Characteristics of the burrows of Slater's skink, *Liopholis slateri*

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Slater's skink, *Liopholis slateri*, is an endangered, burrow dwelling scincid, confined to the desert river floodplains of central Australia. This species has undergone a significant population decline over the past 40 years probably due to a loss of suitable habitat for burrow construction caused by changes in land use, the invasion of exotic weeds and altered fire regimes. In this paper we describe the characteristics of natural burrows and their physical association with other environmental features. Lizards were found to construct relatively complex, multi-entranced (up to 10 entrances) burrow systems in mounds of soil, ranging from 4.5–33 cm in height and 3.12–10.36 m basal circumference, that had formed under shrubs ranging from 0.42–3.22 m in height. We also found that the temperature inside one burrow was substantially lower during the hottest part of the day, and showed substantially less daily temperature variation than experienced outside of the burrow. We found no evidence that lizards had a preferred compass direction for orientating their burrow openings. This study provides baseline data to enable the development of artificial burrow systems for use in future habitat restoration projects, possible translocations and captive breeding programmes.

Key words: arid zone, artificial burrows, *Egernia* refuges, lizard, conservation.

INTRODUCTION

Many species require secure refuges in suitable habitat for their survival. Many threatened species, including spiders (Yanez & Floater, 2000), reptiles (Grillet et al., 2010; Milne et al., 2003), birds (Paredes & Zavalaga, 2001) and mammals (Beyer & Goldingay, 2006) have limited distribution or abundance because suitable refuges are in short supply. Refuge loss can result from stochastic events such as fire (Beyer & Goldingay, 2006), from human induced habitat modifications such as forestry (Lindenmayer et al., 1990), agriculture (Milne, 1999), from the physical removal of shelter sites such as fallen logs collected as firewood or the ornamental 'moss rocks' used by the endangered broad headed snake, *Hoplocephalus bungaroides* (Shine & Fitzgerald, 1989). In all of these cases where refuge reduction becomes a threat to population persistence, an established conservation strategy is to supplement refuges with artificial structures, such as nesting boxes for hollow nesting birds and mammals (Beyer & Goldingay, 2006; Franzreb, 1997; Spring et al., 2001), or artificial burrows for burrow dwelling animals (Grillet et al., 2010; Souter et al., 2004; Sullivan et al., 2000; Webb & Shine, 2000). Artificial refuges can be used either to augment existing populations (Grillet et al., 2010; Souter et al., 2004) or to encourage the establishment of new translocated populations of endangered species (Beyer & Goldingay, 2006; Milne & Bull, 2000).

Reptiles commonly use burrows as refuges (Cooper et al., 2000; Greer, 1989). Some species dig their own burrows (Chapple, 2003; Greer, 1989), while others take over burrows constructed by other animals (Davidson et al., 2008; Fellows et al., 2009; Grillet et al., 2010; Newman, 1987). Burrows provide shelter and protection from adverse climatic conditions (Christian & Weavers, 1994), from stochastic events like fires (Fenner & Bull, 2007) and from predators (Cooper et al., 2000; Fenner et al., 2008). The entrances of burrows also provide ambush sites to catch passing prey (Milne et al., 2003). Artificial burrows must provide all of these features, and a vital first step in their design is to document the structures of preferred natural burrows (Milne & Bull, 2000).

Slater's skink, *Liopholis slateri* (Scincidae), is an endangered, burrow dwelling lizard from central Australia that has undergone a significant reduction in abundance and distribution, apparently due to the loss of suitable burrow habitat (Pavey et al., 2010). This paper describes the characteristics of natural burrows from two populations of the lizard in a first step towards the possible design of artificial burrows.

Slater's skink occurs in open shrub land habitat on alluvial clay-based soils close to drainage lines in the southern arid regions of the Northern Territory and northern arid regions of South Australia (Horner, 1992; Pavey, 2007; Storr, 1968). It is listed as endangered under the Environment Protection and Biodiversity Act 1999, and is considered one of Australia's most threatened reptile species (Pavey et al., 2010). It is an obligate burrowing species that constructs multi-entrance burrow systems in the pedestal (mound) of soil that builds up around the base of some shrubs and small trees, particularly native fuschia

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(*Eremophila spp.*) and corkwood (*Hakea spp.*) (Pavey, 2004; Pavey et al., 2010). These grow predominantly on the flood plains around perennial creeks. Slater's skink has undergone significant population decline over the past 40 years, associated with changes in land use, altered fire regimes and the spread of the invasive buffel grass, *Cenchrus ciliaris*, which overgrows the pedestals where the lizards normally dig their burrows (Pavey, 2004). The skink has disappeared completely from sites where it was previously abundant, and only seven small, highly fragmented populations are now known within the MacDonnell Ranges and Finke bioregions of central Australia (Pavey et al., 2010). The species faces ongoing threats to its persistence from the high disturbance regimes of its floodplain habitat, and the invasion of that habitat by exotic weeds in central Australia (Pavey, 2004), as well as a natural loss of Slater's skink burrow systems (and potential habitat) due to flood events (Pavey, unpublished data).

The current study aimed to describe the structure of the burrow systems used by Slater's skink, their physical association with other environmental features and aspects of the internal burrow environment. The purpose of this work was to provide baseline data to enable the development of artificial burrow systems for use in future habitat restoration projects, possible translocations and captive breeding programs.

METHODS

Study sites

The study was conducted between 30 September 2010 and 17 January 2011, in Owen Springs Reserve (23°50'S; 133°27'E), located 60 km west of Alice Springs in the MacDonnell Ranges bioregion of the Northern Territory, Australia. We surveyed two separate skink populations (22 km apart) known from within the reserve. At Site 1 lizards occupied about 10 ha, while at Site 2 lizards were only found within 0.25 ha. Both sites were on clay-based alluvial plains, located close to the base of stony hills rising from the plains (Pavey et al., 2010). Although buffel grass was widespread in the reserve, it had not established dense stands within either of the two study sites. At each site most of the shrubs were mounded with deposits of sand and clay that had accumulated around the base of the trunk. This mounding has been reported previously from historic sites (Henzell, 1972), and extant sites containing Slater's skinks (Pavey et al., 2010). The dominant mounded shrubs at Site 1 were *Eremophilia sturtii, E. maculata*, *E. duttonii* and *Acacia victoriae* (Pavey et al., 2010), while *E. sturtii* and *H. leucoptera* dominated Site 2. The ground surface was typically bare of other vegetation in between shrubs, in areas where buffel grass had not invaded.

Shrub and mound parameters

Measurements were collected from all 20 burrow systems that were identified as occupied by *L. slateri* during the study (six at Site 1 and 14 at Site 2), and from 15 additional burrow systems (12 at Site 1 and three at Site 2), that were unoccupied during this study but had been recorded as occupied in a previous study (Ford, 2009). For each burrow system we recorded ten descriptive parameters of the mound and its associated shrub that were likely to affect the microclimate and microhabitat. These were: shrub species, presence of other plant species on the mound, shrub height (from ground level), shrub foliage circumference (measured 1.2 m above ground level, or at its widest point if the shrub was under 1.2 m in height), vertical distance between the lowest foliage and the top of the mound, mound height (ground level to top of mound), mound basal circumference, distance to the next nearest mounded shrub, distance to the nearest other cover (grass, shrub etc.) and the number of burrow openings in the mound.

External burrow features

For each burrow opening within each burrow system, we measured four parameters: burrow entrance diameter (at its widest point), distance from burrow entrance to the centre of the mound (externally), compass direction faced (taken from 0° north) and height of the base of the burrow entrance above ground level. Because individual burrow openings within a single burrow system may not be independent, we derived the mean values of the burrow entrance parameters (except for direction) for each burrow system for analyses.

Internal burrow structure

At the end of the study we excavated one burrow system from Site 1 that had been used by an adult lizard (snout-vent length 103 mm; jaw width 16 mm; weight 35 g) but had been abandoned during the study season. Our sample size was restricted to minimize disturbance of the populations. The mound was 17 cm high, and 7.18 m in basal circumference, and was at the base of an *A. victoriae* shrub (2.17 m high, foliage circumference 10.41 m). Ruby saltbush (*Enchylaena tomentosa*) and buffel grass (*Cenchrus ciliaris*) were also growing on the mound. We sprayed expanding foam filler (Selleys® No More Big Gaps) into each burrow entrance until no more foam could be added to the entrance, or until foam appeared at another burrow entrance. The foam filler was allowed to set overnight to form a mold of the internal burrow structure, and was dug out the following day. We replaced the disturbed soil back around the base of the tree to resemble the original mound structure, but without any burrows.

Temperature data

We placed three data loggers (Tinytag®) with temperature probes around one burrow system, in the following locations: a) on the ground surface, next to a burrow entrance and in direct sun, b) in the shade at the base of the shrub at the top of the mound and c) 15 cm inside (at a depth of 12 cm below the mound surface), in a north westerly facing burrow entrance. These recorded ambient temperatures every 30 min over the study period (30 September–17 January). Additional data loggers set up at several other burrow systems at the start of the study were destroyed by dingoes (*Canus lupus dingo*).

Statistical analysis

We used independent sample *t*-tests to examine whether any of the mound or shrub parameters measured differed between currently and previously occupied burrow systems. We then used a two-way ANOVA to compare the mound and shrub parameters between study sites and occupied and unoccupied burrow systems. We also used Chi squared tests in order to determine whether lizards had a preferred orientation for their burrow opening on the mound. All statistics were performed in PASW (SPSS) v.18.

RESULTS

Shrub and mound parameters

Of the 35 burrow systems, 30 were associated with *Eremophila sturtii* (16 at Site 1 and 14 at Site 2), three with *A. victoriae* (2 at Site 1 and 1 at Site 2) and one of each (at Site 2) with *H. leucoptera* and *E. tomentosa*. Two other *Eremophila* species, *E. maculata* and *E. duttoni* had mounds but no lizard burrows. The mounds containing burrow systems were largely void of vegetation or other debris (such as fallen leaves and branches) although small clumps of grasses (native and exotic) and small chenopod shrubs/sub-shrubs were present, typically on the outer edges, on most mounds (Table 1).

Table 1. The number of mounds containing a *Liopholis slateri* burrow system on which plant species (apart from the main shrub) were present. A total of 35 mounds were sampled.

Other plant species present	Number of mounds
Chenopods	9
Native grasses	5
Buffel grass	3
Chenopods and native grasses	13
Chenopods and buffel grass	2
Sapling shrub	1
No other plants present	2

None of the eight measured shrub and mound parameters (Table 2) differed significantly between currently occupied and recently occupied burrow systems. There was no indication that minor infestation with buffel grass led to lizards abandoning mounds, since four of the five mounds with buffel grass remained occupied. However, none of the mounds examined had the dense buffel grass cover found in areas where the grass had become more established. Mound characteristics differed significantly between the two sites, with shrub height, foliage circumference, mound height and distance to the nearest mounded shrub all significantly greater at Site 1 than Site 2 (Table 3, Fig. 1). Comparisons between mounds under *E. sturtii* and mounds under other shrub species showed a significantly larger gap between the lowest foliage and the mound top for *E. sturtii* (one-way ANOVA; $F_{1,33}$=6.01; p=0.020) but no other differences. The number of burrow openings in a mound ranged from 1–10 (Table 2), but was not significantly associated with any other mound or shrub parameter. Although there were shallower mounds in the two study sites, no currently occupied or previously occupied burrow system was found in any mound less than 4.5 cm high.

External burrow features

External burrow measurements (Table 2) did not differ significantly between currently occupied and recently occupied burrow systems or between the two sites. When we divided each mound into four 90° segments, with the segment edges representing the four primary compass directions, we found no deviation from a random distribution of orientations among the 114 burrow entrances (χ^2=4.64, df=3, p=0.20).

Internal burrow structure

The excavated burrow consisted of two separate systems with no obvious internal connection. Each system was a cluster of connected burrow openings. *In situ* the two burrow systems were separated by the roots and underground trunk of the shrub, with the nearest burrow openings of the two systems being located 78 cm apart on the mound surface. There was no indication that underground components of the buffel grass or the ruby saltbush that were also growing on the mound, had penetrated into any burrows or had influenced the internal directions of the individual burrows. The first system (the system the occupant was last observed using) consisted of two burrow openings. One of these was an apparently frequently used burrow entrance and the other was a 'pop hole' (a thinly covered/concealed opening, located higher up the mound and covered by sand). These were connected

Table 2. Summary of each of the eight shrub and mound parameters and the three burrow parameters, displaying the range, mean and standard error (SE) of each parameter measured.

Shrub/mound parameters	*n*	Range	Mean	SE
Shrub height (m)	35	0.42–3.22	1.86	0.11
Shrub foliage circumference (m)	35	1.83–13.96	7.29	0.50
Foliage to mound (cm)	35	0–33.0	19.12	1.25
Mound height (cm)	35	4.5–33.0	14.90	1.10
Mound circumference (m)	35	3.12–10.36	6.21	0.32
Distance to next nearest shrub (m)	35	0.6–7.80	2.82	0.31
Distance to other cover (m)	35	0.6–6.30	1.99	0.20
Number of burrow openings	35	1–10	3.26	0.30
Burrow parameters	***n***	**Range**	**Mean**	**SE**
Burrow opening diameter (mm)	35	31.25–77.0	47.93	1.76
Burrow to centre of mound (cm)	35	0.5–106	39.10	39.69
Burrow height in the mound (cm)	35	1.0–17.0	8.26	6.96

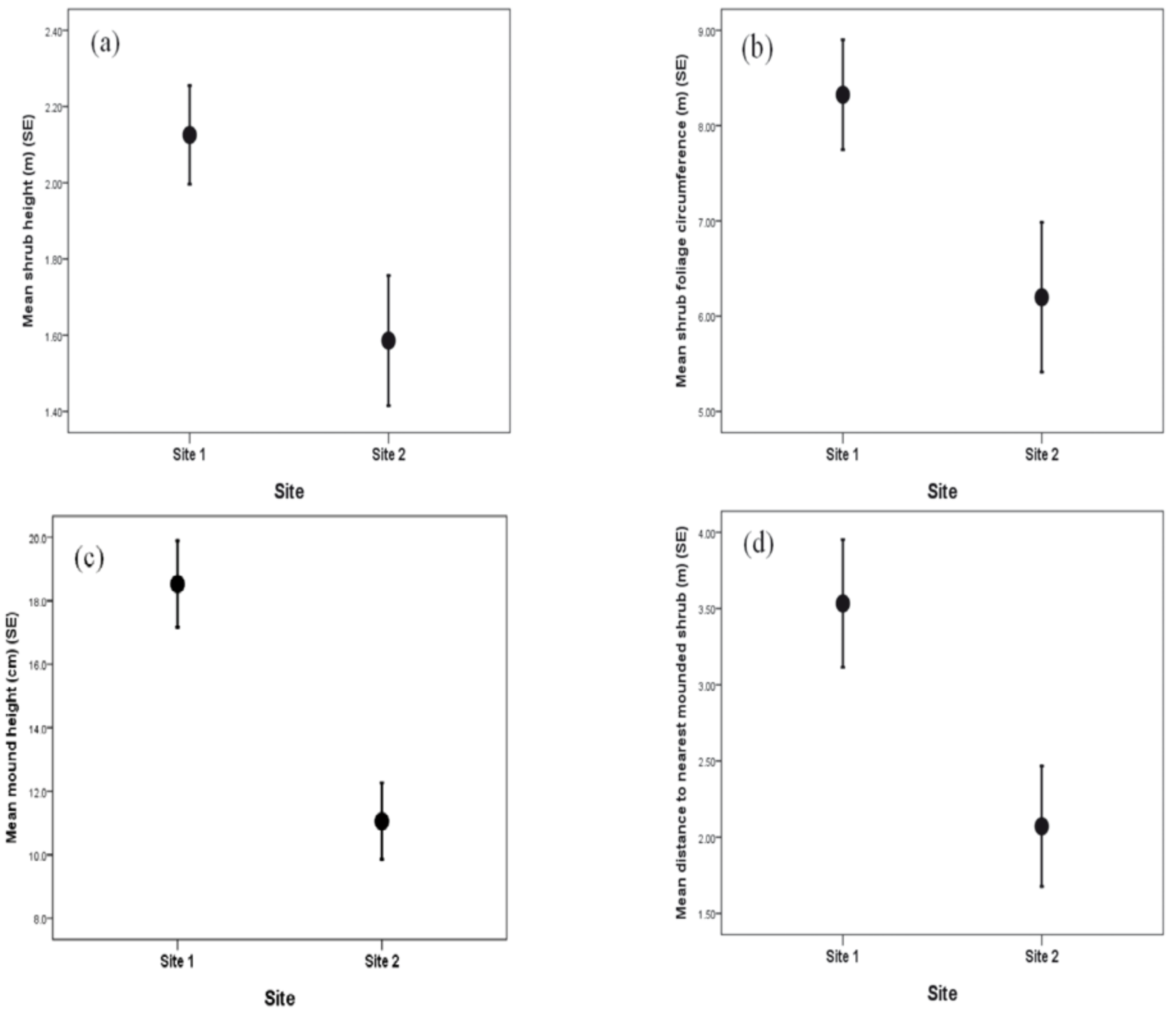

Fig. 1. Means (+/- SE) for (a) shrub height, (b) shrub foliage circumference, (c) mound height and (d) distance to nearest mounded shrub around *Liopholis slateri* mounds.

by a U-shaped tunnel (64 cm in length) with a small (9 x 7 x 2 cm) cavity (32 cm from the main burrow entrance) at the bottom (22 cm vertically below the top of the mound). Since the mound was only 17 cm high, this suggests that these burrow systems are not necessarily confined solely to the mounded pedestal but can penetrate into the ground surface under the mound. The second system consisted of seven connected burrow openings, with five well used burrow entrances and two concealed 'pop holes'. Each of the seven burrow openings branched off from a central connecting tunnel, starting at one burrow entrance and ending at another entrance. The total length of the burrows in this second burrow system was 157 cm. There was also a small (10 x 10 x 2 cm) cavity at the lowest point (12 cm vertically below the top of the mound) of this system, similar to that observed in the first. This was located 15 cm from the closest burrow entrance, and led off from the central tunnel at a junction where tunnels from four burrow entrances joined the central tunnel. The total length of both of the tunnel systems within the mound was 221 cm. The internal tunnel diameters at their narrowest width were between 21–30 mm. Each tunnel retained a consistent diameter along its length (except for the two chambers, see above), and there was little variation between tunnels of the two systems. Although the sample size was too small for statistical analysis, tunnels leading to pop-holes tended to be narrower than other tunnels.

Temperature data

The data logger placed 15 cm inside the burrow entrance recorded higher minimum daily temperatures, lower average and maximum daily temperatures and a smaller daily thermal range than either of the outside locations (Table 4). The mean temperature over the season, for each half hour of the day (Fig. 2) showed that in the burrow there were substantially lower temperatures in the hottest part of the day, and substantially less daily temperature variation than outside of the burrow.

DISCUSSION

This study supports previous suggestions that shrubs with mounds are a critical habitat resource for Slater's skink (Pavey, 2004; Pavey et al., 2010). In our study, *E. sturtii* was the dominant shrub species at the sites and it was used by Slater's skinks for constructing burrow systems. Lizards were found to construct burrow systems in mounds that ranged from 4.5–33 cm in height and 3.12–10.36 m

Table 3. Two-way analyses of variance comparing the effect of study site (Site 1 and Site 2) and occupancy status (Currently Occupied and Previously Occupied) on shrub height, shrub foliage circumference, mound height and distance to the nearest mounded shrub. *P* values in *italics* are significant <0.05.

		Site		Occupancy status		Site x Occupancy status	
Parameter	df	F	*P value*	F	*P value*	F	*P value*
Shrub height	1,31	5.96	*0.021*	0.65	0.423	0.07	0.791
Shrub foliage circumference	1,31	4.80	*0.036*	0.49	0.489	0.11	0.738
Mound height	1,31	13.71	*<0.001*	0.01	0.906	1.95	0.172
Distance to nearest mounded shrub	1,31	7.68	*0.009*	2.01	0.166	0.12	0.721

basal circumference, formed under shrubs ranging from 0.42–3.22 m in height (Table 2), suggesting that lizards will utilize a wide range of mound and shrub sizes. The distance to other mounded shrubs and cover ranged from 0.6–7.8 m (Table 2), indicating that the lizards tend to occupy areas of open habitat. Anecdotal observation also suggests that open habitat with sparse vegetation on and between the mounds is preferred by Slater's skinks (Pavey, 2004). The closely related *L. inornata* has been reported to prefer open areas with less than 30% leaf litter coverage within the vicinity of its burrow system (Daniel, 1998). From these results we can define suitable habitat for Slater's skinks as areas of open shrub land on alluvial plains, with a high proportion of shrubs having mounds higher than 5 cm. This habitat should be the focus for future management strategies and occupancy surveys.

The burrow systems of Slater's skink are relatively complex, consisting of multiple burrow openings connected by a series of tunnels. In the one mound that was excavated there appeared to be two burrow systems without an obvious internal connection. Some other burrowing species in the genus *Liopholis*, for example *L. striata* and *L. kintorei*, have been reported to construct similarly complex burrow systems (Pianka & Giles, 1982; McAlpin et al., 2011). Others have a simpler burrow system consisting of a single 'U' shaped tunnel with two openings (e.g. *L. whitii*, Hickman, 1960). *Liopholis inornata*, for example, also shows geographical variation in burrow structure from a two opening U-shaped burrow system in Western Australia to up to nine openings in eastern Australia (Chapple, 2003; Daniel, 1998; Pianka & Giles, 1982; Webber, 1979). The burrow systems of *Liopholis* species that dig in sandy substrates (*L. inornata, L. kintorei, L. multiscutata, L. striata* and *L. whitii*) all contain thinly covered exit holes or 'pop holes' that serve as escape hatches when the main opening is blocked (Greer, 1989; Hickman, 1960; Pianka & Giles, 1982; Webber, 1979), or when a predator enters another entrance. The Slater's skink burrow systems examined in the current study each contained similar pop holes, suggesting that this is a wide spread feature of *Liopholis* burrow systems.

We found no preferences in the orientation of the burrow openings in Slater's skink burrow systems. Previous studies reported that *L. inornata* preferred to orientate their burrow entrances in a northerly and north-westerly direction (Pianka & Giles, 1982; Webber, 1979), while *L. striata* preferred to orientate its burrow openings in a southerly and south-westerly direction (Pianka & Giles, 1982). In each of those cases the orientation of burrow openings was considered to relate to local basking opportunities and thermoregulatory requirements (Greer, 1989; Pianka & Giles, 1982). *Liopholis inornata* has been observed using the burrow entrance most directly exposed to the sun for diurnal activity, and the burrow entrance last exposed to the sun for evening activity (Greer, 1989; Webber, 1979). Slater's skinks have been observed basking, either partially emerged from the entrance of their burrow or on the mound just in front of the burrow entrance, primarily 2 to 6 hours after sunrise and in the 2 hours before sunset during summer (Pavey et al., 2010). The open habitat (both on and surrounding the mound) combined with multiple burrow openings as observed in Slater's skink burrow systems may provide flexible basking and shade opportunities and reduce the need for individual burrows to have specific orientation relative to the position of the sun.

Arid zone *Liopholis* species (*L. slateri*, *L. inornata*, *L. striata* and *L. kintorei*) can probably persist in regions with extremely high ambient summer temperatures through their obligate use of burrows for shelter (Chapple, 2003; Henzell, 1972; Webber, 1979). Burrows provide a stable environment with reduced temperatures, reduced

Table 4. The ambient minimum, maximum, temperature range and average temperature recorded over the season for each data logger location.

Location of temperature logger	Temperature ^{o}C			
	minimum	maximum	Temperature range (min–max)	average
Burrow	12.0	36.9	24.9	23.3
Shade	6.5	57.6	51.1	24.4
Full sun	7.3	70.2	62.9	29.9

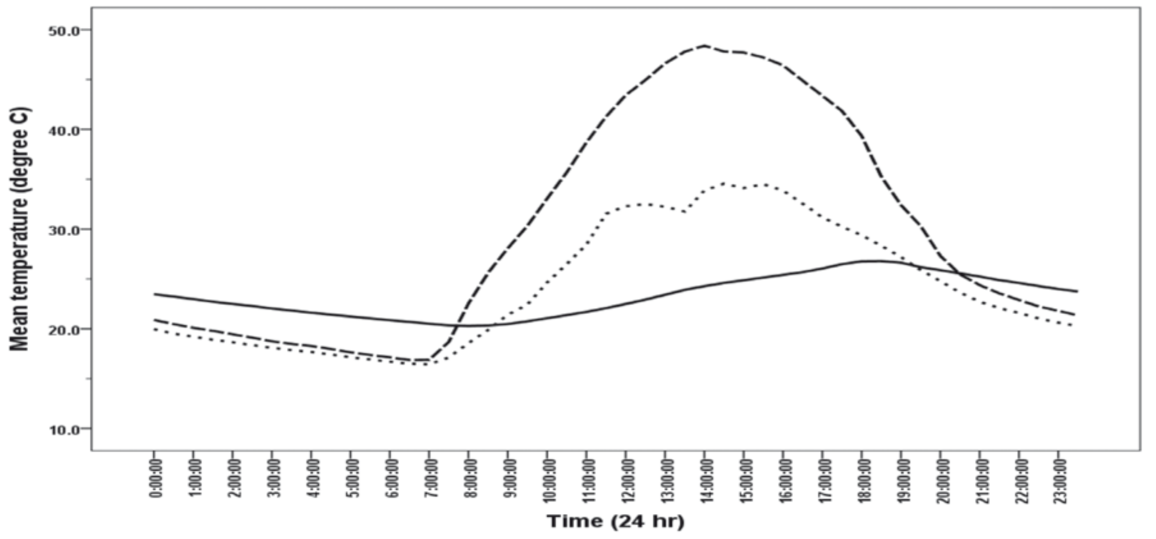

Fig. 2. Mean temperature (°C), for each half hour of day (24 hour) at each data logger location, inside the *Liopholis slateri* burrow (straight line), in the shade (dotted line) and in full sun (dashed line).

temperature ranges and elevated relative humidity to reduce rates of water loss (Chapple, 2003; Henzell, 1972). In sandy environments, the daily variation of soil temperatures also decreases with increasing depth, and there is a considerable phase delay such that the daily maxima at depths of 27 and 37 cm occurred at night and daily minima occurred during the day when surface temperatures were close to maximum (Körtner et al., 2008). Such variation can be used by burrowing skinks for thermal regulation. *Liopholis* species are considered to be posturing heliotherms, modifying their body posture to regulate heat gain, and seeking shade to cool down (Chapple, 2003; Johnson, 1977). *Liopholis inornata* and *L. striata* have a mean active body temperature of 30.1 and 30.9 °C and a maximum voluntary body temperature of 37.9 and 38.5 °C, respectively (Pianka & Giles, 1982). Assuming Slater's skink has a similar body temperature preference, individuals would be able to remain within their preferred range without venturing far from their burrows. Basking wholly or partially in full sun would enable lizards to raise their body temperatures, whilst seeking shelter in the shade or inside the burrow would enable them to lower their body temperature (Table 3).

Strategies to conserve and manage this endangered arid zone skink will require that extant habitat containing mounded shrubs and lizards be carefully managed. The invasion of exotic weeds and altered fire regimes are an ongoing threat to the persistence of this species (Pavey et al., 2010). The restoration of previously occupied habitat through weed control programs could also aid in its recovery. The development and use of artificial burrow systems to reduce the impact of weeds overgrowing existing burrows is a possible future management strategy. Artificial burrow systems could be incorporated into restoration projects, providing additional refuge alternatives in restored habitats, and secure initial refuges for lizards in translocation, relocation or captive breeding programmes. The design of those artificial burrow systems should replicate features of the natural burrows that are described in this paper.

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