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Where to “Rock”? Choice of retreat sites by a gecko in a semi-arid habitat

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Abstract. The Selvagens gecko (*Tarentola boettgeri bischoffi* Joger, 1984) is a medium sized gecko endemic to the Selvagens archipelago, Madeira, Portugal. The biology of this gecko is poorly known and in this study we present the first evidence regarding its habitat use. In 2010 (spring and autumn) and 2011 (spring), we collected data on the characteristics of the habitat surrounding 168 rocks used by these geckos as retreat sites, as well as on 75 randomly selected rocks. We also recorded body measurements of the individuals caught under each rock. In both seasons retreat site occupancy was found to be related to rock area, with geckos being found mainly under large rocks. Interestingly, we found that in spring heavier males, in better body condition, occupied the largest rocks and larger geckos occupied rocks closer to creek beds. Our results shed some light upon the behavioural ecology of this nocturnally active ectotherm, that spends the day under a retreat site: i) intraspecific competition may be an ecological factor prevalent in this species, since larger individuals occupy larger rocks, located in a presumably high quality micro-habitat; ii) the possibility of spring territoriality in males, that compete for good quality shelters.

Keywords. Selvagens, habitat use, retreat sites, territoriality, *Tarentola boettgeri bischoffi*.

INTRODUCTION

Geckos (Gekkota) show a high diversity among reptiles and play a remarkable ecological role, particularly in warm and arid environments (Vitt and Caldwell, 2009). However, knowledge of gecko's ecology lags behind that of other vertebrate taxa (e.g., Downes and Shine, 1998; Ikeuchi et al., 2005), and only recently attracted increasing attention (Hibbitts et al., 2012; Lisicic et al., 2012; Vasconcelos et al., 2012a; Ibrahim, 2013). We suspect that the slow progress in knowledge about this group has been mainly due to their specific features (e.g., largely nocturnal, mostly living in inaccessible areas and difficult to capture).

Understanding the use of a species' microhabitat is key for a good knowledge of its ecology and for guiding con-

servation actions (Huey, 1991; Kacoliris et al., 2009). Due to their dependence on environmental temperature, the selection of suitable retreat sites is of particular importance to ectotherm lizards such as geckos, particularly in temperate zones. The habitat surrounding retreat sites may influence physiological performance and individual behaviour (Huey, 1991; Hibbitts et al., 2012) and, consequently, impact upon population and community dynamics (Pulliam and Danielson, 1991; Rosenzweig, 1991). The choice of suitable retreat sites may also promote social interactions, because favourable sites may be used by more than one individual (Kearney et al., 2001), and this may lead to the development of site-defence behaviour (Preten and Case, 1998).

Territorial behaviour is common among lizards (e.g., Baird et al., 1996), and has been gradually shown in

geckos. Adults of the Australian gecko *Heteronotia binoei* defend retreat sites (Bustard, 1968), whereas most males of the Barking Gecko *Ptenopus garrulus garrulus* establish their territory before the females' emergence from winter dormancy (Hibbits et al., 2012). Studies in captivity also showed gecko territorial behaviour: paired male leopard geckos *Eublepharis macularius* displayed more territorial marking than single males when exposed to a neutral test arena (Sakata et al., 2002), and encounters between male desert geckos *Coleonyx reticulatus* triggered aggressive behaviour (Dial, 1978). However, we have no knowledge of any kind of territoriality in other species (Frankenberg, 1992; Johnston and Bouskila, 2007).

The Selvagens gecko (*Tarentola boettgeri bischoffi* Joger, 1984) is a medium sized crepuscular and nocturnal gecko endemic to the Selvagens archipelago, Madeira, Portugal. This sub-species can be found in three isolated populations in the three main islands: Selvagem Grande, Selvagem Pequena and Ilhéu de Fora, occurring entirely within a protected area (Rebelo, 2008). In the island of Selvagem Grande, it is distributed from the sea level to the arid central plateau, where it reaches the highest abundance (Oliveira et al., 2010). The simple landscape of the central plateau provides an ideal site for the study of gecko ecology, as every single retreat site (loose stones) can be verified over large areas.

In this study we aimed to assess the habitat use by *T. b. bischoffi*, comparing the features of confirmed retreat sites, in the spring and the autumn seasons, with the features of potential retreat sites where the geckos were absent. We hypothesized that a key feature of the retreat site – its size – should be positively selected, as well as features associated with the resources that the immediate vicinity of the retreat site may provide, such as distance to shrubs or to humid sites. Furthermore, we also tested if there was a relationship between the quality of the retreat site and the individual traits (sex, body size and body condition) of the geckos that used them, looking for indirect evidence of retreat site defense.

MATERIALS AND METHODS

Study area

This study was carried out in the volcanic island of Selvagem Grande (30°8'45"N, 15°51'51"W), located in the eastern Atlantic, 300 km South of Madeira and 150 km North of the Canary archipelago. The island's surface is roughly 270 ha and the main topographical feature is a 150 ha stony desert plateau (at 200 m a.s.l.) that supports an arid ecosystem (Oliveira et al., 2010) (Fig. 1). The climate is sub-tropical and semi-arid, with a rainy season in the boreal winter (Campos and Grana-



Fig. 1. Central plateau of Selvagem Grande. A dry creek bed can be seen in the foreground, and virtually all the regularly-spaced shrubs are *Suaeda vera*

deiro, 1999). Annual precipitation is low, but torrential, producing flash floods that created a network of approximately 0.5 m deep dry creek beds criss-crossing the plateau. There are no major rocky formations over the plateau, and practically all loose rocks can be lifted. Plant cover is increasing, after the successful eradication of rabbits and mice in 2003 (Oliveira et al., 2010). Herbaceous annuals now cover large parts of the plateau after the rains, but from May to October most of the plateau is devoid of herbs. During these months plant cover is restricted to regularly spaced shrubs, mainly of Shrubby sea-blite *Suaeda vera* with some individuals of the Macaronesian endemic *Schizogyne sericea*. Due to wind action, all shrubs are pyramid shaped and rarely grow over 1 m high. The distance among shrubs is remarkably similar (0.82 ± 0.35 m; R. Rebelo, pers. obs.) over most of the plateau, reflecting low water availability during long periods.

Selvagem Grande is an important breeding station for several species of seabirds and, other than *T. b. bischoffi*, has two other resident terrestrial vertebrates, namely an endemic sub-species of Madeira wall lizard *Teira dugesii selvagensis* and the Berthelot's pipit *Anthus berthelotii berthelotii* (Oliveira et al., 2010).

Data collection

We sampled three 1-ha plots on three occasions, grouped in two distinct seasons: spring (April 2010 and May 2011) and autumn (September 2010). In each visit, we lifted all loose rocks in each site, checking for the presence of geckos. This procedure was repeated twice in each sampling season. We collected data on habitat characteristics surrounding 168 rocks used as a retreat site by the geckos (spring $n = 129$, autumn $n = 39$), as well as on 75 randomly selected rocks (spring $n = 45$, autumn $n = 30$). We measured the following habitat characteristics: rock area (cm^2 ; width \times length, square root transformed for the statistical analyses), distances to the nearest rock and to the nearest shrub (cm), the maximum height of the nearest shrub (cm), canopy diameter (cm; estimated by the square root of the product of the longest canopy axis by its perpendicular) and registered the presence or absence of creek beds in the immediate vicinity (< 5 cm) of each rock. Abbreviations used are as follows: rock area (RA), distances to the nearest rock (DR), distances to the nearest shrub (DS), maximum height of the nearest shrub (SMH), canopy diameter (CD) and creek beds (CB).

Whenever possible, we captured geckos by hand and recorded their snout-vent length (SVL) with callipers, to the nearest 0.1 mm, and their body mass with spring scales to the nearest 0.05 g. We assigned one of the following reproductive categories to each gecko: adult female (pregnant and non-pregnant), adult male – identified by the two post-cloacal prominences corresponding to the hemipenes – or juvenile. Other studies of geckos found no differences in size at maturation between both sexes (Leclair and Leclair, 2011; Kubistch et al., 2012), and therefore individuals with $\text{SVL} \geq 4$ cm were considered adults, based on the smallest size of gravid females, as the eggs are easily seen through the body wall (Rebelo, pers. obs.). All captured individuals had both eyes photographed and were

individually identified by their iris pattern using the matching software Interactive Individual Identification System (Rocha et al., 2013). The iris pattern of *T. b. bischoffi* has been observed to remain stable during periods up to four years and consequently the method can be deemed suitable for long-term mark-recapture studies (Rocha and Rebelo, 2014). To avoid pseudoreplication, recaptured geckos were excluded from the analysis.

After the eyes were photographed and the body measurements were taken, all geckos were released at their initial point of capture.

Statistical analyses

To compare the rocks used as retreat sites and the habitat surrounding them with the random selection of rocks in each season, we performed Generalized Linear Models (GLMs) with a binomial error distribution and a logistic link function. As no correlation was found between the variables, we fitted all possible simple models relating gecko presence/absence with the habitat characteristics using the *dredge* function from the MuMin R package and then we ranked them following the Akaike information criterion with the correction for small sample sizes (AIC_c). We then employed a model averaging approach on models with $\Delta\text{AIC}_c \leq 2$ to obtain parameter estimates across the range of best final models and computed the odds ratios (OR) of the model-averaged selected variables for each season. Values of $\text{OR} > 1$ indicate a positive association between the variable and the presence of geckos, while $\text{OR} < 1$ indicate a negative association.

To assess the condition of the geckos occupying the larger rocks, we first performed linear regressions of the cubic root of body mass against SVL for each sex/age class (females, males and juveniles), and used the residuals as an estimate of body condition of all the individuals captured in spring (the relatively low sample size did not allow us to address this question for the autumn). The data met all the assumptions of linear regression. To further explore the question of which *Selvagens* geckos occupy larger rocks during spring, we used GLMs relating rock area with SVL, mass (cubic root transformed) and body condition for each sex/age. Statistical analyses were conducted with the R software, version 2.15.3 (R Development Core Team 2013).

RESULTS

The number of geckos found and their body parameters are depicted in Table 1. Although ~95% of the individuals were found alone, in several occasions there were two geckos sharing the same rock. Interestingly, in almost every case the two individuals were of different sexes, suggesting that males (the larger sex) may be more tolerant of females than of other males. However, the sample size was too low to proceed to further analyses.

Data dredging originated four models that better explained the retreat site use by geckos in spring and seven models in autumn (Table 2). In both seasons, rock

Table 1. Number of geckos, mean and standard error for SVL (mm) and MASS (g) during spring and autumn.

Individuals	Independent variable	Spring		Autumn	
		mean \pm SE	n	mean \pm SE	n
All individuals	SVL	56.45 \pm 0.76	123	51.27 \pm 1.59	39
Males		61.50 \pm 0.51	54	58.10 \pm 0.90	15
Females		57.28 \pm 0.63	47	54.45 \pm 0.98	12
Juveniles		42.25 \pm 1.67	22	39.56 \pm 2.70	12
All individuals	MASS	7.48 \pm 0.25	122	5.86 \pm 0.43	39
Males		8.77 \pm 0.16	54	8.44 \pm 0.78	15
Females (all)		8.04 \pm 0.34	47	5.92 \pm 0.33	12
Females (pregnant)		8.80 \pm 0.42	28		
Females (non-pregnant)		6.93 \pm 0.47	19		
Juveniles		2.88 \pm 0.33	21	2.57 \pm 0.37	12

area was present in all the models. In autumn, distance to the nearest shrub was included in three models, height of the nearest shrub and creek beds in two, and shrub canopy diameter in only one (Table 2).

According to the averaged-models from both seasons, for a one-unit increase in rock area we expect a probability slightly higher than 50% of finding a gecko under a rock (spring OR = 1.10; autumn OR = 1.09; Table 3).

Considering the entire spring sample, the larger rocks were occupied by individuals with longer SVL ($P < 0.05$; Table 4), heavier mass ($P < 0.05$; Table 4) and in better body condition ($P < 0.05$; Table 4). Considering each sex separately, a similar pattern was found only for adult males – heavy individuals in better body condition occupied large rocks ($P < 0.05$; Table 4). Furthermore, individuals found in the rocks close to the creek beds were larger ($P < 0.05$; Table 5) than individuals found distant to the creek beds. When considering sex/age classes separately, no differences were found (Table 5). We did not analyse the relations between gecko body dimensions and habitat variables in the autumn due to the relatively small sample size, referring to data collected only in one year.

DISCUSSION

This study showed that the distribution of the Selva-gens gecko in this island's plateau may be explained by the size of available retreat sites (rock area). Furthermore, we also showed that heavy males and in good condition tended to occupy the larger retreat sites, and larger indi-

Table 2. Models originated by the data dredging procedure for both spring and autumn seasons. CB = creek beds, CD = canopy diameter, DR = distance to nearest rock, DS = distances to the nearest shrub, RA = rock area and SMH = maximum height of the nearest shrub; df stands for degrees of freedom.

Rank	Model	Estimate \pm SE of slope coefficient	AICc	AICc weight	df
Spring					
	Null Model	Y ~ 1	1.02 \pm 0.19	172.09	146
1	Y ~ RA	-1.22 \pm 0.59	150.00	0.38	2
2	Y ~ RA + CB	-1.26 \pm 0.60	150.80	0.25	3
3	Y ~ RA + DS	-1.50 \pm 0.69	151.38	0.19	3
4	Y ~ RA + CD	-1.41 \pm 0.75	151.43	0.18	3
Autumn					
	Null Model	Y ~ 1	0.19 \pm 0.26	87.37	61
1	Y ~ RA	-1.99 \pm 0.84	80.17	0.23	2
2	Y ~ RA + DS	-2.66 \pm 0.99	80.33	0.22	3
3	Y ~ RA + SMH	-2.46 \pm 1.19	81.57	0.12	3
4	Y ~ RA + CB	-1.90 \pm 0.85	81.58	0.11	3
5	Y ~ RA + DS + SMH	-3.22 \pm 1.30	81.63	0.11	4
6	Y ~ RA + CD	-2.61 \pm 1.05	81.73	0.11	3
7	Y ~ RA + DS + CB	-2.55 \pm 0.99	81.78	0.10	4

Table 3. Parameter estimates, p-values (P) and odds ratio for the averaged models of each season. Results are shown only for significant variables: *, $P < 0.05$; **, $P < 0.01$; ***, $P < 0.001$. Mean and standard error of occupied rocks (OcRs) and control rocks (CtRs) are reported per season.

Variables	Estimate	P	Odds ratio	Mean \pm SE OcRs	Mean \pm SE CtRs
Spring					
Slope coefficient	-1.64 \pm 0.70				
Rock Area	0.10 \pm 0.03	***	1.10	31.95 \pm 1.19	23.26 \pm 1.06
Autumn					
Slope coefficient	-2.68 \pm 1.18				
Rock Area	0.09 \pm 0.03	**	1.09	33.21 \pm 1.93	25.16 \pm 1.63

viduals tended to occupy retreat sites close to the dry creek beds.

The size of retreat sites has already been demonstrated to be a good predictor of its use by other species of rock-dwelling geckos (Shah et al., 2004; Croak et al., 2008; Vasconcelos et al. 2012a). The area of a retreat site

Table 4. Results of GLMs relating gecko morphological features with occupancy of larger rocks during spring. *, $P < 0.05$; **, $P < 0.01$; ***, $P < 0.001$; df, degrees of freedom.

Individuals	Independent variable	Estimate \pm SE	df	T	P
All individuals	SVL	0.34 \pm 0.13	126	2.678	**
Males		0.25 \pm 0.45	51	0.556	0.581
Females		0.40 \pm 0.45	46	0.898	0.374
Juveniles		-0.19 \pm 0.22	21	-0.842	0.410
All individuals	MASS	12.02 \pm 3.47	115	3.463	***
Males		24.79 \pm 12.27	44	2.020	*
Females (all)		17.97 \pm 10.05	43	1.788	0.081
Females (pregnant)		0.91 \pm 15.98	24	0.057	0.955
Females (non-pregnant)		29.10 \pm 14.84	18	1.960	0.067
Juveniles		-6.80 \pm 6.31	20	-1.078	0.294
All individuals		BODY CONDITION	16.22 \pm 7.91	114	2.052
Males	55.48 \pm 21.57		45	2.573	*
Females (all)	19.42 \pm 11.82		43	1.643	0.108
Females (pregnant)	3.81 \pm 17.76		24	0.214	0.832
Females (non-pregnant)	28.56 \pm 19.57		18	1.459	0.163
Juveniles	9.12 \pm 7.50		19	-1.217	0.239

Table 5. GLMs results relating geckos morphological features with the proximity to creek beds during spring. *, $P < 0.05$; **, $P < 0.01$; ***, $P < 0.001$; df, degrees of freedom.

Individuals	Independent variable	Estimate \pm SE	df	T	P
All individuals	SVL	0.08 \pm 0.03	125	2.375	*
Males		0.02 \pm 0.08	52	0.190	0.849
Females		0.11 \pm 0.08	46	1.282	0.200
Juveniles		0.17 \pm 0.07	21	0.235	0.814
All individuals	MASS	2.44 \pm 0.94	115	2.585	**
Males		2.86 \pm 2.31	45	1.239	0.215
Females (all)		4.07 \pm 2.16	43	1.881	0.060
Females (pregnant)		6.52 \pm 3.82	24	1.704	0.088
Females (non-pregnant)		1.32 \pm 2.89	18	0.457	0.648
Juveniles		0.39 \pm 2.33	20	0.166	0.868
All individuals	BODY CONDITION	0.21 \pm 1.43	115	0.146	0.884
Males		5.33 \pm 3.32	44	1.608	0.108
Females (all)		3.28 \pm 2.20	43	1.491	0.136
Females (pregnant)		7.40 \pm 4.06	24	1.823	0.068
Females (non-pregnant)		-1.95 \pm 3.87	18	0.503	0.614
Juveniles		-3.60 \pm 3.51	20	-1.026	0.305

might not be necessarily the environmental cue used by the *Selvagens* gecko in order to choose a rock. It might simply correlate with other equally or more important attributes, such as size and three-dimensional structure of the space used as a retreat site (Shah et al., 2004; Croak et al., 2008); or with the thickness of the rock (Croak et al., 2008; Huey et al., 1989), that may enhance thermoregulation, provide effective protection from predators, and/or a site for encountering potential mates (Schlesinger and Shine, 1994; Downes and Shine, 1998; Shah et al., 2004). For a nocturnally active ectotherm that spends the day under a retreat site, the quality and availability of this resource could thus be an important determinant of habitat selection with potential consequences for its fitness. In fact, patterns of habitat use during the mating and reproductive seasons in our study site (spring) were mainly influenced by the size of the available retreat sites and, for larger geckos, by the presence of a scarce resource, i.e., water. Water availability has an obvious importance in organisms inhabiting harsh and seasonal environments (Beck and Jennings, 2003). Even if only available in soil moisture, water may contribute to an increase in food (insect) availability in the immediate vicinity of the retreat sites. These two aspects can, in turn, shape social interactions, particularly retreat site defence by males.

In contrast to more complex environments, the landscape in the *Selvagem Grande* central plateau is strongly dominated by only one species of shrub, *S. vera*, and the bushes are very similar in size and shape, making the vegetation highly homogeneous. Other studies carried out in arid habitats reported a weak or even the lack of association between saxicolous reptiles, including geckos, and canopy cover (Croak et al., 2012). In this study, habitat variables were selected in all the models, but there wasn't a variable consistently selected in both seasons. In this landscape, shrubs constitute the only effective wind barrier; their dead leaves, as well as other vegetable material, accumulate more easily beneath shrubs than in the open areas, and presumably insect abundance may also be higher below shrubs.

T. b. bischoffi co-occurs in the *Selvagens* archipelago with Madeira wall lizards *T. d. selvagensis* and both species' selection of retreat sites can be influenced by their ecological interactions. However, while *T. d. selvagensis* are very abundant along the sea bird colonies on the cliffs, they are relatively rare on the central plateau.

Our results allow us to infer some interesting aspects of the *Selvagens* gecko behavioural ecology that merit further studies. First, intraspecific competition may be an ecological factor prevalent in this species whereby larger individuals (especially males) occupy larger rocks. Second, as the breeding season corresponds to the spring

months, our results suggest the occurrence of spring territoriality in males that compete for good quality shelters. Published literature shows that smaller subordinate male geckos are forced by larger dominant males to occupy low quality shelters (Downes and Shine, 1998), or that juvenile geckos occupy smaller rocks than adults (Vasconcelos, et al., 2012a). Moreover, male *Selvagens* geckos were not observed sharing retreat-sites with other males (Rebelo, pers. obs.), similarly to what has been found in other arid habitats, (Schlesinger and Shine, 1994; Downes and Shine, 1998; Vasconcelos et al., 2012a), reinforcing our suspicions about the occurrence of spring territorial behaviour in the *Selvagens* gecko.

To the extent of our knowledge, this is the first study on habitat use patterns of *Tarentola boettgeri bischoffi*. This study aimed to shed some light in the basic ecological aspects of a threatened subspecies, living on an island whose vegetation is recovering from centuries of occupation from rabbits and mice. This species belongs to the most species-rich genus of geckos of NW Africa and the Eastern Atlantic islands (Vasconcelos et al., 2012b). Given the conservative morphology of all the species of this genus, we expect that our findings will trigger future research on habitat selection patterns and territoriality in this group.

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