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# Activity Area during the Breeding Season of *Varanus gouldii* (Reptilia : Varanidae) in an Urban Environment

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*Abstract*

The activity area of ten *Varanus gouldii* in Karrakatta Cemetery, Perth, Western Australia, was measured by daily locations obtained by telemetry, during the breeding season (October–December) in 1992. The mean size of activity area was 8·91 ha; activity area was positively correlated with body size. There were significant overlaps in activity areas and no evidence of territoriality for male or female *V. gouldii*. The animals often foraged in areas of dense leaf litter near the periphery of their activity area and retreated to burrows that were more centrally located.

## Introduction

There are few detailed studies of the foraging, activity or home-range areas for goannas (Green and King 1978; Auffenberg 1981, 1988; Stanner and Mendelssohn 1987; Auffenberg *et al.* 1991; Thompson 1992; Weavers 1993). This is possibly because of their habit of foraging widely, their wariness, the large periods of field study necessary to develop an accurate measure of the occupied areas, and other methodological difficulties (Green and King 1978).

Thompson (1992) observed that *V. gouldii* in Karrakatta Cemetery would forage in a particular area for a number of days before moving to another area. However, it was not known whether the daily foraging areas of these goannas were confined within a larger activity area, with each lizard often returning to areas previously foraged, or whether goannas usually moved to new areas and only occasionally (by chance) returned to areas previously foraged. Other goannas [*V. rosenbergi* (Green and King 1978), *V. komodoensis* (Auffenberg 1981), *V. griseus* (Stanner and Mendelssohn 1987), *V. olivaceus* (Auffenberg 1988), *V. bengalensis* (Auffenberg *et al.* 1991), *V. varius* (Weavers 1993)] appear to confine their movements to a defined area over an extended period. Little is known of the spatial ecology of *V. gouldii* other than the size of foraging area and distance travelled daily at Karrakatta Cemetery (Thompson 1992) and distance travelled in desert locations (Pianka 1970).

The objective of this study was to estimate the size of the activity area of *V. gouldii* in Karrakatta Cemetery during the breeding season and to assess the extent to which this is affected by body size and sex. The daily locating of goannas has also enabled some information to be added to that reported by Thompson (1992) on how these goannas utilise space.

## Materials and Methods

### *Study Area*

Karrakatta Cemetery (115°47′E, 31°55′S) lies within the metropolitan area of the City of Perth, and has been used as a burial ground since 1897. It has a total area of 106 ha (53 ha allocated

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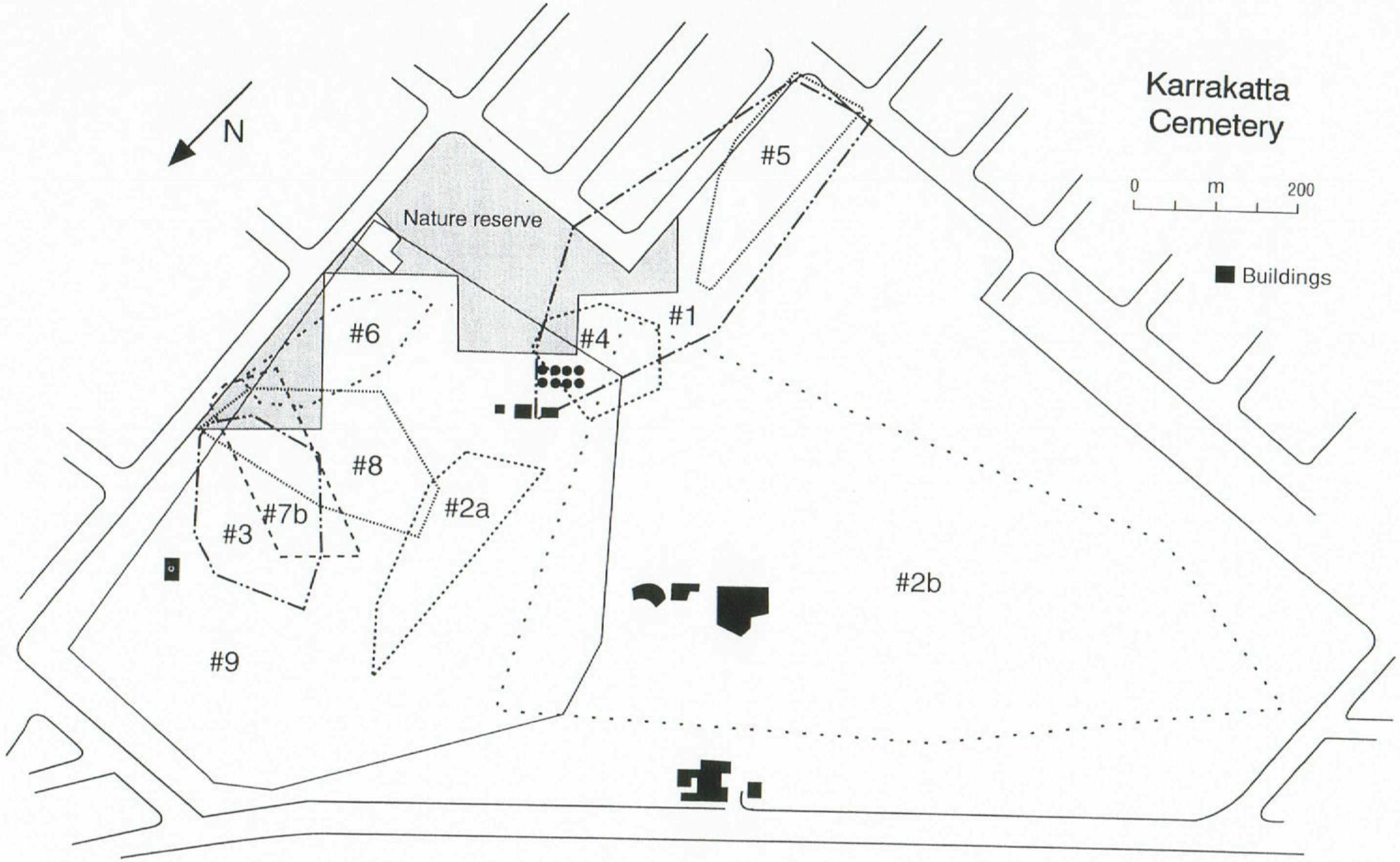


**Fig. 1.** Activity areas for six female and four male *Varanus gouldii* in Karrakatta Cemetery during the 1992 breeding season.

to burial plots and 53 ha to roads, ornamental gardens and buildings), with most of the available land now used for burial sites (Fig. 1). The main roads within the cemetery are bitumen and secondary roads are gravel. Most human activity occurs around a number of buildings, although all sections of the cemetery are regularly visited.

Before the development of the cemetery, the area contained banksia, red gum and tuart trees. It has been subsequently planted with a range of exotic shrubs and trees, and much of the northern, central and eastern areas are now grassed. Numerous rose gardens have been developed to the south and east of the main entrance. In addition, an area of approximately 7 ha of public land next to the south and south-eastern sections of the cemetery has been set aside by the local council as a nature reserve (Fig. 1). This area is densely planted with a wide variety of native and exotic trees, shrubs and grasses.

*V. gouldii* is abundant throughout the cemetery and the adjacent nature reserve, although individuals can be difficult to locate and capture because of their cryptic habits and alertness. These goannas forage in the cemetery and nature reserve and retreat to burrows in the nature reserve, and under grave coverings (Thompson 1992). Two females, one in December 1991 and the other in December 1993, were observed to lay eggs; this coincides with Pianka's (1970) observations of *V. gouldii* laying eggs between November and December in southern Western Australia. Given that these goannas emerge from their inactive winter period in about late September (Thompson 1992), it was therefore concluded that mating and egg-laying occurs between September and December for this population of *V. gouldii*.

### *Capture and Release*

Ten *V. gouldii* (four males and six females) were captured and released at the same point in the south-eastern section of Karrakatta Cemetery between 17 October and 27 November 1992. The sex of all lizards was determined at either the beginning or conclusion of the study by everting the hemipenes of males. The approach adopted by Auffenberg *et al.* (1991, p. 10) of extruding the hemipenes of those males that did not immediately do so upon capture, by 'doubling the tail at its base while at the same time pressing the thumb against the thickened area on the inner curve of the tail and pushing cranially' was used. Particular attention was paid to the sexing of the goannas as it has been reported that it is difficult to sex some species of varanids in the field (Green and King 1978; Auffenberg *et al.* 1991; King and Green 1993) as females of some species of varanids can evert a smaller, less well-developed organ (King and Green 1993) that can be difficult to distinguish from the hemipenes of juvenile males if care is not taken. All goannas used in this study were of a size that indicated they were sexually mature adults and it is unlikely that any juvenile males were misclassified as females or females confused for males. Nevertheless, because of the possibility of mistaking the sex of varanids, it is strongly recommended that the results and comments relating to variations due to the sex of the lizards be viewed with caution. Body mass was measured for all goannas both before they were fitted with a transmitter and at the conclusion of the study. The snout-to-vent length (SVL) of each goanna was measured when the transmitters were removed.

### *Radio-tracking*

A miniature radio-transmitter (11 g; Bio-tel, South Australia) was attached to the lateral aspect of each lizard's tail. It was sewn into a denim harness that was glued (with Selleys 'kwik grip') to the lizard's skin to encircle the abdomen and tail both in front of and behind the rear limbs. The effective operating life of the transmitter batteries was approximately 75 days. A Bio-tel RX3 receiver with a 3EY directional antenna, operating in the 150–151 MHz band, was used to locate each lizard every day. The time when the lizards were located varied between 0700 and 1700 hours from day to day, to ensure that a representative sampling of daily movements for each goanna was recorded (i.e. including both night-time resting places and day-time foraging areas). Locational fixes of lizards were accurately plotted on a map using the number and location of individual grave sites.

The frequency of locational fixes for each lizard was influenced by a number of factors. Sufficient data should be accumulated to develop a statistically reliable estimate of activity areas and locational fixes should represent the proportion of time that the lizard spends in a given area. However, each location should be independent of the previous location, and sufficient time should elapse between sightings to enable the animal to move from one end of its activity area to the other (White and Garrott 1990, p. 147). If a lizard's position was located late one afternoon, then it was not located before noon the next day, to ensure that its location was independent of the previous day's record.

It was assumed that neither the attached transmitter nor the locating of lizards each day affected their normal behaviour. The public regularly frequent all sections of the cemetery and it is probable that the varanids have adjusted to their presence. There was no obvious variation in the movement patterns of tracked *V. gouldii* compared with other goannas observed in previous studies (Thompson 1992) or the lizards without transmitters that were observed during this study. Care was taken to minimise the disturbance caused to the lizards when locating their positions, but lizards that were located out of their burrows often detected our presence before we located them. It is also assumed that the goannas studied are representative of the entire population of *V. gouldii* within Karrakatta Cemetery.

### *Analyses of Activity Areas*

There is considerable variation in the estimations of activity areas or home-range sizes generated by the various probabilistic and non-probabilistic methods available (Rose 1982; Christian and Waldschmidt 1984; Harris *et al.* 1990; White and Garrott 1990). The biological assumptions underlying these various approaches, the sample-size biases, and the sensitivity to extreme and boundary locations have been criticised by several authors (Jennrich and Turner 1969; Macdonald *et al.* 1980; Schoener 1981; Anderson 1982; Harris *et al.* 1990). White and Garrott (1990) suggest that the observations should be statistically independent (i.e. with sufficient time transpired between observations), that the analysis methodology not be unduly influenced by 'outliers' and, for bivariate models, that the distribution of locational fixes is bivariately normally distributed. In addition, if a section of the activity area includes space not foraged [e.g. water (Auffenberg *et al.* 1991) or buildings (as in this study)], then that area should be excised from the activity area to avoid overestimating the area used.

Three methods were used to assess the activity area occupied by *V. gouldii* for the duration of this study. The first was that recommended by Samuel and Garton (1985) for weighted ellipses. The Cramer–von Mises statistic was used in conjunction with this statistic to test the goodness-of-fit of the data to the bivariate normal distribution (SAS code from White and Garrott 1990). The widely reported approach recommended by Jennrich and Turner (1969) to estimate activity areas was also used for comparison with data from other studies. As pointed out by Macdonald *et al.* (1980), Anderson (1982), White and Garrott (1990) and Harris *et al.* (1990), no technique for estimating the area occupied by an animal is without problems. As a consequence, a third direct method was used in this study to estimate activity areas. The boundary of all locational fixes was transcribed onto a plan of the cemetery. The activity area was determined for the smallest convex polygon that included all the locational fixes, excluding buildings regularly frequented by people, the area within 25 m of these buildings, cemetery perimeter roads, the verges and the area beyond. This technique will be subsequently referred to as the 'direct' polygon method. Chi-square statistical comparisons (Zar 1988) of the proportional use of space within the activity areas were conducted, with the proportion of the activity area calculated by the 'direct' polygon method.

## Results

### *Activity Area*

The mean SVL and mass of the 10 *V. gouldii* studied from 17 October to 31 December 1992 at Karrakatta Cemetery was 323 mm (s.e. = 5·8; mean SVL of four males 336 mm, s.e. = 3·7; mean SVL of six females 314 mm, s.e. = 7·4) and 460 g (s.e. = 49·5) at the beginning and 467 g (s.e. = 48·6; mean mass of four males 597·5 g, s.e. = 74·1; mean mass of six females 380·2 g, s.e. = 33·5) at the conclusion of the study.

The mean activity area of all goannas, as measured by the 'direct' polygon method, was 8·91 ha (s.e. = 4·0); the mean activity area for males of 18·84 ha (s.e. = 8·06) was not significantly different ($t_3 = 2\cdot05$, $P = 0\cdot13$) from the 2·29 ha (s.e. = 0·23) for females (Table 1). The size of the activity area was significantly correlated with body

**Table 1. Estimates of activity area for individual *Varanus gouldii* at Karrakatta Cemetery**

| Lizard no.: | 1 | *2a* | *2b* | 3 | 4 | *5b* | 6 | *7b* | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|---|
| Mass at the beginning of study (g) | 464 | 300 | 740 | 468 | 330 | 280 | 393 | 465 | 448 | 710 |
| Mass at conclusion of study (g) | 474 | 304 | 746 | 466 | 329 | 296 | 405 | 480 | 467 | 704 |
| SVL at conclusion of study (mm) | 330 | 334 | 340 | 330 | 300 | 290 | 310 | 335 | 315 | 345 |
| Likely sex[A] | M | F | M | M | F | F | F | F | F | M |
| No. days monitored | 69 | 39 | 34 | 62 | 75 | 56 | 74 | 37 | 72 | 62 |
| Minimum no. of locations to record largest activity area | 61 | 39 | 40 | 59 | 14 | 36 | 57 | 17 | 72 | 40 |
| Measured convex polygon (direct polygon method) (ha) | 6·50 | 2·18 | 32·09 | 3·36 | 1·60 | 2·23 | 2·02 | 2·43 | 3·28 | 33·40 |
| Unweighted activity area (ha) | 13·75 | 4·03 | 179·94 | 5·64 | 2·78 | 4·91 | 2·89 | 4·47 | 4·39 | 71·19 |
| −95% CI | 10·97 | 2·99 | 130·86 | 4·44 | 1·83 | 3·83 | 2·33 | 3·29 | 3·52 | 56·12 |
| +95% CI | 17·74 | 5·72 | 263·08 | 7·39 | 2·90 | 6·54 | 3·70 | 6·42 | 5·64 | 93·29 |
| $W^2$ [B] | 13·73 | 5·04 | 7·49 | 9·05 | 14·25 | 9·11 | 13·48 | 6·61 | 11·80 | 11·36 |
| $P_{int}$ [C] | 0·01 | 0·01 | 0·01 | 0·01 | 0·01 | 0·01 | 0·01 | 0·01 | 0·01 | 0·01 |
| Weighted activity area (ha) | 9·7 | 3·36 | 48·21 | 4·75 | 1·92 | 3·59 | 2·31 | 4·03 | 3·43 | 63·56 |
| −95% CI | 7·74 | 2·50 | 35·06 | 3·75 | 1·54 | 2·79 | 1·86 | 2·97 | 2·75 | 50·11 |
| +95% CI | 12·52 | 4·77 | 70·48 | 6·23 | 2·45 | 4·77 | 2·96 | 5·79 | 4·40 | 83·29 |
| $wW^2$ [D] | 14·24 | 1·99 | 6·76 | 5·74 | 15·68 | 7·54 | 13·33 | 7·02 | 9·16 | 12·41 |
| $wP_{int}$ [E] | 0·01 | 0·01 | 0·01 | 0·01 | 0·01 | 0·01 | 0·01 | 0·01 | 0·01 | 0·01 |

[A] See note in Methods on sex determination.
[B] $W^2$ = value of the Cramer–von Mises goodness-of-fit statistic.
[C] $P_{int}$ = interpolated probability level of $W^2$.
[D] $wW^2$ = value of the Cramer–von Mises goodness-of-fit statistic for weighted estimates.
[E] $wP_{int}$ = interpolated probability level of $wW^2$.

mass ($r = 0 \cdot 91$, $t_8 = 8 \cdot 3$) and SVL ($r = 0 \cdot 60$, $t_8 = 2 \cdot 7$) and is best represented by the regression equations:

$$A = -25 \cdot 9 + 0 \cdot 0744\,M \quad (F_{1,8} = 36 \cdot 56,\ P < 0 \cdot 001)$$

$$A = -126 + 0 \cdot 418\,SVL \quad (F_{1,8} = 4 \cdot 56,\ P = 0 \cdot 065)$$

where area (A) is measured in hectares, mass (M) in grams and SVL in millimetres.

The mean activity area for the 10 *V. gouldii*, as measured by the Jennrich and Turner (1969) method, was 29·4 ha (s.e. = 18·0; for males 67·6 ha, s.e. = 40·2; for females 3·91 ha, s.e. = 0·36) (Table 1). The mean weighted activity area for all *V. gouldii* was 14·49 ha (s.e. = 7·03; for males 31·6 ha, s.e. = 14·4; for females 3·1 ha, s.e. = 0·33). The Cramer–von Mises goodness-of-fit statistic was higher for six of the unweighted activity area estimates (goannas #2*a*, #2*b*, #3, #5*b*, #8 and #9) than the weighted activity-area estimates, suggesting that the six unweighted ellipses fit the data better than the weighted ellipses (Table 1). However, none of the distributions were bivariately normal ($P \leq 0 \cdot 01$).

The mean minimum number of locational fixes (days), required to obtain the maximum activity area, with the Jennrich and Turner (1969) method, for all goannas was 41·3 (for males 47·2; for females 39·3). The last locational fix provided the maximum activity area for two of the 10 *V. gouldii*.

### *Use of Activity Area*

There were substantial overlaps in the activity areas (Fig. 1) of radio-tracked lizards. Besides those tracked by transmitter, other *V. gouldii* were also observed within the activity areas of these lizards. Of the total of 580 times that the 10 goannas were located, on 352 of these occasions they were found in a burrow, on 186 occasions they were found foraging and for 42 times they were inactive and sunning or emerging from a burrow. Males used significantly ($\chi^2 = 12 \cdot 66$, d.f. = 1, $P < 0 \cdot 05$) more new burrows (72·5% of all burrow locations) compared with females (52·3% of all burrow locations) during the study. On seven occasions, a *V. gouldii* was recorded in a burrow that had been used by another goanna included in this study (#1 and #4, #4 and #9, #3 and #7, #3 and #8, #6 and #8, #2*a* and #9, #8 and #9).

All goannas, except #2*a* and #2*b*, had a relatively small area on the periphery of their activity areas that had a substantial ground cover of leaf litter either in the nature reserve or along the road verge. Of these goannas, #1, #3, #5 and #8 were located foraging significantly ($\chi^2 = 50 \cdot 88$, $33 \cdot 38$, $66 \cdot 51$, $32 \cdot 42$, respectively; d.f. = 1, $P < 0 \cdot 05$) more often in this leaf-littered area than would be predicted on the basis of the proportional size of the area relative to the total activity area. Lizards #2*b* (twice), #6, #7*b* and #8 (once each) were located up trees.

## Discussion

### *Size of Activity Area*

The area occupied by lizards over an extended period can vary according to their location, sex, age, dominance, breeding status, foraging pattern and mass (Rose 1982; Christian and Waldschmidt 1984). It is difficult to draw comparisons between the areas occupied by *V. gouldii* at Karrakatta Cemetery and those reported for other goannas, because of the differing approaches used to define, collect and calculate occupied areas, and the varying number of sightings taken over varying periods. However, it is noted that *V. rosenbergi* has a reported mean home-range size of 7·8 ha [Green and King (1978) after adjustment by Christian and Waldschmidt (1984) for sample size], *V. komodoensis* a mean foraging-area of 4200 ha (Auffenberg 1981), *V. olivaceus* a mean foraging-area size of 1·48 ha (Auffenberg 1988), male *V. bengalensis* a mean home-range size of 5·3 ha and females a mean home-range size of 4·4 ha (Auffenberg *et al.* 1991), male *V. griseus* a mean home-range size of 98·4 ha and females a mean home-range size of 31·9 ha (Stanner and Mendelssohn 1987), and male *V. varius* a mean home-range size of 65 ha (Weavers 1993).

A number of studies have shown a positive correlation between a lizard's body mass and its home-range size (see reviews by Turner *et al.* 1969; Christian and Waldschmidt 1984). It is therefore not surprising to find that the activity area of *V. gouldii* in this environment varies with size. However, Auffenberg *et al.* (1991) report no relationship for *V. bengalensis* between body size and home-range area. Body mass of goannas is likely to be much more variable than SVL (as it changes according to the availability of food and reproductive condition) and therefore might be expected to be a less reliable predictor of the size of a lizard's activity area. However, in this situation, body mass was a more reliable predictor of activity area.

The four male *V. gouldii* used significantly more burrows than the females during the study and there is a significant positive correlation ($r = 0{\cdot}75$, $t_8 = 3{\cdot}24$, $P < 0{\cdot}05$) between the size of the activity area and the ratio of new burrows to total number of burrows occupied. This might be an expected result as there are more opportunities for burrows in a larger activity area and survival pressures would require these lizards to be able to locate a safe burrow within close proximity of any position within their activity area should they be disturbed. It would therefore seem reasonable for the number of known burrows to be proportional to the size of the activity area. Additional data is required to determine whether there is a relationship with breeding behaviour and the number of burrows used.

Given the widely foraging nature of these goannas and the limited period of the study, it is probable that their home-range size is larger than the reported activity area. However, the mean activity area for *V. gouldii* (both males and females) at Karrakatta Cemetery is larger than that predicted by Christian and Waldschmidt (1984) for their home-range size, on the basis of data from other foraging lizards, taking into account body mass. Stanner and Mendelssohn (1987) also reported home-range sizes for *V. griseus* to be much larger than would be predicted by the Turner *et al.* (1969) regression equation based on interspecific lizard data. The hand-drawn home-range size estimates for the larger *V. bengalensis* in southern Pakistan are smaller than the male and larger than the female activity areas of *V. gouldii* at Karrakatta Cemetery (Auffenberg *et al.* 1991). Weavers (1993) reports male *V. varius* to have a mean home-range size of 65 ha, which is much larger than that predicted by these regression equations on the basis of their mass. This would suggest that the areas occupied by goannas are generally larger than those of other lizards, even accounting for body mass, but highly variable and dependent on factors such as the availability of food and shelter. The influence of breeding behaviour on home-range size of *V. gouldii* is unknown and a possible area for future study.

### *Territoriality*

No indication of territoriality was evident for *V. gouldii* at Karrakatta Cemetery, as activity area boundaries overlapped and particular burrows were used by more than one *V. gouldii*. This is consistent with earlier findings for *V. rosenbergi* on Kangaroo Island, South Australia (Green and King 1978), *V. komodoensis* (Auffenberg 1981), *V. griseus* (Stanner and Mendelssohn 1987), *V. bengalensis* (Auffenberg *et al.* 1991) and *V. gouldii* (Thompson 1992), which all have substantial overlap in the boundaries of the areas they occupied.

### *Use of Activity Area*

Thompson (1992) reported that *V. gouldii* in Karrakatta Cemetery shifted foraging areas every few days, foraging more often in shaded areas as the daily temperature increased and foraging more intensively in areas of relatively high concentrations of leaf litter. The results of this study concur with the earlier findings of Thompson (1992). *V. gouldii* did not use the space within their activity area homogenously. Tracked goannas generally retreated each night into one of a large number of different burrows that were most often centrally located in their activity area. During the day they foraged in areas close to the boundary of their activity area, in the leaf litter.

The habitat of *V. gouldii*, the 'sand monitor', is often described as ground-dwelling (Wilson and Knowles 1988; Cogger 1992). Wilson and Knowles (1988) report that when *V. gouldii* is disturbed it will rarely ascend a tree but will most often bolt to a burrow. The same retreat pattern is evident for *V. gouldii* at Karrakatta Cemetery. It is therefore of interest to note that some goannas were located up trees with no evidence to suggest that they had been chased into this situation. This movement into the tree canopy may have been to forage or for shade.

### *Effect of Sample Size on Activity Area and Home-range Size*

The mean number of locational fixes needed to obtain the largest recorded activity area for *V. gouldii* in this study was 41·3, with males having a slightly higher mean (47·2) than females (39·3). However, the activity area increased until the last day for two *V. gouldii* (#2*a* and #8) that were studied. It is known that the number of sightings influences the calculation of activity area or home-range size (Rose 1982; Christian and Waldschmidt 1984). Rose (1982) makes the point that lizards that are not territorial and wander in search of food or a mate may continually increase their activity area or home-range size as the number of sightings increases. Some goannas may fall into this category. Stanner and Mendelssohn (1987) reported that home-range size did not plateau with increased sightings for a small number of *V. griseus*, although the maximum home-range area was determined for most after 30–70 sightings. It could therefore be expected that the home-range size of these widely foraging *V. gouldii* at Karrakatta Cemetery may be larger than the activity areas reported here and may have increased with time. Auffenberg (1981) reports that some *V. komodoensis* are transient, and it is probable that for other species of varanids there will also be some individuals that wander, continually increasing their activity area and thus their home-range with time. There was, however, no evidence of this transient behaviour in the *V. gouldii* at Karrakatta Cemetery, as all 10 goannas returned to retreats and foraging areas used earlier in the study period. Further study of the varanids at Karrakatta Cemetery over an extended period would therefore be necessary to be confident that the size of the activity area had reached a plateau for all varanids. In this situation the activity area could then be described as the home range of *V. gouldii* if Burt's (1943) definition of 'all the area traversed by an individual in its normal activities' is adopted without a time frame.

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