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## Prevalence and intensity of blood parasites in insular lizards

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### ABSTRACT

Parasites are important in understanding population dynamics and ecology of hosts. In several Mediterranean islands, little is known about lizards' blood parasites. We studied the relations between haemoparasites and an endemic lizard host, *Podarcis lilfordi* (Günther, 1874) on Aire Island (Menorca, Balearic Islands, Spain). The infection intensity was about 1% of the red blood cells and 95% of the individuals were infected. These values are higher than in continental populations of the genus *Podarcis*. The reduced genetic variability and/or the high density in islands are proposed to explain such differences. More adults than juveniles were infected, probably because they were more often exposed to parasites during their lifetime. In adult lizards, prevalence was higher in males, may be as a consequence of their higher activity levels and more frequent physical contacts during male–male interactions. We found that infected individuals were larger than uninfected ones. A higher prevalence in adults is responsible of these differences. The intensity of infection was similar between age and sex classes. Prevalence remains stable between seasons, while parasite load increases in summer, as the availability of resources and body condition decreases. We found a relation between prevalence, intensity and body condition, with a higher prevalence and parasite load in individuals with lower condition.

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### 1. Introduction

Parasites compete with hosts for resources, causing adverse effects on many aspects as their population growth and regulation (Holmes, 1995; Hudson, 1998), spatial distribution (Price, 1980; Bouma et al., 2007), reproductive success (Schall, 1996) and sexual selection (Hamilton and Zuk, 1982). The parasite–host system shows a temporal and spatial flexibility reflected in the variation of prevalence and parasite infestation within a species or population. The parasitism on *Podarcis* lizards has been studied in several populations, but in few of them on blood parasites [*Podarcis bocagei* (Seoane, 1884) and *Podarcis carbonelli* Pérez-Mellado, 1981 (Roca and Galdón, 2010), *Podarcis muralis* (Laurenti, 1768) (Amo et al., 2005) and some introduced populations of *P. muralis* and *Podarcis sicula* (Rafinesque-Schmaltz, 1810) in North America (Burke et al., 2007)].

The haemogregarines (Apicomplexa: Adeleorina), are protozoan parasites of a wide variety of species, including reptiles. Blood parasites from lacertid lizards of the Iberian Peninsula and Canary Islands are currently classified within the genera *Hepatozoon* or *Hemolivia* (Roca and Galdón, 2010). The haemogregarines observed in this study are tentatively assigned to these two genera, because a deeper identification presents serious difficulties (Roca and Galdón,

2010). Haemogregarines shows an indirect cycle, including, at least, two hosts: a final vertebrate host, where they appear in the form of gametocytes in the blood cells, mostly in erythrocytes (in many cases, this is the only known phase of the parasite, see Telford, 2008) and an invertebrate vector. In lizards the most common vectors are ticks and mites (Telford, 2008), acquired when lizards share suitable places to bask or hide. The effects of haemogregarines in their carriers have been little studied, but, at least, we know that they destroy red blood cells causing anemia (Caudell et al., 2002). Furthermore, the presence of gametocytes in blood cells indicates the presence of schizonts in internal organs, causing additional damages (Svahn, 1974). Under laboratory conditions, blood parasites can even cause the death of the lizards (Schall, 1996). We do not have enough information to determine whether this occurs in natural populations.

Apparently only few studies have assessed parasite load on insular *Podarcis* lizards (Galdón et al., 2006; Roca et al., 2009; Huyghe et al., 2010). However, insular areas are ideal scenarios to study the effects of ecological factors on life-history traits of organisms. In the absence of human intervention, gene flow between islands is limited or absent. Some lizard populations of the Balearic lizard, *Podarcis lilfordi* (Günther, 1874) in Menorca (Balearic Islands, Spain) live in small islets, with limited trophic resources and lacking predators (Pérez-Mellado, 1989). Thus, insular populations can attain higher densities than continental ones and, therefore, individuals can interact more frequently with conspecifics. We expect to find higher rates of parasitism in insular habitats than in

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continental populations. But, also, parasitism should be higher than in other insular populations coexisting with predators. Since the conditions are less favorable in summer at Mediterranean islands (Pérez-Mellado and Corti, 1993), we expect to find higher infection rates than during spring because individuals have fewer resources to cope with infestation. During four consecutive years, we studied the prevalence and intensity of haemoparasites in the Balearic lizard from Aire Island (Menorca). As in other small coastal islets, the parasite–host equilibrium probably suffered less disruption than in larger islands or continental areas.

## 2. Materials and methods

*P. lilfordi* is an endemic lizard of the Balearic Islands. It is a medium-sized lacertid lizard (snout–vent length, SVL, to 81 mm. for males and to 75 mm. for females; Pérez-Mellado, 1998). The study was conducted during the spring and summer of years 2007, 2008, 2009 and 2010 in Aire Island, a small islet of Menorca. It is a typical Mediterranean coastal islet, with a vegetation highly influenced by its environmental characteristics (strong winds, high salinity and long drought periods). Vegetal cover is dominated by low shrubs and a variety of herbaceous species. Lizard densities can be very high, over 4000 individuals per hectare (Pérez-Mellado et al., 2008).

Lizards were collected by noosing. For each individual, we recorded age, sex, SVL, tail length and weight. Body condition was estimated from the residuals of the regression of log transformed weight versus log transformed SVL (e.g. Schall and Pearson, 2000 or Garcia-Ramirez et al., 2005 and references therein). Following Schall and Pearson (2000), we grouped individuals according to their condition, creating a ranking variable of body condition of individuals above (positive residuals) or below (negative residuals) average body condition. Schall and Pearson (2000) refer to individuals as healthy or unhealthy, as their condition was “positive” (above average of the residuals) or “negative” (below average of the residuals).

To obtain blood samples, we made a slight cut in the dorsal side of the tail with a sterile scalpel. With the detached drop blood we obtained a blood smear *in situ*. Sometimes, blood samples were obtained by clipping off the tail tip, using tail tips to extract DNA for other purposes. Specimens were always released at the site of capture. Blood smears on microscopic slides were air dried in the field. In the lab, slides were fixed in absolute methanol for 10 min and then stained in Giemsa for 20 min. Samples were analyzed using an optical microscope at 400×. The only blood parasites identified were haemogregarines (see above). The intensity of parasitism was estimated on a total of 2000 cells. Prevalence was estimated as the percentage of infected individuals.

The statistical analyses have been carried out in R environment (ver. 2.12.1, R Development Core Team, 2010). To compare the prevalence of infestation among different groups of age and sex classes, body condition or seasons we used G or Fisher’s exact tests, according to Zar (2010). Comparisons of the intensity of infection of lizards were done with one-way ANOVAs or Kruskal–Wallis tests.

## 3. Results

The prevalence of infestation by haemogregarines in *P. lilfordi* from Aire Island was 95.05% (499 of 525 individuals). We found significant differences in prevalence between adults and juveniles (G-test,  $G=5.98$ ,  $df=1$ ,  $p=0.01$ ), with a higher prevalence in adults than in juveniles (uninfected/infected: 20/463 and 6/36, respectively). Among adults, prevalence was also significantly different between sexes (G-test,  $G=3.93$ ,  $df=1$ ,  $p=0.047$ ), with a higher prevalence in males (uninfected/infected males and females: 8/289 and 12/174, respectively). There were no differences in prevalence

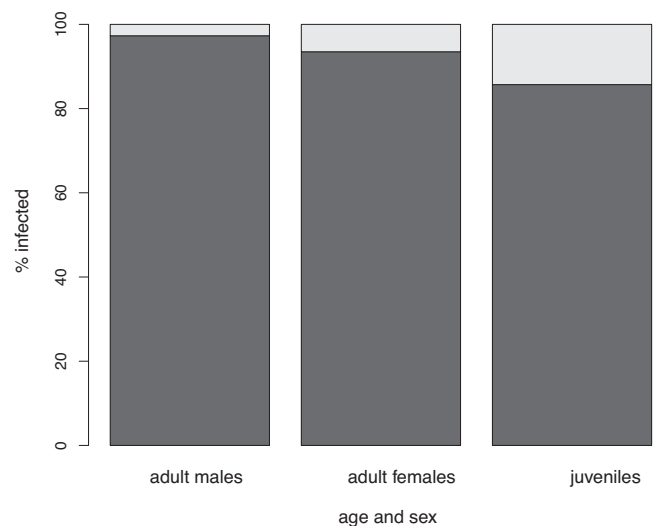


Fig. 1. Percentage of adult males, adult females and juveniles infected and uninfected.

between females and juveniles (G-test,  $G=2.50$ ,  $df=1$ ,  $p=0.11$ ; Fig. 1). In addition, we do not detected differences in the prevalence between spring and summer samples (Fig. 2), either for the whole set of individuals under study (G-test,  $G=0.11$ ,  $df=1$ ,  $p=0.74$ ), or within each age and sex category (males: Fisher’s test,  $p=0.49$ , females: Fisher’s test,  $p=0.56$ , juveniles, Fisher’s test,  $p=0.66$ ). In addition, no differences were found among years (Fisher’s test,  $p=0.06$ ).

The intensity of infection ranged from 0 to 351 infected cells in 2000 observed red cells (mean  $\pm$  SE =  $17.51 \pm 1.19$ ). There were no differences in the intensity of infection between adults and juveniles (adults: mean  $\pm$  SE =  $17.73 \pm 1.28$ ; juveniles: mean  $\pm$  SE =  $15.00 \pm 2.35$ ; one-way ANOVA,  $F_{1,523}=0.40$ ,  $p=0.53$ ), nor between each age and sex category (adult males: mean  $\pm$  SE =  $17.93 \pm 1.33$ ; adult females: mean  $\pm$  SE =  $17.36 \pm 2.54$ ; juveniles: mean  $\pm$  SE =  $15.00 \pm 2.35$ ; one-way ANOVA,  $F_{2,523}=0.20$ ,  $p=0.82$ ). Preliminary comparative data for only two seasons showed that parasite load varied significantly between seasons (Fig. 3), being higher during summer (spring: mean  $\pm$  SE =  $14.45 \pm 1.05$ ; summer: mean  $\pm$  SE =  $21.80 \pm 2.42$ ; Kruskal–Wallis test,  $\chi^2=7.28$ ,  $p=0.007$ ). In fact, the overall differences between seasons were due to those of adult males (Kruskal–Wallis test,  $\chi^2=4.53$ ,  $p=0.03$ ). In females (one-way

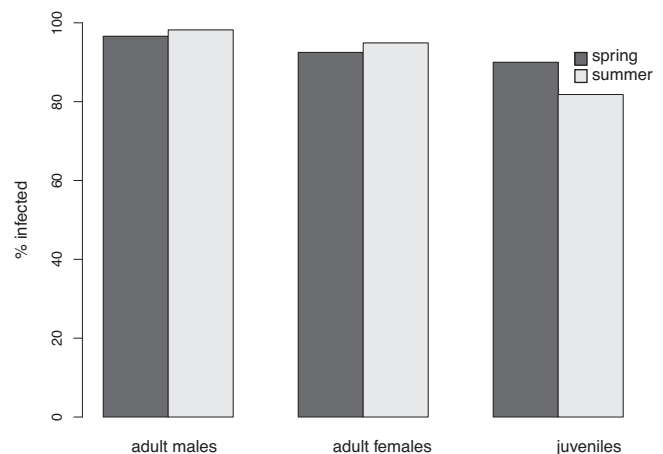
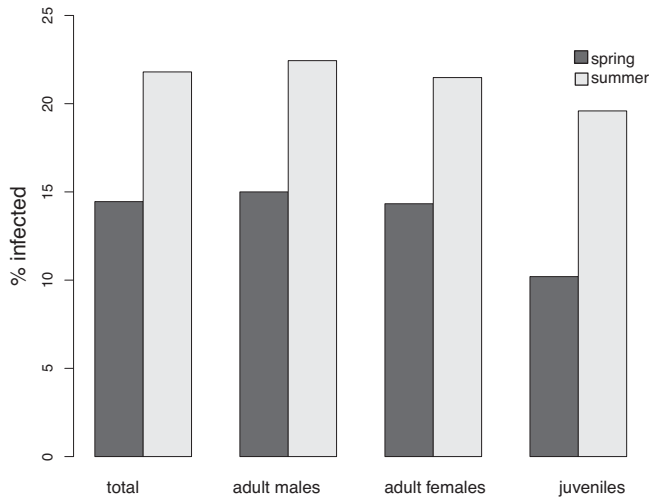


Fig. 2. Percentage of adult males, adult females and juveniles infected in each season.

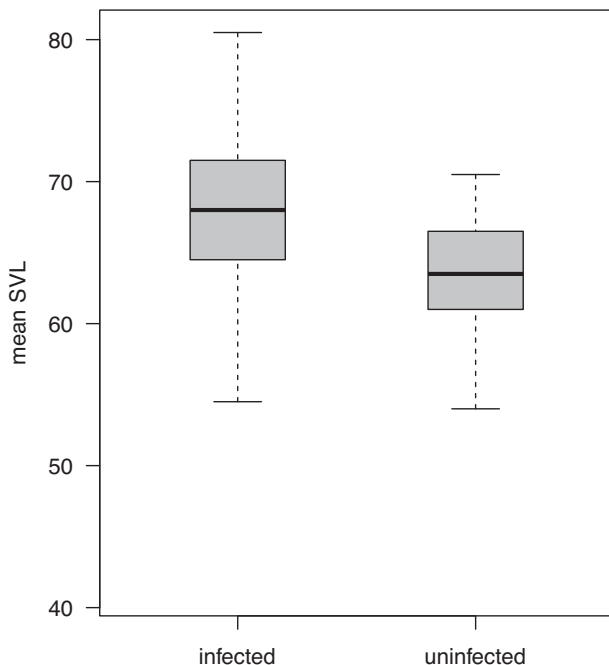


**Fig. 3.** Mean of infected cells (in 2000 erythrocytes) by season and age-sex categories.

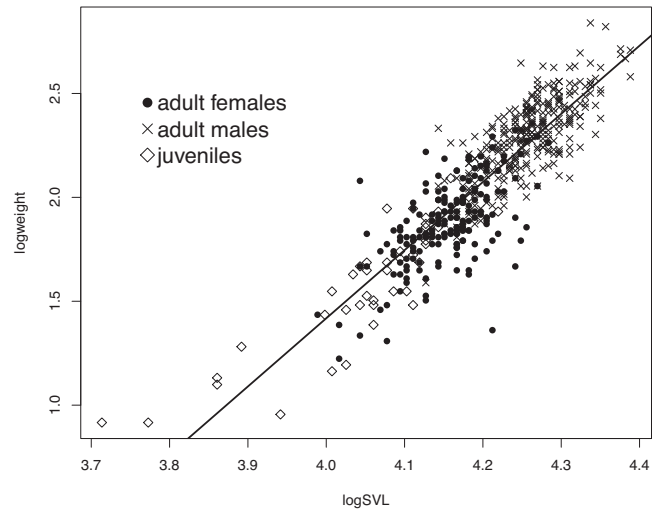
ANOVA,  $F_{1,184} = 1.95$ ,  $p = 0.16$ ) and juveniles we did not find significant differences (Kruskal–Wallis test,  $\chi^2 = 1.66$ ,  $p = 0.20$ ).

Infected individuals are larger than uninfected ones (SVL: infected mean  $\pm$  SE =  $67.55 \pm 0.25$ , non infected mean  $\pm$  SE =  $63.65 \pm 1.03$ ; one-way ANOVA,  $F_{1,523} = 12.13$ ,  $p < 0.001$ ; Fig. 4). Differences in prevalence between age and sex groups might be responsible for the differences in SVL between infected and non infected lizards. For this reason, we studied the relationship between body size and prevalence in males, females and juveniles separately. In this case, we found no relation between body size and prevalence, with only marginal differences in adult males (adult males: one-way ANOVA,  $F_{1,295} = 3.78$ ,  $p = 0.05$ ; adult females: one-way ANOVA,  $F_{1,184} = 1.41$ ,  $p = 0.32$ ; juveniles: one-way ANOVA,  $F_{1,40} = 0.20$ ,  $p = 0.66$ ). Similarly, we found no relation between body size and intensity ( $r^2 = 0.005$ ;  $F_{1,523} = 2.86$ ,  $p = 0.09$ ).

After removing the effect of SVL ( $r^2 = 0.81$ ;  $F_{2,509} = 804$ ,  $p < 2.2 \times 10^{-16}$ ), body condition was significantly different between



**Fig. 4.** Mean ( $\pm$ SE) body size (mm) of infected and uninfected lizards.



**Fig. 5.** Relation between body size (mm) and weight (g).

groups ( $F_{2,509} = 804$ ,  $p < 2.2 \times 10^{-16}$ ; Fig. 5), and the condition of lizards was lower in summer for the whole group of lizards under study ( $F_{1,503} = 177.06$ ,  $p < 2 \times 10^{-16}$ ), as well as for adult males ( $F_{1,288} = 50.07$ ,  $p = 1.134 \times 10^{-11}$ ), adult females: ( $F_{1,177} = 45.58$ ,  $p = 2.02 \times 10^{-10}$ ) and juveniles ( $F_{1,38} = 18.94$ ,  $p = 9.82 \times 10^{-5}$ ). Analyzing prevalence and condition category (see Section 2), we found that prevalence was lower among individuals with better condition (positive residuals of the body condition) than from those lizards with a lower condition (negative residuals of the body condition), both in adult males and females (for adult males: Fisher's test,  $p = 0.01$ ; for adult females: Fisher's test,  $p = 0.04$ ). We also found differences in the intensity of infestation for all individuals (Kruskal–Wallis test  $\chi^2 = 17.22$ ,  $df = 1$ ,  $p = 3.3 \times 10^{-5}$ ). We detected higher parasitemia among individuals with lower body condition. These differences were also found in adult males (Kruskal–Wallis test  $\chi^2 = 13.36$ ,  $df = 1$ ,  $p < 0.001$ ), but not separately in females and juveniles, although the number of infected cells was also higher in individuals with lower body condition.

#### 4. Discussion

This is the first study on blood parasites of the Balearic lizard. In fact, the Mediterranean lacertid lizards have been little studied from this viewpoint, especially in insular species. Prevalence of the Balearic lizard from Aire Island reached 95%, one of the highest even recorded (see references below). Only in the case of *Gallotia atlantica* (Peters and Doria, 1882) from Alegranza Island (Canary Islands, Spain), a lizard–blood parasite system with a prevalence of 100% was described (García-Ramírez et al., 2005). Thus, the prevalence in *P. lilfordi* is higher than prevalence found in continental populations of lacertid lizards as *P. muralis* (Amo et al., 2005), *P. bocagei*, or *P. carbonelli* (Roca and Galdón, 2010, see Table 1). In Tenerife Island, Oppliger et al. (1999) found in *Gallotia galloti* (Oudart, 1839) a low prevalence of hematozoans (Table 1). Burke et al. (2007) found no blood parasites in North American introduced populations of *P. muralis* and *P. sicula*, probably due to the absence of specific vectors and the recent introduction of these populations.

The higher prevalence observed in Aire Island could be related with the bottleneck effect and the degree of inbreeding, intrinsic to the origin of many insular populations. That is, the loss of genetic variability was proposed as one of the causes that can erode the resistance to parasitism (Hamilton et al., 1990). Particularly, in populations where individuals are closely related, the expected low level of genetic variability would facilitate a parasite found lower

**Table 1**  
Prevalence of infestation by blood parasites in different lacertid lizards' species.

Specie	Origin	Prevalence (%)	Authors
<i>Podarcis lilfordi</i>	Insular	95%	Present study
<i>Gallotia atlantica</i>	Insular	100%	Garcia-Ramirez et al. (2005)
<i>Podarcis muralis</i>	Continental	58%	Amo et al. (2005)
<i>Podarcis bocagei</i>	Continental	74.7%	Roca and Galdón (2010)
<i>Podarcis carbonelli</i>	Continental	69.7%	Roca and Galdón (2010)
<i>Gallotia galloti</i>	Continental	17.8–20.0%	Oppliger et al. (1999)
<i>Podarcis muralis</i>	Continental	0%	Burke et al. (2007)
<i>Podarcis sicula</i>	Continental	0%	Burke et al. (2007)

genetic resistance in the host (Shykoff and Schmid-Hempel, 1991). The lack of predation and competitors allow high lizard densities in several Mediterranean islets. In Aire Island the density reaches over 4000 individuals per hectare (Pérez-Mellado et al., 2008). Lizards' density can be an important factor, as it increases the exposure to mites of infected conspecifics, although the critical factor would be the density of the intermediate hosts (Svahn, 1974). The Balearic lizard lacks social organization, but the high density could act as a promoter of higher probabilities of infection, even if in some studies no relation between density and prevalence was found (Godfrey et al., 2006).

The prevalence of adults was higher than in juveniles. This result agrees with those obtained in *Iberolacerta cyreni* (Müller and Hellmich, 1937) by Amo et al. (2004), *Tiliqua rugosa* (Gray, 1825) (Smallridge and Bull, 2000) and *G. galloti* (Oppliger et al., 1999). Adults monopolize the best foraging and basking places where, probably, they are more exposed to vectors of blood parasites. Juveniles are normally located at less favorable areas. In fact, on Aire Island, the proportion of different age classes is significantly different at different areas of the islet (Pérez-Mellado et al., 2007; Garrido and Pérez-Mellado, in press). In addition, parasite prevalence is significantly different between males and females (see similar results in Klein, 2004). Two hypotheses have been proposed to explain these differences. First, the higher prevalence in males of *P. lilfordi* may be related to an increased activity of males in comparison with females (Pérez-Mellado et al., unpublished data) as it was proposed for *Sceloporus occidentalis* Baird and Girard, 1852 (Tälleklint-Eisen and Eisen, 1999). Second, a higher prevalence may also be related to aggressive behavior and male–male interactions, frequently observed in Aire Island. Such encounters often end up with males bite each other's the tail and even caudal autotomy and tail consumption by the opponent may occur (Pérez-Mellado, 1997). This behavior would increase the chances of transmission of blood parasites between males, as in the case of *Gallotia stehlini* (Schenkel, 1901) (Matuschka and Bannert, 1989). The level of aggressiveness is mediated by high levels of testosterone. Thus, males are more likely to be infected than females, because of the immunosuppressive effects of testosterone (Klein, 2004). We found that infected lizards were larger than the uninfected ones. Amo et al. (2004) also found that prevalence was higher in larger *I. cyreni*. In a study conducted exclusively with adult individuals of *P. muralis*, no differences were found (Amo et al., 2005). In our case, observed differences were clearly due to a higher prevalence in adult males.

We found no significant differences in prevalence among the four years of study. The stability of prevalence for long periods of time was also detected in other species of reptiles (Smallridge and Bull, 2000; Salkeld and Schwarzkopf, 2005). Between spring and summer, prevalence remained also stable for males, females and juveniles. No differences between seasons were found in other species (Amo et al., 2004, 2005; Godfrey et al., 2006). We suggest

that some individuals were infected in previous years and maintained parasite infection, while new infestations occurred at the beginning of the activity period and then remained stable. The absence of differences between years and seasons would reflect the stability of parasite–host interaction in the system under study.

Regarding parasite load, the intensity was reduced to about 1% of the cells, lower than in other insular populations (Garcia-Ramirez et al., 2005) and higher than in continental areas (Smallridge and Bull, 2000; Amo et al., 2005). Blood parasites do not reproduce within lizard red blood cells (Olsen, 1977). Therefore, as Bouma et al. (2007) suggest, hosts replace infected erythrocytes gradually and higher infection intensity might result from multiple reinfections. Thus, the high densities in islands may be the underlying reason because parasitic load in *P. lilfordi* is higher than intensity observed in *Podarcis* species from continental areas. Oppliger et al. (1998) showed that in captivity, after four weeks, parasite load of individuals living in overcrowded terraria was three times higher than in individuals from lower density terraria. Between groups, we found a similar intensity of infection by blood parasites in adults and juveniles, as it was in adult males and females. Amo et al. (2006) observed a similar situation in *Timon lepidus* (Daudin, 1802).

Body condition of individuals declined in summer for each category. Parasite load changed significantly for the overall population and for adult males separately, with higher values in summer. Juveniles and adult females showed a slight tendency to an increase in the intensity of infection. In lizard of continental populations, differences in parasite load between seasons were related with reproductive effort (Salvador et al., 1996). During the breeding season, males invest a large amount of energy in mating strategies, regulated by testosterone levels. Thus, males can experience an immunocompetence handicap during the breeding season, as suggested by Folstad and Karer (1992). However, in coastal islet around Menorca, mating period starts in February and can last until the end of July (Perera and Pérez-Mellado, 2004) and daily activity is almost continuous throughout the year. Therefore, another factor, other than reproductive effort, could be also responsible for the change in parasitic load and the loss of body condition.

In Mediterranean islets, trophic availability is limited (Pérez-Mellado and Corti, 1993; Pérez-Mellado, 1989) and the climate is characterized by strong short-term and seasonal fluctuations (Fuentes, 1984), leading to significant variations in food resources. During summer, the drought is strong at the islet under study, imposing a dramatic decrease in terrestrial arthropods. As a result, individuals could not have enough available food resources to maintain a suitable body condition to resist parasites, as they do during spring. In addition, during summer, the diet changes and plant matter consumption increases (Pérez-Mellado and Corti, 1993). In gut and intestinal parasites, the degree of herbivory is related with parasitism (Roca, 1999). There is no evidence of a direct relation in blood parasites and herbivory. But parasite vectors (acari) are more abundant in soils covered with vegetation (Resh and Carde, 2003), thus, the exposure of lizards to vectors of haemogregarines is higher while feeding on plants where they are more abundant (Biaggini et al., 2009 and references therein). Consequently, temporal changes in parasite load may be due to changing levels of host immunity as a result of a lower body condition and/or a seasonal variation in exposure to vectors and subsequent reinfections (Telford, 1984 in Brown et al., 2006). Males show higher mobility (Pérez-Mellado et al., 2007) and interact more frequently with conspecifics (Salvador et al., 1996), probably leading to an increase in exposure to parasite's vectors from infected conspecifics (Klein, 2004). In spring, these contacts are also usual, but in summer, as the condition of lizards is lower, the ability to cope with reinfestation declines and, consequently, the virulence of the new infestations may become more evident.



According with categories proposed by Schall and Pearson (2000), we found a higher prevalence in lizards with a lower condition, probably due to their reduced ability to fight against infection (see similar results in Cooper et al., 1985; Smallridge and Bull, 2000; Amo et al., 2006). These differences did not appear in juveniles, probably they were less exposed to parasites because of a shorter time to be infected. In addition, juveniles are normally located at less favorable areas. We found a higher intensity infection in individuals of lower body condition only in adult males, reinforcing the hypothesis that male–male interactions increases their probability of reinfection.

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