night, from 1 (carbohydrates) in the first two hours, to 0.71 (fat) later in the night.	Float	NA

NEE_variableRER_minus_rewarming_kJ	Total nighttime energy expenditure in the previous column (variable RER), minus rewarming costs, in kiloJoules.	Float	NA
O2_ml_night	Total nighttime oxygen consumption in mL O_2.	Float	NA
Tc_mean_C	Mean chamber temperature through the night	Float	NA
Tc_range_C	Range of chamber temperatures in Celsius		
Tc_min_C	Minimum chamber temperature for the night	Float	NA
Tc_max_C	Maximum chamber temperature for the night	Float	NA
Avg_EE_ hourly_torpid	Average energy expenditure over all torpid hours that night, in kiloJoules; NA if the individual did not use torpor. Accounts for variable RER.	Float	NA
Avg_EE_ hourly_normo	Average energy expenditure over all normothermic hours that night, in kiloJoules. Accounts for variable RER.	Float	NA
Percentage_avg	Percentage energy spent in torpor relative to normothermy. Uses constant RER value of 0.85 all night. Calculated as (Avg_EE_hourly_torpid/ Avg_EE_hourly_normo)*100	Float	NA
Percentage_avg_varRER	Percentage energy spent in torpor relative to normothermy. Uses varying RER values as presented in paper. Calculated as (Avg_EE_hourly_torpid/ Avg_EE_hourly_normo)*100	Float	NA
Comments	Comments	Character	NA

Summary of ambient temperatures for all sites

On nights that torpor measurements were collected.

Dataset file

Identity: Ta_AllSites_summ.csv
Size: 57 records, not including header row, 2 kilobytes.
Format and storage mode: comma delimited
Header information: The first row of the file contains the variable names. See below for detailed descriptions of the column contents
Alphanumeric attributes: Mixed
Special characters/fields: If no information is available for a given record, or if a value is not appropriate, this is indicated by NA. 0's indicate true zero.

Variables

Variable name	*Variable definition*	*Storage type*	*Variable definitions*
Row	Row number, excluding header	Integer	NA
Site	Abbreviated site code where experiment was performed	Character	See Site table above
Hour2	Military time (only hour, not minutes), over which temperature was averaged.	Integer	e.g. 19 = 7pm, 1 = 1am
Mean_Ta	Mean ambient temperature over that hour	Float	NA
Min_Ta	Minimum ambient temperature over that hour	Float	NA
Max_Ta	Maximum ambient temperature over that hour	Float	NA

Summary of chamber temperatures for all individuals

Dataset file

Identity: Tc_AllSites_summ.csv
Size: 57 records, not including header row, 2 kilobytes.
Format and storage mode: comma delimited
Header information: The first row of the file contains the variable names. See below for detailed descriptions of the column contents
Alphanumeric attributes: Mixed
Special characters/fields: If no information is available for a given record, or if a value is not appropriate, this is indicated by NA. 0's indicate true zero.

Variables

Variable name	*Variable definition*	*Storage type*	*Variable definitions*
Row	Row number, excluding header	Integer	NA
Site	Abbreviated site code where experiment was performed	Character	See Site table above
Hour2	Military time (only hour, not minutes), over which temperature was averaged.	Integer	e.g. 19 = 7pm, 1 = 1am
Mean_Tc	Mean chamber temperature over that hour	Float	NA
Min_Tc	Minimum chamber temperature over that hour	Float	NA
Max_Tc	Maximum chamber temperature over that hour	Float	NA

Scholander-Irving curve measurements with broad-bill hummingbirds

Controlled conditions: Metabolic rate measurements on eight *Cynanthus latirostris* individuals at 5°C temperature steps under basal conditions, in Harshaw Creek.

Dataset file

Identity: Broadbill.csv
Size: 39 records, not including header row, 2 kilobytes.
Format and storage mode: comma delimited
Header information: The first row of the file contains the variable names. See below for detailed descriptions of the column contents
Alphanumeric attributes: Mixed
Special characters/fields: If no information is available for a given record, or if a value is not appropriate, this is indicated by NA. 0's indicate true zero.

Variables

Variable name	*Variable definition*	*Storage type*	*Variable definitions*
Row	Row number, excluding header	Integer	NA
ID	Individual ID	Integer	NA
Temp_C	Temperature of the controlled chamber in degrees Celsius	Float	NA
N_T	Character code denoting whether the measurement was on a normothermic or torpid individual	Character	N = Normothermic; T = Torpid
VO2_all	Average VO2 or oxygen consumption, with one value per row for both normothermic and torpid measurements	Float	NA
VO2_Normothermic	Average VO2 for just normothermic measurements	Float	NA

Field conditions: Oxygen consumption measurements, in mL O_2/min, from all 15 *Cynanthus latirostris* individuals in the main study, under natural temperature cycles and photoperiods, in both Harshaw Creek and Sonoita Creek.

Dataset file

Identity: BBLH_ VO2_field.csv
Size: 572 records, not including header row, 24 kilobytes.
Format and storage mode: comma delimited
Header information: The first row of the file contains the variable names. See below for detailed descriptions of the column contents
Alphanumeric attributes: Mixed

Special characters/fields: If no information is available for a given record, or if a value is not appropriate, this is indicated by NA. 0's indicate true zero.

Variables

Variable name	*Variable definition*	*Storage type*	*Variable definitions*
Site	Abbreviated site code where experiment was performed	Character	See Site table
Bird_no	Individual ID, as links to other datasets	Character	NA
Bird_numeric	Just the numeric component of Bird_no	Integer	NA
Time	Time at which file was saved and VO2 measured, since last file save (usually ~ every 15 minutes)	DateTime	NA
VO2	Average VO2 or oxygen consumption (in mL/min) over measurement period	Float	NA
Time2	Hour of measurement	Integer	NA
Temperature	Temperature of the chamber in degrees Celsius, averaged over the time of the measurement	Float	NA
Torpid_not	Category of measurement: whether normothermic, torpid, entering torpor, or in the rewarming phase	Character	NA = measurement was excluded from plotting and analyses; Normo = bird was normothermic; Entry = Bird was entering torpor, so value was not a stable one; Torpid = bird was in torpor; Rewarm = bird was rewarming, so value was not a stable one.