Animal behaviour

Tree-hugging koalas demonstrate a novel thermoregulatory mechanism for arboreal mammals

Natalie J. Briscoe1,†, Kathrine A. Handasyde1, Stephen R. Griffiths2, Warren P. Porter3, Andrew Krockenberger4 and Michael R. Kearney1

1Department of Zoology, University of Melbourne, Melbourne, Victoria, Australia
2Department of Zoology, La Trobe University, Bundoora, Victoria, Australia
3Department of Zoology, University of Wisconsin, Madison, WI, USA
4School of Marine and Tropical Biology, James Cook University, Cairns, Australia

How climate impacts organisms depends not only on their physiology, but also whether they can buffer themselves against climate variability via their behaviour. One of the way species can withstand hot temperatures is by seeking out cool microclimates, but only if their habitat provides such refugia. Here, we describe a novel thermoregulatory strategy in an arboreal mammal, the koala Phascolarctos cinereus. During hot weather, koalas enhanced conductive heat loss by seeking out and resting against tree trunks that were substantially cooler than ambient air temperature. Using a biophysical model of heat exchange, we show that this behaviour greatly reduces the amount of heat that must be lost via evaporative cooling, potentially increasing koala survival during extreme heat events. While it has long been known that internal temperatures of trees differ from ambient air temperatures, the relevance of this for arboreal and semi-arboreal mammals has not previously been explored. Our results highlight the important role of tree trunks as aboveground ‘heat sinks’, providing cool local microenvironments not only for koalas, but also for all tree-dwelling species.

1. Introduction

During extreme heat events, terrestrial endotherms must avoid gaining excessive heat from their environment, while simultaneously losing the heat produced by their own metabolism [1]. Low water availability or high humidity can further compound this problem by constraining the use of evaporative cooling, which is the primary method of heat loss in many endothermic species [2,3]. Behavioural thermoregulation—selecting microclimates or adopting postures or orientations that aid with the regulation of body temperature—has been cited as a key strategy that can buffer animals against future climate change [4–6]. However, use of behavioural thermoregulation may be constrained by the availability of suitable microclimates or associated costs such as lost foraging time or increased predation risk [7,8]. With extreme heat events predicted to become more severe and frequent under anthropogenic climate change [9], a thorough understanding of how organisms regulate their exposure to extreme conditions at the microclimate scale is crucial if we are to predict their performance under future climate change and protect habitats that provide suitable refugia [10,11].

We investigated behavioural thermoregulation in a broadly distributed arboreal mammal, the koala (Phascolarctos cinereus). Koalas do not seek shelter in dens and can suffer high mortality during extreme heat events, which often coincide with periods of low rainfall [12]. When exposed to air temperatures above 25–30°C in the laboratory, koalas maintain a relatively constant body temperature by greatly increasing evaporative water loss [13]. In the wild,
however, koalas rarely drink and during dry periods may not have access to free water (e.g. dew on leaves)—potentially restricting this species’ capacity to sustain high levels of evaporative cooling [14]. We therefore predicted that in the wild koalas would use behavioural adjustments to minimize their reliance on evaporative cooling. To investigate this, we tested whether koalas altered their behaviour and microhabitat use during hot weather. We then used a biophysical model of heat exchange to predict heat loss requirements of koalas adopting different behavioural strategies.

2. Methods

(a) Behaviour and microclimate data

Koalas (n = 37) in southeastern Australia (38°20' S, 145°22' E) fitted with radio collars (Sirtrack, New Zealand) were radio-tracked during the day in both winter (June–August 2009) and summer (December–March 2010 and 2011). Behavioural observations (posture, activity, height and location in the tree) and tree species were recorded before microclimatic data were measured for 10 min as close as possible to the koala (less than 0.5 m) using a portable weather station (WeatherHawk, USA) mounted on an extendable pole. To measure available microclimatic data were recorded for 10 min as close as possible to the koala (less than 0.5 m) using a portable weather station (WeatherHawk, USA) mounted on an extendable pole. To measure available microclimates and tree species composition within the study site, a set of random GPS coordinates were generated (n = 319) and, at each point, microclimate and habitat data were collected from the closest tree (more than 1 m tall) at a randomly generated compass direction, height and distance from the trunk. Records were divided into ‘hot’ (air temperature > 30°C) and ‘mild’ (air temperature ≤ 25°C) weather, coinciding with temperatures at which koalas greatly increase the use of evaporative cooling in the laboratory [13]. Additional behavioural data were collected by walking a 600 m long × 50 m wide transect within the study site and recording posture and location in the tree of all observed individuals (n = 130) during hot and mild weather.

(b) Tree trunk temperatures

Data on tree trunk temperatures during hot weather were collected during hot weather. Animals adopted postures with higher surface area exposed (Fisher’s exact test: p < 0.001, n = 223), were more frequently observed with all limbs outstretched and oriented themselves so that they appeared to be hugging the trunks or large lower branches of trees (figure 2a). Consistent with this, koalas were observed sitting on the main trunks of trees much more frequently during hot weather (65%) than in mild weather (30%; \( \chi^2 = 25.85, p < 0.001, n = 223 \)) and were also lower in the tree, with koala height negatively related to air temperature (F1,110 = 22.81, p < 0.001). Tree use also differed between hot and mild weather: koalas significantly increased their use of A. mearnsii from 5% in mild (air temperature ≤ 25°C) conditions to 29% during hot weather (Fisher’s exact test: p = 0.009, odds ratio: 7.95).

Air temperature, humidity and wind speed at sites occupied by koalas did not differ from available microclimates in either hot or mild weather (all p-values > 0.41). Microclimates selected by koalas did, however, have lower solar radiation in hot weather (F1,35 = 2.174, p = 0.046, mean difference: 111 W m\(^{-2}\)), but solar radiation in microclimates used by koalas showed no relationship with height or location in the tree, and was not lower in A. mearnsii trees (although it

(c) Koala heat loss requirements

To further assess whether differences in tree trunk temperatures were likely to be driving koala behaviour patterns, we used an analytical model of heat exchange for an ellipsoid furred endotherm [15] to predict potential heat loss via conduction to tree trunks. This model predicts metabolic rate and required heat loss of an endotherm based on a specified set of organism properties and environmental conditions. The model was modified to include conductive heat exchange based on the equation for conductive heat exchange of a flat plate:

\[
q_{\text{cond}} = \frac{kA(T_1 - T_2)}{d},
\]

where \( k \) is the thermal conductivity of compressed ventral fur, \( A \) is the surface area in contact with the trunk, \( T_1 \) and \( T_2 \) are skin and trunk surface temperatures, respectively and \( d \) is the depth of compressed ventral fur (see the electronic supplementary material, tables S1 and S2).

3. Results

Koala posture during the day varied between hot and mild weather (figure 1). During hot weather, animals adopted postures with higher surface area exposed (Fisher’s exact test: p < 0.001, n = 223), were more frequently observed with all limbs outstretched and oriented themselves so that they appeared to be hugging the trunks or large lower branches of trees (figure 2a). Consistent with this, koalas were observed sitting on the main trunks of trees much more frequently during hot weather (65%) than in mild weather (30%; \( \chi^2 = 25.85, p < 0.001, n = 223 \)) and were also lower in the tree, with koala height negatively related to air temperature (F1,110 = 22.81, p < 0.001). Tree use also differed between hot and mild weather: koalas significantly increased their use of A. mearnsii from 5% in mild (air temperature ≤ 25°C) conditions to 29% during hot weather (Fisher’s exact test: p = 0.009, odds ratio: 7.95).

Air temperature, humidity and wind speed at sites occupied by koalas did not differ from available microclimates in either hot or mild weather (all p-values > 0.41). Microclimates selected by koalas did, however, have lower solar radiation in hot weather (F1,35 = 2.174, p = 0.046, mean difference: 111 W m\(^{-2}\)), but solar radiation in microclimates used by koalas showed no relationship with height or location in the tree, and was not lower in A. mearnsii trees (although it
was lower in *E. obliqua* and non-*Eucalyptus* species other than *A. mearnsii*; electronic supplementary material, table S3).

By contrast, tree temperature profiles showed strong congruence with observed koala behaviour patterns. During hot weather, average tree surface temperatures of the four dominant tree species at the site were significantly lower than local air temperatures ($t_{1,18} = -8.1544, p < 0.001$). Relative to air temperature, surface temperatures of the base and lower trunk were significantly cooler than the branches and canopy, and the magnitude of these differences varied between tree species ($F_{3,15} = 1.863, p = 0.179$; region $F_{3,45} = 95.494, p < 0.001$; species × region $F_{9,45} = 8.996, p < 0.001$). The coolest surfaces recorded belonged to the non-food tree species, *A. mearnsii* (figure 2b), which was more frequently used during hot weather. This species had base and mid-trunk temperatures that were up to 8.9°C (average 6.7°C) and 6.7°C (average 5.1°C) cooler than air temperature, respectively. By contrast, average base and mid-trunk surface temperatures of *E. obliqua* were just 1.87°C and 1.46°C cooler than air temperature. Average branch and canopy temperatures of all species were within 1.4°C of air temperature (figure 2b).

(a) Koala heat loss requirements

Predicted conductive heat lost to tree trunks during hot weather was substantial, with simulations indicating that this behaviour could reduce or even prevent the need for evaporative cooling (figure 2c and electronic supplementary material, table S1). For example, an 11.3 kg male koala sitting in full shade and experiencing an air temperature of 35°C and
wind speed of 0.1 m s$^{-1}$) would need to lose 10.33 W of heat to maintain a constant body temperature. Our simulations indicate that conductive heat loss to a cool trunk could account for 68% (7.07 W) of this required heat loss, which would otherwise primarily occur via evaporative cooling. Over the course of a typical hot day in southeastern Australia, required evaporative heat loss for a tree-hugging koala in an A. mearnsii tree was predicted to be less than half that of an individual not adopting this thermoregulatory strategy (figure 2c).

4. Discussion

The ability of an organism to behaviourally thermoregulate is dependent on the availability and spatial arrangement of microclimates within their environment [4,5]. Many terrestrial species can exploit cooler, more stable, subterranean environments during hot environmental conditions [16] or lose heat conductively to cool ground surfaces [17]. Animals restricted to the arboreal environment cannot exploit these thermoregulatory options—however, our study reveals, for the first time, that analogous cool microclimates can be available to these species in the form of cool tree trunks. For koalas, tree-hugging behaviour greatly reduced predicted heat loss requirements, and water savings from this behaviour could be critical for the survival of this species during heat waves when water availability is limited [14], or under high humidity when evaporative cooling is inefficient [2].

Our results are consistent with, and may help explain, previous studies of koalas in more northern populations that found seasonal [18] and weather-dependent differences in tree use, with koalas using non-food trees more frequently during hot days [6,19]. Combined, these results emphasize the importance of behavioural thermoregulation for koalas [6] and highlight that trees (including non-food trees) that provide cool tree trunks or dense shade are an important component of habitat quality for this species.

Our results demonstrate that tree trunks can provide cool microclimates for arboreal animals during extreme heat; however, there was also considerable variation in trunk temperatures both within individual trees and across species. Like leaf temperatures, tree trunk temperatures are likely to be the result of complex heat exchange processes [20], including heat exchange between tree surfaces and the external environment, thermal inertia and cooling owing to water flow within the trunk [21,22]. While plant physiologists have long monitored cambium temperatures [22], a greater understanding of how plant species traits and local factors interact to drive tree surface temperatures during hot weather—and how these are exploited by animals—is needed. Cool tree trunks are likely to provide important microhabitat for a broad range of tree-dwelling species, including primates, leopards, birds and invertebrates during hot weather, and should be considered when assessing habitat suitability under current and future climates [10].

Acknowledgements. We thank J. Larson for conducting measurements of fur conductivity and the Arthur Rylah Institute for Environmental Research (DEPI) for providing access to the thermal camera.

Data accessibility. Spreadsheet model of heat exchange for an ellipsoid furred endotherm (modified for koalas) uploaded as the electronic supplementary material. Koala behaviour, microclimate and tree temperature data uploaded to Dryad Digital Repository: doi:10.5061/dryad.49j7t.

Funding statement. This research was supported by a Holsworth Wildlife Research Endowment to N.J.B. and an Australian Research Council linkage grant to M.R.K. (LP0989537) and was conducted with AEC approval (University of Melbourne) and permits from the Department of Environment and Primary Industries, Victoria.

References


