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# Understanding the relationship between body temperature and activity patterns in the giant Solomon Island skink, *Corucia zebrata*, as a contribution to the effectiveness of captive breeding programmes

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**Abstract.** The behaviour and body temperatures of the Giant Solomon Islands skink, *Corucia zebrata*, have been observed in a semi-naturalistic enclosure. *Corucia zebrata* is a non-basker that thermoregulates by selecting microhabitats where operative temperatures enable body temperatures of around 30°C to be maintained. Body temperatures were significantly higher during sunny weather, but there was no significant difference in body temperature variance. Body temperatures were significantly lower than operative temperatures in open locations or dappled sunlight, but higher than operative temperatures in shaded locations. Coefficients of determination ( $r^2$ ) showed that lizard body temperatures had less association with operative temperatures during sunny weather. The frequency of activity was greater in sunny weather, but the distances travelled during locomotory activity were not significantly different between weather conditions. The lizards were observed less frequently at the upper levels of the canopy during sunny weather. Enclosure design for captive animals should reflect both thermal and structural diversity to enable target body temperatures and appropriate levels of activity to be achieved. Captive breeding programmes may be the only means left for conserving *C. zebrata*, and information on the relationship between activity and thermal biology is crucial for effective captive breeding programmes.

**Key words:** Activity patterns; conservation; *Corucia zebrata*; operative temperatures; thermal environment; thermoregulation.

## Introduction

The importance of body temperatures for a reptile to perform essential tasks is well known (Avery, 1982; Huey, 1982). The principal method employed, behav-

Journal thermoregulation, requires the expenditure of time, energy and water, and the need to regulate to specific temperatures may determine when and where reptiles are active, how much food they need and the amount of energy available for growth and reproduction. The implications are that an inability to thermoregulate behaviourally may impose serious constraints on husbandry programmes, particularly when the projected outcome is for reintroductions to natural habitat. Insight on the focal species requires knowledge of several key parameters. Critical are the body temperatures that optimise physiological performance and the way the animal interacts with operative temperatures to alter rates of heat exchange with the environment (Bakken, 1992). The relationship with operative temperatures is therefore crucial for providing insight into both behaviour and thermal biology, and although there is now a large database on reptilian thermoregulation in the literature, much of it concerns species from temperate or desert habitats (Avery, 1982); little attention has focused on species from tropical forest. However, there is a need for such information, for whilst many tropical reptiles experience comparatively little temperature variation and may be sensitive to temperature changes (Lillywhite and Gatten, 1995), others experience and require a greater variation in temperature than might be expected (Hertz, 1992).

It is particularly important that a species thermal profile is identified when it is under threat from extinction in its wild state; the Solomon Islands Skink (*Corucia zebrata*) falls into this category. It is a large (up to 1 kg) herbivorous arboreal lizard that inhabits large trees with extensive epiphytic growth in tropical forest (Parker, 1983), and is unusual for a lizard in that it has a prehensile tail to assist movement. In 1992, the species was listed on Appendix II of the Berne Convention, but its numbers in the wild have declined to such an extent since then that it is currently now subject for inclusion in Appendix I. The problems for *C. zebrata* relate to local hunting and the international pet trade especially in respect of the USA, where between 1992 and 1995 alone, 12,000 animals were exported by the trade (Hoover, 1998). Prior to this period, around 7500 animals were exported annually, again mainly to the USA (McCoy, 1980). These numbers are very likely a serious threat for wild populations since the animal is a slow breeder producing only one to two offspring every one to two years. These factors coupled to a limited geographical distribution (McCoy, 1980) and additional pressure from loss of natural forest habitat through logging and slash and burn farming practices suggests that, although wildlife conservation efforts would realistically be better directed at protection of natural habitats, captive breeding may now be increasingly necessary for the survival of *C. zebrata*, and detailed information on the species biology to underpin captive breeding is urgently needed.

There is, however, little published information on *C. zebrata* in this respect. Recently Harmon (2002) observed communal living habits, morphology and reproductive condition in 12 individuals from rain forest on Santa Isabel whilst Balsai (1995) has described general husbandry and breeding in captive animals. There are no data available on thermal biology or movement patterns. Our intentions here are to pro-

vide baseline information on thermoregulatory behaviour and body temperature levels derived from observations of *C. zebrata* in a simulated tropical forest subject to natural light through glass. We recognise that information from free-living animals provide the most accurate data for investigating thermoregulation, but tracking and relocating *C. zebrata* in tropical forests may be difficult and time consuming (Harmon, 2002). In naturalistic enclosures, these problems are minimized and have been recognised as a way of providing insight into reptilian thermoregulation under a range of conditions (Lee, 1996; Lee and Mills, 2000).

### Materials and methods

Data were recorded for approximately one day a week between September 2001 and September 2002 on a total of nine lizards: five adults, two of which were males, and four unsexed sub adults. The adults were wild caught two years previously and the sub adults born in captivity. The enclosure was 7.5 by 10 m horizontally and 3.2 m vertically, and was one of a series of animal units at the Taylor Hill Annexe of Huddersfield Technical College. The unit received natural light through glass with temperature controlled by thermostat, and an automatic sprinkler maintained the humidity level. Created in 1997 the unit had a mature growth of tropical vegetation consisting of low growing plants (i.e. *Rhoeo*, *Dracaena*, *Ixora* and *Asplenium* sp.) and species of medium height (i.e. *Hibiscus*, *Monstera* and *Ficus* sp.). The canopy plants were primarily *Jasminum*, *Passiflora*, *Cyperus*, *Allamanda* and *Psiguria* sp. The roof surface of the unit divided into 78 individual glass panes of which about 25 had significant plant cover thus reducing initial sunlight by about 30%. Lower vegetation further reduced passing light so that final sunlight reaching the floor was at most ca. 30%. The plant structure created a light effect ranging from deep shade and open sunny areas through to a mosaic of smaller patches of sunlight and shade.

Records were made of the location of the lizards vertically and horizontally in addition to their position in relation to sunlight (or bright light on overcast days) and their behaviour recorded. Behaviour was monitored continuously and the categories defined as: *basking*, lizards body in full sunlight; *partial basking*, a mosaic of sunlight and shade falling on the body; *shade*, positioned in an area where there was no sunlight. *Locomotory activity* is self-explanatory and defined as both the number of bursts of activity and approximate distances travelled during each movement, with the latter recorded in centimeters after the animal came to rest. The animal's location in the canopy was recorded against a vertical grid system based on three heights from the ground level. The vertical divided from the ground to 0.7 m (height 1), 0.7 to 2 m (height 2) and 2 to 3.2 m (height 3).

Body temperatures ( $n = 2859$ ) were measured at approximately every 10 min non-invasively with a Digitron OS 204 infrared detector that measures skin surface temperature (emissivity of reptiles = 0.95; Tracy, 1982). This instrument has a residual error of  $\pm 0.1^\circ\text{C}$ , but needs to be applied close to the lizard — at approximately 15 cm — to give an accurate reading. Use of this approach in

*C. zebrata* produced no apparent disturbance to our animals, in the sense that no additional or suppression of activity or behaviour appeared to have been a consequence of measurement. In general the differences between skin surface and cloacal temperatures can be described as a function of

$$T_b - T_{ss} = 0.776(T_{ss} - T_a) + T_a,$$

where  $T_b$  is body temperature,  $T_{ss}$  skin surface temperature and  $T_a$  air temperature (Alberts and Grant, 1997). The difference is approximately 2°C and the equation

$$T_b - T_{ss} = 0.00114x + 1.1195, \quad r^2 = 0.7$$

estimates the differences from body mass  $x$  in g (Meek, 1999, based on data in Alberts and Grant, 1997).

To test for thermoregulation, operative temperatures were recorded simultaneously with body temperatures during the summer months since this was the time of year when the enclosure experienced the greatest extremes of heat loads. Operative temperatures were measured using four water-filled black-painted copper cylinders (Bakken, 1992) that measured 16.5 cm in length, 5.5 cm in diameter and 1 mm thick, and which were slightly smaller than the adult lizards and slightly larger than the sub adults. They were placed in key locations of the habitat: — one in full sunlight at the top of the canopy where the highest operative temperatures were expected — defined here as  $T_{o(\text{open})}$ , two placed in dappled sunlight to record intermediate operative temperatures ( $T_{o(\text{dapple})}$ ) and one in full shade ( $T_{o(\text{shade})}$ ) to record the lowest operative temperatures. For direct comparisons with  $T_{o(\text{dapple})}$ , the nearest dappled sunlight model to the lizard was used. The models were measured with the same thermometer used for the lizards. It was assumed that the lizards could achieve any body temperature between these extremes by positioning themselves in the appropriate microhabitats, and could, for example, track operative temperatures in dappled sunlight by spending 50% of time in either sun or shade, or by being positioned half in sun and half in shade (Christian et al., 1983). The temperatures of these models represent the approximate potential heat exchange — radiation, convection and conduction — between lizards and the contemporary environment. An inherent characteristic of the size differences between the models and the lizards were that the larger adults would have expected to heated up more slowly and the sub adults rather quicker than the models, but models nevertheless give a more meaningful measurement of the thermal environment than air or substrate temperatures, and provide better insight into the temperatures at which a lizard would equilibrate if it made no thermoregulatory movements, postural or physiological adjustments (Bakken and Gates, 1975; Bakken, 1992). The type of model used to measure operative temperature has been the subject of debate (e.g., Shine and Kearney, 2001), but it would appear that model attributes are less critical than originally thought (Vitt and Sartorius, 1999; Shine and Kearney, 2001). Hollow-walled copper tubes have a low heat capacity and respond readily to changes in radiation levels, and have value in predicting the amounts of time operative temperatures exceed given thermal

thresholds. They have rather less value when predicting heating and cooling rates in reptiles because of differences in thermal time constants (Shine and Kearney, 2001).

### *Statistical analysis*

Statistical tests were applied to the means of body temperature of individual lizards and corresponding means of operative temperatures, activity and canopy heights. This approach ensured there was no pseudoreplication for these variables. Therefore the statistical comparisons are based on the means of nine lizards in total and paired means of corresponding variables. ANOVA, *t*-tests (paired or two-sample) were used for statistical comparison of the data set means at the 95% interval with non parametric Mann-Whitney tests applied to the equality of medians of activity and canopy location. All mean values are given with one standard deviation. This method of analysis, where repeated behaviour patterns are not treated as independent events, has been subject to criticism for underestimating the degrees of freedom and hence the possibility of inappropriately accepting the null hypothesis and committing a type II statistical error (Wilson and Dugatkin, 1996). However we used the above approach in preference to the method of treating each measurement as an independent event to avoid overestimating the degrees of freedom (Lombardi and Hurlbert, 1996).

To ascertain any relationship between body temperatures and operative temperatures, measurements of scale effects — the amount of variation of body temperature that can be explained by variation in operative temperatures — was determined from  $r^2$ . The adjusted  $r^2$  has been used which is less sensitive to  $n$ , i.e.  $r^2$  will not increase as a consequence of sample size alone.

## **Results**

### *Body temperatures*

The general range of body temperatures during overcast weather was from 21-39°C ( $n = 2162$ ) and in sunny weather from 24-40°C ( $n = 825$ ). Means and variances of individual lizard body temperatures have been calculated, and ANOVA applied to these subsets. Overcast weather body temperatures (grand mean =  $29.2 \pm 1.1^\circ\text{C}$ ) ( $\pm$  S.D.) were lower than sunny weather (grand mean  $30.5 \pm 1.4^\circ\text{C}$ ) with the difference significant,  $F_{1,16} = 4.45$ ,  $p = 0.05$ . Variances in body temperatures during cloudy weather (mean of individual variances =  $6.1 \pm 3.0^\circ\text{C}$ ) were smaller than when the weather was sunny (grand mean =  $8.0 \pm 3.9^\circ\text{C}$ ), but the difference was not significant  $F_{1,16} = 1.37$ ,  $p = 0.25$ .

### *Relationship with operative temperatures*

Summary statistics of operative temperatures are shown in table 1. As expected the highest operative temperatures were recorded for  $T_{o(\text{open})}$  followed by  $T_{o(\text{dapple})}$  and

**Table 1.** Summary statistics of general operative temperatures (°C) during sunny and overcast weather.

Overcast	Mean	Variance	Minimum	Maximum	<i>n</i>
$T_{o(\text{shade})}$	27.8	7.2	23	38	944
$T_{o(\text{dapple})}$	30.4	15.2	24	43	944
$T_{o(\text{open})}$	31.9	19.3	25	46	944
Sunny					
$T_{o(\text{shade})}$	28.8	7.3	25	40	826
$T_{o(\text{dapple})}$	35.8	16.8	30	49	826
$T_{o(\text{open})}$	36.1	5.3	32	45	826

**Table 2.** Comparisons of means and variances of general *C. zebrata* body temperatures with mean or variances of operative temperatures in open ( $T_{o(\text{open})}$ ), dappled ( $T_{o(\text{dapple})}$ ) and shaded ( $T_{o(\text{shade})}$ ) locations during either overcast or sunny weather using analysis of variance. The *F*-statistic and level of significance *p* indicate when mean or variances in body temperatures departed significantly from operative temperatures.

	$T_{o(\text{open})}$		$T_{o(\text{dapple})}$		$T_{o(\text{shade})}$	
	<i>F</i>	<i>p</i>	<i>F</i>	<i>p</i>	<i>F</i>	<i>p</i>
Means (overcast)	25.9	0.0001*	4.55	0.05*	9.8	0.006**
Means (sunny)	82.4	0.0001*	54.6	0.0001*	8.9	0.009**
Variances (overcast)	11.9	0.003*	5.4	0.03*	0.12	0.73 <sup>n.s.</sup>
Variances (sunny)	5.26	0.04**	11.73	0.003*	0.25	0.62 <sup>n.s.</sup>

\*, mean body temperatures or variances were significantly lower.

\*\*, significantly higher, than comparable operative temperatures.

No significant difference between means or variances is shown as *n.s.*

Degrees of freedom are (1, 16) in all tests.

$T_{o(\text{shade})}$ . This was the pattern either under overcast or sunny conditions although comparative operative temperatures were higher during sunny weather. Details of the differences between operative temperatures during summer are given in table 2, with mean lizard body temperatures simultaneously measured at this time, using analysis of variance. The results showed that lizard body temperatures were significantly lower than either  $T_{o(\text{open})}$  or  $T_{o(\text{dapple})}$ , but significantly higher than  $T_{o(\text{shade})}$  during either overcast or sunny weather. These results indicate maintenance of body temperatures within the thermal ranges of  $T_{o(\text{shade})}$  and  $T_{o(\text{dapple})}$  during all weather conditions.

#### *Variance in body temperature and operative temperature*

Using body temperature variance as a method of determining thermoregulatory precision (Huey and Slatkin, 1976) assumes that the lizards were regulating around a mean value. The method has been the subject of much discussion with some evidence that reptiles may regulate between lower and upper set points (Berk and Heath, 1975; Barber and Crawford, 1977). Variance in body temperature may however provide insight for predicting whether a reptile can achieve greater body

**Table 3.** Relationship between body temperatures and operative temperatures determined by coefficients of determination ( $r^2$ ) during sunny and overcast weather. The  $r^2$  values are thus shown as percentages of body temperatures that can be explained by any given group of operative temperatures and are based on  $r^2$  for individual lizards against corresponding operative temperatures. Each mean is derived from  $n = 9$  lizards. Mean  $r^2$  are given with standard deviations and ranges.

	$T_{o(\text{shade})}$		$T_{o(\text{dapple})}$		$T_{o(\text{open})}$	
	Mean	Range	Mean	Range	Mean	Range
Overcast	$69.9 \pm 10.0$	56.6-87.9	$63.8 \pm 18.2$	34.5-91.2	$61.4 \pm 22.3$	22.0-89.0
Sunny	$46.6 \pm 19.0$	12.0-67.6	$31.9 \pm 16.2$	7.8-53.6	$44.4 \pm 15.6$	21.9-66.2

temperature precision by restricting activity to microenvironments with limited thermal variance (Hertz and Huey, 1981). Comparisons using ANOVA are shown in table 2 of mean variances of body temperatures during the summer months that were directly comparable to corresponding mean variance in operative temperatures at the same period; the sample sizes for operative temperatures at this time are given in table 1. Results showed that body temperature variance was greater than operative temperatures only during sunny weather in relation to  $T_{o(\text{open})}$ ; all the other comparisons either showed agreement or that body temperature variances were significantly lower. These results suggest some degree of thermoregulatory precision in *C. zebrata*.

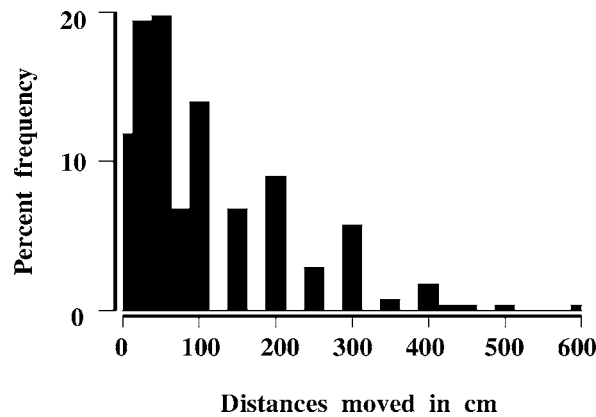
#### *Extent of tracking of body temperatures with operative temperatures*

Coefficients of determination ( $r^2$ ) have been employed to evaluate the extent of tracking of body temperatures with operative temperatures. The results are shown in table 3 and are based on the means of  $r^2$  for individual lizards and corresponding operative temperatures. Higher  $r^2$  values were found when the weather was overcast. Body temperatures tracked  $T_{o(\text{shade})}$  to a greater extent than other operative temperatures including during sunny weather. Paired  $t$ -tests indicated that overcast weather  $r^2$  values were significantly higher;  $T_{o(\text{shade})}$   $t = 3.25$ ,  $p = 0.01$ ,  $T_{o(\text{dapple})}$   $t = 3.86$ ,  $p = 0.005$ ,  $T_{o(\text{open})}$   $t = 2.46$ ,  $p = 0.04$ . However, two sample  $t$ -tests on  $r^2$  within weather conditions indicated that body temperatures did not have significantly greater association with any particular operative temperature; overcast  $t$  from 0.25 to 1.04 ( $p$  from 0.31 to 0.88), sunny weather  $t = 0.27$  to 1.76 ( $p$  from 0.09 to 0.79). These results suggest less association with operative temperatures as the weather became hotter and is supporting evidence for thermoregulation with the primary effort concerned with avoiding excessive heat loads.

#### *Activity*

During overcast weather the overall median percentage amount of time each individual lizard was observed active was 21.9% (range = 12.6-29.6,  $n = 9$ ). The comparable information for sunny weather showed greater frequency of movement





**Figure 1.** Frequencies of distances travelled during locomotory movements in *C. zebrata*. The graph represents the pooled data sets from overcast and sunny weather and is shown as percentage frequencies of the total sample.

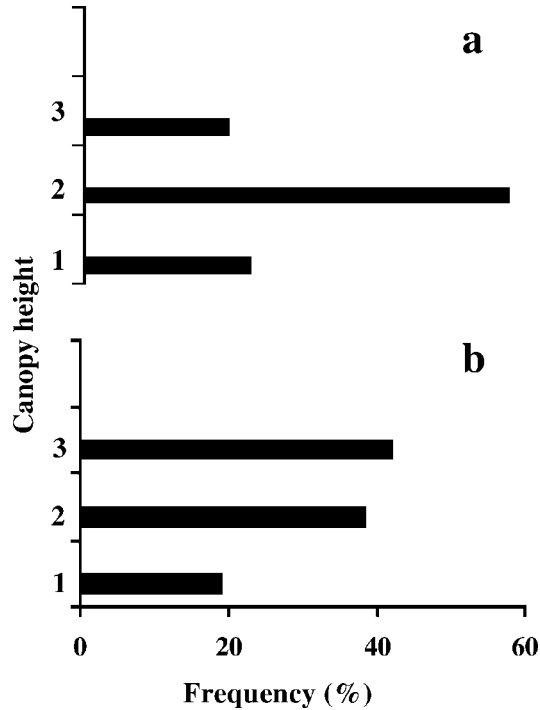
(median = 30.6, range = 20.6-36.1,  $n = 9$ ). A Mann-Whitney test indicated that the differences were significant,  $W = 55.0$ ,  $p = 0.008$ . Greater distances were covered during overcast weather activity (median = 90, range 26-189 cm) than sunny weather (median = 50, range 20-400 cm). However a Mann-Whitney test indicated that the differences were not significant,  $W = 96.5$ ,  $p = 0.35$ . The frequencies of distances covered during locomotory movement with the weather data sets pooled are shown in fig. 1.

#### *Canopy height location*

The percentages of time the lizards were located in each area of the vertical grid of the canopy during different weather conditions are shown in fig. 2. During overcast weather the lizards spent more time in the upper level of the canopy (height 3). A Mann-Whitney test indicated that this difference was significant; sunny median = 22%, overcast median = 45%,  $W = 116.5$ ,  $p = 0.007$ . The shift was mainly to height 2 in sunny weather (median = 57.5%), which although greater was not significantly different to the time spent at this height when the weather was overcast (median = 38.5%,  $W = 66.0$ ,  $p = 0.09$ ).

#### **Discussion**

Classically, the interpretation of the present results, for example the absence of basking, would have suggested that *C. zebrata* thermoconformed (Huey, 1982). However, the extent of departures of body temperatures from operative temperatures have indicated a degree of active thermoregulation in *C. zebrata* — albeit imprecisely — by the selection of microenvironments with the desired temperatures for activity. This fits the general patterns of thermoregulation observed in certain



**Figure 2.** Time spent at different heights in the canopy in a) sunny and b) overcast weather. The data are shown as the percent frequencies of total observations the lizards were observed at each height in the canopy. See text for further details.

other tropical forest reptiles (table IV of Huey, 1982), where only 28.6% (Rand and Humphrey, 1968) and 27.3% (Duellman, 1978) of species in respectively Brazil and Ecuador were baskers. Imprecise thermoregulation has certain advantages for reptiles in that it may, for example, increase potential activity times by avoiding the activity costs associated with precise thermoregulation (Somero, 1978) with the relatively high ambient temperatures of tropical forests facilitating this by enabling sufficiently high body temperatures for activity. Differences in body temperatures, including those associated with weather conditions found in *C. zebrata* have been observed in other reptiles (e.g., Smith and Ballinger, 1994; Mathies and Andrews, 1997; Rock et al., 2000), and although the number of lizards used in our study were too few to examine size class differences in body temperatures meaningfully in *C. zebrata*, it is known that this may be particularly important for gravid females in certain reptiles by influencing embryonic growth and neonate performance (Beuchat and Ellner, 1987; Beuchat, 1988; Shine and Harlow, 1993; Alberts et al., 1997; Andrews et al., 2000).

The shift from the upper levels of the enclosure in *C. zebrata* during hot sunshine and hence to greater vegetation cover may be a subtle compensatory mechanism to maintain foraging and avoid overheating and if so would be good supporting

evidence for thermoregulation. However, such behaviour may not necessarily be employed in free living individuals that may utilize hollows in trees for this purpose (Parker, 1983; Harmon, 2002). This reduces the activity required for avoiding excessive heat when the sun is shining and artificial enclosures with natural sunlight, but limited vegetation cover may constrain movement and reduce spacing between individuals during sunny weather. Inbuilt features that facilitate partial cover in the upper part of the canopy can alleviate this problem by reducing the likelihood of individual contact and also enable effective thermoregulation. Hide boxes make a useful substitute in artificial environments, particularly if they can be placed in such a way that a range of temperatures, appropriate for physiological processes, can be attained inside the boxes, and could be adopted for reintroduction programs into regenerated forest to enhance rest site availability. Thermal factors are known to interact with social dominance in certain reptiles forcing some individuals to use cooler retreat sites (Downes and Shine, 1998); multiple choice retreat sites are a way of overcoming this.

The diet of *C. zebrata* consists mainly of coarse leaf material gathered through foraging behaviour, a lifestyle that has an analogy in the South American green iguana (*Iguana iguana*). Both species exhibit large size, modified colons, large nematode and microbe populations (Iverson, 1979), and attaining appropriate body temperatures may be critical for this dietary regime since small differences in body temperature may influence digestive efficiency in *I. iguana* (Troyer, 1987; Marken Lichtenbelt, 1993). The lifestyle of *I. iguana* results in limited activity — most of the day is spent inactive (Iverson, 1979; Thornton, 2000) — which is similar to *C. zebrata*. The major difference between *I. iguana* and *C. zebrata* is that the latter is a crepuscular and/or nocturnal forager.

How close an approximation is the behaviour of captive animals to the behaviour of animals in the field is a frequently asked and valid question even when the captive animals are in simulated natural conditions. On this point we take the view of Chizar et al. (1995), who argued that whilst field experimentation provides the only pathway to answering questions of behavioural ecology, it seems reasonable to treat processes observed in captivity as hypotheses in the sense that such observations can be a valuable source of ideas. For example field observations coupled with observations of captive animals can at the very least give indications of the effects of captivity on behaviour and physiology. Captive breeding has been proposed as a significant part of conservation programs both for reintroductions back to the wild state and as an eventual substitute for the trade in wild caught animals. However research has now shown that it may not be enough simply to breed and raise animals to adulthood since thermal influences on the development of neonates may have long lasting influences on later behaviour (Beuchat and Ellner, 1987; Beuchat, 1988; Shine and Harlow, 1993; Andrews et al., 2000), and individuals bred and raised in inappropriate thermal regimes may have limited value in reintroduction programs. Design and construction of appropriate naturalistic enclosures with attention to the thermal environment must contribute in a significant way to alleviating this problem.

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