



Factors affecting the spatial ecology of the lizard *Liolaemus wiegmanni* in the pampasic coastal dunes of Argentina

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Home ranges of lizards are the result of both internal (body condition, reproductive status) and external factors, such as habitat features and resource availability. Habitat modification induced by introduced plants affects habitat use for lizards by changing food abundance, environmental temperatures or by homogenising the habitat structure. We compared the home range of the lizard *Liolaemus wiegmanni* in two situations: a partially forested habitat (20% of the total surface covered by *Acacia longifolia*) and a non-forested habitat. Twelve adult lizards were radio-tracked in the forested habitat and ten in the non-forested site. Home ranges were calculated using the minimum convex polygon method. The mean home range size was $37.80 \pm 17.95 \text{ m}^2$ and was not different between both habitat types. Home ranges of males were 1.6 times larger than those of females. Abundance of food was highest in the forested habitat, without an apparent effect on home range size. Home range in *L. wiegmanni* showed a marked association with mixed patches of native grassland, bare sand substrates and scarce coverage of exotic trees. Our data suggest that movements in *L. wiegmanni* may be mainly related to structural features (and their associated thermal cues) of specific microhabitat types. Although low levels of forestation with *A. longifolia* have less effect on the home range size and movements of lizards, we cannot ignore previous results showing that occurrence, abundance and body condition of *L. wiegmanni* are negatively affected by extensive forestation of exotic plants both at local and landscape scales in pampasic dunes.

Key words: exotic plants, grasslands, home range, *Liolaemus*, radio-telemetry, sand lizard

INTRODUCTION

The home range of individuals represents complex and dynamic patterns of space use resulting from routine activities associated with basic life-history traits (Rose, 1982; Börger et al., 2006). Home ranges can be shaped by both internal (e.g., body condition, reproductive status) and external (e.g., habitat structure and composition, food abundance, social system) determinants, in addition to changes of ecological requirements during an individual's lifetime (Perry & Garland, 2002; Börger et al., 2008; Halloy et al., 2013). In a broader ecological context, home ranges can reveal information about the spatial ecology, resource holding capacity and social systems operating at population level (Civantos, 2000).

The home range of lizards is determined by factors such as sex, age, body size and habitat productivity and complexity (Perry & Garland, 2002). Male home ranges may depend on the presence and dispersion of females, while for females the selection of home ranges is more dependent on reproductive sites and food (Van Sluys, 1997; Frutos & Belver, 2007). Larger and more

dominant individuals tend to have larger home ranges (Perry & Garland, 2002; Haenel et al., 2003). Lizards may also shift their home range location and size in response to changing environmental conditions (Haenel et al., 2003; Wone & Beauchamp, 2003; Scouler et al., 2011), with home range sizes inversely related to food levels and levels of habitat complexity (Simon, 1975; Perry & Garland, 2002; Verwaijen & Van Damme, 2008). In addition, the spatial distribution of individuals can be modified by anthropogenic disturbances such as habitat modification through invasive species or through grazing (Wasiolka et al., 2009; Pettigrew & Bull, 2011; Bateman & Ostoja, 2012). In responses to these changes, lizards can modify their mobility depending on different food availability (Pettigrew & Bull, 2014), access to thermally suitable patches (Valentine et al., 2007; Stelletelli et al., 2013a, Hacking et al., 2014) and risk of predation (Hawlena et al., 2010; Stelletelli et al., 2015a).

Liolaemus comprises 250 species and is the richest genus of Iguanian lizards in South America. More than 150 species of *Liolaemus* recorded in Argentina (Abdala & Quinteros, 2014), and data on home ranges are only

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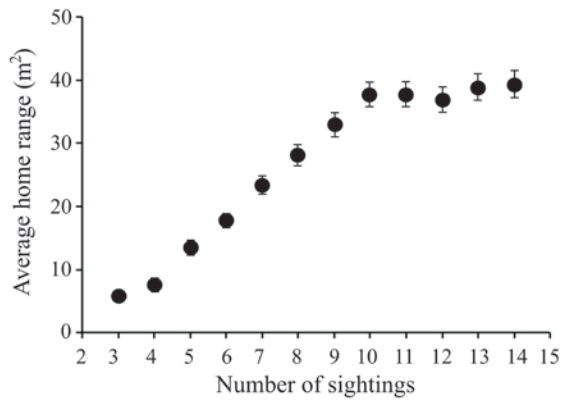


Fig. 1. Average minimum convex polygon method area, MCP (± 1 SD) versus number of sightings for *Liolaemus wiegmanni* ($n=22$) on pampasic coastal dunes of Argentina. MCP area increases until the empirical curve reaches an asymptote after ten sightings.

available for a small subset of them (Frutos & Belver, 2007; Frutos et al., 2007; Frutos, 2009; Kacoliris et al., 2009; Robles & Halloy, 2009; Cabrera & Scrocchi, 2012). Males have usually larger home ranges than females, to optimise their reproductive success and to cover their higher energy requirements (Simonetti & Ortiz, 1980; Rocha, 1999; Frutos & Belver, 2007; Robles & Halloy, 2009; Kacoliris et al., 2009; Cabrera & Scrocchi, 2012). However, although radiotelemetry has been used successfully in previous home range studies with other small lizards (Muth et al., 1978; Munger, 1984; Sound & Veith, 2000; Haenel et al., 2003; Germano, 2007; Wasiolka et al., 2009; Stevens et al., 2010; Nicholson & Richards, 2011; Romijn et al., 2014), so far it has not been applied to the family of Liolaemidae. Telemetry is a key approach to analysing how free-living animals use space and time in response to environmental factors (Naef-Daenzer et al., 2005) and provides detailed information about active as well as inactive animals which would be otherwise difficult to record (Díaz et al., 2006).

The sand lizard *Liolaemus wiegmanni* is one of four species of lizards inhabiting pampasic coastal dunes of Argentina (Gallardo, 1977; Ávila et al., 2009) and together with nine other species belongs to the *L. wiegmanni* clade

(Etheridge 2000; Ávila et al. 2009). *Liolaemus wiegmanni* is diurnal and insectivorous, with a sit-and-wait foraging strategy (Aun et al., 1999). Males show a similar body size to females (snout-vent length, SVL: 42–64 mm) but are more brightly coloured (Ceí, 1993). The species is oviparous, with an annual reproductive period from early September to late January, and a post-reproductive period from February to August (Martori & Aun, 1997; Vega, 2001). In the pampasic coast, *L. wiegmanni* uses vegetation cover of semi-fixed dunes (Vega, 2001; Block, 2014). Along the Buenos Aires province, this habitat has been progressively modified by urbanisation, forestation and exotic trees (Isla, 2013). However, knowledge about possible shifts of spatial habitat use in response to changing environments is still scarce (Vega et al., 2000), although it is known that the spatial distribution, abundance and body condition of *L. wiegmanni* is compromised by reductions in habitat quality (Stellatelli et al. 2013b; 2015b).

The aim of this study is to use telemetry to compare the spatial ecology of *L. wiegmanni* between native (grassland) and modified (partially covered by *Acacia longifolia*) habitats of coastal sand dunes. In particular, we determine the effect of sex, habitat structure and abundance of arthropods on home range size, and compare the structural configuration of the habitats within home ranges. We hypothesised that the presence of *A. longifolia* will reduce food abundance and replace the specific microhabitats that *L. wiegmanni* usually prefers. Thus, in forested habitats, lizards will move longer distances and establish larger home ranges than in more pristine habitats. We also predict that males of *L. wiegmanni* will have home ranges larger than females.

MATERIALS AND METHODS

Study sites

The study was conducted during February and March 2011 at two sites of approximately 80 ha each, located in the coastal dunes of Faro Querandí Natural Reserve (37°22'28"S, 57°04'50"W) and Mar de las Pampas village (37°18'7"S, 57°01'47"W), Buenos Aires province, Argentina. These two sites differ with respect to the

Table 1. Home range size (m²) and average distance (m) between two consecutive sighting points within the territory of *Liolaemus wiegmanni* in forested and non-forested habitats. n =number of observations; \bar{X} =mean; SE=standard error.

	Forested habitat ($n=5$)			Non-forested habitat ($n=6$)		
	$\bar{X}\pm\text{SE}$	Minimum	Maximum	$\bar{X}\pm\text{SE}$	Minimum	Maximum
<i>Home range (m²)</i>						
Female	28.59 \pm 4.25	15.47	42.24	30.96 \pm 7.20	5.63	53.11
Male	52.28 \pm 7.91	31.97	78.81	45.93 \pm 8.77	18.11	78.23
<i>Distance per move (m)</i>						
Female	3.80 \pm 1.85	0.68	5.56	4.38 \pm 3.31	1.74	10.29
Male	2.72 \pm 0.44	2.20	3.30	3.36 \pm 2.50	0.66	10.12
<i>Total distance moved (m)</i>						
Female	26.92 \pm 16.82	6.87	50.04	42.47 \pm 31.09	19.16	102.98
Male	33.94 \pm 21.22	17.6	59.50	41.23 \pm 28.46	7.31	69.22

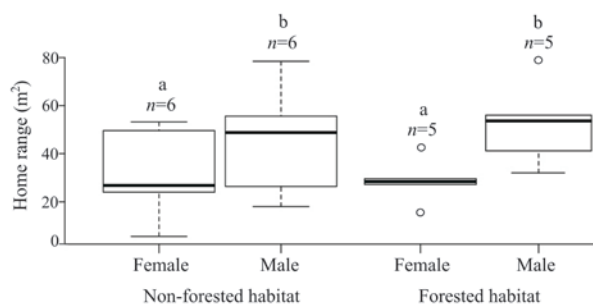


Fig. 2. Home range area of *Liolaemus wiegmanni* (m²). Horizontal bar denotes median, vertical bar denotes range, upper/lower boundary of box denotes quartile, and point denotes outliers. The letters over the bars indicate significant differences according to Tukey test ($\alpha=0.05$). n =number of samples

presence or absence of exotic tree species. The non-forested habitat (Faro Querandí Natural Reserve) maintains the native plant community (mainly comprised of the herbs *Poa lanuginosa*, *Panicum racemosum* and *Androtrichum trigynum* and *Cortaderia selloana*, as well as the shrubs *Senecio crassiflorus*, *Achyrocline satureoides*, *Discaria americana*, *Tessaria absinthioides* and *Baccharis notoserigila*). The forested habitat (Mar de las Pampas) had approximately a quarter of the total surface of the native grassland replaced by plantations of *Acacia longifolia*, and lizards are generally less frequently observed compared to the Faro Querandí Natural Reserve (Stellatelli et al. 2015b). The climate lacks dry seasons (Burgos & Vidal, 1995), with an annual mean rainfall of 930 mm; the mean annual temperature is 14°C with a maximum of 21°C in January and a minimum of 7.5°C in July (Servicio Meteorológico Nacional, <<http://www.smn.gov.ar>>).

Field surveys

Home ranges were studied by radiotracking 22 adult individuals. During the days of sampling (17–24th February and 1–8th March) the weather was characterised by continuous sunshine ($22.30 \pm 0.37^\circ\text{C}$; cloud cover $27.91 \pm 7.91\%$; wind speed 22.31 ± 2.14 km/h) and a high level of activity in lizards. Ten lizards in the forested habitat (5 females and 5 males) and twelve lizards in the non-forested habitat (6 females and 6 males) were captured by hand and noose. In the forested habitat, only individuals that were within a 2 m radius to the nearest acacia tree were captured. Sex was determined based on secondary sexual characters (Ceï, 1993). Each lizard was measured (snout-vent length, SVL) with digital calipers (SC111001, Schwyz MR., Buenos Aires, Argentina, 0.01 mm), and weighed with a portable digital balance (CH02, Diamond premium MR., China, 0.01 g). A 0.5 g radio transmitter (TXB-001 G, TELENAX MR.) was attached to the back of each individual with cyanoacrylate gel (Goodman et al., 2009). Radio transmitters represented less than 10% of lizard body mass (Knapp & Abarca, 2009). After the device was installed, the individuals were released at the site of capture.

Radio tracking started on the day after capture, aiming to reduce any irregular behaviour. Individuals were located using a LA12-Q portable receiver VHF (AVM Instrument Company Ltd., California, USA) with a three-element Yagi antenna. Radiotracking took place between 0900 and 1800 hours, the maximum activity period (Vega, 2001), using sampling intervals of approximately 2.5 hours following recommendations for small lizards by Hansteen et al. (1997) and Wasiolka et al. (2009). To keep lizards undisturbed upon recording its position, a small numbered flag was inserted into the ground 2 m north of the individual position; flags were moved to the original position of lizards at the end of the day. To estimate the position of each relocation point (flag), distances to two fixed markers were measured and x/y co-ordinates were calculated for all location points. Movement distances were defined as the straight-line distance between consecutive relocations. The total distance travelled by lizards throughout the study (m), and the mean distance per move (displacement <1 m) were calculated using the Calhome Program (MS-DOS v. 1.0, 1994; Kie et al., 1994).

To analyse the spatial distribution of lizards with respect to the structural features of the habitat, we determined substrate type (sand with or without leaf litter) and the physiognomic type of plants (trees, shrubs, sub-shrubs and herbs, following Cabrera & Zardini, 1978). The availability of microhabitats was estimated by measuring the relative percentage of coverage using 25 m² grids. We randomly set 35 grids in the forested habitat and 35 grids in the non-forested habitat, and calculated the number of replicates using species accumulation curves (Gyeseł & Lyon, 1987). Once individuals' home ranges were delimited, the total cover of each microhabitat type was estimated visually along each home range (Gyeseł & Lyon, 1987).

Food abundances were estimated using pitfall traps (12×15 cm, with eight 2×3 cm lateral holes drilled in each one, 1 cm below the top) filled with a formalin-saturated NaCl solution and detergent as a tensioactive agent, and covered with a plastic roof. Fifty traps were equally distributed in 10 transects separated 100 m from each other in each habitat type. Traps were buried into sand at

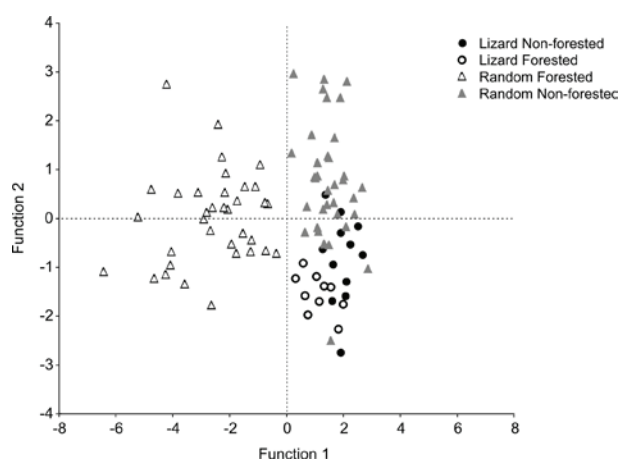


Fig. 3. Functions 1 and 2 from the discriminant functions analysis (DFA) performed on the habitat use data for *Liolaemus wiegmanni*, as well as on data from randomly chosen points.

Table 2. Mean (\pm standard deviation) percentage of cover of bare sand, leaf litter, trees, shrubs, clumps and herbs in two pampasic habitats (forested versus non-forested) compared using Kruskal-Wallis tests ($\alpha=0.05$). H =Kruskal-Wallis statistic; n =number of samples; df =degrees of freedom; p =probability value. Different letters in parentheses indicate significant differences (Dunn's post hoc test, $\alpha=0.05$).

	Forested habitat ($n=35$)	Non-forested habitat ($n=35$)	Forested home range ($n=10$)	Non-forested home range ($n=12$)	H	df	p
Trees	21.03 \pm 9.42 (a)	0.00 \pm 0.00 (b)	4.50 \pm 3.54 (b)	0.00 \pm 0.00 (b)	82.14	3	<0.001
Shrubs	6.21 \pm 8.04 (a)	26.39 \pm 16.72 (b)	29.57 \pm 7.31 (b)	38.24 \pm 13.40 (b)	47.22	3	<0.001
Sub-shrubs	2.46 \pm 4.47 (a)	9.87 \pm 10.47 (b)	0.39 \pm 0.83 (a)	2.00 \pm 1.65 (a)	20.83	3	<0.001
Clumps	7.02 \pm 10.18 (a)	6.74 \pm 11.44 (a)	24.08 \pm 12.33 (b)	13.66 \pm 16.67 (b)	16.97	3	<0.001
Herbs	9.87 \pm 7.41 (a)	11.30 \pm 8.26 (a)	10.27 \pm 10.11 (a)	11.13 \pm 6.05 (a)	1.91	3	0.755
Leaf litter	25.19 \pm 8.25 (a)	11.77 \pm 5.72 (b)	6.22 \pm 2.17 (c)	4.38 \pm 1.81 (c)	62.78	3	<0.001
Bare sand	28.19 \pm 12.26 (a)	33.91 \pm 11.49 (b)	24.94 \pm 4.35 (a)	30.56 \pm 8.75 (b)	8.47	3	<0.050

10 m intervals along the transect (Canepuccia et al., 2009). All traps were simultaneously removed after 30 days and samples were taken to the laboratory for analysis. Arthropods were determined to the level of order, only considering those orders (Hymenoptera, Araneae, Orthoptera, Diptera, Hemiptera, and Coleoptera) and range of size (0.26–196.25 mm³) represented in the diet of *L. wiegmanni* in pampasic coastal sand dunes and inland grasslands (Aun et al., 1999; Vega, 2001).

Data analysis

Home range size was calculated using minimum convex polygons (MCPs, Calhome Program, MS-DOS v. 1.0, 1994; Kie et al., 1994). Ninety five per cent of the relocation points were used to estimate the home range of each individual in order to exclude outlier data points (e.g., when a lizard was temporarily away from its usual range; Robles & Halloy, 2009). For determining the smallest number of detections to generate robust MPCs, we constructed data area curves using the number of sightings versus the mean home range area for all individuals (Rose, 1982; Halloy & Robles, 2002; Ribeiro et al., 2009). In our study, the MCP area increased until the empirical curve reached an asymptote after ten sightings (Fig. 1). No relationship between the number sightings above 10 was found with home range size ($r^2=0.019$; $F_{1,108}=2.18$; $p=0.142$); therefore, only those individuals with a minimum of ten sightings were considered to estimate their home range.

Normality and homoscedasticity were evaluated by Kolmogorov-Smirnov and Shapiro-Wilks tests, respectively (Zar, 1984). In order to fit both assumptions, data were \log_{10} transformed. Two-way ANOVA [factors: habitat (forested, non-forested) and sex] and Tukey's post-hoc comparison ($\alpha=0.05$), were used to estimate whether individuals differed in home range sizes and travelled distances (Zar, 1984). Simple Linear Regression Analysis was performed to estimate whether home ranges were related to SVL (Zar, 1984). Kruskal-Wallis test and Dunn's post hoc comparison ($\alpha=0.05$) were used to compare the percentage of cover of each

type of microhabitat outside and inside home ranges. Discriminant-function analysis (DFA) was used to assess whether structural features inside home ranges differed from random plots. Functions created by DFA of the original variables maximise the separation between groups indicating which of the variables contributed the most to the group separation (Zar, 1984). Mann-Whitney U tests ($\alpha=0.05$) were used to compare the abundance of each food item between the two study sites (Zar, 1984).

RESULTS

Overall average home range size of *L. wiegmanni* was 37.80 m² (SE=17.95 m², $n=22$). Home range size was not related to SVL ($r^2=0.08$, $F_{1,20}=1.81$, $p=0.193$). Home ranges of males were 1.64 times larger than those of

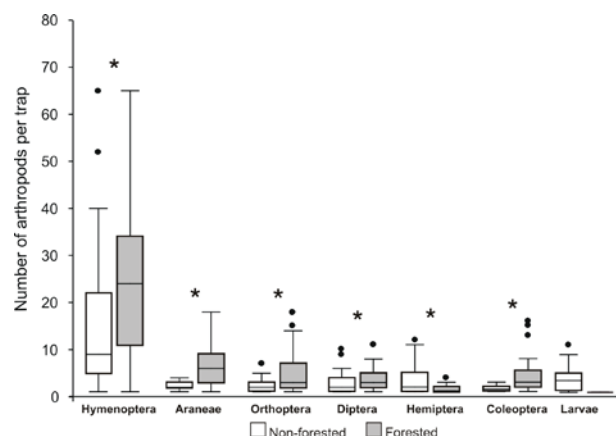


Fig. 4. Comparison of the abundance of each food item between the forested ($n=50$) and the non-forested habitat ($n=50$). Results show the number of arthropod orders that are potentially consumable by *L. wiegmanni* according to Aun et al. (1999) and Vega (2001). Horizontal bar denotes median, vertical bar denotes range, upper/lower boundary of boxes denotes quartile, point denotes outliers. Asterisks (*) indicate significant differences between forested and non-forested sites (Mann-Whitney U test, $\alpha=0.05$).

females ($F_{1,20}=6,688$, $p=0.019$; post-hoc Tukey test: $p<0.05$; Fig. 2; Table 1). The home range of individuals inhabiting the forested habitat was not different from those inhabiting non-forested habitat (Two-way ANOVA: $F_{1,20}=0.070$, $p=0.793$; Fig. 2; Table 1), and there were no interactions between habitat type and sex that could explain these variations ($F_{1,20}=0.340$, $p=0.567$). The mean distance travelled between two consecutive movements was 3.63 m ($\pm SD=2.26$ m), and was not significantly different between habitats (Two-way ANOVA: $F_{1,20}=0.408$, $p=0.531$) or sexes ($F_{1,20}=0.948$, $p=0.344$), nor was there a significant interaction among these factors ($F_{1,20}=0.005$, $p=0.939$; Table 1). The mean total distance travelled per individual was 36.29 m ($\pm SD=24.32$ m), was not significantly different between habitats ($F_{1,20}=1.069$, $p=0.316$), or sexes ($F_{1,20}=0.072$, $p=0.791$), nor was there a significant interaction among these factors ($F_{1,20}=0.131$, $p=0.722$; Table 1).

Microhabitat composition inside individual home ranges were significantly different from randomly sampled points in both habitats (Table 2). The forested habitat showed a significantly higher percentage of substrate covered by leaf litter, a significantly lower percentage of bare sand and a significantly lower coverage of native shrubs and sub-shrubs than the non-forested habitat (Table 2). All individuals included a similar type and percentage of cover of native shrubs and herbs in their home range, while coverage of *A. longifolia* trees was rare or absent (Table 2).

Based on discriminant functions, shrubs, trees, sub-shrubs, leaf litter and bare sand contributed significantly to separate the centroids of the four groups (lizard's home ranges from forested sites, lizard's home ranges from non-forested sites, random points from forested sites and random points from non-forested sites; Fig. 3; Table 3). The first discriminant function accounted for 87.3% of the total variance and was significantly correlated with shrubs, trees and bare sand, while the

second discriminant function (12.2%) was significantly correlated with the percentage of leaf litter and sub-shrubs (Fig. 3; Table 3). Table 4 shows that each of the four groups was correctly classified with 87.23% accuracy. These results show that the home range of *L. wiegmannii* included native shrubs and sub-shrubs and bare sandy soils as the main structural components in both types of habitats. Conversely, home ranges were negatively associated with trees of *A. longifolia* and soils covered with leaf litter.

The abundance of arthropods potentially consumable by *L. wiegmannii* was significantly higher in the forested habitat than in the non-forested (Hymenoptera: $U=666.00$, $n=50$, $p<0.05$; Araneae: $U=1840.00$, $n=50$, $p<0.001$; Orthoptera: $U=1009.50$, $n=50$, $p<0.05$; Diptera: $U=499.50$, $n=50$, $p<0.05$; Coleoptera: $U=935.50$, $n=50$, $p<0.001$). The only exception were Hemiptera, which were more abundant in the non-forested habitat ($U=473.50$, $n=50$, $p<0.05$; Fig. 4).

DISCUSSION

During the post-reproductive season, mean home range size of *L. wiegmannii* in grasslands of pampasic coastal dunes was 37.8 m², and did not differ between forested and non-forested habitats. Mean home range of males was 1.64 times larger than that of females. This range of intraspecific sexual variation is similar to other species belonging to the *L. wiegmannii*'s clade (Etheridge, 2000; Ávila et al., 2009; *Liolaemus lutzae*: $X_{male}=59.8$ m², $X_{female}=22.3$ m², Rocha, 1999; *L. multmaculatus*: $X_{male}=33.52$ m², $X_{female}=21.31$ m²; Kacoliris et al., 2009). Other species of *Liolaemus* showed bigger home ranges at however similar sexual differences (*L. koslowskyi*: $X_{male}=140.43$ m², $X_{female}=40.70$ m², Frutos & Belver, 2007; *L. quilmes*: $X_{male}=161$ m², $X_{female}=31$ m², Robles & Halloy, 2009; *L. kuhlmanni*: $X_{male}=775.9$ m², $X_{female}=157.7$ m², Simonetti & Ortiz, 1980; *L. espinozai*: $X_{male}=257.9$ m², $X_{female}=79.44$ m², Cabrera & Scrocchi, 2012). It is generally assumed that males have larger territories to increase their reproductive success, while in females the home range is primarily determined by energetic needs, possibly resulting in smaller areas (Rose, 1982; Perry & Garland, 2002). In *Liolaemus*, intersexual differences in home range size can be maintained regardless of reproductive condition (Frutos, 2007; Robles & Halloy, 2009; Cabrera & Scrocchi, 2012). Although the present study was conducted during the post-reproductive season, on several occasions we observed one male together with two or three females basking near the same shrub. The local sex ratio of *L. wiegmannii* is biased in favour of females (0.35; Stellatelli, 2014), suggesting a polygynous mating system.

Individuals from the habitat characterised by *A. longifolia* plantations travelled similar distances as those from the non-forested habitat, leading to indiscernible home range sizes. In the forested habitat, *L. wiegmannii* moved within sites that resembled the structural heterogeneity of native grasslands. Their location was positively related to patches of native shrubs mixed with bare sand substrates and scarce coverage of *A. longifolia*.

Table 3. Summary statistics of discriminant functions and linear correlations (r) between original variables and discriminant functions. (*) Largest absolute correlation between the variable and any discriminant function.

Statistic	Discriminant Function	
	1	2
Eigenvalue	4.156	0.581
χ^2	186.628	42.282
df	18	10
p	<0.001	<0.001
Percent variance	0.873	0.122
Linear Correlation		
Leaf litter	0.080	-0.510*
Bare sand	-0.625*	0.301
Trees	-0.836 *	-0.210
Shrubs	0.433 *	-0.223
Sub-shrubs	0.137	0.607*
Clump herbs	0.087	-0.574

Table 4. Classification results of the discriminant-function analysis (DFA). The numbers in parentheses are percentages of cases that were grouped correctly. The percentage of grouped cases correctly classified was 87.23%.

Group	<i>n</i>	Lizard/Non-forested	Lizard/Forested	Random/Non-forested	Random/Forested
Lizard/Non-forested	12	6 (50.00)	3	3	0
Lizard/Forested	10	2	8 (80.00)	0	0
Random/Non-forested	35	1	1	33 (94.28)	0
Random/Forested	35	0	0	0	35 (100.00)

Home range in lizards is related to the diversity and the structure of the vegetation, where individuals occupy patch areas of overall higher quality (Jones & Droge 1980; Ruby & Dunham, 1987; Gil et al., 1988). Individuals of *L. wiegmanni* are more exposed to shade in forested habitat (Block et al., 2013, 2014). Lizards require heat to maximise physiological processes such as locomotor performance and/or foraging efficiency (Angilletta et al., 2002; Pianka & Vitt, 2003). In heterogeneous patches such as native pampasic grasslands, different levels of vegetation cover allowed lizards to actively select them according to their thermal demands (Huey & Pianka, 1977; Díaz & Cabezas-Díaz, 2004). Like other species of *Liolaemus* (Labra et al., 2001; Martori et al., 1998), *L. wiegmanni* regulates its body temperature by shuttling to different microhabitats and substrate temperatures that vary in their exposure to sunlight at different times of the day (Block et al., 2013). Thus, *L. wiegmanni* establishes its home range in remnant patches of native shrubs and bare sand soils that provide better thermoregulation opportunities (Block et al., 2014; Stelletti et al., 2013b).

Abundance of arthropods was higher in forested than in non-forested habitats. Therefore, there was no clear link between arthropod abundance and home range size in *L. wiegmanni*. As is the case of *A. longifolia* in the pampasic dunes, exotic trees can increase the abundance of arthropods because they increase the stability of microclimate and resource availability (Holmes, 1990; Wilkie et al., 2007). Consequently, other factors such as actual availability of food rather than just abundance might explain a similar home range size in both habitat types. Access to potential prey could be influenced by their abundance as well as their distribution (Lo-Cascio & Capula, 2011), risk of exposition to predators (Pérez-Tris et al., 2004) and thermoregulatory needs (Brown & Griffin, 2005). Furthermore, individuals of *L. wiegmanni* may have set minimum home range sizes to include adequate amounts of food, refuges and thermal suitable sites under varying conditions of vegetation structure.

Home range location in *L. wiegmanni* showed a marked association with mixed patches of native grassland, bare sand substrates and scarce coverage of exotic trees, whereas arthropod abundance appears to have played only a minor role. Our data suggest that movements and home range size could be mainly guided by structural features of specific microhabitat types. The presence, abundance, and body condition of *L. wiegmanni* are negatively affected by forestation activities at both local and landscape scales (Stelletti et al., 2013b; 2015b; Block, 2014). Contrary to our expectations, however, low levels of forestation with *A. longifolia* had little effect on

home range size and movements of *L. wiegmanni*. This should be considered when taking into account strategies to protect this species in the pampasic coastal dunes.

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REFERENCES

- Abdala, C.S. & Quinteros, A.S. (2014). Los últimos 30 años de estudios de la familia de lagartijas más diversa de Argentina. Actualización taxonómica y sistemática de Liolaemidae. *Cuadernos de Herpetología* 28, 55–82.
- Angilletta, M.J., Niewiarowski, P.H. & Navas, C.A. (2002). The evolution of thermal physiology in ectotherms. *Journal of Thermal Biology* 27, 249–268.
- Aun, L., Martori, R. & Rocha, C. (1999). Variación estacional de la dieta de *Liolaemus wiegmanni* (Squamata: tropiduridae) en un agroecosistema del sur de Córdoba, Argentina. *Cuadernos de Herpetología* 13, 69–80.
- Ávila, L.J., Morando, M., Pérez, D.R. & Sites Jr., J.W. (2009). A new species of *Liolaemus* from Añelo sand dunes, northern Patagonia, Neuquén, Argentina, and molecular phylogenetic relationships of the *L. wiegmanni* species group (Squamata, Iguania, Liolaemini). *Zootaxa* 2234, 39–55.
- Bateman, H.L. & Ostojka, S.M. (2012). Invasive woody plants affect the composition of native lizard and small mammal communities in riparian woodlands. *Animal Conservation* 15, 294–304.
- Block, C. (2014). *Selección de hábitat a escala de paisaje y microhábitat en lagartijas arenícolas: herramientas para el manejo sustentable del ecosistema dunicola costero de la Provincia de Buenos Aires*. PhD Thesis. Universidad Nacional de Mar del Plata, Mar del Plata, Argentina.
- Block, C., Stelletti, O.A., García, G.O., Vega, L.E., et al. (2014). Thermoregulation in coastal sand dunes: impacts of the habitat modification on the Wiegmann's lizard. In *Lizards: Thermal ecology, genetic diversity and functional role in ecosystems*, 75–97. Kiernan M.P. (ed). Nova Science Publisher, Inc. New York.
- Block, C., Stelletti, O.A., García, G.O., Vega, L.E. & Isacch, J.P.

- (2013). Factors affecting the thermal behavior of the sand dune lizard *Liolaemus wiegmannii* in natural and modified grasslands of temperate coastal dunes from Argentina. *Journal of Thermal Biology* 38, 560–569.
- Börger, L., Danziel, B.D. & Fryxell, J.M. (2008). Are there general mechanisms of animal home range behaviour? A review and prospects for future research. *Ecology Letters* 11, 637–650.
- Börger, L., Franconi, N., Ferretti, N., Meschi F., et al. (2006). An integrated approach to identify spatiotemporal and individual-level determinants of animal home range size. *American Naturalist* 168, 471–485.
- Brown, R.P. & Griffin, S. (2005). Lower selected body temperatures after food deprivation in the lizard *Anolis carolinensis*. *Journal of Thermal Biology* 30, 79–83.
- Burgos, J.J. & Vidal, A.L. (1995). Los climas de la República Argentina según la nueva clasificación de Thornthwaite. *Meteoros* 1, 3–32.
- Cabrera, M.P. & Scrocchi, G.J. (2012). Áreas de acción en *Liolaemus espinozai* (Squamata: Liolaemidae) en Campo El Arenal, Catamarca, Argentina. *Acta Zoológica Lilloana* 56, 54–65.
- Cabrera, A. & Zardini, E. (1978). *Manual de la flora de los alrededores de Buenos Aires*. Argentina: ACME.
- Canepuccia, A.D., Cicchino, A., Escalante, A., Novaro, A. & Isacch, J.P. (2009). Differential responses of marsh arthropods to rainfall-induced habitat loss. *Zoological Studies* 48, 174–183.
- Cei, J.M. (1993). *Reptiles del centro, centro oeste y sur de la Argentina, Monografía XIV*. Italy: Museo Regionale di Scienze Naturali Torino.
- Civantos, E. (2000). Home range ecology, aggressive behaviour, and survival in juvenile lizards, *Psammadromus algirus*. *Canadian Journal of Zoology* 78, 1681–1685.
- Díaz, J.A., Monasterio, C. & Salvador, A. (2006). Abundance, microhabitat selection and conservation of eyed lizards (*Lacerta lepida*): a radiotelemetric study. *Journal of Zoology* 268, 295–301.
- Díaz, J.A. & Cabezas-Díaz, S. (2004). Seasonal variation in the contribution of different behavioural mechanisms to lizard thermoregulation. *Functional Ecology* 18, 867–875.
- Etheridge, R. (2000). A review of lizards of the *L. wiegmannii* group (Squamata, Iguania, Tropicuridae), and a history of morphological change in the sand-dwelling species. *Herpetological Monographs* 14, 293–352.
- Frutos, N. (2009). *Dominio vital, movimiento y ritmo de actividad en una comunidad de saurios patagónicos del clado Liolaemini: un análisis evolutivo*. PhD Thesis. Universidad Nacional de Córdoba, Córdoba, Argentina.
- Frutos, N. & Belver, L.C. (2007). Dominio vital de *Liolaemus koslowskyi* Etheridge, 1993 (Iguania: Liolaemini) en el noroeste de la provincia de La Rioja, Argentina. *Cuadernos de Herpetología* 21, 83–92.
- Frutos, N., Camporro, L.A. & Ávila, L.J. (2007). Ámbito de hogar de *Liolaemus melanops* Burmeister, 1888 (Squamata: Liolaemini) en el centro de Chubut, Argentina. *Gayana* 71, 142–149.
- Gallardo, J.M. (1977). *Reptiles de los alrededores de Buenos Aires*. Argentina: EUDEBA.
- Gil, M., Pérez-Mellado, V. & Guerrero, F. (1988). Estructura del hábitat y dominios vitales en *Podarcis hispanica* (Steindachner, 1870). *Miscelanea Zoologica* 12, 273–281.
- Goodman, R.M., Knapp, C.R., Bradley, K.A., Gerber, G.P. & Alberts, A.C. (2009). Review of radio transmitter attachment methods for West Indian rock iguanas (genus *Cyclura*). *Applied Herpetology* 6, 151–170.
- Germano, J.M. (2007). Movements, home ranges, and capture effect of the endangered Otago Skink (*Oligosoma ottagense*). *Journal of Herpetology* 41, 179–186.
- Gysel, L.W. & Lyon, L.J. (1987). Análisis y evaluación del hábitat. In *Manual de técnicas de gestión de vida silvestre*, 331–334. Rodríguez-Tarrés, R. (Ed). USA: The Wildlife Society.
- Hacking, J., Abom, R. & Schwarzkopf, L. (2014). Why do lizards avoid weeds?. *Biological Invasions* 16, 935–947.
- Haenel, G.J., Smith, L.C., & John-Alder, H.B. (2003). Home range analysis in *Sceloporus undulatus*: a test of spatial relationships and reproductive success. *Copeia* 1, 113–123.
- Halloy, M., Robles, C., Salica, M.J., Semhan, R., et al. (2013). Estudios de comportamiento y ecología de lagartijas de los géneros *Liolaemus* y *Phymaturus* (Iguania: Liolaemini). *Cuadernos de Herpetología* 27, 15–26.
- Halloy, M. & Robles, C. (2002). Spatial distribution in a neotropical lizard, *Liolaemus quilmes* (Liolaemidae): site fidelity and overlapping among males and females. *Bulletin of Maryland Herpetological Society* 38, 118–129.
- Hansteen, T.L., Andreassen, H.P. & Ims, R.A. (1997). Effects of spatiotemporal scale on autocorrelation and home range estimations. *Journal of Wildlife Management* 61, 280–290.
- Hawlena, D., Saltz, D., Abramsky, Z. & Bouskila, A. (2010). Ecological trap for desert lizards caused by anthropogenic changes in habitat structure that favor predator activity. *Conservation Biology* 24, 803–809.
- Holmes, P.M. (1990). Dispersal and predation of alien *Acacia* seeds: effects of season and invading stand density. *South African Journal of Botany* 56, 428–434.
- Huey, R.B., & Pianka, R.R. (1977). Seasonal variation in thermoregulatory behavior and body temperature of diurnal Kalahari lizards. *Ecology* 58, 1066–1075.
- Isla, F.I. (2013). From touristic villages to coastal cities: the costs of the big step in Buenos Aires. *Ocean & Coastal Management* 77, 59–65.
- Jones, S.M. & Droge, D.L. (1980). Home range size and spatial distributions of two sympatric lizard species (*Sceloporus undulatus*, *Holbrookia maculata*) in the sand hills of Nebraska. *Herpetologica* 36, 127–132.
- Kacolis, F.P., Williams, J.D., Ruiz de Arcaute, C. & Cassino, C. (2009). Home range size and overlap in *Liolaemus multimaculatus* (Squamata: Liolaemidae) in pampean coastal dunes of Argentina. *South American Journal of Herpetology* 4, 229–234.
- Kie, J.G., Baldwin, J.A. & Evans, C.J. (1994). *Calhome Electronic User's Manual*. United States Forest Service. USA: Fresno and Albany.
- Knapp, C.R. & Abarca, J.G. (2009). Effects of radio transmitter burdening on locomotor ability and survival of iguana hatchlings. *Herpetologica* 65, 363–372.
- Labra, A., Soto-Gamboa, M.A. & Bozinovic, F. (2001). Behavioral and physiological thermoregulation of Atacama desert-dwelling *Liolaemus* lizards. *Ecoscience* 8, 413–420.
- Lo-Cascio, P. & Capula, M. (2011). Does diet in lacertid lizards reflect prey availability? Evidence for selective predation in the Aeolian wall lizard, *Podarcis raffonei* (Mertens, 1952)

- (Reptilia, Lacertidae). *Biodiversity Journal* 2, 89–96.
- Martori, R.M., Vignolo, P. & Cardinale, L. (1998). Relaciones térmicas en una población de *Liolaemus wiegmannii* (Iguania: Tropicuridae). *Revista Española de Herpetología* 12, 19–26.
- Martori, R. & Aun, L. (1997). Reproductive and fat body cycle of *Liolaemus wiegmannii* in Central Argentina. *Journal of Herpetology* 31, 578–581.
- Munger, J.C. (1984). Home ranges of horned lizards (*Phrynosoma*): circumscribed and exclusive?. *Oecologia* 62, 351–360.
- Muth, A., Philbin, R. & Vic-Muth, J. (1978). A temperature sensitive tracking telemetry system for small reptiles (Reptilia, Lacertilia). *Journal of Herpetology* 12, 533–536.
- Naef-Daenzer, B., Früh, D., Stalder, M., Wetli, P. & Weise, E. (2005). Miniaturization (0.2 g) and evaluation of attachment techniques of telemetry transmitters. *Journal of Experimental Biology* 208, 4063–4068.
- Nicholson, K.E. & Richards, P.M. (2011). Home range size and overlap within an introduced population of the Cuban Knight Anole, *Anolis equestris* (Squamata: Iguanidae). *Phyllomedusa* 10, 65–73.
- Pianka, E.R. & Vitt, L.J. (2003). *Lizards: windows to the Evolution of Diversity*. USA: University of California Press.
- Pérez-Tris, J., Díaz, J.A. & Tellería, J.L. (2004). Loss of body mass under predation risk: cost of antipredatory behaviour or adaptive fit-for-escape?. *Animal Behaviour* 67, 511–521.
- Perry, G., & Garland, T. (2002). Lizard home ranges revisited: effects of sex, body size, diet, habitat, and phylogeny. *Ecology* 83, 1870–1885.
- Pettigrew, M. & Bull, C.M. (2014). Prey capture behaviour by pygmy bluetongue lizards with simulated grazing. *New Zealand Journal of Ecology* 38, 45–52.
- Pettigrew, M. & Bull, C.M. (2011). The impact of heavy grazing on burrow choice in the pygmy bluetongue lizard, *Tiliqua adelaidensis*. *Wildlife Research* 38, 299–306.
- Ribeiro L.B., Sousa, B.M. & Gomides, S.C. (2009). Range structure, microhabitat use, and activity patterns of the saxicolous lizard *Tropidurus torquatus* (Tropiduridae) on a rock outcrop in Minas Gerais, Brazil. *Revista Chilena de Historia Natural* 82, 577–588.
- Robles, C. & Halloy, M. (2009). Home ranges and reproductive strategies in a neotropical lizard, *Liolaemus quilmes* (Iguania: Liolaemidae). *South American Journal of Herpetology* 4, 253–258.
- Rocha, C.F.D. (1999). Home range of the Tropidurid Lizard *Liolaemus lutzae*: sexual and body size differences. *Revista Brasileira de Biologia* 59, 125–130.
- Romijn, R.L., Nelsona, N.J. & Monksc, J.M. (2014). Forest geckos (Mokopirirakau ‘Southern North Island’) display diurno-nocturnal activity and are not reliant on retreats. *New Zealand Journal of Zoology* 41, 103–113.
- Rose, B. (1982). Lizard home ranges: methodology and functions. *Journal of Herpetology* 16, 253–269.
- Ruby, D.E. & Dunham, A.E. (1987). Variation in home range size along an elevational gradient in the iguanid lizard *Sceloporus merriami*. *Oecologia* 71, 473–480.
- Scouler, K.M., Caffry, W.C., Tillman, J.L., Finan, E.S., et al. (2011). Multiyear home range ecology of Common Sideblotched Lizards in Eastern Oregon with additional analysis of geographic variation in home range size. *Herpetological Monographs* 25, 52–75.
- Simon, C.A. (1975). The influence of food abundance on territory size in the iguanid lizard *Sceloporus jarrovi*. *Ecology* 56, 993–998.
- Simonetti, J. & Ortiz, J.C. (1980). Dominio en *Liolaemus kuhlmani* (Reptilia: Iguanidae). *Anales del Museo de Historia Natural de Valparaíso* 13, 167–172.
- Sound, P. & Veith, M. (2000). Weather effects on intrahabitat movements of the western green lizard, *Lacerta bilineata* (Daudin, 1802), at its northern distribution range border: a radio-tracking study. *Canadian Journal of Zoology* 78, 1831–1839.
- Stelletti, O.A., Vega, L.E., Block, C. & Cruz, F.B. (2015a). Non-native vegetation induces changes in predation pressure and escape behavior of two sand lizards (Liolaemidae: *Liolaemus*). *Herpetologica* 71, 136–142.
- Stelletti, O.A., Vega, L.E., Block, C. & Cruz, F.B. (2015b). Responses of two sympatric sand lizards to exotic forestations in the coastal dunes of Argentina: some implications for conservation. *Wildlife Research* 41, 480–489.
- Stelletti, O.A. (2014). *Ecología de lagartijas arenícolas en hábitats modificados de la costa bonaerense*. PhD Thesis. Universidad Nacional de Mar del Plata, Mar del Plata, Argentina.
- Stelletti, O.A., Vega, L.E., Block, C. & Cruz, F.B. (2013a). Effects on the thermoregulatory efficiency of two native lizards as a consequence of the habitat modification by the introduction of the exotic tree *Acacia longifolia*. *Journal of Thermal Biology* 38, 135–142.
- Stelletti, O.A., Vega, L.E., Block, C. & Cruz, F.B. (2013b). Effects of tree invasion on the habitat use of sand lizards. *Herpetologica* 69, 455–465.
- Stevens, T.A., Evans, M.C., Osborne, W.S. & Sarre, S.D. (2010). Home ranges of, and habitat use by, the grassland earless dragon (*Tympanocryptis pinguicolla*) in remnant native grasslands near Canberra. *Australian Journal of Zoology* 58, 76–84.
- Valentine, L.E., Roberts, B. & Schwarzkopf, L. (2007). Mechanisms driving avoidance of non-native plants by lizards. *Journal of Applied Ecology* 44, 228–237.
- Van Sluys, M. (1997). Home range of the saxicolous lizard *Tropidurus itambere* in Southeastern Brazil. *Copeia* 3, 623–628.
- Vega, L. (2001). Herpetofauna: diversidad, ecología e historia natural. In *Reserva de Biosfera Mar Chiquita: características físicas, biológicas y ecológicas*, 213–226. Iribarne, O. (Ed.). Argentina: Editorial Martín.
- Vega, L., Bellagamba, P., & Fitzgerald, L. (2000). Long-term effects of anthropogenic habitat disturbance on a lizard assemblage inhabiting coastal dunes of Argentina. *Canadian Journal of Zoology* 78, 1–8.
- Verwajien, D. & Van Damme, R. (2008). Wide home ranges for widely foraging lizards. *Zoology* 111, 37–47.
- Wasiolka, B., Jeltsch, F., Henschel, J. & Blaum, N. (2009). Space use of the spotted sand lizard (*Pedioplanis l. lineoocellata*) under different degradation states. *African Journal of Ecology* 48, 96–104.
- Wilkie, L., Cassis, G. & Gray, M. (2007). The effects on terrestrial arthropod communities of invasion of a coastal heath ecosystem by the exotic weed bitou bush

(*Chrysanthemoides monilifera* ssp. *rotundata* L.). *Biological Invasions* 9, 477–498.

Wone, B. & Beauchamp, B. (2003). Movement, home range and activity patterns of the Horned Lizard, *Phrynosoma mcallii*.

Journal of Herpetology 37, 679–686.

Zar, J.H. (1984). *Biostatistical analysis*. USA: Prentice Hall.

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