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SHORT COMMUNICATION

Human pressure, parasitism and body condition in an insular population of a Mediterranean lizard

Mario Garrido[1] · **Valentín Pérez-Mellado**[1]

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Abstract Many wild populations of lizards in the Mediterranean Basin inhabit small islands frequently visited by humans. Reptiles respond to humans as potential predators by escaping to refuges or by increasing antipredator behaviours which lead to a loss of body condition and may have important consequences for fitness. We assessed effects of human pressure on parasitism and body condition of the endangered insular lizard *Podarcis lilfordi* in Aire Island (Balearic Islands, Spain). Two areas differing in the number of visitors were compared at different seasons: spring, with almost no human pressure, and summer, when the major bulk of visitors arrive. Compared across seasons, the lizards from areas frequented by humans suffered a greater loss of body condition and showed a less parasitism reduction compared to individuals from the undisturbed area. Therefore, human disturbance seems to have deleterious effects on body condition and other fitness-related drivers, as parasitism. Results evidence important consequences of tourism for short- and long-term fitness of individuals and should be considered when designing conservation plans or management strategies.

Keywords Human pressure · Host-parasite system · Island · Ectoparasites · *Podarcis lilfordi* · Body condition

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✉ Mario Garrido
gaiarrido@usal.es

[1] Department of Animal Biology, University of Salamanca, Salamanca, Spain

Introduction

There is an increasing concern about the damage caused by humans in natural populations, especially in the most vulnerable ones. Over the last few decades, several populations of different lizards' species are in decline in Europe and increased tourism has been proposed to be a determinant factor in this decline (Corbett 1989; Amo et al. 2006). Human disturbance has been mainly associated with changes in the behaviour of animals, which has even been taken as an index of disturbance effects (Carney and Sydeman 1999). Reptiles respond to humans as potential predators by escaping to refuges or increasing antipredator behaviours (Amo et al. 2006; Martín and López 1999; Pérez-Tris et al. 2004). Thus, individuals lose time available for other activities as foraging and may experience further physiological costs, including a decrease in body condition (Martín and López 1999; Pérez-Tris et al. 2004). Such loss of energy may affect other physiological requirements; avoidance of predation takes precedence over immune function, so the ability to cope with parasitism is reduced (Navarro et al. 2004). Under experimental conditions, individuals exposed to a predator showed higher rates of parasitism (Navarro et al. 2004).

Throughout the summer, several reptiles' populations in Mediterranean islets are exposed to a large number of visitors but their impact on local wildlife populations has not been tested. For the endangered lizard *Podarcis lilfordi*, tourism is considered one of its major threats (IUCN 2013). It has been even proposed to control the number of visitors to the islands where the species is present (IUCN 2013). In this study, we examined body condition and ectoparasite load of individuals of *P. lilfordi* in Aire Island. We compared areas with different influx of visitors and during different seasons: spring, when visitors are sporadic, and summer, when the bulk of visitors arrive. Moreover, in summer, drought is particularly intense and resources scarce, so lizards suffer a decrease in body condition (Garrido and Pérez-Mellado 2013a). We predict that individuals living in the most visited areas suffer a greater loss in body condition and greater rates of parasitism in response to human presence.

Material and methods

P. lilfordi is a medium-sized lacertid lizard endemic of the Balearic Islands. The study was conducted during the 2007–2010 period in Aire Island (39°48′3″N 4°17′24″E), a small islet off Menorca (Balearic Islands, Spain). In Aire, the main accessible area for visitors is a narrow track of 465 m between the dock, on the northern coast, and the lighthouse in the south (Fig. 1). Two reports on the human use of Aire Island (Borrás et al. 2009; Marsinyach and López 2009) point out that tourist pressure is particularly intense during summer while during spring visitors were sporadic, 82.3 and 3.7 people per day, respectively. Almost all the visitors remain in the vicinity of the jetty or visit the lighthouse using the track. So, visitors concentrate around the track and during summer. Visitors are not allowed to stay overnight. Mean stay rarely go beyond 2 h; however, visitors who spend all day on the island are not uncommon to see in summer (pers. obs.). We divided the lizards into those found in the visitors' area, covering the entire area in the vicinity of the track, and those from the undisturbed area, the rest of the island, almost free of humans. Lizards included in visitors' area were captured no more than 4 m away from either side of the track. To ensure that captured individuals are under the sole influence of one zone, we delimited a transition zone of 60 m between the influence of the track and away from it. This transition zone was delimited according to *P. lilfordi*'s home range in Aire Island ($\overline{x}$±SE, 55.74±4.68 m^2; n=766; Pérez-Mellado et al. 2013). Lizards from undisturbed area were captured outside these limits. No differences in microhabitat characteristics exist between both areas; the only difference among areas is the presence of summer visitors.

Lizards were collected by noosing and snout-vent length (SVL); body weight and sex were recorded. The residuals of the regression of body weight on SVL were used as an index of body condition (Schulte-Hostedde et al. 2005). Condition was estimated separately for each sex due to sexual dimorphism in this population (Garrido and Pérez-Mellado 2013b). Ectoparasites were counted in situ with a ×5 magnifying lens inspecting the whole body. In Aire, lizards exhibit high rates of infection by mites, acquired indirectly when sharing suitable places for basking, foraging or hiding or by direct contact with infected conespecifics (Garrido and Pérez-Mellado 2013a, b). Mites can damage tissues, deplete fluids, trigger the immune response and serve as vectors of diseases (Wakelin 1996). In all cases, ectoparasites observed were larvae of chigger mites, assigned to family Trombiculidae (M. Moraza, pers. comm.). Lizards from each area were marked with different colour pens. Throughout the study period, marked individuals from one area were not seen in the other area. In addition, lizards already studied were easily recognised by the tiny lengthwise tail cut made to extract blood samples for other studies (Garrido and Pérez-Mellado 2013a, b). Lizards already captured were discarded. Thus, during the study, each individual was studied only once.

Statistical analyses were carried out in R environment (ver. 2.12.1, R Development Core Team 2010). We applied GLMs for males and females separately, as they showed differences in parasite load (Table 1). As parasite load distribution did not show homogeneous variances, we applied GLM's with a Poisson's distribution or, if overdispersion was detected, quasi-Poisson GLMs were fitted (Quinn and Keough 2002). Season, area and year were introduced as factors in the models

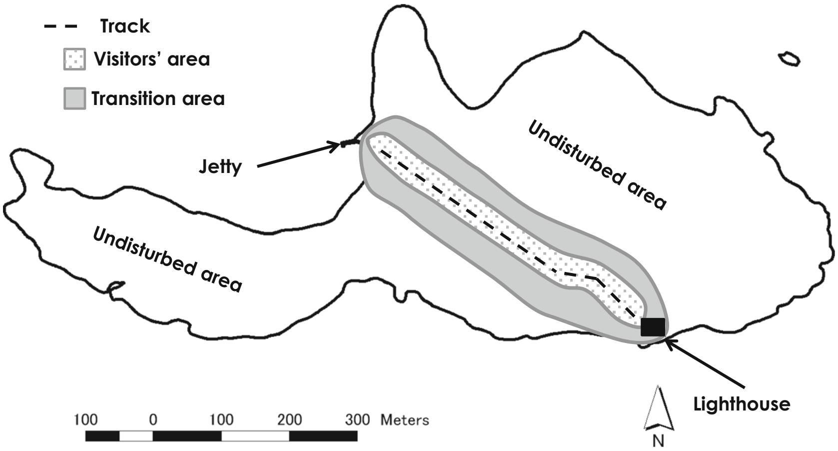

Fig. 1 Map of Aire Island including the approximate limits of the area influenced by humans (visitors' area), that is, the area of high human pressure. This area includes a perimeter of no more than 4 m on each side of the track. Then, we delimited a transition area of 60 m where we do not captured lizards, to avoid doubtful results in relation with human influence. The rest of the island was almost free of humans and we consider it as an undisturbed area (see more details in the text)

to test their effects in parasite load. In all cases, we employed a forward selection procedure adding, at each step, those variables with the greatest F value (Quinn and Keough 2002). Then, we fitted a multiplicative model, including interaction terms of the variables retained in the additive model. To select the best model, we considered at each step the larger value of adjusted r^2 along with the minimal value of Akaike's information criterion (AIC) and the Bayesian information criterion (BIC, Quinn and Keough 2002). Post hoc comparisons were made using the 'multcomp' R package (Hothorn et al. 2009).

Results

For both sexes, results for ectoparasite load were similar. Except season×area, all interaction terms were not significant (all $P>0.05$) and not retained in the minimal models (quasipoisson GLMs). Across seasons, parasite load was lower during summer (♂♂ $F_{1,\ 291}=26.29$, $P=5.42\times10^{-7}$; ♀♀ $F_{1,\ 180}=32.26$, $P=1.55\times10^{-8}$). Differences among years (♂♂ $F_{3,\ 288}=15.65$, $P=1.87\times10^{-9}$; ♀♀ $F_{3,\ 177}=13.01$, $P=1.06\times10^{-7}$) were due to lower parasite load in 2007 ($P<0.005$ in all cases). Anyway, as year-area interaction was not significant, differences among areas remained stable over years. No differences were found among areas (♂♂ $F_{1,\ 292}=1.72$, $P=0.19$; ♀♀ $F_{1,\ 181}=0.49$, $P=0.48$) but the interaction season-area was significant (♂♂ $F_{1,\ 287}=12.57$, $P<0.001$; ♀♀ $F_{1,\ 176}=17.04$, $P=5.69\times10^{-5}$). Thus, not all the areas vary among seasons in the same way, differences among areas changed throughout the seasons. Parasite loads decreased in summer in the undisturbed area (♂♂ $F_{1,\ 96}=61.11$, $P=7.30\times10^{-12}$; ♀♀ $F_{1,\ 62}=63.64$, $P=4.33\times10^{-11}$) but not in the visitors' area (♂♂ $F_{1,\ 196}=2.47$, $P=0.12$; ♀♀ $F_{1,\ 117}=3.40$, $P=0.07$). While in spring, we did not detect differences among areas (♂♂ $F_{1,\ 176}=2.09$, $P=0.15$; ♀♀ $F_{1,\ 103}=2.73$, $P=0.10$), in summer, such differences were found (♂♂ $F_{1,\ 116}=16.43$, $P=9.20\times10^{-5}$; ♀♀ $F_{1,\ 76}=15.67$, $P<0.001$; Table 1).

Ectoparasite load could be related with body size. However, Gaussian GLMs showed that in both seasons, males from the visitors' area were larger (spring: $F_{1,\ 176}=11.43$, $P<0.001$; summer: $F_{1,\ 115}=22.11$, $P<0.001$), while females had similar body sizes in both areas (spring: $F_{1,\ 105}=0.06$, $P=0.81$; summer: $F_{1,\ 77}=1.41$, $P=0.24$). Moreover, parasite load was not related to SVL (Gaussian GLMs) during spring (♂♂ $F_{1,\ 177}=0.07$, $P=0.79$; ♀♀ $F_{1,\ 103}=0.36$, $P=0.55$). In summer, parasitism increased with SVL only in the visitors' area (visitors: ♂♂ $F_{1,\ 64}=16.04$, $P=0.0002$; ♀♀ $F_{1,\ 44}=6.13$, $P=0.02$; undisturbed: ♂♂ $F_{1,\ 49}=3.98$, $P=0.52$; ♀♀ $F_{1,\ 30}=0.35$, $P=0.56$).

Gaussian GLMs revealed that, between seasons, body condition decreased in a more pronounced way in the visitors' area (♂♂ $F_{1,\ 191}=55.55$, $P=3.08\times10^{-12}$; ♀♀ $F_{1,\ 113}=38.00$, $P=1.12\times10^{-8}$) than in the undisturbed area (♂♂ $F_{1,\ 95}=7.91$,

Table 1 Counts of mites ($\overline{x}$±SE) on males and females by area and season and year

Males					Females				
Per area and season		Visitors	Undisturbed	Total	Per area and season		Visitors	Undisturbed	Total
Total		104.86±10.4 (197)	111.32±11.3 (97)	100.72±7.97 (294)	Total		81.61±9.07 (119)	73.48±12.58 (64)	78.77±7.34 (183)
Spring		116.43±14.1 (131)	154.26±18.47 (46)	129.11±11.58 (177)	Spring		94.49±12.35 (73)	133.47±20.09 (32)	106.37±10.64 (105)
Summer		81.91±13.15 (66)	40.61±5.69 (51)	57.3±8.21 (117)	Summer		61.15±12.46 (46)	13.5±2.71 (32)	41.6±7.87 (78)
Per year	2007	2008	2009	2010	Per year	2007	2008	2009	2010
Total	15.51±4.48 (31)	114.46±19.54 (78)	88.57±10.45 (103)	134.31±15.81 (82)	Total	10.95±3.25 (19)	88.02±14.99 (42)	84.07±12.45 (69)	88.83±14.49 (53)

Numbers in parentheses are sample sizes (*n*)

P=0.006; ♀♀ $F_{1,\ 62}$=10.48, P=0.002; Fig. 2). Similarly, males from the visitors' area were in a better condition in spring ($F_{1,\ 171}$=8.88, P=0.003) but did not in summer ($F_{1,\ 115}$=0.007, P=0.93). A somewhat different tendency was found for females: condition was similar among areas in spring ($F_{1,\ 101}$=0.05, P=0.82), but was marginally poorer for females from the visitors' area in summer ($F_{1,\ 74}$=3.32, P=0.07). Mite load and body condition were negatively correlated in spring (spring: ♂♂ $F_{1,\ 172}$=6.28, P=0.01; ♀♀ $F_{1,\ 99}$=7.45, P=0.01; summer: ♂♂ $F_{1,\ 115}$=0.05, P=0.83; ♀♀ $F_{1,\ 75}$=0.11, P=0.75) in the same way in both areas (mite load: area: P<0.62; F>0.43 in all cases).

Discussion

Confirming our predictions, loss of body condition and intensity of infection were more intense where and when human pressure is higher. In spring, no differences in body condition between females from both areas were observed but females from the visitors' area exhibited a lower condition in summer. Similarly, males from the undisturbed area showed a lower condition in spring to those in the disturbed zone, while in summer no differences were detected. That is, body condition's trends were different at each area. Loss of body condition was more pronounced in the visitors' area for both sexes, suggesting a negative effect of human disturbance. To frequently perform escape responses is costly (Kramer and McLaughlin 2001; Gleeson and Hancock 2002) and could represent the greatest daily energy expenditure in reptiles (Christian et al. 1997). So, visitors' area lizards may experience accumulative physiological costs resulting in a more pronounced loss of body mass (Martín and López 1999; Pérez-Tris et al. 2004) which could affect the ability to invest in defence against parasites (Cooper et al. 1985; Navarro et al. 2004).

Parasite load decreased in summer in both sexes. Lizards are more active during breeding season and many resources are invested in reproductive effort. But once breeding season finishes, resources could be allocated to fight against parasites (Salvador et al. 1996; Amo et al. 2005; Bouma et al. 2007). Alternatively, parasite numbers may decrease towards the end of the season because of less suitable climatic conditions. A more detailed analysis revealed that trends in ectoparasite loads across seasons were similar in both areas of the island. During spring, parasite load were similar in both areas, while in summer, undisturbed lizards carried fewer mites. In other words, parasite load was maintained through seasons in visitors' area but decreased in undisturbed area, as previously observed in other lizard species (Amo et al. 2005). This could be due to perceived risk of predation. That is, under conditions of limited resource availability, escape behaviuor takes precedence over immune defence (Navarro et al. 2004). In addition, the use of refuges to avoid predators entails physiological and parasitic costs: loss of body mass due to thermal constraints and acquisition of mites previously released by other conspecifics (Martín and López 1999; Leu et al. 2010). However, this is unlikely in *P. lilfordi* as typically remains in sight after fleeing (Pérez-Cembranos et al. 2013).

Alternatively, immune function in disturbed lizards may be compromised via the known immunosuppressive effects of elevated corticosterone levels (e.g. Romero and Wikelski 2002; Navarro et al. 2004) rather than through simple caloric restrictions. Finally, lizards that spend more time escaping in visitors' area can have higher probabilities to encounter and accrue more mites.

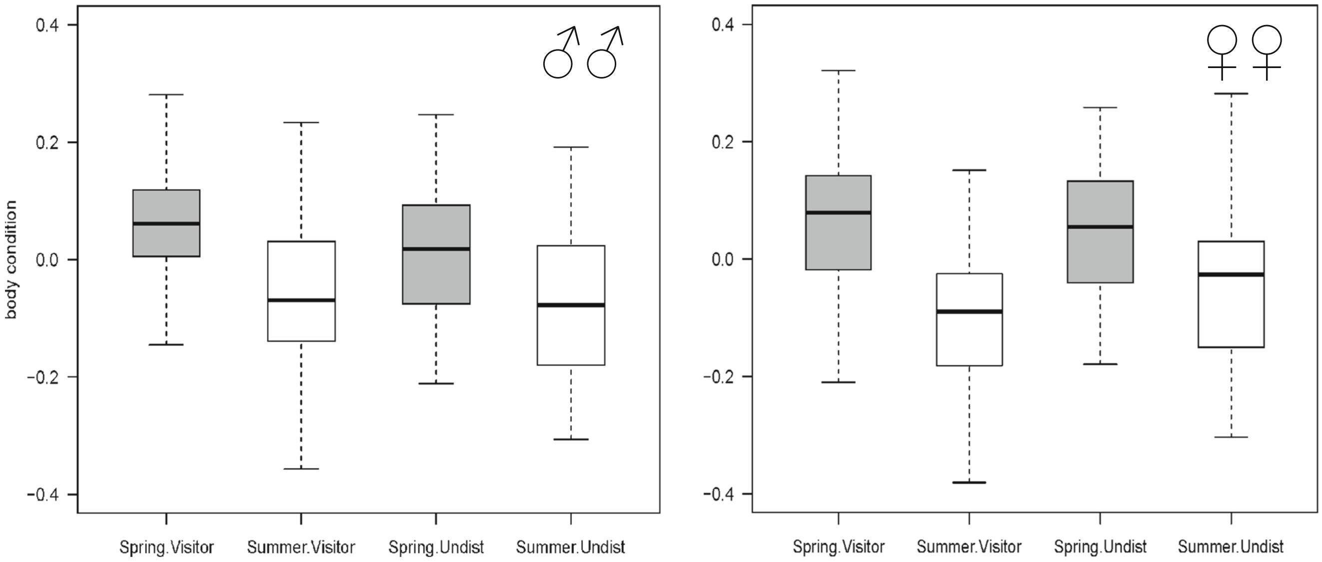

Fig. 2 Boxplot of body condition of males and females in both areas (*Visitor* visitors' area, *Undist* undisturbed area) for spring and summer

Parasite load and condition were negatively correlated only during spring, when mating is more intense. In this season, only the lizards in better body condition would allocate energy for both breeding and defence against parasites. Alternatively, decreasing of parasite load in summer may obscure the expected relation between both variables. Interestingly, just in summer, a positive correlation between parasitism and body size appeared in visitors' area. Probably, in less disrupted areas, larger lizards obtained enough resources to have a good defence against parasites, while this trend was absent in visitors' area, where lizards performed more escape responses (Amo et al. 2006).

For reptiles, only just few studies have investigated the detrimental effects of tourism on wild populations (Amo et al. 2006; Romero and Wikelski 2002), even if tourism has been proposed as one of the major threats for the conservation of lizard populations (Corbett 1989). Individuals frequently exposed to humans are in a competitive disadvantage due to consequences over their fitness and offspring (Amo et al. 2006). Moreover, disturbance from tourism is further exacerbated by the fact that Mediterranean islands receive the bulk of visitors during summer, when resources available for wild populations are scarcer (Pérez-Mellado and Corti 1993). Thus, these results should be taken into account when designing conservation plans or management strategies.

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