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Body temperatures of an arboreal monitor lizard, *Varanus tristis* (Squamata: Varanidae), during the breeding season

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Based on a sample of cloacal body temperatures taken from four species of varanids in the semi-arid regions of Western Australia, Pianka (1994) reported *Varanus eremius* and *V. gouldii* to be good thermoregulators, while arboreal *V. caudolineatus* and *V. tristis* did not regulate as well. In addition, the mean body temperature for *V. tristis* (34.8°C) was significantly lower than that for *V. eremius* (37.3°C), *V. gouldii* (37.7°C) and *V. caudolineatus* (37.8°C). Pianka's (1994) temperature recordings were taken on live varanids collected opportunistically in the field.

Our objective was to determine if the body temperature of *V. tristis* in the western Great Victoria Desert during the part of the day (1100 to 1800 h) when the lizards are active are generally lower than body temperatures reported for other varanids.

Methods. The study site in the Great Victoria Desert (28°12′S, 123°35′E) is a complex mosaic of sandridges and interdunal flats with a vegetation of spinifex (*Triodia basedowii*), Marble Gum trees (*Eucalyptus gongylocarpa*), Mallee trees (*Eucalyptus concinna*), Acacia (*Acacia aneura* and others) and other small bushes and grasses.

Seven *V. tristis tristis* were captured after following their tracks to a retreat in a hollow log or hollow tree branch between 11 and 29 September, 1995. After determining sex (everting hemipenes), weighing and measuring [snout-to-vent length (SVL) and total length (TL)] a miniature radio-transmitter (7 g, approximately 21 mm × 12 mm × 5 mm; less than 5% of body mass) from Holohil Systems, Canada was surgically inserted into its abdominal cavity. Transmitters were removed at the conclusion of the experiment using a similar procedure. Lizards were held overnight and released at their place of capture the next day. Surgical procedures and transmitters seemed to have little impact on lizard behaviour, as movement or activity patterns of *V. tristis* during the first seven days after release did not differ from those over the subsequent seven days. One *V. tristis* subsequently laid ten eggs while she contained an internal transmitter, nine of which hatched.

Temperature sensitive transmitters issued a sound pulse, the period between pulses decreasing with increased body temperature. The interval between beeps was recorded to the nearest 0.01 second (using a stopwatch) numerous times throughout the day from 11 September until 8 November, 1995. Collection of data for most lizards was terminated before 8 November when battery power for transmitters became insufficient to detect the signal from a distance. This did not affect the pulse rate for temperature sensitive transmitters but only the strength of the signal. A Biotelemetry receiver (RX3) with a 3EY directional antenna operating in the 150-151.5 MHz band was used to determine body temperatures at multiple times during the day.

Before implantation, temperature sensitive transmitters were calibrated in a water bath at seven temperatures between 10 and 40°C. The curvilinear relationship between temperature and time between pulses was determined by fitting a quadratic equation to the data. Visual inspection of the fitted line indicated no value deviated by more than 1°C from the line.

Results. One *Varanus tristis* could not be located using its transmitter after 5 days, so data for this lizard were excluded from all analyses. Four hundred and fifty-three separate body temperature (T_b) observations were taken for the remaining six *V. tristis* (table 1). Mean field maximum T_b for six *V. tristis* was 40.0°C ($\pm\ s$ 1.75, $n = 6$). To establish the overall pattern of thermoregulation, mean T_b for six *V. tristis* were calculated for each h between 0600 and 2100 h and are plotted in figure 1. Mean T_b between 1100 and 1800 h, the activity period, was 33.2°C ($\pm\ s$ 4.27). Mean T_b ranged between 32 and 35°C when calculated for hourly periods between 1100 and 1800 h (fig. 1). Large standard deviations shown in figure 1 indicate a wide variation in T_b among days, and as the lizards' increase their T_b in the morning. The pattern of thermoregulation indicated that *V. tristis* have a relatively rapid increase in T_b after 0815 h which peaks about 1330 h.

Body temperatures of five *V. tristis* were recorded hourly between 0600 and 2000 h for a 'typical' day (4 October; minimum ambient temperature (T_a) of 12°C, maximum

Table 1. Sex, mass, snout-to-vent length, number of observations and maximum body temperature for *V. tristis*.

	Identification letter					
	B	D	E	F	G	H
Body mass (g)	265	220	280	218	300	343
SVL (mm)	272	252	276	250	274	288
Sex	m	f	m	f	m	f
Total number of days monitored	55	28	45	23	47	21
Total number of temperature observations	61	69	92	76	86	69
Mean T_b	30.1	28.1	29.3	27.9	27.9	26.5
Maximum T_b recorded	39.0	38.1	42.5	39.9	41.6	38.7

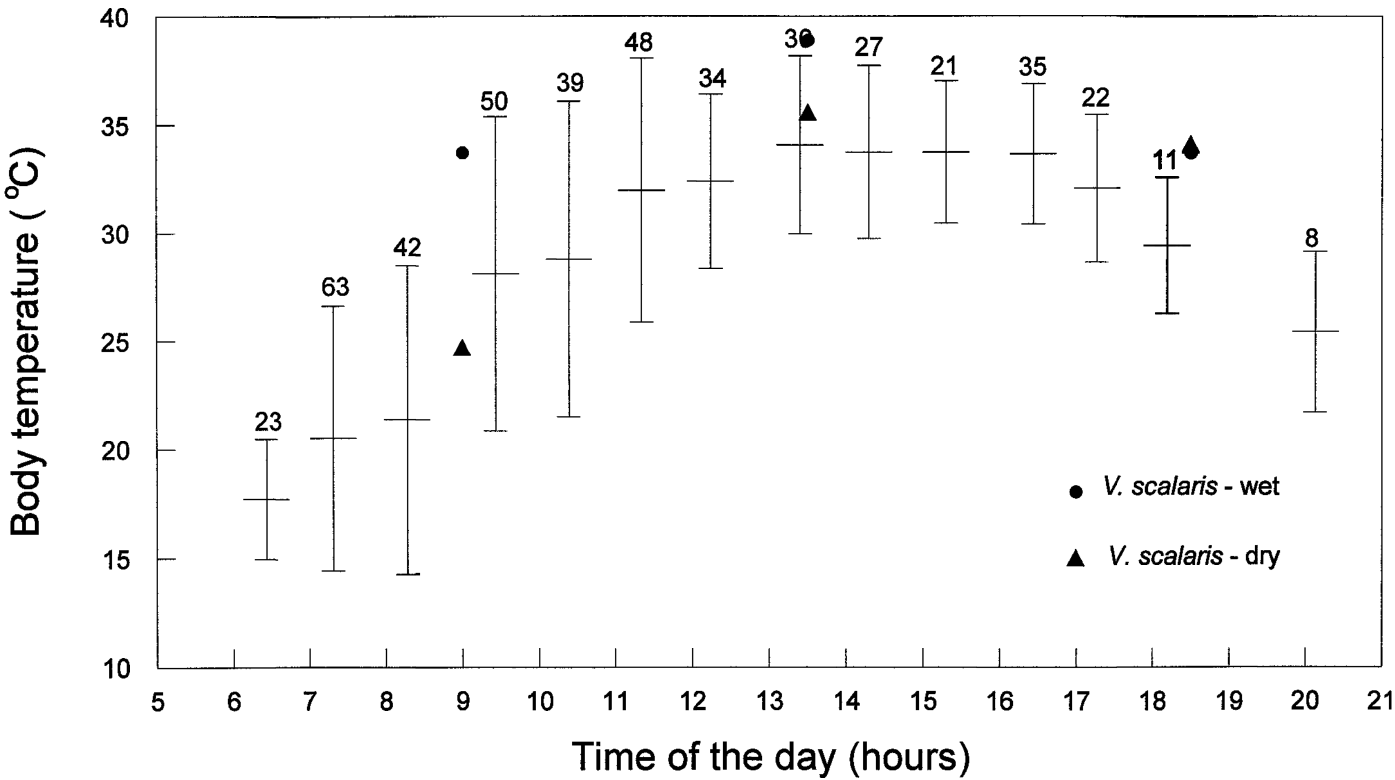

Figure 1. Mean body ($\pm 1s$) temperatures for six *V. tristis*, with number of observations each hour. Values plotted at the mean time for each hourly period. The dots are mean T_bs for *V. scalaris* during the wet and the triangles for the dry (Christian and Bedford, 1996).

T_a of 33°C, maximum wind speed 2.6 m sec^{-1} with minimal cloud cover; T_a conditions were recorded at Yamarna weather station approximately 8 km north east of the study site) in the middle of the study period. This example provides an indication of the extent of individual variation and individual concurrence with the overall pattern. There was no significant difference in the T_bs of the five *V. tristis* measured hourly (repeated measures ANOVA $F_{4,52} = 1.24$, $P = 0.304$) on 4 October. The greatest variation occurred during the late morning increase in T_b to a relatively constant T_b between 30 and 34°C (between 1215 and 1430 h) and again between 1430 and 1700 h after which T_bs again converged until about 1815 h. This variation in the morning probably reflects the time that each *V. tristis* emerged to bask.

Discussion. The highest T_b for six *V. tristis* ranged between 38.7 and 42.5°C with a mean of 40°C. Pianka (1994) reports unusually high maximum body temperatures of 44.2°C and 47.3°C for two *V. tristis*. Both of these temperatures are appreciably higher than the maximum recorded in this study. The critical thermal maximum for *V. tristis* is unknown. However, a body temperature of 47°C is close to the lethal limit for most lizards (Curry-Lindahl, 1979) and above that for *V. griseus* (43°C, Vernet et al., 1988), *V. olivaceus* (41.6-42.4°C, Auffenberg, 1988), *V. komodoensis* (42.7°C, Auffenberg, 1981) and *V. bengalensis* (42.3-44.7°C, Auffenberg, 1994). These high values might have resulted from forcing these two *V. tristis* into locations that increased their body temperature while they were being located or caught. A fleeing *V. tristis* will probably take temporary refuge anywhere to avoid being caught and may have moved to a position that increased its body temperature to levels that it would normally avoid.

Mean T_b between 1100 and 1800 h was 33.2°C. Christian and Bedford (1996) report pre-dawn T_b for the slightly-smaller, arboreal *V. scalaris* (from the tropics of northern Australia) in the wet season as 21.7°C and 18.5°C in the dry season; during the morning (0700-1100 h) the mean T_b was 33.7°C in the wet and 24.7°C in the dry; around midday (1100-1600 h) the mean T_b as 38.9°C in the wet and 35.6°C in the dry; and in the late afternoon (1600-2100 h) the mean T_b as 33.7°C in the wet and 34.1°C in the dry. These mean T_bs for *V. scalaris* are generally significantly higher than the comparable mean temperatures for the same time periods for *V. tristis* [in the morning (0700-1100 h, 24.3 ± 7.80°C, $t_{193} = 16.47$ for *V. scalaris* the wet season, $P < 0.05$), and around mid-day (1100-1600 h, 33.0 ± 4.71°C, $t_{159} = 15.88$ for *V. scalaris* the wet, $t_{159} = 7.01$ for the dry, $P < 0.05$, respectively), and in late afternoon (1600-2100 h, 31.6 ± 4.17°C, $t_{75} = 4.15$ for *V. scalaris* the wet, $t_{75} = 4.99$ for the dry, $P < 0.05$, respectively)] in the Great Victoria Desert during September to October (fig. 1). This would suggest the T_b of *V. tristis* when it was able to thermoregulate was generally lower than that for *V. scalaris* during their active periods.

Comparative body temperatures for other varanids are generally higher than those reported here for *V. tristis* (table 2) thus supporting Pianka's (1994) general statement that the active body temperature for *V. tristis* is lower than that for other varanids. Field active

Table 2. Field active body temperatures for varanids.

Species	T_b °C	Measurement	Source
V. bengalensis	34.5	Field active mean	Wikramanayake and Green, 1989
V. bengalensis	32.6	Field and captive active mean, (preferred foraging *Tb*)	Auffenberg, 1994
V. caudolineatus	37.8	Field active mean	Pianka, 1994
V. eremius	37.3	Field active mean	Pianka, 1994
V. giganteus	36.7	Field active mean	Pianka, 1994
V. giganteus	36.4	Field active mean, summer	Heger and Heger, 1993
V. gilleni	37.4	Field active mean	Pianka, 1994
V. gouldii	35.5	Field active mean	King, 1980
V. gouldii	37.1	Field active mean	Licht et al., 1966
V. gouldii	37.7	Field active mean	Pianka, 1994
V. gouldii	35.9	Midday mean, wet season	Christian and Weavers, 1996
V. griseus	36.1	Field active mean, summer	Vernet et al., 1988
V. griseus	32.1-38.4	Field active mean	Sokolov et al., 1975
V. komodoensis	35.5	Overall mean from 0600-1800 h	Wikramanake et al., 1993
V. komodoensis	32-40	Field active mean between 1000-1700 h	Auffenberg, 1981
V. mertensi	34.0	Midday mean, wet season	Christian and Weavers, 1996
V. olivaceus	31-32.2	Field active mean between 1100-1600 h	Auffenberg, 1988, from figure 5-11
V. panoptes	36.4	Midday mean, wet season	Christian and Weavers, 1996
V. rosenbergi	35.6	Field active mean	King, 1980
V. rosenbergi	36.3	Midday mean, summer	Christian and Weavers, 1996
V. s. salvator	30.4	Field active mean	Traeholt, 1995
V. salvator	29.9	Field active mean	Wikramanayake and Green, 1989
V. scalaris	38.9	Midday mean, wet season	Christian and Bedford, 1996
V. tristis	34.8	Field active mean	Pianka, 1994
V. tristis	33.2	Field active mean 1100-1800 h	This study
V. varius	35.5	Field active mean	Stebbins and Barwick, 1968

T_b for the semi-aquatic *V. mertensi* and *V. salvator* are generally lower than for terrestrial species, as are the field active T_b of *V. olivaceus* and *V. bengalensis.* These lower body temperatures probably are associated with their choice of habitat (Wikramanayake and Green, 1989). Whether the generally lower T_b for *V. tristis* compared with other terrestrial varanids reflects a physiological difference or a variation based on the season or how it uses its habitat is unknown. Christian and Weavers (1996) report significant differences within and between seasons in T_b among varanid species (*V. panoptes*, *V. gouldii* and *V. mertensi*) living in tropical northern Australia. *Varanus tristis* is a dark-bodied, widely-foraging, arboreal varanid from the subgenus *Odatria* that is found in a variety of habitats in the northern four-fifths of Australia. In the Great Victoria Desert, *V. tristis* have large activity areas, move almost in a direct line from tree to tree and seldom deviate to forage during the breeding season, are possibly ambush predators that change their perches regularly (Thompson et al., 1999). Before a conclusive statement can be made on their relative T_b, the field active T_b for *V. tristis* from other parts of the Australian continent should be examined.

Varanus tristis generally began increasing their T_b from when it was first recorded in the morning (from about 0600 h) probably as a result of conductive heat gain. A more rapid increase was generally evident after 0930 h, which was probably due to heat gain by radiation occurring when *V. tristis* bask on a tree limb. Small peaks in T_b at about 1100 h evident in 3 of 5 individuals monitored hourly on October 4 could correspond to the end of the initial basking activity often evident in varanids (King, 1980; King et al., 1989; Green et al., 1991). Comparative data for five individual *V. tristis* on 4 October, when ambient temperature at 0600 h was 19°C, at 0900 h was 25.5°C and the maximum was 33°C, suggest consistency among individuals in how *V. tristis* regulate their T_b during the breeding season.

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