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Unusual findings on host-tick interactions through carnivore scat analysis

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Abstract In the course of a study on the diet of two Portuguese carnivores, the red fox (*Vulpes vulpes* Linnaeus) and the common genet (*Genetta genetta* Linnaeus), 276 ticks were found inside the 940 scats analyzed. Prevalence in samples was 7.6% for both predators. Association of ticks with prey identified on scats, resulted in new data for Portugal on host-tick interactions [e.g. *Ixodes acuminatus* (Neumann, 1901) and wood mouse] and tick distribution pattern. These unusual findings, besides shedding some light on the host-tick Portuguese assemblage, revealed scats as a new source of biological information.

Keywords Ticks · Carnivores · Scat analysis · Portugal

Introduction

Parasites are closely associated with their hosts in a trophic relation, which influences both the parasite and their host. These interactions range over several temporal scales, from the history of individual infection or epidemic outbreak to time scales of co-existence or co-evolution (Hudson et al. 2002). However, whatever the scale considered, the first step to understand these associations, and its repercussions on both actors, is to describe the parasite community of each species.

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Due to their mobile and independent adult forms (Georgi 1985), which feed on a wide variety of vertebrate hosts, transmitting several other parasites (e.g., *Rickettsia* sp.—Sousa et al. 2006; *Borrelia* sp.—De Michelis et al. 2000) that cause mortality and distress to livestock, human and wildlife (Randolph et al. 2002), parasites arthropods of Acari: *Ixodidae* (i.e. ticks) have a high economic and conservation (Cleaveland et al. 2002) importance. Therefore, the knowledge of the tick community associated with each vertebrate is fundamental to predict and minimize its impact.

The traditional approach to the assessment of ticks-hosts interactions is to extract them from captured vertebrate hosts (e.g. Akucewich et al. 2002) or recently killed individuals (e.g. Sréter et al. 2005). Although allowing to control sample structure (e.g. host's species, sex, age and, in some cases, hierarchic position), these approaches are time and money consuming, and are extremely difficult to implement when low density or highly protected species are the target (e.g. Beyer and Grossman 1987). Due to these limitations alternative approaches should be used to complement the conventional methods or to overcome their methodological pitfalls.

Scats are today a common tool on carnivores' diet analysis (Reynolds and Aebischer 1991), species identification (e.g. Paxinos et al. 1997) and population structure assessment (e.g. Taberlet et al. 1997), being also used to survey helminth infections (e.g. Rosalino et al. 2006). However, so far, its use as an indirect source of information, regarding prey ectoparasites was never reported. Therefore, our aim is to demonstrate the additive value of predators' scats as the sampling unit to the understanding of the tick community affecting the prey of two Mediterranean carnivores, the red fox (*Vulpes vulpes* Linnaeus) and the common genet (*Genetta genetta* Linnaeus).

Material and methods

From November 1994 to September 1995, genet and fox populations inhabiting a region of central Portugal (Sintra-Cascais Natural Park, 38°40′ N to 39°0′ N and 9°15′ W to 9°30′ W) were monitored. The study area, covering a surface of 14,583 ha, is characterized by a highly humanized landscape, mainly due to its location in the vicinity of Lisbon, the country's capital. According to its physiographic and biotic characteristics, two main areas can be defined: the northern and southern plains, dominated by a mosaic landscape of Mediterranean scrubland (*Quercus coccifera*, *Cistus* sp. and *Ulex* sp.) mixed with agricultural fields and patches of pine trees (*Pinus pinea*); and the central Sintra mountain, where the human influence is evidenced by a large surface of deforested areas and the plantations of exotic trees (maritime pine *Pinus pinaster*, blackwood *Acacia melanoxylun*, eucalyptus *Eucaliptus globosus*, and cedar of Goa *Cupressus lusitanica*) together with few strongholds of oak trees (*Quercus* sp.).

The main aim of the previous study was to determine the predators' feeding habits through scat analyses (e.g. Rosalino and Santos-Reis 2002). As a consequence of significant differences in the species marking behavior (e.g. Palomares 1993; Sadlier et al. 2004), different strategies were used to collect scats: linear road transects for the fox and latrines search for the genet. Transects and latrines were visited fortnightly during the entire study period, resulting in the collection of 352 fox and 588 genet scats.

After collection, scats samples were processed following standard procedures (Reynolds and Aebischer 1991) and non-digested prey remains (e.g. arthropod pieces of exoskeleton, seeds, shells, feathers, hairs, bones, teeth and scales of vertebrate prey) separated and, whenever possible, identified to species (for details see Rosalino and Santos-Reis 2002).

Mixed with the food remains several ticks were also found and stored in a 70% ethanol solution. Specific identification of ticks was achieved using standard taxonomic keys (Cordas et al. 1993; Dias 1994). Prevalence was defined as the percentage of scats containing a particular tick species.

In order to group the data collected from both predators, the number of ticks was randomized, by diving it by the number of scats analysed per species. Due to the skewed distribution of the data (Kolmogorov-Smirnov test—Siegel and Castellan 1988) and the inexistence of data for some sub-samples, differences between sub-samples (e.g. gender comparisons) were tested using Mann–Whitney (U) and Kruskal–Wallis (H) tests (Siegel and Castellan 1988).

Results

A total of 523 and 1922 prey were respectively identified in red fox and common genet scats, being the majority (66% and 58%) mammals (Table 1). Among the food remains found, we collected 276 partly digested adult ticks, belonging to six different species: *Ixodes acuminatus* (Neumann 1901), *I. hexagonus* (Neumann 1902), *I. ricinus* (Linnaeus 1758), *I. ventalloi* (Gil Collado 1936), *Rhipicephalus pusillus* (Gil Collado 1938) and *R. turanicus* (Pomerantsev, Matikasvili, Lototzki 1940) (Table 2). These ticks were detected mainly in spring and early summer (Fig. 1).

Although the majority of ticks were collected in genet scats (186 vs. 90 in fox scats), when these values are corrected for the number of scats analyzed no differences were found in the number of ticks per carnivore scat ($U = 59.500$, $df = 1$, $P > 0.478$). The prevalence in samples, considering only ticks absence/presence and scats collected in spring and summer, was similar for the fox (7.67%) and the genet (7.65%). The number of ticks per scat ranged from 0 to 15 for the fox and 0 to 12 for the genet, being the mean infestation intensity (overall value: 3.8 ± 3.5) slighter higher in the genet (4.1 ± 3.4 vs. 3.3 ± 3.7 in fox) but the difference was not statistically significant ($U = 476$, $P = 0.118$).

Table 1 Number of prey/food items identified in the fox and genet scats [P.O.—percentage of occurrence = (Number of preys of a particular item/Total number of prey)*100]

Prey/Food Items (*N*)	Fox		Genet	
	N	P.O.	*N*	P.O.
Mammals				
Insectivora	0	0	152	7.9
Rodentia	27	5.1	815	42.4
Lagomorpha	315	60.2	146	7.6
Artiodactyla	5	1.0	0	0
All mammals	347	66.3	1113	57.9
Birds	52	9.9	214	11.1
Reptiles	12	2.3	30	1.6
Arthropods	24	4.6	295	15.4
Fruits	49	9.4	168	8.7
Other plant material	23	4.4	31	1.6
Eggs	5	1.0	14	0.7
Gastropods	0	0	28	1.5
Garbage	11	2.1	28	1.5
Total	523	100	1921	100

Table 2 List of ticks identified in the fox and genet scats (*n*—Number of ticks and stage; p—Prevalence)

Tick species	Mammal scats					
	Fox		Genet		Total	
	n	p (%)	*n*	p (%)	*n*	p (%)
Ixodes acuminatus	–	–	1F	0.17	1	0.11
Ixodes hexagonus	4M; 7F	0.85	–	–	11	0.32
Ixodes ricinus	1F	0.28	1M	0.17	2	0.21
Ixodes ventalloi	1F	0.28	–	–	1	0.11
Rhipicephalus pusillus	38M; 38F	5.97	72M; 110F	6.97	258	6.60
Rhipicephalus turanicus	1M	0.28	2M	0.32	3	0.32
Total	43M; 47F	7.67	75M; 111F	7.63	276	7.66

M—male; F—female

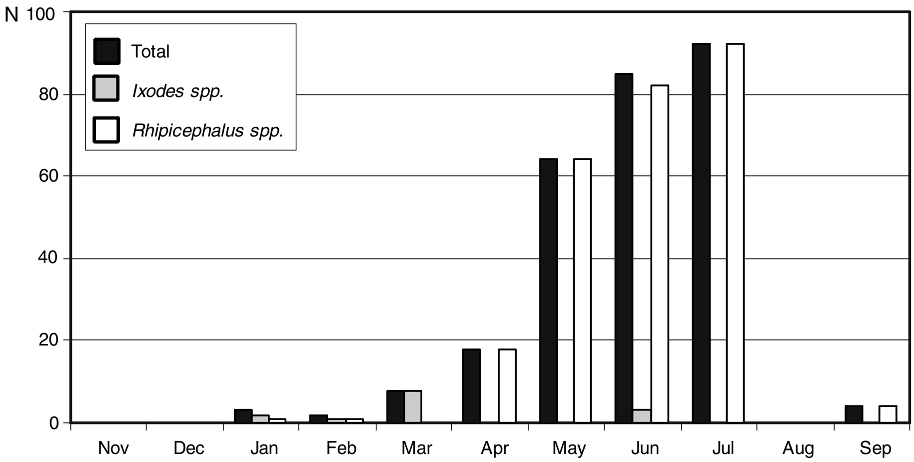

Fig. 1 Total number of ticks (*N*) collected monthly in fox and genet scats from Sintra-Cascais Natural Park

The prevalence of each tick species differed significantly (H = 12.419, df = 5, $P = 0.029$), with *Rhipicephalus pusillus*, a Palearctic species present throughout Portugal, Spain, Southern France and Morocco (Dias 1994), being the most common, reaching 93% of all collected ticks (84% in fox scats and 98% in genet scats). No differences were detected between the number of male and female ticks collected (U = 72.000, df = 1, $P > 0.05$).

Two of the parasites (*Ixodes acuminatus* and *I. ricinus*) were found only in scats deriving from meals exclusively composed by the wood mouse (*Apodemus sylvaticus* Linnaeus), and two other (*I. hexagonus* and *I. ventalloi*) in scats resulting from meals where the wild rabbit (*Oryctolagus cuniculus* Linnaeus) was the single prey consumed. *R. pusillus* was the least specific tick species since it was present in scats containing the majority of the different mammal prey (Table 3).

Considering only eutherian preys, *Oryctolagus cuniculus* was the most common mammal in scats that also contained ticks, representing 60.3% of the consumed preys (Table 3).

Table 3 Ticks found in each genet and fox scats and mammal prey eaten in respective meals. Only scats that comprised just one prey species where considered

Prey\Ticks	*I. acuminatus*			*I. hexagonus*			*I. ventalloi*			*I. ricinus*			*R. pusillus*			*R. turanicus*		
	N	F	M	*N*	F	M	*N*	F	M	*N*	F	M	*N*	F	M	*N*	F	M
Genet																		
Oryctolagus cuniculus													14	40	30	1		1
Apodemus sylvaticus	4	1								2		1	2	9	4			
Arvicola sapidus													1	2	1			
Eliomys quercinus													1	1	2			
Microtus sp.																1		1
Mus sp.													2	1				
Rattus norvegicus													4	4	7			
Rattus rattus													10	13	7			
Fox																		
Oryctolagus cuniculus				3	5	3	1	1		1	1		20	36	37	1		1

N—number of preys identified in scats containing the ticks; F—female; M—male

Discussion

The finding of six ticks species in common genet and red fox scats collected in Sintra-Cascais Natural Park, confirmed scat analysis as a good complementary method in the evaluation of tick-host associations. All the tick species identified were already known for Portugal (Dias 1994), but due to the lack of systematic surveys on the ticks distribution patterns, the species herein reported are described for the first time for the study area.

Two possible origins for the collected ticks can be hypothesized: first they could be the result of grooming behaviors, which are common among several carnivores (e.g. Neal and Cheeseman 1996); secondly, they could be ingested as prey parasites. Although, grooming is common in mammalian predators, even between social group members (e.g. badgers—Neal and Cheeseman 1996), several studies aiming the feeding ecology of carnivores in western Portugal did not detect ticks in scats (e.g. badgers—Rosalino et al. 2005; otters—Freitas et al. 2007; common-genets, Egyptian mongooses, stone-martens and red foxes—Santos et al. 2007). Moreover, when grooming is focused on parasite-defense, it frequently also involves fur ingestion (Mooring et al. 2004), which was not detected in our scat samples. This, together with the fact that ticks ingested with preys are usually more intact than those groomed, since usually carnivores ingest partly intact preys (Hiiemae 2000), and consequently unbroken prey ticks, lead us to assume that the detected ticks where prey parasites.

Although their adult life cycle restrict the parasitic feeding period to more or less one month per year (Urquhart et al. 1987), a high number of ticks ($N = 276$) was detected and these could be assigned to a specific mammal prey found in the predator's scats, since most of these only contained the non-digested remains of a single mammal prey. Nevertheless, as it should be expected considering their life cycle (Sonenshine 1991), adult ticks were mainly found in the hottest months of the year (May–July), a fact that might restrict the efficacy of this method to a short time period and specific climatic conditions. For example, the adult forms of the most common species in our study (*Rhipicephalus pusillus*), concentrates its activity between April and June (Dias 1994).

The obtained prevalence (7.66%) is most likely underestimated since no tick larvae or nymph where detected, which are the main tick stages commonly found on small wild mammals (e.g. rodents) (Santos-Silva et al. 2006a). The detectability of these life stages is impossible to untangle without the use of other methods for tick inventories, since it could indicate a scat methodological pit-fall. The ability to detect larvae and nymphal tick stages using the standard scat analysis methods (Reynolds and Aebischer 1991) is greatly reduced due to their extremely reduced body size; moreover the body of these instars have a thinner chitin layer and a higher reduction in the protection dorsal scutum, (Georgi 1985), which favors their digestibility.

Since the number of adult ticks found on rodents is usually very low, as we detected in other studies conducted in Portugal, where from a total of 553 rodents captured only 40 were parasitized with ticks, mainly with immature forms, which corresponded to an adults prevalence of 2.5% (Santos-Silva unpublished data), we believe that the high number of detected adult ticks suggests the adequacy of the described method as a complement in studying ticks-hosts associations, being innovative as well.

Association between ticks found in each scat and prey eaten on that meal allowed the identification of several potential tick-host relationships. Most of the meals referred to the consumption of only one type of prey, especially when referring to rabbit's predation, but sometimes more than one prey was consumed. To be conservative, only single-prey scats were considered, and thus several potential associations could be inferred. *Ixodes acuminatus*, was only found in scats containing just the wood mouse undigested remains, revealing a potential new host- tick interaction for Portugal and corroborating the high specificity observed in France or Spain (Morel 1965a, b; Gilot et al. 1976). These tick species revels endophilic and monotropic behaviors that could explain the association of adult forms with *Apodemus sylvaticus* (Morel 1965a, b). In fact, the original description of the tick type by Neumann (1901) was based on observations of two females collected on *Apodemus agrarius* in Italy, which is closely related to *Apodemus sylvaticus* in Portugal.

Inversely, *Rhipicephalus pusillus* showed an opportunistic behavior, since it was detected in scats containing the majority of the mammal species preyed by foxes and common genets: wild rabbit, wood mouse, Southern water vole *Arvicola sapidus* Miller, black and Norway rat (*Rattus rattus* Linnaeus and *R. norvegicus* Erxleben, respectively), mices *Mus* sp. and Garden dormouse *Eliomys quercinus* Linnaeus. On the other hand, *R. pusillus* was the principal species recovered on scats, and is associated mainly to *Oryctolagus cuniculus*, which was the most common mammalian prey eaten by genets and foxes in the scats containing ticks (Table 3). This fact corroborates again the potentiality of this method to approach specificity of tick-host associations. The infestation of wild rabbits by adult form of *Ixodes hexagonus* is already known but not usual; we have registered the same association in a recent study where one female of the same specie was detected parasitizing *Oryctolagus cuniculus* (Santos-Silva, unpublished data). The infestation of *Microtus* sp. by *R. turanicus* was already mentioned elsewhere in Europe (Gunther's vole, *Microtus guentheri* Danford and Alston—Walker et al. 2000), but is the first record reported for Portugal.

Due to the small sample size, several potential associations should be considered as indicative and more data is needed to confirm it. The same prudence should be used when considering the association between *Microtus* sp. with *R. turanicus* and *Apodemus sylvaticus* with adult *I. ricinus*, since no reference is available mentioning these mammals as hosts of adults of these tick species. Exceptionally in this case, grooming behavior should not be discarded, as genet constitutes a host for both tick species in Portugal (see Annex). The unusual findings described in this work, besides giving some enlightening on the host-tick Portuguese assemblage, revealed scats as a new source of biological information. The potentialities of the described indirect source of information on tick-host association, are enhanced by the fact that carnivores are more kin to predate animals which maximize their energy intake (Pianka 1983). This behaviour is usually associated with low capture and killing energetic costs, either by predating clustered prey, or old/sick animals (Bueno 1996). Therefore, our parasite sampling data is a biased sample of the true host population since parasitized animals are more susceptible to the sampling process (i.e. predation) than non-parasitized individuals (Wilson et al. 2002). These predators' characteristics maximize the overview of the tick communities associated with carnivore preys. To conclude, we think that, although this method is good complementary approach to determine ticks diversity, prevalence and host association in a particular area, its successful application should be limited to situations where adult ticks abundance is higher and when mammals constitute the bulk of carnivores' diet.

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Annex

Updated checklist of Portuguese host specificity of the tick species considered herein and authors who first identified them in Portugal

***Ixodes acuminatus* Neumann (1901)**	
Mustela putorius	Santos-Silva (unpublished data)
Rattus norvegicus	Dias (1995)
***Ixodes hexagonus* Leach (1815)**	
Bos taurus	Caeiro (1999)
Canis l. familiaris	Caeiro (1999)
Canis lupus	Dias et al. (1994)
Erinaceus europaeus	Caeiro (1999)
Felis catus domesticus	Caeiro (1999)
Genetta genetta	Santos-Silva (unpublished data)
Herpestes ichneumon	Dias et al. (1994)
Lutra lutra	Santos-Silva (unpublished data)
Martes foina	Dias et al. (1994)
Meles meles	Dias et al. (1994)
Mustela nivalis	Caeiro (1999)
Mustela putorius	Tendeiro (1962)
Myotis myotis	Dias et al. (1994)
Oryctolagus cuniculus	Caeiro (1999)
Rhinolophus ferrumequinum	Dias et al. (1994)
Sus scrofa domesticus	Caeiro (1999)
Sus scrofa ferus	Caeiro (1999)
Vulpes vulpes	Tendeiro (1962)
***Ixodes ventalloi* Gil Collado (1936)**	
Apodemus sylvaticus	Dias et al. (1994)
Asio flameus	Santos-Silva et al. (2006b)
Canis l. familiaris	Santos-Silva (unpublished data)
Crocidura russula	Dias and Santos-Reis (1989)
Elyomis quercinus	Dias and Santos-Reis (1989)
Erinaceus europaeus	Dias (1985)
Felis catus domesticus	Santos-Silva (unpublished data)
Mus spretus	Dias and Santos-Reis (1989)
Mustela nivalis	Dias and Santos-Reis (1989)
Oryctolagus cuniculus	Dias and Santos-Reis (1989)
Rattus norvegicus	Santos-Silva (unpublished data)
Vulpes vulpes silacea	Dias (1985)

Annex continued

Ixodes ricinus **Linnaeus (1758)**	
Apodemus sylvaticus	Caeiro (1992)
Bos taurus	Caeiro (1999)
Canis l. familiaris	Caeiro (1999)
Canis lupus	Dias et al. (1994)
Capra hircus	Caeiro (1999)
Cervus elaphus	Caeiro (1992)
Crocidura russula	Caeiro (1992)
Dama dama	Tendeiro (1962)
Elyomis quercinus	Caeiro (1992)
Erinaceus europaeus	Caeiro (1999)
Felis catus domesticus	Caeiro (1999)
Genetta genetta	Santos-Silva (unpublished data)
Herpestes ichneumon	Santos-Silva (unpublished data)
Homo sapiens	Tendeiro (1962)
Lepus capensis	Caeiro (1999)
Mus spretus	Dias et al. (1994)
Mustela nivalis	Caeiro (1992)
Mustela putorius	Caeiro (1992)
Oryctolagus cuniculus	Caeiro (1999)
Ovis aries	Caeiro (1999)
Sus scrofa ferus	Caeiro (1999)
Vulpes vulpes	Tendeiro (1962)
Rhipicephalus pusillus **Gil Collado (1936)**	
Apodemus sylvaticus	Caeiro (1992)
Bos taurus	Caeiro (1999)
Bubo bubo	Silva et al. (2001)
Canis l. familiaris	Caeiro (1999)
Canis lupus	Dias et al. (1994)
Cervus elaphus	Caeiro (1992)
Crocidura russula	Caeiro (1992)
Dama dama	Dias et al. (1994)
Elyomis quercinus	Caeiro (1992)
Erinaceus europaeus	Caeiro (1999)
Felis catus domesticus	Caeiro (1999)
Felis silvestris	Caeiro (1992)
Genetta genetta	Caeiro (1992)
Herpestes ichneumon	Santos-Silva (unpublished data)
Lepus capensis	Caeiro (1999)
Meles meles	Tendeiro (1962)
Mus spretus	Caeiro (1992)
Mustela nivalis	Dias et al. (1994)
Mustela putorius	Tendeiro (1962)
Oryctolagus cuniculus	Tendeiro (1962)
Ovis aries	Caeiro (1999)
Sus scrofa ferus	Caeiro (1999)
Vulpes vulpes	Tendeiro (1962)
Rhipicephalus turanicus **Pomerantsev, Matikashvili and Lototsky (1940)**	
Aquila nipalensis	Santos-Silva et al. (2006b)
Bos taurus	Santos-Silva (unpublished data)
Bubo bubo	Silva et al. (2001)
Buteo buteo	Santos-Silva et al. (2006b)
Canis l. familiaris	Caeiro (1999)
Capra hircus	Santos-Silva (unpublished data)
Genetta genetta	Santos-Silva (unpublished data)
Herpestes ichneumon	Santos-Silva (unpublished data)

Annex continued

Homo sapiens	Santos-Silva (unpublished data)
Martes foina	Santos-Silva (unpublished data)
Mustela putorius	Santos-Silva (unpublished data)
Oryctolagus cuniculus	Caeiro (1999)
Ovis aries	Gilot and Pautou (1981); Papadopoulos et al. (1992)
Vulpes vulpes silacea	Santos-Silva (unpublished data)

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