

## Synopsis of the helminth communities of the lacertid lizards from the Balearic and Canary Islands

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Helminth communities of reptiles have usually been considered as depauperate and isolationist, with low abundance and species richness when compared to other vertebrates. Nevertheless there are some insular reptile populations in which this general rule is not fulfilled. In this study, we compare helminth faunas from two groups of lizards living in two different archipelagos and having different feeding habits. Lacertid lizards from Canary Islands, belonging to the endemic genus *Gallotia*, showed by contrast with other lacertids, a tendency to high consumption of plant matter and to rich and diverse helminth communities. Differences were found even between the lizards living in different islands, being the “giant lizard” *G. stehlini* the most herbivorous and *G. atlantica* the most carnivorous. *Podarcis* spp. from Balearic Islands showed lower tendency to herbivory which was not mirrored in their helminth communities. The composition and structure of helminth communities of lacertid lizards from both archipelagos are related to the conditions of insularity and the phylogeny of the hosts.

**Key words:** Balearic Islands; Canary Islands; helminthes; lizards.

**Sinopsis de las comunidades helmínticas de los lagartos de las Islas Baleares y Canarias.** Las comunidades helmínticas de los reptiles han sido consideradas generalmente como depauperadas y aislacionistas, con escasa riqueza y abundancia de especies comparadas con otros vertebrados. Sin embargo esta norma general no se cumple en algunas poblaciones de reptiles insulares. En el presente estudio se comparan las helmintofaunas de dos grupos de lagartos que habitan dos archipiélagos diferentes, y que exhiben distintas estrategias de alimentación. Los lagartos de las Islas Canarias, pertenecientes al género *Gallotia*, mostraron, en contraste con otros lacértidos, una tendencia hacia un alto consumo de materia vegetal y al establecimiento de ricas y diversas comunidades helmínticas. Se encontraron diferencias entre lagartos que habitan diferentes islas, siendo *G. stehlini* el más herbívoro y *G. atlantica* el más carnívoro. Las lagartijas *Podarcis* spp. de las Islas Baleares mostraron menor tendencia hacia el herbivorismo, tendencia que no se ve reflejada en sus comunidades helmínticas. La composición y estructura de las comunidades helmínticas de los lagartos de ambos archipiélagos se conforman de acuerdo con las condiciones impuestas por la insularidad y por la filogenia de los hospedadores.

**Key words:** Islas Baleares; Islas Canarias; helmintos; lagartos.

Studies on the community ecology of parasites of European reptiles, and particularly lacertids, have increased in the last years. In this context, islands have received less attention, although they are very interesting areas since

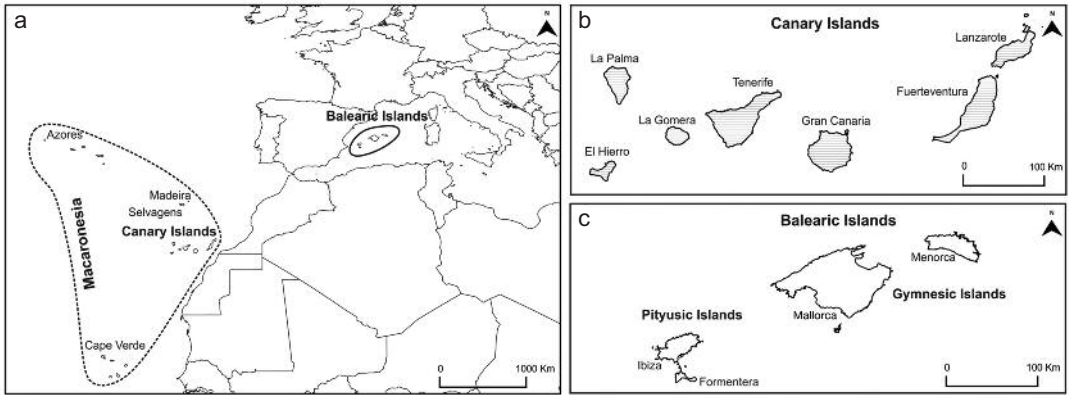
they show peculiar conditions that may influence the characteristics of the populations of both parasites and hosts. From the point of view of the lizard hosts, pressure by terrestrial predator is lower for insular lizards than for

their continental relatives (NOVOSOLOV *et al.*, in press). This results in: (i) high lizard densities increasing intraspecific competition (including cannibalism on juveniles) and favouring conservative reproductive strategies (CARRETERO, 2006); (ii) lower, unpredictable prey availability promoting alternative trophic strategies, including kleptoparasitism and herbivory (PÉREZ-MELLADO & CORTI, 1993; VAN DAMME, 1999; CARRETERO, 2004); (iii) a trend to larger body size and more accentuated sexual dimorphism (MEIRI, 2007; NOVOSOLOV *et al.*, in press). Last but not least, the above-mentioned processes display substantial phylogenetic signal and depend on the time of evolution in insular conditions (CARRETERO, 2006). All these aspects are potentially important for the formation of parasite communities, namely in terms of promoting reproductive isolation between islands, increasing probability of infestation by conspecifics while decreasing that from heterospecifics, creating new infestation pathways and providing different usually more complex host environments. The island syndrome has also been reported in nematode parasites, with loss of genetic diversity and a niche enlargement (NIEBERDING *et al.*, 2006). The founder host may reach islands with only a subset of their parasite fauna, resulting in a decrease in species richness when compared with the continental relatives. This loss of richness has been detected also in helminth species of small mammals of Mediterranean islands, which was correlated with the area of the island and distance from mainland and decrease of host specificity (MAS-COMA *et al.*, 2000; GOÛY DE BELLOCQ *et al.*, 2002).

In the two last decades our laboratory has carried out studies about helminth

parasites from Mediterranean and Atlantic islands (i.e. ROCA *et al.*, 1987; ROCA, 1993, 1999; ROCA & HORNERO, 1994; MARTIN & ROCA, 2004a,b; CARRETERO *et al.*, 2006; ROCA *et al.*, 2006, 2009; JORGE *et al.*, 2012). We focused on the archipelagos of the Balearic and Canary Islands both administratively belonging to Spain but located at different geographic areas, namely in the Mediterranean Sea and the Atlantic Ocean, respectively (Fig. 1a), which have undergone quite divergent paleogeographic histories (see below). Lacertid lizards inhabiting each archipelago are also different. The Balearic Islands are occupied by two endemic species of the genus *Podarcis* Wagler, 1830, widely ranging the Mediterranean Basin, belonging to the Palearctic clade of Lacertini (ARNOLD *et al.*, 2007). By contrast, lacertids living in the Canary Islands are represented by species of the endemic genus *Gallotia* Boulenger, 1916, a lineage phylogenetically distant from most other lacertids including *Lacerta* or *Podarcis* (HARRIS *et al.*, 1998; ARNOLD *et al.*, 2007; PAVLICEV & MAYER, 2009). Abovementioned characteristics of the history of both archipelagos and their lizards, and also reproductive isolation conducting to new host species and subspecies (MACA-MEYER *et al.*, 2003; COX *et al.*, 2010), and so new possibilities for new parasite species (and subspecies), could give rise to the current parasite faunas of these hosts.

Canary Islands are volcanic. They erupted from the sea and are considered as “oceanic islands”, that is, never being connected to the African continent. They are located off the north west coast of Africa (Fig. 1a), at 27°37'–29°24' N, 13°37'–8°10' W, and



**Figure 1:** Localization of the Balearic and Canary Islands. (a) General localization. (b) Canary Islands. (c) Balearic Islands.

comprises seven main islands and a number of peripheral islets (Fig. 1b) having a total surface of 7493.65 km<sup>2</sup> and being their maximum elevation 3718 m above sea level (Teide Volcano in Tenerife island). They form the biogeographical region of Macaronesia together with Cape Verde, Madeira, Azores and Selvagens archipelagos (Fig. 1a). Balearic Islands are “continental islands” that were part of the continent before reaching to be islands. In fact they constituted a part of the Iberian Peninsula known as “Balearic headland”. Successive fractures and isolations gave rise to the actual conformation of this archipelago (CAVAZZA & WEZEL, 2003). They are located east of the Iberian Peninsula (Fig. 1a), at 40°05′-38°38′ N, 4°19′-1°09′ E, and comprises five main islands and a number of peripheral islets (Fig. 1c) having a total surface of 5014 km<sup>2</sup>, ranging in elevation from the sea level to 1445 m above sea level.

In this study we synthesize the results obtained in the parasitological analysis of lizards of both archipelagos and we compare their parasite faunas in the light of the biotic and abiotic features of the hosts.

## MATERIALS AND METHODS

*Gallotia* lizards from the Canary Islands were captured in the main islands (Lanzarote, Fuerteventura, Gran Canaria, Tenerife, La Palma, La Gomera and El Hierro) during several periods between 1994 and 1997. From 1987 to 1989, *Podarcis lilfordi* were captured in some peripheral islets surrounding Mallorca and Menorca islands (Gymnesic islands) and *Podarcis pityusensis* were captured in Pityusic islands (Ibiza and Formentera) and some peripheral islets. The number of specimens of sampled lizards is detailed in Table 1. All lizards were captured by hand and were killed with an overdose of chloroform. The body cavity, digestive tract, heart, lungs, and liver were removed, opened, and placed in Ringer’s solution for examination. Helminthes were removed, washed in distilled water, fixed, and mounted according to standards techniques. Parasites were identified, when possible, to species, and the number and location of individuals of each parasite species were recorded.

The use of descriptive ecological terms follows BUSH *et al.* (1997). Brillouin’s index

**Table 1:** Host species and number of individuals analyzed in each archipelago.

Island	Lizard Species	Number of inspected hosts
<b>Balearic Islands</b>		
Gymnesian (islets surrounding Mallorca and Menorca)*	<i>Podarcis lilfordi</i>	386
Pityusic (islets surrounding Ibiza and Formentera)*	<i>Podarcis pityusensis</i>	564
<b>Canary Islands</b>		
Lanzarote	<i>Gallotia atlantica</i>	70
Fuerteventura	<i>Gallotia atlantica</i>	42
Gran Canaria	<i>Gallotia stehlini</i>	33
Tenerife	<i>Gallotia galloti</i>	27
La Palma	<i>Gallotia galloti</i>	27
La Gomera	<i>Gallotia caesaris</i>	21
El Hierro	<i>Gallotia caesaris</i>	318

\*For details see ROCA & HORNERO (1994).

of diversity was used for calculating diversity according to MAGURRAN (2004).

## RESULTS

Seventeen helminth species (two Trematoda, four Cestoda, 10 Nematoda and one Acanthocephala) were found in the Balearic hosts. Twenty four (one Trematoda, five Cestoda, 17 Nematoda and one Acanthocephala) were recorded in Canarian hosts. Table 2 shows the presence/absence of helminth species recorded in the hosts.

Global prevalence of infection and overall diversity parameters for each host are given in Fig. 2 and Table 3, respectively.

In all the hosts, Pharyngodonidae nematodes (species of the genera *Skrjabinodon*, *Spauligodon*, *Parapharyngodon*, *Thelandros*, *Tachygonetria* and *Alaeuris*) were the main component of their helminthes infracommunities. The helminthes found as larval forms were located in the body cavity of the hosts, whereas those found as adults were located at different sites (Table 2).

## DISCUSSION

Helminth faunas of lizards from both archipelagos were globally similar in including widespread helminth species, as the nematodes *Skrjabinodon medinae* and *Parapharyngodon* spp., the cestodes *Nematotaenia tarentolae* and *Oochoristica* spp., and several cestode and nematode larval forms.

Nevertheless, some differences are also found between both helminth faunas, namely regarding the endemisms. *Pseudoparadistomum yaizaensis* is an endemic genus and species parasitizing only *Gallotia atlantica* from Lanzarote Island (ROCA, 2003). This finding was interesting because (i) no dicrocoeliids had been found from other reptiles in Macaronesia; and (ii) another member of the same family was found in the Balearic Islands, *Paradistomum mutabile* which is distributed in the European Mediterranean Basin (ROCA & HORNERO, 1994; ROCA, 1995). Since geographical separation of gene stocks is important in speciation phenomena, we could suggest an origin of *P. yaizaensis* from *P. mutabile*, considering that there may have been interchanges of helmin-

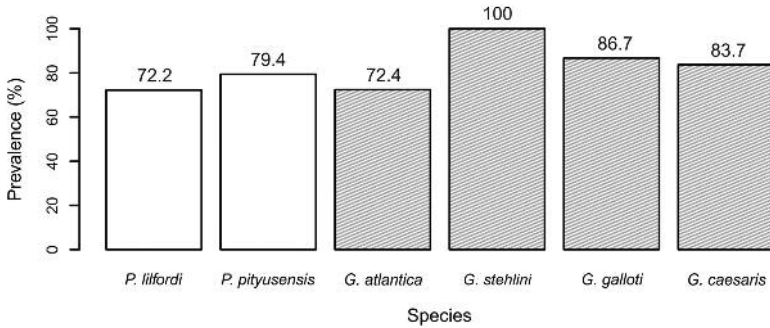
**Table 2:** Presence/absence of the recorded helminth species in each host. P.l. *Podarcis lilfordi*; P.p. *P. pityusensis*; G.a. *Gallotia atlantica*; G.s. *G. stehlini*; G.g. *G. galloti* and G.c. *G. caeasaris*.

Helminth species	Site	P.l.	P.p.	G.a.	G.s.	G.g.	G.c.
<b>Digenea</b>							
<i>Paradistomum mutabile</i>	Gall bladder	•	•				
<i>Pseudoparadistomum yaizaensis</i>	Small intestine			•			
<i>Brachylaima</i> sp.	Small intestine	•	•				
<b>Cestoda</b>							
<i>Oochoristica agamae</i>	Small intestine				•		
<i>Oochoristica gallica</i>	Small intestine		•				
<i>Nematotaenia tarentolae</i>	Small intestine		•		•		
<i>Diplopylidium acanthotetra</i> (larvae)	Body cavity		•	•			
<i>Dipylidium</i> sp. (larvae)	Body cavity			•			
<i>Mesocestoides</i> sp. (larvae)	Body cavity		•	•			•
<b>Nematoda</b>							
<i>Skrjabinodon medinae</i>	Caecum	•	•			•	
<i>Spauligodon cabrerai</i>	Caecum	•	•				
<i>Spauligodon atlanticus</i>	Caecum			•	•	•	•
<i>Spauligodon</i> sp.*	Caecum					•	•
<i>Parapharyngodon micipsae</i>	Caecum	•	•	•	•	•	•
<i>Parapharyngodon echinatus</i>	Caecum		•	•	•		
<i>Parapharyngodon bulbosus</i>	Caecum	•	•		•		
<i>Thelandros galloti</i>	Caecum					•	•
<i>Thelandros filiformis</i>	Caecum				•	•	•
<i>Thelandros tinerfensis</i>	Caecum					•	•
<i>Alaeuris numidica</i>	Caecum				•	•	•
<i>Tachygonetria dentata</i>	Caecum				•		•
<i>Tachygonetria macrolaimus</i>	Caecum				•		•
<i>Tachygonetria conica</i>	Caecum				•		
<i>Tachygonetria numidica</i>	Caecum				•		
<i>Skrjabielazia hoffmanni</i>	Small intestine	•		•	•		
<i>Skrjabielazia pyrenaica</i>	Stomach						•
<i>Strongyloides ophiusensis</i>	Small intestine		•				
<i>Abbreviata</i> sp.	Small intestine	•					
<i>Acuarua</i> sp. (larvae)	Body cavity	•	•				
<i>Spirurida</i> gen sp. (larvae)	Body cavity	•	•				•
<b>Acanthocephala</b>							
<i>Centrorhynchus</i> sp. (larvae)	Body cavity	•	•				•

\*Unpublished data.

thes between both groups of lacertid lizards, *Podarcis* and *Gallotia*, as suggested by the composition of both helminth faunas. Other helminth species or subspecies endemic to the Canary Islands, as *Spauligodon atlanticus*, *Spauligodon* sp, *Thelandros galloti*, *T. filiformis*, *T. tinerfensis* and *Alaeuris numidica canariensis*

were *Gallotia* specialists (*sensu* EDWARDS & BUSH, 1989) since they have been found in several *Gallotia* lizards and not in other hosts. Balearic lizards also harboured only two endemic helminth species, one of them, *Strongyloides ophiusensis*, being found in *Podarcis pityusensis* but not in *P. lilfordi*. One of



**Figure 2:** Overall prevalence of infection of the searched lizard hosts.

the most interesting differences among the endemisms is related to the *Spauligodon* species. In the *Gallotia* hosts, two different not related but resembling *Spauligodon* species are present, *S. atlanticus* parasite of *G. atlantica* and *Spauligodon* sp. found in the *Gallotia* species from the western islands (JORGE *et al.*, 2011). Their colonization patterns are still unclear, and could have resulted from the host only colonizing the islands with a different subset of the two species, or extinctions or one of this species resulting from a host switch from another species. In the *Podarcis* present in the Balearic Islands, only one species has been found, *S. cabrenae*, probably resulting from colonization by descent.

Family Pharyngodonidae is considered as good indicator of the diet of reptiles (ROCA, 1999). In the different genera of this family parasitizing reptiles, two lines can be distinguished based mainly on the disposition of the genital papillae (PETTER, 1966). One of these lineages evolved in carnivorous reptiles (genera *Pharyngodon*, *Spauligodon*, *Skryabinodon* and *Parapharyngodon*) and the other one in herbivorous reptiles (genera *Alaeuris*, *Mehdiella*, *Tachygonetria* and *Thelandros*) (PETTER & QUENTIN, 1976; ROCA, 1999). Both groups of Balearic and Canarian lizards harboured species belonging to the lineage of carnivorous reptiles, but

**Table 3:** Overall diversity parameters (mean  $\pm$  SD, with the range in parentheses) from the searched hosts.

Host	No. of helminth species/host	No. of helminthes/host	Brillouin's diversity index
<b>Balearic Islands</b>			
<i>Podarcis lilfordi</i>	0.93 $\pm$ 0.74 (0 - 4)	7.45 $\pm$ 12.84 (0 - 110)	0.108 $\pm$ 0.200 (0 - 0.815)
<i>Podarcis pityusensis</i>	1.35 $\pm$ 1.02 (0 - 5)	16.44 $\pm$ 31.22 (0 - 420)	0.242 $\pm$ 0.292 (0 - 1.211)
<b>Canary Islands</b>			
<i>Gallotia atlantica</i>	1.0 $\pm$ 0.8 (0 - 4)	16.3 $\pm$ 21.2 (0 - 156)	0.13 $\pm$ 0.24 (0 - 0.89)
<i>Gallotia stehlini</i>	4.9 $\pm$ 1.6 (2 - 7)	468.2 $\pm$ 644.6 (31 - 2734)	1.2 $\pm$ 0.4 (0.2 - 1.7)
<i>Gallotia galloti</i>	1.72 $\pm$ 0.18 (0 - 4)	54.4 $\pm$ 14.28 (0 - 373)	0.55 $\pm$ 0.09 (0-1.86)
<i>Gallotia caesaris</i>	1.4 $\pm$ 1.0 (0 - 5)	47.3 $\pm$ 68.5 (0 - 350)	0.3 $\pm$ 0.4 (0 - 1.0)

only Canarian ones had eight helminth species typical of herbivorous reptiles. This suggested a strong tendency to herbivory of these hosts. Diversity of helminth communities has also been used to estimate the tendency of reptiles to eat plant matter. Herbivorous reptiles tend to contain richer and more diverse communities than carnivorous ones (ROCA, 1999). According to this, *Gallotia stehlini* and *G. galloti* from the Canary Islands showed major tendency to herbivory than other species from the archipelago, because their helminth communities were highly rich and diverse, so we may consider them as rich helminth communities (AHO, 1990). This was in accordance to the presence of Pharyngodonidae typical of herbivorous reptiles (MARTIN & ROCA, 2004a,b).

Diet analysis of gut contents (PÉREZ-MELLADO & CORTI, 1993; BROWN & PÉREZ-MELLADO, 1994; ROCA, 1999; CARRETERO *et al.*, 2001; VALIDO & NOGALES, 2003; ROCA *et al.*, 2005; CARRETERO *et al.*, 2006) allowed these Balearic and Canarian lizard species to be located in a continuum of the food type strategy, in extremes are strict carnivory and herbivory. Near of the end of herbivory we found *G. stehlini*, the “Giant lizard” from Gran Canaria Island which eats more than 94% of plant matter. *Gallotia galloti* from Tenerife and *G. caesaris* from El Hierro and La Gomera islands were omnivorous with marked tendency to herbivory (between 70% and 85% of plant matter). Remarkably, *Gallotia* lizards consumed stems and leaves of the plants, which are of low profitability and require long fermentation periods for symbiotic flora to act (CARRETERO, 2004). By contrast, both Balearic lizards *P. pityusensis* and *P. lilfordi* (PÉREZ-MELLADO & CORTI,

1993; CARRETERO *et al.*, 2001), and also the populations of *G. atlantica* from Lanzarote and Fuerteventura islands (authors' unpublished data), eat mainly arthropods and a little amount of plant matter, usually the most profitable parts such as fruits, seeds, flowers or pollen, and so we found them near of the end of carnivory.

Results from the analysis of helminthes (MARTIN & ROCA, 2004a,b; MARTIN & ROCA, 2005; ROCA *et al.*, 2005) placed these lizard species in the same carnivory-herbivory continuum, according to their helminth community features mentioned above. We found a full coincidence of the position of *G. stehlini* in the continuum, due to its helminthological characteristics (high diversity, presence of many Pharyngodonidae of the lineage of herbivorous reptiles). It is the biggest and the most herbivorous lizard, with the most diverse helminth community. High coincidence was also found in the case of *G. galloti* showing relatively high diversity and presence of some peculiar species of Pharyngodonidae, as happens with *G. caesaris*. Low diversity and absence of pharyngodonids typical of herbivorous reptiles placed *G. atlantica* and both *Podarcis* at the end of the carnivory, in accordance with the results of their feeding habits. The tendency to a restricted herbivory (consumption of the most energetic parts of plants) observed in Balearic lizards (PÉREZ-MELLADO & CORTI, 1993) is not reflected in their helminth communities. Thus, ROCA (1999) suggested that they are primarily carnivorous reptiles and we suggest the same for *G. atlantica*. It has been proposed that such differences between both lizard genera are related to the different times of evolution under insular conditions (CARRETERO,

2004). In particular, the absence or the impoverishment of terrestrial predatory species releasing lizards for devoting more time for eating (PÉREZ-MELLADO & CORTI, 1993) together with prolonged lizard basking at high temperatures (MÁRQUEZ *et al.*, 1997) and the retention of prey items in a compartmented rectal caecum (HERREL *et al.*, 2004) would not only enhance prey digestion (ZIMMERMAN & TRACY, 1989), but also provide a favourable ambient for distinctive, more complex helminth communities.

In accordance with the reasons mentioned above, we can conclude the following: (i) the composition and structure of helminth communities of these reptile hosts are related to their phylogeny and their feeding habits; (ii) the tendency to the herbivory is much more marked in Canary lacertid lizards than in Balearic ones.

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