# ECOLOGY, ENERGETICS AND THERMAL BIOLOGY OF SUGAR GLIDERS

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# ABSTRACT

*Petaurus breviceps* inhabit tropical to cool-temperate regions within Australia and New Guinea. Despite their small body size (115-160 g) populations persist even in areas, such as the New England region, where ambient temperature ($T_a$) frequently falls below 0°C over winter. Small mammals encounter a variety of energetic stresses at low $T_a$ as a result of high thermal conductance requiring high metabolic rates (MR) for normothermic thermoregulation. Additionally insectivorous and nectarivorous species, such as sugar gliders, are confronted with seasonal reductions to food resources over winter. In order to survive and reproduce under these conditions, sugar gliders must employ a variety of behavioural and physiological strategies that include huddling and daily torpor. Although these strategies appear pivotal to their survival, almost all available information on this species is derived from captive animals and little is known on the seasonal adjustments of wild sugar gliders in terms of their thermal biology and behaviour. Moreover, little is known about the extent to which these adjustments are governed by reduced food availability and/or detrimental environmental conditions.

I used temperature telemetry to measure the body temperature ($T_b$) and activity of 33 sugar gliders at two study areas over 3.5 years (late-autumn to mid-summer; May 2002–September 2004). Field MRs (FMR) of six gliders were also measured using doubly labelled water techniques. I also performed a food-supplementation experiment in order to quantify for the first time the effect that food *ad libitum* (food-supplemented site) has on the nature of energy saving strategies and frequency of torpor use in free-ranging gliders when compared with gliders under natural seasonal food restrictions (non-supplemented site). In addition, I carried out laboratory experiments using open-flow respirometry to quantify energy expenditure and $T_b$ fluctuations of gliders under simulated environmental conditions. These included measurements of MR of single gliders, 2 and 6 huddling gliders, single gliders in a simulated nest and "wet gliders" at a variety of $T_a$s (6–27°C) below the thermoneutral zone.

In the field, sugar gliders used a variety of ecological, behavioural and physiological strategies that included huddling with conspecifics in a well-insulated nest hollow and adopting a spherical shape such that thermal conductance was reduced. In the laboratory, gliders huddling with just one other individual were able to reduce their resting MR (RMR) by 24-31% and shift the lower critical limit ($T_{LC}$) of their thermoneutral zone down 2.5°C relative to single gliders resting at $T_a$=10-20°C. Six gliders huddling together were able to reduce RMR by ~40% and shift $T_{LC}$ down by ~15°C. Similarly, single gliders in a simulated nest were able to reduce MR by 10% relative to single gliders without a nest. Conversely, "wet gliders" had a RMR almost

double that of dry gliders at 16°C. FMRs of gliders were ~3.8 times that of basal MR (BMR), with FMR increasing in response to both increased duration of activity and reduced $T_a$. Sugar gliders also reduced activity in response to adverse environmental conditions such as rainfall and low $T_a$ that make remaining active/foraging too energetically expensive. Other energy-conservation strategies included reducing normothermic resting $T_b$ during the diurnal rest-phase, decreased activity and the use of daily torpor in order to make more substantial reductions in MR should adverse environmental conditions persistently restrict foraging.

The type of energy saving strategies employed by gliders differed among individuals and between the sexes, indicating that gliders are able to respond flexibly and immediately to both short-term and long-term environmental stresses. Female gliders typically reduced activity in winter, whereas male gliders increased activity. This was likely the result of differing energetic expenditure between the sexes as a consequence of reproductive expenses and body size. In general, sugar gliders used torpor relatively infrequently, with torpor used on 5.3% of animal nights (N=1846, n=16). Female gliders at both sites used torpor more frequently than male gliders. Torpor was apparently used in response to low resource availability and low $T_a$ and/or rainfall at which times foraging was likely either restricted or too energetically expensive. In the laboratory, gliders entered torpor only three times. The lowest minimum torpor $T_b$ was 13.0°C at which time a steady state $\dot{V}O_2$ of 0.17 ml $O_2$ $g^{-1}h^{-1}$ was recorded at $T_a$=8.9°C. This represented a saving of approximately 75% on BMR.

Gliders apparently faced some degree of energetic shortfall as a result of food restrictions over winter. Food-supplementation affected the type of energy saving strategies employed by gliders, with food supplemented gliders using torpor less frequently (2.9% of 862 animal nights, n=16) than gliders at the non-supplemented site. However, torpor still occurred, and at both sites was predominantly used by female gliders. Food supplementation also did not abolish the effect of climatic conditions upon the activity patterns of sugar gliders, with both male and female gliders typically reducing the time spent active at low $T_a$ and when it was raining. Thus, energy saving strategies, including torpor, are a function of both food availability and adverse environmental conditions that make foraging too energetically expensive.

# DECLARATION

I certify that the substance of this thesis has not already been submitted for any degree and is not currently being submitted for any other degree or qualification.

I certify that any help received in preparing this thesis, and all sources used, have been acknowledged in this thesis.

[redacted]

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# LIST OF ABBREVIATIONS

| | |
|---|---|
| ADMR | Average daily metabolic rate |
| AMR | Active metabolic rate |
| ANCOVA | Analysis of covariance |
| ANOVA | Analysis of variance |
| ATP | Adenosine triphosphate |
| BAT | Brown adipose tissue |
| BMR | Basal metabolic rate |
| DEE | Daily energy expenditure |
| FMR | Field metabolic rate |
| Imbota NR | Imbota Nature Reserve |
| $L_{LT}$ | Lower lethal limit |
| LSR | Long Swamp Road |
| MR | Metabolic rate |
| REM | Rapid eye-movement |
| RMR | Resting metabolic rate |
| SDA | Specific dynamic action |
| $T_a$ | Ambient temperature |
| $T_b$ | Body temperature |
| $T_{holl}$ | Nest hollow $T_a$ |
| $T_{LC}$ | Lower critical limit |
| TMR | Torpor MR |
| TNZ | Thermoneutral zone |
| $T_{set}$ | Set point $T_b$ |
| $T_{UC}$ | Upper critical limit |
| $U_{LT}$ | Upper lethal limit |
| $\dot{V}O_2$ | Rate of oxygen consumption |