Journal of Arid Environments 73 (2009) 378–380

Contents lists available at ScienceDirect

Journal of Arid Environments

journal homepage: www.elsevier.com/locate/jaridenv

Short communication

The scorpion *Buthus occitanus* as a profitable prey for the endemic lizard *Podarcis atrata* in the volcanic Columbretes islands (Mediterranean, Spain)

A.M. Castilla [a,b,*], A. Herrel [c]

[a] Estación Biológica de Sanaüja, Museo Nacional de Ciencias Naturales (CSIC), Ministerio de Ciencia e Innovación; Ap. Correos no. 35, 25280 Solsona, E-Lleida, Spain
[b] Department of Biodiversity and Evolutionary Biology, National Museum of Natural Sciences (CSIC), C/José Gutiérrez Abascal 2, E-28006 Madrid, Spain
[c] Department of Organismic and Evolutionary Biology, Harvard University, 26 Oxford Street, Cambridge, MA 02138, USA

ARTICLE INFO

Article history:
Received 30 January 2008
Received in revised form
21 September 2008
Accepted 22 September 2008
Available online 5 November 2008

Keywords:
Cross predation
Poison
Predator prey interactions
Sexual dimorphism
Venom

ABSTRACT

To understand the dynamics of small populations in arid environments, particularly in small insular ecosystems, it is crucial to understand the interactions between species inhabiting these environments. Here we investigate the interactions between lizards and scorpions in a small arid insular ecosystem in the Mediterranean. Experimental observations suggest that scorpions are regarded as prey by lizards. However, the response of lizards was sex-dependent, with males being more likely to attack scorpions than females. This can be associated with the larger body and head size, and bite forces in males, presumably making scorpions a profitable prey. Predation on lizards by scorpions has been also documented, suggesting a classic case of cross predation.

1. Introduction

To understand the dynamics of small populations in extreme arid environments, particularly in small insular ecosystems it is crucial to understand the interactions between species inhabiting these environments. Often, lizards and scorpions are dominant players in such ecosystems and may interact in different ways. For example, they may tolerate each other without predatory interactions, lizards can prey on scorpions, scorpions can prey on lizards, and either species can be prey or predator (i.e. so-called cross predation). The nature of the interaction is however, crucially important in determining the dynamics of these impoverished and arid insular ecosystems.

Several examples of interactions between lizards and scorpions have been described in the literature. For example, in Saudi Arabia lizards and scorpions are mutually tolerant. The scorpions never sting the lizards and even provide them protection by stinging potential enemies (AlSaleh and AlJohany, 1995). More commonly, lizards are predators of scorpions (Colli et al., 1998; Mouton et al., 2000), even if they are extremely venomous (e.g., *Centruroides*) (O'Connell and Formanowicz, 1998). However, some species (e.g., the gekkonid *Phytodactilus*) avoid to get stung by them (Zlotkin et al., 2003).

To our knowledge, little is known about scorpions in the diet of European lizards (Barbadillo et al., 1999; but see Castilla et al., 1987, 1991), despite the fact that these may be very abundant components of arid ecosystems. The lizard (*Podarcis atrata*) and the scorpion (*Buthus occitanus*) are very abundant on the island Columbrete Grande (Mediterranean, Spain), with ca. 1000 lizards per hectare (Castilla and Bauwens, 1991) and up to 7000 scorpions per hectare (Castilla and Pons, 2007). Although lizards are diurnal and scorpions nocturnal, the probability of encounters is high as both species use rocks and burrows as retreats and diurnal refuges, and compete for food including invertebrates and juvenile lizards (Castilla, 1995a,b).

B. occitanus is considered a dangerous species with highly toxic venom (Simard and Watt, 1990), nevertheless, scorpions have been found in the stomach contents and faecal pellets of *P. atrata* (Castilla et al., 1987; personal observations). However, it is currently unclear whether lizards actually consider scorpions as potential prey.

The objective of our study was to examine under experimental conditions, the response of the lizard *P. atrata* towards scorpions (*B. occitanus*) of different body size, and to test for sexual differences in the response. *P. atrata* shows clear sexual dimorphism in body and head size and body mass, with males being larger than females (Castilla and Bauwens, 1991). Bite forces are also higher in

* Address for correspondance. Estación Biológica de Sanaüja, Museo Nacional de Ciencias Naturales (CSIC), Ministerio de Ciencia e Innovación; Ap. Correos no. 35, 25280 Solsona, E-Lleida, Spain.
E-mail addresses: aurora@mncn.csic.es (A.M. Castilla), anthony.herrel@ua.ac.be (A. Herrel).

0140-1963/$ – see front matter © 2008 Published by Elsevier Ltd.
doi:10.1016/j.jaridenv.2008.09.005

males (Herrel et al., 1996) which could make large scorpions a more profitable prey for males.

2. Materials and methods

P. atrata is an actively foraging lizard endemic from the Columbretes archipelago (39°55′N, 0°40′E, Mediterranean, Castellón, Spain). The islands are characterized by high aridity (average annual mean temperature of 17 °C and 265 mm rainfall/year) and by a scarcity of terrestrial insects (Castilla and Bauwens, 1991). Lizards also consume the intertidial isopod *Ligia italica* (Castilla et al., 2008).

The study was conducted on the island Columbrete Grande (13 ha) during the last week of May 2006, between 10.00 and 13.00 h. Ambient temperature ranged from 21–22 °C, and relative humidity from 66–74%. Experiments were performed in a vegetated area near human habitation. Because the use of dead scorpions could facilitate the realization of the experiment, we first tested the response of lizards to dead and live scorpions. We found differences in their responses (see results), and we subsequently only used live scorpions.

We captured 27 scorpions of intermediate size (mass: 0.89–1.6 g; body length: 22–26 mm; tail length: 27–30 mm, $n = 12$), and 9 of large size (mass: 2–2.3 g; body length: 27–28 mm; tail length: 28–31 mm, $n = 9$). They were released in their original burrows at the end of the experiments.

To be sure that the lizards were hungry at the time of the experiment we first offered them a mealworm (e.g., a preferred prey) attached to a noose. If the reaction of the lizard was positive (e.g., direct attack) we immediately offered a scorpion (see a similar method in Castilla and Van Damme, 1996). Behaviors were classified as ignore (no response for 3 min), attack (movement of the lizards towards the scorpion) or flee (movement of the lizard away from the scorpion).

We tested 119 different adult lizards with snout-vent length between 60 and 70 mm, and body mass between 5 and 10 g. All tested lizards were marked with a colour dot on the head or on the dorsum to ensure that they were tested only once. Females were captured and checked for the presence of enlarged follicles or eggs, and most of them (77%, 44 of 57) were gravid. Differences in response (attack: yes or no) towards the scorpions by lizards of both sexes were compared using Chi^2 tests. We used SPSS V13 (SPSS Inc. Headquarters, Chicago, Illinois 60606) for all statistical analysis. The experiments were approved by the University of Antwerp Ethics Committee.

3. Results

The response of *P. atrata* to the mealworm was positive in all cases ($n = 83$). The response towards live or dead scorpions was different for females ($Chi^2 = 7.04$; $df = 2$; $P = 0.02$). None of the females attacked the live scorpions (Table 1). A higher percentage of males attacked dead scorpions, but the response towards live or dead was not significant ($Chi^2 = 2.6$; $df = 2$; $P = 0.27$) (Table 1).

Live scorpions showed a characteristic defensive posture (e.g., curling the metasoma with the sting positioned above the most anterior region of the body) when were presented to the lizards. The response of *P. atrata* towards live scorpions was different depending on the size of the scorpions. Scorpions of intermediate size were attacked more often than the large ones (Table 2). Sexual differences in the response to scorpions were significant for intermediate scorpions ($Chi^2 = 12.274$; $df = 2$; $P = 0.002$), but not for large ones ($Chi^2 = 2.1685$; $df = 2$; $P = 0.33$) (Table 2). One scorpion (body length = 23 mm, body mass = 0.90 g) accidentally escaped from the noose and was subsequently attacked and consumed by a male lizard (svl = 67 mm, body mass = 8.5 g).

4. Discussion

The results of our study indicate that *P. atrata* perceive scorpions as a profitable prey. Additional observations have shown that *P. atrata* run after small scorpions (mass: 0.05 g; body length < 10 mm; tail length < 12 mm) and consume them easily. However, the importance of scorpions as prey for this lizard should be verified by quantifying the frequency by which this prey is consumed, through the examination of stomach contents or faecal pellets.

Females were less willing to attack scorpions than males. This could be associated with the fact that most females in our study were gravid (80%, 33 out of 41). But a more likely explanation is that females are smaller than males (Castilla and Bauwens, 1991) and have lower bite forces (Herrel et al., 1996), thus making scorpions more difficult to kill and handle. Female lizards also showed a lower propensity to cannibalize on juveniles than did males (Castilla and Van Damme, 1996).

In other lizards, the foraging repertoire when attacking scorpions includes vigorous shaking of the prey clutched in the jaws, and the throwing of prey from the mouth (O'Connell and Formanowicz, 1998). That behaviour of throwing the prey was observed when *P. atrata* consumed the isopod *L. italica* (Castilla et al., 2008), but was not observed with scorpions. However, because we did not let the lizards to consume the prey, we have no data on feeding behaviour against scorpions, but only sporadic observations.

Our results also indicate that lizards tended to run after intermediate size scorpions more often than towards bigger ones. The lizard *Cnemidophorus gularis* directed more violent attacks towards large scorpions than to small ones (O'Connell and Formanowicz, 1998). Future studies should be conducted to explore and compare feeding behaviour among lizard species of different sizes and morphologies.

P. atrata readily attacked scorpions despite they are venomous species and showed a defensive behaviour. We have observed that the venom of scorpions can injure the lizards without killing them (Castilla and Herrel, unpublished). Thus, the apparent lack of reluctance of *P. atrata* to attack scorpions could be influenced by

Table 1
Response of adult male and female *Podarcis atrata* towards dead and live scorpions (*Buthus occitanus*). Indicated is the relative occurrence of each behaviour (in percentages) and the sample size (n).

Response	Intermediate size			
	Dead		Alive	
	Males ($n = 10$)	Females ($n = 6$)	Males ($n = 10$)	Females ($n = 10$)
Ignore	10	50	30	70
Attack	**90**	**50**	**60**	**0**
Flee	0	0	10	30

Table 2
Response of adult male and female *Podarcis atrata* lizards towards live scorpions (*Buthus occitanus*) of different body sizes. Indicated is the relative occurrence of each behaviour (in percentages) and the sample size (n).

Response	Intermediate size		Big size	
	Males ($n = 20$)	Females ($n = 21$)	Males ($n = 22$)	Females ($n = 20$)
Ignore	40	52	41	40
Attack	**50**	**5**	**32**	**15**
Flee	10	43	27	45

their apparent resistance to their venom. Future experimental studies should confirm quantitatively these observations.

On the Columbretes islands, scorpions have been observed to prey upon lizards (Castilla, 1995a), providing a clear example of "cross predation" (refs in McCormick and Polis, 1982). The high abundance of lizards in Columbretes can potentially have a very high impact on scorpion populations if this is a readily available food item. Future studies should evaluate how important the lizard–scorpion relationship could be for either species. The nature of the interaction must be crucially important in determining the population dynamics of the two most abundant terrestrial species of this arid insular ecosystem.

Acknowledgements

We would like to thank the Generalitat Valenciana and the Secretaria General de Pesca Marítima (Ministerio de Agricultura, Pesca y Alimentación) to give permission to work in the islands. To we would like to thank Marta Aguiló (GV), Guim Llacuna and Javier Pérez (Escuela de Capacitación Agraria de Solsona) for their help during the field work. We also thank Pep Perolet and the boats CAT-CAT, Clavel I and Super Bonanza for transportation. We thank Dirk Bauwens and two referees for useful and interesting comments on the manuscript. This work was conducted on a contract "Ramón and Cajal" from the Spanish National Science Foundation (CSIC, Ministerio de Educación y Ciencia) (to AMC), and the Project MEC CGL2005-00391/BOS (J. Martín & P. López, MNCN-CSIC).

References

AlSaleh, S.A., AlJohany, A.M., 1995. Studies on the association between the spiny-tailed lizard *Uromastyx aegyptius (Agamidae)* and the black scorpion *Androctonus crassicauda* (Buthidae). Arab Gulf Journal of Scientific Research 13, 689–694.

Barbadillo, L.J., Lacomba, J.I., Pérez-Mellado, V., Sancho, V., López Jurado, L.F., 1999. In: Canarias, Baleares y (Ed.), Anfibios y reptiles de la Península Ibérica. Planeta S.A, Barcelona.

Castilla, A.M., 1995a. Interactions between lizards *Podarcis hispanica atrata* and scorpions (*Buthus occitanus*). Boletín de la Sociedad de Historia Natural de las Baleares 38, 47–50.

Castilla, A.M., 1995b. Conspecific eggs and juveniles in the diet of the insular lizard *Podarcis hispanica atrata*. Boletín de la Sociedad de Historia Natural de las Baleares 38, 121–129.

Castilla, A.M., Bauwens, D., 1991. Observations on the natural history, present status, and conservation of the insular lizard *Podarcis hispanica atrata*. Biological Conservation 58, 69–84.

Castilla, A.M., Van Damme, R., 1996. Cannibalistic propensities in the lizard *Podarcis hispanica atrata*. Copeia 1996 (4), 991–994.

Castilla, A.M., Pons, G., 2007. Primeros datos sobre la población de escorpiones (*Buthus occitanus*) en las islas Columbretes (Mediterráneo, España). Boletín de la Sociedad de Historia Natural de las Baleares 50, 267–278.

Castilla, A.M., Jiménez, J., Lacomba, I., 1987. Los reptiles de Columbretes, in: Alonso Matilla, L.A., Carretero, J.L., Garcia-Carrascosa, A.M. (Eds.), Islas Columbretes. Contribución al estudio de su medio natural. Generalitat Valenciana, Valencia, pp. 181–194.

Castilla, A.M., Bauwens, D., Llorente, G.A., 1991. Diet composition of the lizard *Lacerta lepida* in central Spain. Journal of Herpetology 25, 30–36.

Castilla, A.M., Vanhooydonck, B., Catenazzi, A., 2008. Feeding behavior of the Columbretes lizard *Podarcis atrata*, in relation to the marine species, *Ligia italica (Isopoda, Crustaceae)*. Belgian Journal of Zoology 138 (1), 146–148.

Colli, G.R., Zatz, M.G., da Cunha, H.J., 1998. Notes on the ecology and geographical distribution of the rare *gymnophthalmid* lizard *Bachia bresslaui*. Herpetologica 54, 169–174.

Herrel, A., Van Damme, R., De Vree, F., 1996. Sexual dimorphism of head size in *Podarcis hispanica atrata*: testing the dietary divergence hypothesis by bite force analysis. Netherlands Journal of Zoology 46, 253–262.

McCormick, S., Polis, G.A., 1982. Arthropods that prey on vertebrates. Biological Reviews 57, 29–58.

Mouton, P.L., Geertsema, H., Visagie, L., 2000. Foraging mode of a group-living lizard, *Cordylus cataphractus (Cordylidae)*. African Zoology 35, 1–7.

O'Connell, D.J., Formanowicz, D.R., 1998. Differential handling of dangerous and non-dangerous prey by naive and experienced Texas spotted whiptail lizards, *Cnemidophorus gularis*. Journal of Herpetology 32, 75–79.

Simard, J.M., Watt, D.D., 1990. Venoms and toxins. In: Polis, G.A. (Ed.), The Biology of Scorpions. Stanford Univ. Press, Stanford.

Zlotkin, E., Milman, T., Sion, G., Werner, Y.L., 2003. Predatory behaviour of gekkonid lizards, *Ptyodactylus* spp., towards the scorpion *Leiurus quinquestriatus hebraeus*, and their tolerance of its venom. Journal of Natural History 37, 641–646.