

WATER TURNOVER AND THE NORTHERN RANGE OF THE KOALA (*PHASCOLARCTOS CINEREUS*)

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CURRENTLY, koalas in their northern range are experiencing an extended dry period. If, as proposed by Ellis and co-workers (1995), koalas select summer time browse on the basis of leaf moisture, then drought affected trees may become unsuitable. Examining the variables affecting water balance for the koala should provide insight into the possible effects of climate change on the distribution of this species.

The water turnover of all three sub-species of koalas has been studied in a range of habitats and seasons (Eberhard 1972; Degabriele 1977; Degabriele et al. 1978; Nagy and Martin 1985; Krockenberger 1993; Ellis et al. 1995). At Springsure, a sub-humid region in central Queensland (24° 07' S 148° 05' E), water turnover of koalas (*P. c. adustus*) was higher in summer (59.9 mL kg^{-0.8} day⁻¹ or 72.8 mL kg^{-0.71} day⁻¹) than winter (50.8 mL kg^{-0.8} day⁻¹ or 61.1 mL kg^{-0.71} day⁻¹) and it was postulated that this may have been due to increased evaporative water loss during summer (Ellis et al. 1995). The rate of water turnover for koalas between seasons positively correlated with the moisture content of selected trees in that study, suggesting that browse choice was driven by water requirements in summer but energy demands in winter. The authors postulated that the amount of browse consumed was dictated by energy demands and the water intake was incidental and may have been excess to requirements.

St Bees Island, a wet tropical island in central Queensland (20° 55' S 149° 26' E), offered us the opportunity to replicate the Springsure study using the same sub-species at sites of similar latitude but with contrasting water availability profiles. Water turnover was determined during winter (July 2001) and summer

(February 2002) to enable comparison with the study at Springsure. We examined the relationship between water turnover rates (WTR) and browse moisture (percentage water) and compared the effect of climatic variation, especially relative humidity in summer, on the water turnover of the koala.

Historically, St Bees Island receives substantially higher rainfall than Springsure in most months and the coastal islands experience milder temperatures than Springsure. During our study, mean night-time temperatures and relative humidity (9am) at St Bees Island were higher than Springsure (Table 1).

Water turnover rates were determined using the isotopically labeled water method (Lifson et al. 1955; Nagy & Peterson 1988; Ellis & Carrick 1992). Faecal pellet analysis (Ellis et al. 1999) revealed that *Eucalyptus tereticornis* represented more than 90% of the diet of koalas on St Bees Island (*unpub data*). Leaves of *E. tereticornis* were collected during the isotope dilution periods and analysed for moisture content according to the method of Melzer (1994).

To facilitate comparisons with the previous study at Springsure (Ellis et al. 1995), six adult male koalas were treated with tritium during July 2001. Five females were also treated to allow gender comparisons. During February 2002, few animals could be located within a reasonable time (two consecutive days were used for the injection procedure) and in a suitable area for catching and processing, due to extreme weather conditions. Hence, six females (one with a very small pouch young) and only two males were sampled. This also included three sub-adults; one male and two females. While

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Season Site	R e l a t i v e Humidity 9am	Temperature		Browse Moisture
		Min °C	Max °C	(% ± SE)
Winter				
St Bees	63%	16	22	56.6±0.5
Springsure	55%	1	23	46.6±1.5
Summer				
St Bees	74%	26	33	51.4±1.0
Springsure	56%	19	33	61.7±3.7

Table 1. Climatic conditions and browse moisture content during tritium dilution periods for koalas at St Bees Island and Springsure, central Queensland.

not affecting the average water turnover, inclusion of these sub-adults affected average weights (Table 2). Comparison of the average weight of adult animals only (6.3 ± 0.4 kg, St Bees, summer) showed no significant difference between the two sites in either season.

Water turnover of koalas on St Bees Island (Table 2) was higher during summer than winter ($t_{17}=4.28$, $P < 0.001$). There was no significant effect of gender

although the water turnover of females tended to be higher than males. During summer, water turnover of koalas was significantly greater at St Bees Island than Springsure ($t_{12}=4.48$, $P < 0.001$). There was no significant difference in water turnover between the two sites during winter ($t_{15}=1.65$, $P = 0.12$), although the average at St Bees Island was 16% greater, which was consistent with the comparatively higher browse moisture content recorded concurrently. During winter, sufficient males

Koala	Sex	Age class	Jul-01		Feb-02	
			Wt	WTR (mL kg ^{-0.71} day ⁻¹)	Wt	WTR (mL kg ^{-0.71} day ⁻¹)
A0	m	adult	8.5	81.9	7.4	82.4
A1	m	adult	9.6	69.1		
C1	m	adult	6.9	61.8		
H1	m	adult	8.1	51.5		
L0	m	adult	5.1	74.6		
M0	m	adult	5.9	60.9		
T2	m	sub adult			2.1	90.3
D1	f	adult	6.6	86.6	6.4	109.7
E1	f	adult	7.5	81.3	6.5	106.5
F1	f	sub adult			3.0	89.8
I1	f	adult	6.8	91.7		
J0	f	adult			6.4	109.8
J1	f	adult	3.9	58.4		
K0	f	adult	7.0	64.0		
N1	f	sub adult			2.9	85.3
R2	f	adult			4.7	90.7
average			6.9	71.1	4.9	95.6
n			11	11	8	8
SE			0.5	4.1	0.8	4.2

Table 2. Water turnover (WTR ± SE) of koalas at St Bees Island, central Queensland.

were examined at St Bees Island for comparison with Springsure. When males only were compared the result was unchanged; there was no significant difference in water turnover between St Bees Island and Springsure ($t_{10}=0.94$, $P=0.37$).

On St Bees Island, browse moisture content during winter was significantly higher than summer ($t_{44}=4.5$; $P<0.001$). Comparison of 95% confidence intervals indicates that there were significant differences between browse moisture on St Bees Island and Springsure during both seasons. Browse moisture on St Bees Island was higher than at Springsure in winter, but lower in summer (Table 1).

It is possible to determine the ratio of energy requirements at St Bees Island compared to Springsure by considering the mass of browse and dry matter intake. Under these conditions the observed water turnover of koalas at St Bees in winter could occur if the koalas required only 74% of the energy used by their Springsure counterparts. Springsure experiences colder nights than St Bees Island (Table 1). During the sampling period the average minimum temperature at Springsure was only 1°C (Ellis *et al.* 1995) whereas minimum island temperatures averaged 16°C (Bureau of Meteorology 2005). The thermoneutral zone for koalas has been estimated at 14.5°C to 24.5°C and at 4.6°C, heat production almost doubles (Degabriele & Dawson 1979). Therefore, during winter, koalas at Springsure could be predicted to face increased metabolic demand to maintain body temperature whereas at St Bees Island overnight temperatures were within the thermoneutral zone. Our results for water turnover and leaf moisture suggest that koalas at St Bees Island may have had lower energy requirements, but the higher leaf moisture of their diet could account for the higher observed water turnover. Small changes in the leaf moisture of browse actually eaten could confound this component of the study if it differed from our measured values of available browse. However, based on our results, it appears that in winter, water turnover of koalas was dictated by the incidental water intake in their browse, which was consumed on the basis of energy requirements. This supports the hypothesis of Ellis and co-workers (1995).

During summer, day-time temperatures were similar at both sites (Table 1) so would contribute equally to evaporative water demand. However, night temperatures were considerably higher at St Bees Island (26°C) compared to Springsure (19°C) and this coincides with the period of maximum activity for koalas (Melzer 1994; Logan & Sanson 2002). In a separate study of the metabolism and heat balance of captive koalas, panting increased by 56% and evaporative water loss increased by 28% as ambient temperatures increased from 20°C to

25°C (Degabriele & Dawson 1979). As relative humidity increases, respiratory evaporative water loss is less efficient for cooling due to the extra metabolic cost of panting. Therefore, in summer, koalas at St Bees Island could be expected to use relatively more water than their drier-climate counterparts for cooling, compounding the effect of the higher night time temperatures at the island and increasing the water turnover rate.

Ellis and co-workers (1995) postulated that water turnover would be positively correlated with browse moisture; using their averaged values we derived an equation ($WTR = 0.77 \% \text{ water} + 25.0$) which closely predicted the measured water turnover for koalas in winter at St Bees (predicted 68.9 mL kg^{-0.71} day⁻¹; recorded 71.1 mL kg^{-0.71} day⁻¹). On this basis, our results support their hypothesis that water turnover is dictated by the moisture of browse, which is selected to meet energy, rather than water, demands. However, our summer time results deviated significantly from the prediction of this equation. During summer the predicted value at St Bees was 64.8 mL kg^{-0.71} day⁻¹; the actual rate was 95.6 mL kg^{-0.71} day⁻¹, indicating that the koalas were consuming significantly more browse, or somehow obtaining free water. Water turnover was higher than would be predicted based on metabolic demands, but also well in excess of the prediction derived from the Springsure experiments. This departure from a condition where ample water is available in the diet may indicate that the high water requirements of koalas living in regions of high overnight temperature and humidity may be the limiting factor to its geographical range.

Our prediction is that the capacity for the koala to thermoregulate in conditions of extreme heat will depend on the availability of water as leaf moisture or free water, and the efficiency of respiratory evaporative water loss for cooling. Koalas occur in areas that regularly experience day time ambient temperatures greater than 40°C, but are naturally absent from coastal areas north of latitude 18°S (Thompson 2006). The higher night time temperature and relative humidity of the coastal regions, rather than the maximum day time temperature, appears to be a limiting factor for the natural populations. Comparing the distribution of the koala to relative humidity (Bureau of Meteorology 2005) reveals that the bioregional delineation of the koala's range corresponds closely to regions experiencing an average 9am relative humidity of less than 80% in February. Based on our results across a narrow latitudinal range, we hypothesise that the northern coastal distribution of the koala may be primarily limited by the physiological limitations of respiratory evaporative water loss as a cooling mechanism.

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