Population density, microhabitat use and activity pattern of the Indian rock lizard, *Psammophilus dorsalis* (Agamidae)

Rajkumar S. Radder[1,2], Srinivas K. Saidapur[1] and Bhagyashri A. Shanbhag[1,*]

[1]Department of Zoology, Karnatak University, Dharwad 580 003, India
[2]Present address: Building A 08, The School of Biological Sciences, University of Sydney, NSW 2006, Australia

The rock lizard, *Psammophilus dorsalis* is found in rocky hills in southern India. We estimated the population density of *P. dorsalis* in three sites, each measuring ~0.5 ha, area around the village Hampi (Karnataka). The density of rock lizards was found to be ~90 per ha. The population of adults is characterized by a female-biased sex ratio. Males are larger than females and gorgeous with nuptial colours during breeding season, while females are mottled and difficult to distinguish from the stones. The species exhibits a clear sex-specific niche separation. Males occupied higher perches than females; the latter were generally found at lower heights or on ground. The daily activity pattern of the lizards of both sexes typically involves basking in the morning hours (up to 0930 h) followed by other activities such as foraging, moving, and searching for mates and oviposition sites (during breeding season). The lizards were sighted in large numbers during their peak activity period, the morning phase. The sightings declined in the afternoon (1300–1545 h) with a rise in air temperature, as they retreated to shady areas and crevices. However, during the breeding season the lizards continued their activity even during afternoons, possibly associated with the reproductive events. In the late afternoon (1600–1700 h), with a decline in ambient temperature, the lizards once again appeared in the open for foraging and

*For correspondence. (e-mail: bhagyashri_shanbhag@hotmail.com)

so on. The chief proximate factor controlling diurnal bimodal activity pattern in *P. dorsalis* appears to be ambient temperature.

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POPULATION dynamics, microhabitat use and activity pattern are the important components of animal ecology. The time of day when animals emerge from refuge and engage in activities such as basking, foraging, searching for mates and so on may be restricted to certain periods of the day or year. Indeed, most reptiles exhibit high activity during discrete times of the day/year and the factors controlling such periodicity interact in a complex manner[1–4]. In reptiles, patterns of daily activity range from nocturnal to diurnal with various intermediate conditions and in some cases activity rhythms are not encountered[2,5,6]. Further, the activity patterns may be unimodal or bimodal depending upon the species/subspecies, or among different populations of the same species living in different climatic conditions and geographic locations[2].

Lizard communities may achieve resource partitioning by spatial or temporal separation in their activity patterns depending upon the habitat, prey availability and thermal ecology[1,2,7–12]. An intra-specific separation in the spatial dimension may also be of paramount importance. For example, in many species of arboreal lizards, males occupy higher perches than their female counterparts and juveniles[7,8]. Studies on activity pattern and habitat selection are limited to mostly temperate-zone lizards[2,4]. Activity patterns in reptiles that live in rocky hill areas of the tropics that experience high diurnal variation in ambient temperature, are of great interest. Studies on the ecology of rock lizards are needed to clarify their life histories, long-term monitoring of population dynamics and evolve conservation programmes. This study on the Indian rock lizard, *Psammophilus dorsalis* (Agamidae) describes its population density, microhabitat selection and activity patterns with reference to sex and season.

P. dorsalis is a medium-sized rock lizard found in southern India[13]. The lizards are seen on bare rocks on hills of Chitradurga, Sravanabelagola, Koppal, Kamalapur and Hampi areas in Karnataka. They breed seasonally from April to August[14]. The dorsal body colouration and size vary between the sexes (Figure 1 *a* and *b*). Adult males are bigger than females. Three study sites were selected based on our pilot field studies. The criteria used to select the sites were such that these areas are ~ 1 km apart separated by roads and agricultural fields (thus minimizing chances of migration of lizards from one site to the other). The study sites were ~ 0.5 ha each and located near the village Hampi (15°18′N 75°2′E). These are hilly areas with rocks of various heights and ruins of Vijayanagar Empire belonging to the 14th century. Inscriptions of *P. dorsalis* are also encountered on stones of these ruins in one of the study sites. The area exhibits little or no vegetation (Figure 1 *c*) and annual diurnal temperature ranges from 20° to 47°C. Human disturbances at these sites were relatively low.

Random searches for *P. dorsalis* were conducted during the breeding (April–August 2001; $n = 13$ days) and post-breeding (November 2001–February 2002: $n = 7$ days) seasons with naked eyes and where necessary, using field binoculars. The lizards are shy and do not allow a closer approach. The survey was conducted between 0800 and 1230 h, 1300 and 1545 h and from 1600 – until sunset. Point sighting method was adopted to collect data, as it is suitable for the rocky hill habitat. Point sightings are mapped records of static locations of the lizards made while walking gradually along a predetermined path around each study site. Because the study sites consist of boulder fields, during census walk we could readily sight all emergent lizards from the edges of the mapped study plots. The survey consisted of inspecting the chosen site twice using the same path during each part of the day. Six such surveys were conducted for each site covering different phases of the reproductive cycle. Upon spotting an adult specimen, its sex and perch height (in m) were recorded. Sex was identified by colour and morphological traits such as thickness of tail base and head size, which are prominent in the case of male. It was not possible to record perch height for all individuals,

Figure 1. ***a***, Male *Psammophilus dorsalis*; ***b***, female *P. dorsalis* and ***c***, a view of one of the study sites. Note the prominent sexual dimorphism.

since some of them were spotted at a height that was inaccessible for measurement. For convenience, the microhabitat was divided as 'stones' and 'rocks' based on perch height. If the given perches were < 1.0 m in smallest linear dimension they were considered as 'stones', and perches > 1.0 m were considered as 'rocks', according to Grant and Dunham[15]. For each lizard, the type of activity (basking, foraging, moving, or stationary) was recorded. Exposure and orientation of head and body towards the sun for more than 5 min constituted basking. Slow searching movements and rapid darts for prey, catching and chewing prey items indicated foraging activity. Movements that did not involve foraging were grouped under the category 'moving'. Individuals were observed carefully for distinguishing marks and direction of movement to avoid multiple counting. Ambient air temperature was measured using a field thermometer.

All observations were considered as independent samples since the activities rather than individuals were recorded. The assumption of independence is thus valid[16]. Data on each observation of a given day/site were pooled. Since there was no variation in the data between the sites for a given block of survey, pooled data of the three sites were considered for statistical analyses to avoid pseudo-replication. Variations between the number of active lizards sighted during morning, afternoon and late afternoon were analysed by one-way ANOVA followed by Duncan's Multiple Range Test (DMRT). Prior to ANOVA, homogeneity of variance and normal distributions were tested by F-max test and Null–Klassen test respectively, and the assumptions of normality were met. Variation, if any, in the activity pattern between breeding and non-breeding seasons was analysed by Mann–Whitney 'U' test. A three way chi-square test was used to determine the differences, if any, in the activity patterns (basking, foraging and moving) among and between sexes with respect to phase of the day. The relationship between various recorded variables was analysed by Spearman rank correlation. The horizontal distribution of lizards *vis-à-vis* perch height distribution was computed using Lloyd's mean crowding index, $r = m_{c/m}$, $m_c = m + (\sigma^{2/m} - 1)$ with suitable modifications, where m_c is the mean crowding index, m the mean number of individuals per sample area of size i, σ^2 the variance in number of lizards per sample of area size i. In the analyses, sample area size i refers to the height of the perch. Based on the pilot recorded perch heights, we considered $i = 10$ m for the present analyses. Theoretically, an index $r > 1.0$ indicates non-random distribution[17]. However, keeping the influence of unknown and un-measured confounding factors in mind, as a rule, an index > 1.5 was considered as clustered or non-random distribution. Differences, if any, between sexes with respect to perch height were analysed by unpaired Student's t test. Statistical analyses were performed using SPSS and Statistica Softwares. Significance was accepted at $P < 0.05$ level.

A total of 114 h (5 min/lizard) of observation was made. The mean number of lizards sighted during morning hours was significantly greater than that of the afternoon or late afternoon (evening) recordings (ANOVA: df = 251, $F = 130.41$, $P < 0.001$, Table 1). The sighting of lizards declined in all the studied sites between 1300 and 1545 h (Spearman correlation $r = -0.70$, $P < 0.001$, $n = 54$ observation blocks). However, in late afternoon hours (1600–1900 h), the number of lizards sighted increased over afternoon recordings (Figure 2).

On an average, as many as 90 rock lizards per ha were encountered in each of the three sites surveyed. During the breeding season, a maximum of 160 active lizards was sighted from the three study sites. At all times, the number of females was significantly greater compared to the males (Paired 't' test: df = 52, $t = 10.61$, $P < 0.001$). About 192 males and 318 females (n = 18 observations) were sighted in the ~ 1.5 ha area surveyed. In general, the studied activity patterns in both sexes were comparable with respect to a given phase of a day. However, males emerged relatively earlier than females and began basking.

P. dorsalis were generally encountered over sand gravel, stones and rocks, and never on tree trunks. They moved between rocks and fed on insects. The perch height varied significantly between sexes and season (Figure 3 *a*). Females invariably occupied lower perches on stones unlike the males (unpaired t test; $t = 20.8$, $P < 0.01$). The distribution of perch was non-random in females as ~ 74.3% of them perched at a height of < 2.0 m (mean crowding index $r = 1.86$; $i = 10$ m, Figure 3 *b*). On the other hand, in the males perching was random (mean crowding index $r = 0.87$; $i = 10$ m); 8% males perched at heights < 2.0 m; 23.6% at 2.0–4.0 m, 34.8% at 4.0–6.0 m; 17.4% at 6.0–8.0 and 16% at a height > 8 m (Figure 3 *b*). There was thus wide variation in the use of perch height in case of male rock lizards. Further, females perched at comparable heights during both breeding and post-breeding seasons (unpaired t test; $t = 0.85$, $P > 0.05$; Figure 3 *a*). In contrast, males perched at significantly greater height during breeding season compared to post-breeding season (unpaired t test; $t = 15.30$, $P < 0.01$, Figure 3 *a*).

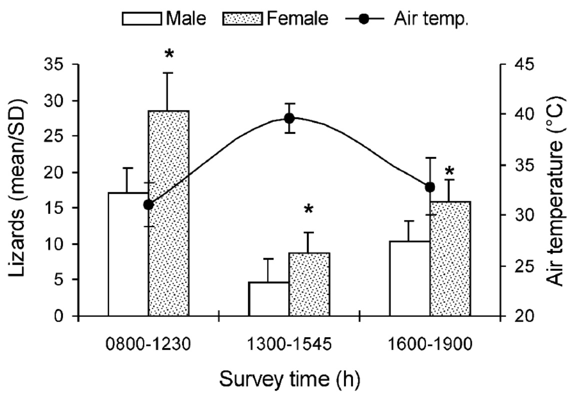

Figure 2. Mean number of male and female *P. dorsalis* sighted during different times of the day and plotted in relation to ambient temperature (mean ± SE). Combined mean of 18 surveys conducted on three sites. *Indicates a significant difference between sexes within a given survey period (based on ANOVA followed by DMRT).

Table 1. Number (mean ± SD) of *Psammophilus dorsalis* sighted in three study areas near village Hampi surveyed during the morning (0800–1230 h), afternoon (1300–1545 h) and late afternoon (1600–1900 h) periods

Time of the day	Male	Female	Total
Site I (n = 6)			
Morning	17.17 ± 5.5[a]	34.17 ± 4.1[a]	51.33 ± 8.2[a]
Afternoon	8.50 ± 1.6	12.00 ± 2.1	20.50 ± 1.8
Late afternoon	12.00 ± 2.7	17.50 ± 2.4[b]	29.50 ± 4.2[b]
Site II (n = 6)			
Morning	17.33 ± 2.4[a]	27.00 ± 3.9[a]	44.33 ± 4.2[a]
Afternoon	3.33 ± 1.2	7.67 ± 1.6	11.00 ± 2.7
Late afternoon	10.67 ± 2.0[b]	16.83 ± 2.6[b]	27.50 ± 3.6[b]
Site III (n = 6)			
Morning	17.00 ± 1.1[a]	24.17 ± 2.2[a]	41.17 ± 2.7[a]
Afternoon	2.50 ± 1.5	6.67 ± 1.5	9.17 ± 2.3
Late afternoon	8.33 ± 3.1[b]	13.00 ± 2.7[b]	21.33 ± 5.6[b]
Combined data from all three sites/0.5 ha area (n = 18)			
Morning	17.17 ± 3.3[a]	28.44 ± 5.5[a]	45.61 ± 6.8[a]
Afternoon	4.78 ± 3.1	8.78 ± 2.9	13.56 ± 5.5
Late afternoon	10.33 ± 2.9[b]	15.78 ± 3.2[b]	26.11 ± 5.6[b]

Superscript ‘a’ indicates significant difference from afternoon and late afternoon sightings and ‘b’ indicates significant difference from afternoon sightings in a given site based on one-way ANOVA followed by DMRT.
n = number of observation blocks.

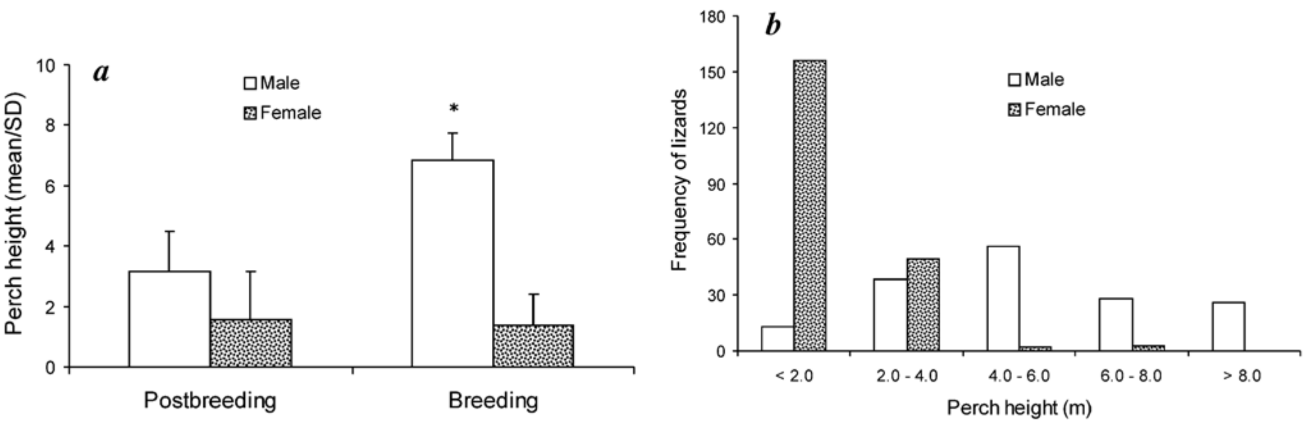

Figure 3. Difference in perch height of *P. dorsalis* in relation to the sex and reproductive phase. *Indicates significant difference between breeding and post-breeding seasons in males (based on unpaired ‘*t*’ test). ***b***, Perch height preference of males and females in *P. dorsalis*. (For both (***a***) and (***b***) n = 161 males and 210 females.)

Frequency of basking, foraging, social displays and movements were significantly greater between 0800 and 1230 h compared to other times of the day (Figure 4). Even within the morning phase, the different activities varied significantly (χ^2 = 143.38, df = 4, P < 0.01). For example, during early morning hours (0800–0930 h), basking activity was predominant (~70% lizards, χ^2 = 39.84, df = 2, P < 0.01), while foraging (~19%) or moving (~ 10%) activities were scarce (Figure 4). During mid part of the morning phase (0930–1030 h), the lizards were very active, exhibited quick responses to human approach and the three recorded activities (basking ~ 30%, moving ~ 24% and feeding 47%) were comparable in magnitude (χ^2 = 5.74, df = 2, P > 0.05). After 1100 h, the basking and foraging activities declined significantly, but overall movement of lizards increased greatly (~ 73%, χ^2 = 49.83, df = 2, P < 0.01).

Between 1300 and 1545 h, the lizards retreated to shady areas and crevices, leaving only ~ 30% of them in the open (Table 1 and Figure 2). They were relatively less mobile and less responsive to human approach. By late afternoon (1600–1900 h), more individuals (57.6%) showed up once again in the open and engaged themselves mostly in foraging (χ^2 = 7.31, df = 2, P < 0.05, Figure 4).

The total number of lizards sighted in a day was comparable during breeding and post-breeding seasons (Mann–Whitney U tests, U = 230.0, 264.50 and 235.0; P > 0.05 for females, males and total number of lizards respectively; Table 2). The number of lizards sighted at different times of the day varied significantly between breeding and post-breeding seasons (Table 2). In the morning hours, a greater number of females were encountered in breeding phase than in the post-breeding phase ($U = 6.5$, $P < 0.05$), resulting in an increase in the total number of lizards sighted during this period ($U = 16.0$, $P < 0.05$). The pattern was similar during late afternoon hours also. On the other hand, the number of males sighted did not differ between breeding and post-breeding phases with respect to morning ($U = 34.50$, $P > 0.05$) or late afternoon ($U = 16.5$, $P > 0.05$) hours (Table 2). Greater number of both females ($U = 14.0$, $P < 0.05$) and males ($U = 11.50$, $P < 0.05$) were sighted in the breeding season than the post-breeding season during afternoons in the three sites studied (Table 2).

Figure 4. Frequency of different activity patterns in *P. dorsalis* between 0830 and 1230 h (peak activity period) and during rest of the day (n = 192 males and 318 females).

Table 2. Number (mean ± SD) of *P. dorsalis* recorded in three study sites in relation to different times of the day, ambient temperature and reproductive phase

Survey time/sex	Breeding phase	Post-breeding phase
Morning (0800–1230 h); mean ± SD		
Male	17.25 ± 4.0	17.00 ± 1.10
Female	30.58 ± 5.3	24.16 ± 2.2*
Total	47.83 ± 7.2	41.16 ± 2.7*
Ambient temp. (°C)	31.20 ± 2.0	30.70 ± 1.70
	(27.0–35.5)	(29.0–33.2)
Afternoon (1300–1545 h); mean ± SD		
Male	5.45 ± 2.9	2.50 ± 1.51*
Female	10.00 ± 3.0	6.66 ± 1.5*
Total	15.75 ± 5.4	9.16 ± 2.1*
Ambient temp. (°C)	38.50 ± 3.0	37.10 ± 1.8
	(34.2–47.0)	(35.2–40.1)
Late afternoon (1600–1900 h); mean ± SD		
Male	11.27 ± 2.5	8.33 ± 3.1
Female	17.09 ± 2.5	13.00 ± 2.7*
Total	28.50 ± 3.9	21.33 ± 5.6*
Ambient temp. (°C)	32.80 ± 1.5	31.50 ± 1.2
	(31.0–35)	(31.2–34.2)

*Indicates significant difference ($P < 0.05$) between breeding and post-breeding phases based on Mann–Whitney 'U' tests. Figures in parentheses indicate range of temperature fluctuations.

The present study areas around Hampi are beset with rocky fields, little or no vegetation and experience high ambient temperature, especially in the afternoon. The rock lizard, *P. dorsalis* coexists with other reptiles such as the skinks, geckos, fan-throated lizard, garden lizard and snakes (based on shed skins seen occasionally). Others include three-striped palm squirrels (*Funambulus palmarum*), monkeys (*Macaca radiata*) and several graminivorous or insectivorous bird species and the omnivorous crows. However, a population density of *P. dorsalis* with as many as 90 specimens per ha suggests their prominence in the area. Also, the inscription of *P. dorsalis* on one of the stones in the ruins of the Vijaynagar Empire belonging to 14th century indicates their abundance in the area even in the past. Reptilian population density may vary widely. For instance, densities ranging from as low as 0.03 ha^{-1} in *Eryx tarticus*[18] to 4244 ha^{-1} in *Anolis acutus*[19] have been reported. Although population size of a given lizard species may not remain static, the present study shows that population size of *P. dorsalis* remains relatively uniform year round. However, the activity patterns contribute to fluctuations in the number of specimens sighted in different times on a given day. A characteristic feature of the adult *P. dorsalis* population is that number of females always dominated that of males. A female-biased sex ratio as seen in *P. dorsalis* may arise from a differential survival rate of males and females due to differences in predation pressure or sexual bimaturism and so on[4,18]. For instance, it is possible that males that perch at higher heights are more vulnerable to predation. On the other hand, females perching on sand gravel and stones have a greater chance of hiding in the crevices with the approach of a predator or any disturbance. However, the factors responsible for female-biased sex ratio in *P. dorsalis* are not precisely known at present.

P. dorsalis show a clear sex difference in their microhabitat preference. Males invariably occupy higher perches than females, more so during the breeding season, possibly to establish and guard their territory. However, males do descend to the ground level for foraging and mating. Likewise, occasionally some females perch at greater heights, though this never matches with that of the males. Nevertheless, a clear niche separation between males and females is obvious in *P. dorsalis*. Previously, both intra- and inter-specific niche separation within a given habitat had been reported for other lizard species. A number of biotic (presence of heterospecifics, conspecifics, inter sexual dietary divergence, etc.) and abiotic (temperature, light, moisture, etc.) factors are known to influence microhabitat preference in lizards[7–12]. Additional studies are needed to elucidate the significance of differences in the perching behaviour of male and female *P. dorsalis*.

On a given day *P. dorsalis* begin their daily activity with basking in the morning sunlight, to attain required body temperature to enable other activities like foraging and social interactions. *P. dorsalis* are most active when air temperature ranges between 30 and 36°C (usually between 1100 and 1230 h). The lizards retreat to shady areas in response to a further rise in temperature (>37°C) during afternoons. In late afternoon (1600 h), a fall in temperature seems to promote a minor peak in activity and lizards emerge from their hideouts to open fields for foraging and other activities until the sunset. The bimodal activity pattern, a major peak in the morning phase (0800–1230 h) and a minor peak in the late afternoon (1600–1900 h) was evident round the year in both sexes. A similar diurnal bimodal activity pattern is also seen in the fan-throated lizard, *Sitana ponticeriana*[20].

It is well known that activity patterns in reptiles are influenced by both exogenous and endogenous factors. The former includes seasonal changes in food availability, moisture, air and soil temperatures[2,21,22] and the latter includes circadian clock and sex steroid profiles[3,6,23,24]. In *P. dorsalis*, the activity peaks were seen when ambient temperature ranged between 30 and 36°C. Air temperatures above 37°C reduced their activities and forced them to retreat to shady areas, possibly to avoid stress due to heat or bright light[2,21,22]. The findings suggest that air temperature is the chief proximate factor controlling diurnal bimodal activity pattern in rock lizards. A delayed emergence (for basking) of rock lizards on cloudy days, when prevailing temperatures are low, supports the above view. A recent study on desert lizards, *Aspidoscelis inornata* and *Aspidoscelis gularis* suggested that diurnal activity pattern is primarily controlled by circadian rhythm[6]. However, it is not known whether such an endogenous circadian rhythm controls activity pattern of *P. dorsalis* also, as data based on experimental manipulation of light–dark cycles are lacking. If we presume that activity pattern in *P. dorsalis* is also controlled by circadian clock, delayed emergence on cloudy/rainy days may indicate masking effect of environmental stimuli over circadian rhythm, as suggested in some reptiles[3,22].

The rock lizards of both sexes exhibit a marked seasonal variation in activity patterns. Active females were more frequently sighted throughout the day during breeding season in contrast to post-breeding phase, unlike their male counterparts. Interestingly, during the breeding phase, both sexes exhibited greater activity even during afternoons, despite high ambient temperature. Such sex-specific activity pattern, especially during the breeding phase, may be attributed to reproductive events such as searching for mates and oviposition sites. In male *P. dorsalis*, plasma testosterone (*T*) levels are high during the breeding season compared to non-breeding season (our unpublished data). Elevated levels of *T* during the breeding season may induce increased activity in males even during the afternoons. A recent study on *Sceloporus jarrovi* has shown that elevated *T* is indeed responsible for increased daily activity of males[24]. Presumably, such extended activities may enhance social interactions with conspecifics and successful breeding.

In summary, the present findings on *P. dorsalis* show a female-biased sex ratio and a density of $\sim 90^{-h}$ in the surrounding areas of Hampi. The microhabitat selection and perching behaviour of the Indian rock lizard differ greatly between the sexes, with males perching at a greater height than their female counterparts. The activity pattern of *P. dorsalis* is bimodal and appears to be controlled by environmental temperature. A possible control of activity pattern in *P dorsalis* by circadian rhythms is yet to be determined.

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