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Small islands as potential model ecosystems for parasitology: climatic influence on parasites of feral cats

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Abstract

The influence of climate on parasite distribution has been demonstrated in different regions worldwide. Despite its small size, Gran Canaria (Canary Islands, Spain) constitutes a 'biodiversity laboratory' due to the huge climatic differences between municipalities. Feral cats may represent a threat to biodiversity due to their predatory behaviour. In addition, they may be a source of pathogens zoonotic to humans. To study the climatic/seasonal influence and prevalence of feral cat parasites throughout the island, a total of 290 stool samples from 29 feral cat colonies were analysed following standard concentration protocols (sodium chloride, formol-ether and zinc sulphate). In total, 13 feline parasitic taxa were found, with the most common species being *Ancylostoma* spp., which, together with *Toxocara* spp., *Toxoplasma gondii* and *Giardia* spp., are considered a concern for human health. Nematodes were the most common parasites in all areas. Nematodes and protozoans were significantly more prevalent in temperate mild (75.0% and 30.0%) than in dry desert areas (29.3% and 18.7%). In contrast, cestodes were significantly more prevalent in dry desert than in temperate mild areas (26.0% and 13.3%). Only protozoans exhibited statistically significant seasonal patterns, mostly in the wet season. Data reported in this study endorse the usage of small and diverse islands such as Gran Canaria to study the climatic influence on parasitic communities in wild/feral animals. Cat colonies require better management to reduce their threat to endemic wildlife, domestic animals and public health, being invasive species that harbour zoonotic parasites.

Introduction

Seasonal and climatic variations have an important influence on vertebrate parasitic diseases worldwide (Elmaleck, 2015; Rondón *et al*., 2017; Short *et al*., 2017), including those affecting domestic carnivores like cats (Okoye *et al*., 2013; Beugnet *et al*., 2014). This climatic influence enables the transmission and maintenance of parasitic species in certain places or even restricts their spread to other regions in the same country (i.e. schistosomiasis in China), as clearly demonstrated in large continental areas, even between neighbouring countries (Martens, 1999; Zhou *et al*., 2008). Marked climatic differences are not only present in large countries, but they can also be found in islands such as Gran Canaria, in Spanish Macaronesia.

Located off the north-western coast of Africa, Gran Canaria is described as a 'miniature continent' due to its 20–21°C temperature at sea level and less than 12°C in highland areas all year round, and a striking difference between the rainy municipalities in the centre-north and very dry ones in the south. Therefore, islands like Gran Canaria could serve as low-scale model ecosystems for parasite epidemiology among different communities of animal species. These different conditions between municipalities may also influence the distribution of vertebrate parasites present in different parts of the island, which include those found in feral cat communities, some of which have zoonotic potential.

Spillover and the emergence of zoonotic disease outbreaks potentially occur when the human–wildlife interface becomes narrower, facilitating the contamination of domestic and peridomestic areas (Mackenstedt *et al*., 2015). In this sense, feral cats clearly act as reservoirs for zoonotic parasites, posing not only a hazard to humans by cohabiting with suburban colonies, but also infecting domestic animals (Morand *et al*., 2014).

Feral cats were introduced to Gran Canaria during the Spanish colonization of the island in the 14th century (Medina & Nogales, 2009), resulting in the establishment of several colonies and their spread to all municipalities of the island. On this island, especially in suburban and rural areas, it is rather common to allow domestic cats to freely enter and leave houses, making them prone to infection from local feral cats through direct or indirect contact. Furthermore, indirect contact implies the consumption of prey with infective stages of parasites, which could later result in an indoor source of zoonotic parasite infection (Morand *et al*., 2014).

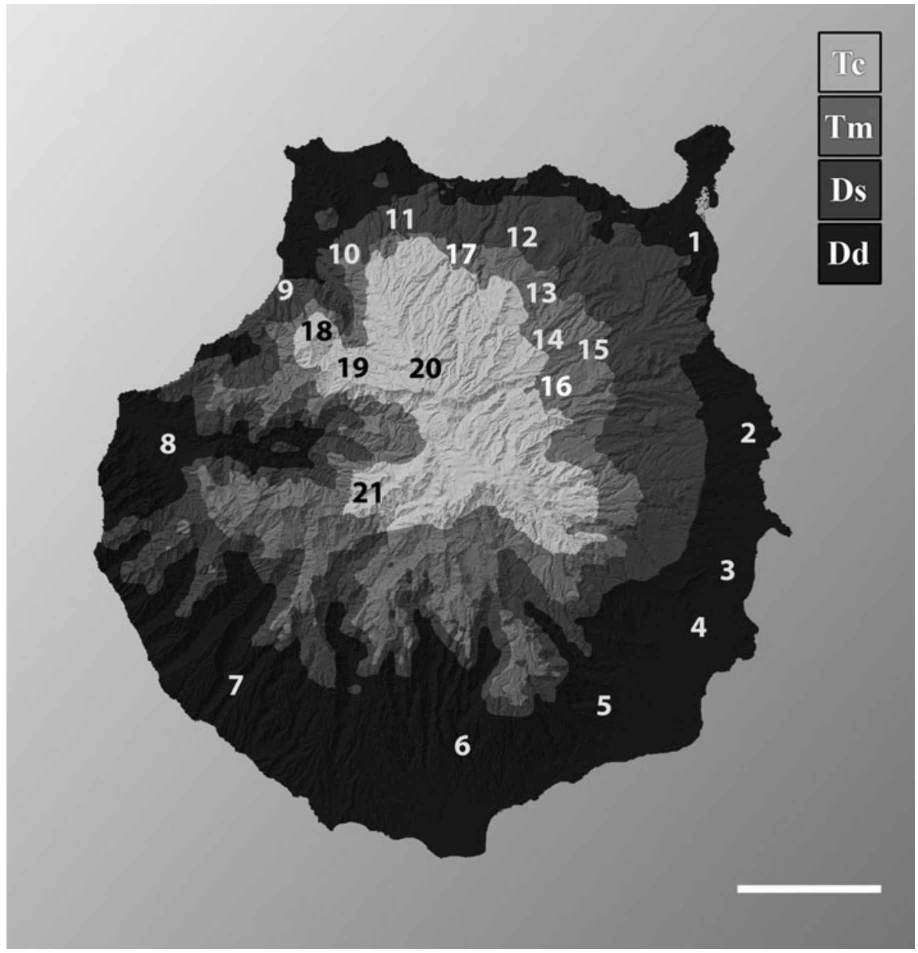

Fig. 1 Gran Canaria and its 21 municipalities. The greyscale represents the following isoclimatic zones: Dd, dry desert; Ds, dry steppe; Tm, temperate mild; Tc, temperate cold. *Municipalities tested twice each sampling row. 1: Las Palmas de Gran Canaria (capital). 2: Telde*. 3: Ingenio*. 4: Agüimes. 5: Santa Lucía*. 6: San Bartolomé de Tirajana*. 7: Mogán. 8: La Aldea de San Nicolás. 9: Agaete. 10: Gáldar. 11:Guía. 12: Firgas. 13: Arucas. 14: Teror. 15: Santa Brígida*. 16: Moya. 17: Valsequillo. 18: Artenara. 19: Valleseco. 20: San Mateo. 21: Tejeda. Scale bar = 10 km.

A neutering–releasing protocol is currently implemented to control these populations. The main objectives are to reduce the number of feral cats and their impact on endemic species, and prevent the public health risks (Rodríguez-Ponce *et al.*, 2016).

This study aims to deepen the epidemiology of feral cat parasites on Gran Canaria and investigate the influence of climatic conditions on their distribution, highlighting those with zoonotic potential. This research provides relevant information for use in cat colony control programmes.

Material and methods

Sampling and processing

Stool samples of randomly selected feral cats were analysed between January 2017 and May 2018. The cats lived in 29 colonies distributed throughout the island's 21 municipalities (fig. 1). The samples consisted of mixed faeces from at least three random cats, freshly deposited on soil. One sample was taken monthly from each municipality, except for Las Palmas de Gran Canaria, the island's capital, where four samples were taken, as this city has the largest number of inhabitants. In the municipalities with more than 30,000 inhabitants (Ingenio, Santa Lucía, San Bartolomé, Santa Brígida and Telde), two samples were taken.

Faeces were stored in dry sterile containers and sent to the Parasitology Laboratory of the Veterinary Faculty of Las Palmas de Gran Canaria University, where they were kept refrigerated until processing within 24–48 h. The European Scientific Counsel Companion Animal Parasites (ESCCAP) guidelines 2020 were considered to determine the techniques used, such as sodium chloride flotation (Carvalho *et al.*, 2012), formol-ether sedimentation (Ritchie, 1948) and zinc sulphate centrifugal flotation (Faust *et al.*, 1938). Larvae of lungworms were also tested using the Baerman–Wetzel method (Giannelli *et al.*, 2015).

Statistics and isoclimatic zones of Gran Canaria

All the statistics were processed using Microsoft Excel 2016 (Microsoft, Washington, US)®, applying the chi-square function, as well as prevalence ratios. Differences were considered significant at $P < 0.05$. A ratio was estimated to study the odds of finding a parasite in an isoclimatic zone depending on the season: the number of samples from an isoclimatic zone where a specific parasite was identified in the wet season was divided by the number of samples taken in the same isoclimatic zone during the dry season where that parasite was also identified.

The samples were grouped by isoclimatic zones and by precipitation: dry season (spring–summer) and wet/temperate season (autumn–winter). Gran Canaria has four different isoclimatic zones (Rodríguez-Ponce *et al.*, 1995), ranging from sea level to the central peak of the island describing concentric circles (fig. 1) as follows: dry desert zone (Dd), around sea level; dry steppe zone (Ds), higher places up to 200 m, with temperatures above 18°C all year round and very dry summers; temperate mild zone (Tm), 200 to 800 m in altitude with winter temperatures below 18°C and heavy rainfall in the wet season, followed by dry and

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hot summers; and temperate cold zone (Tc), from 800 m to the highest point of the island, midlands, with a similar climate throughout the year to the previous zone, but with a lower average temperature during the wet and dry seasons.

Results

Overall results

A total amount of 290 stool samples were analysed for parasites, distributed by municipalities, isoclimatic zones and season, as shown in tables 1–4.

Nematodes were the most prevalent parasites (52.4%). Within this group, *Ancylostoma* spp. appeared in a larger number of samples (28.6%), followed by bronchopulmonary nematodes (28.3%) and the roundworms *Toxocara cati* (11.7%) and *Toxascaris leonina* (2.1%). Other nematodes were present in lower percentages: *Physaloptera* spp. (2.1%) and *Trichuris* spp. (0.7%).

Protozoa were the second most isolated taxa (21.4%). *Giardia* spp. were found in the largest number of samples (12.4%), followed by *Cystoisospora felis* (9.3%), *Cystoisospora rivolta* (1.7%) and *Toxoplasma gondii* (0.7%).

The tapeworms (20.3%) were non-egg-cluster producers from the family Dipylidiidae (*Joyeuxiella* spp. and *Diplopylidium* spp.) (16.6%) followed by *Taenia* spp. (1.4%) and *Mesocestoides* spp. (0.3%).

Isoclimatic and seasonal statistics

Nematodes were identified more than any other parasite group in every isoclimatic zone ($P < 0.05$) (table 4), showing their lowest value in the Dd zone (29.3%). In terms of nematode families, *Ancylostoma* spp. and lungworms were more prevalent than roundworms in Tm and Ds zones ($P = 0.024$). The highest prevalence of all nematode taxa was recorded in the Tc zone. Protozoa were observed in greater numbers in the Tm zone, while cestodes in the Dd zone.

In terms of seasonal patterns, protozoans were significantly more frequent in the wet than in the dry season ($P = 0.003$). Furthermore, the prevalence ratio between wet and dry season was, in all cases, close to unity, except for *Giardia* spp., which was 3.1 times higher in the wet season.

Table 1. Number of samples (*n*) per municipality and their isoclimatic zones (IC).

IC	Municipality/no. of colonies	n
Tc	Artenara/1	10
	Tejeda/1	10
	Valleseco/1	10
	San Mateo/1	10
Tm	Arucas/1	10
	Moya/1	10
	Santa Brígida /2	20
	Teror/1	10
	Valsequillo/1	10
Ds	Agaete/1	10
	Firgas/1	10
	Gáldar/1	10
	Santa María de Guía/1	10
Dd	Agüimes/1	10
	Ingenio/2	20
	Mogán/1	10
	San Bartolomé/2	20
	Santa Lucía/2	20
	Telde/2	20
	Las Palmas de Gran Canaria/4	40
	La Aldea/1	10
Total	21 Municipalities/29 colonies	290

Dd, dry desert; Ds, dry steppe; Tc, temperate cold; Tm, temperate mild.

Discussion

Zoonotic risk and disease reservoir

Few zoonotic species have been isolated in this work such as *Ancylostoma* spp., *T. cati* and *Giardia* spp., with a low prevalence of *T. gondii*. However, the ecology of *T. gondii* on Gran Canaria is a clear example of how much feral cat colonies can affect not only humans but also livestock and wildlife.

Previous studies on Gran Canaria alarmingly revealed more than 60% seropositivity to *T. gondii* in humans and livestock (Rodríguez-Ponce *et al.*, 1995), affecting almost 80% of humans aged over 60 years (Rodríguez-Ponce, 1994). The low detection of oocysts in faeces may also be influenced by the erratic pattern of excretion of this parasite, usually reaching a prevalence of 1% in cats shedding oocysts at any given time (Dubey, 2010; Elmore *et al.*, 2010).

Larva migrans is a relatively important zoonotic disease in certain countries of the world, even regarded as a hazard to travellers (Norris, 1971; Jelinek *et al.*, 1994; Sow *et al.*, 2017). Furthermore, a seroepidemiological study on the visceral *larva migrans* producer, *Toxocara* spp., revealed a prevalence of less than 6% in humans (Jiménez *et al.*, 1997), including a paediatric case of ocular toxocariosis (Cejas *et al.*, 2016). These diseases seem to be more related to children, as they can be more exposed at playgrounds, which are frequented by either cats or dogs, contaminated with larvated eggs of *Toxocara* spp. (Wright *et al.*, 2016) or third-stage larvae of *Ancylostoma* (Jelinek *et al.*, 1994). In addition to direct infection through the environment, toxocariasis can be regarded as a food-borne pathogen since contaminated vegetables are a common source of infection (Healy *et al.*, 2022). Hence, the high prevalences of *Ancylostoma* spp. and *T. cati* reported in this study represent a clear public health problem that must be addressed, particularly considering the probable indoor shedding by contaminated domestic cats.

While genotype F or *Giardia cati* (Feng & Xiao, 2011) (non-zoonotic) is the most common in cats (55.8%) (Ramírez-Ocampo *et al.*, 2017), almost four out of ten isolations (Ramírez-Ocampo *et al.*, 2017) belong to zoonotic species: *Giardia duodenalis sensu stricto* or genotype A (Feng & Xiao, 2011). Every year, more than 150 native cases of giardiosis are documented on the Canary Islands, mainly on the two capital islands – that is, 101 cases in Gran Canaria in 2018 (Canary Islands Health Service, 2018). Thus, the 12% reported in this study should be treated as potential zoonoses. Furthermore, kittens may also harbour other zoonotic species, *Giardia enterica* or genotype B, which in the Canary Islands is only documented

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Table 2. Epidemiological data of the protozoans ordered by isoclimate and season studied.

Season	IZ	Protozoa	*Giardia* spp.	Coccidia	*C. felis*	*C. rivolta*	*T. gondii*	n
O	Tc	17.5	5.0	12.5	12.5	0.00	0.0	40
	Tm	30.0	21.7	15.0	8.3	3.3	3.3	60
	Ds	25.0	15.0	10.0	10.0	0.0	0.0	40
	Dd	18.7	10.0	10.7	8.7	2.0	0.0	150
	O	21.4	12.4	11.7	9.3	1.7	0.7	290
W	Tc	25	7.1	25.1	17.9	3.6	3.6	28
	Tm	35.7	18.6	11.9	9.5	2.4	0.0	42
	Ds	19.2	19.2	0.0	0.0	0.0	0.0	26
	Dd	22.5	11.2	14.2	11.2	3.1	0.0	98
	O	25.3	15.5	13.4	10.3	2.6	0.5	194
D	Tc	0.0	0.0	8.3	0.0	0.0	8.3	12
	Tm	16.7	5.6	5.6	5.6	0.0	0.0	18
	Ds	35.7	7.1	28.6	28.6	0.0	0.0	14
	Dd	11.5	7.7	3.9	3.9	0.0	0.0	52
	O	14.6	6.3	8.3	7.3	0.0	1.0	96

Tc, temperate cold; Tm, temperate mild; Ds, dry desert; Ds, dry steppe; W, wet; D, dry; O, overall; IZ, isoclimatic zone; *n*, total number of samples analysed.

Table 3. Epidemiological data of the cestodes ordered by isoclimate and season studied.

Season	IZ	Cestoda	*Mesocestoides* spp.	Dipylidiidae	*Taenia* spp.	n
O	Tc	12.5	0.0	15.0	0.0	40
	Tm	13.3	0.0	11.7	1.7	60
	Ds	17.5	2.5	12.5	0.0	40
	Dd	26.0	0.0	20.0	2.0	150
	O	20.3	0.3	16.6	1.4	290
W	Tc	10.7	0.0	35.7	0.0	28
	Tm	11.9	0.0	4.8	0.0	42
	Ds	26.9	3.8	11.5	3.8	26
	Dd	31.6	0.0	14.3	3.1	98
	O	23.7	0.5	14.9	2.1	194
D	Tc	16.7	0.0	25.0	0.0	12
	Tm	16.7	0.0	5.6	0.0	18
	Ds	0.0	0.0	21.4	0.0	14
	Dd	15.4	0.0	23.1	0.0	52
	O	13.5	0.0	19.8	0.0	96

Tc, temperate cold; Tm, temperate mild; Ds, dry desert; Ds, dry steppe; W, wet; D, dry; O, overall; IZ, isoclimatic zone; *n*, total number of samples analysed.

in rodents from La Palma (Western Canary Islands) (Fernández-Álvarez *et al.*, 2014). Since no other known potential wildlife sources of *Giardia duodenalis* have been identified, further sampling for molecular studies should be considered to evaluate the real risk of this flagellate from feral cats.

Climatic influence

These data suggest that local climatic conditions seem to be more important than seasons for most parasites, except for protists. In the same line, warmer and more humid areas like the Tm are more ideal for parasites to reproduce. However, linked to the transmission of zoonotic parasites in suburban areas is the adaptation of intermediate hosts to these environments, which is influenced not only by the direct effect of urban development but also climatic conditions (Mackenstedt *et al.*, 2015). The best example highlighted in this study are cestodes.

The tapeworms reported here are non-egg cluster producers from the family Dipylidiidae, which comprises two genera with similar ecology: *Joyeuxiella* spp. and *Diplopylidium* spp. No

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Table 4. Epidemiological data of the nematodes ordered by isoclimate and season studied.

Season	IZ	Nematoda	*Ancylostoma* spp.	*T. cati*	*T. leonina*	*Physaloptera* spp.	*Trichuris* spp.	Lungworms	n
O	Tc	87.5	42.5	35.0	0.15	0.05	0.05	52.5	40
	Tm	75.0	53.3	18.3	0.0	0.05	0.0	51.7	60
	Ds	70.0	52.5	7.5	0.0	0.0	0.0	50.0	40
	Dd	29.3	8.7	4.0	0.0	0.0	0.0	6.7	150
	O	52.4	28.6	11.7	2.1	2.1	0.7	28.3	290
W	Tc	89.3	46.4	71.4	7.1	14.3	7.1	50	28
	Tm	73.8	50	2.4	0.0	2.4	0.0	42.9	42
	Ds	76.9	57.7	19.2	0.0	0.0	0.0	50	26
	Dd	34.7	8.2	0.0	0.0	0.0	0.0	10.2	98
	O	56.7	29.4	13.4	1.0	2.6	1.0	28.4	194
D	Tc	83.3	33.3	41.7	33.3	0.0	0.0	58.3	12
	Tm	77.8	61.1	0.0	0.0	5.6	0.0	72.2	18
	Ds	57.1	42.9	14.3	0.0	0.0	0.0	50	14
	Dd	19.2	9.6	1.9	0.0	0.0	0.0	0.0	52
	O	43.8	27.1	7.3	4.2	1.0	0.0	28.1	96

Tc, temperate cold; Tm, temperate mild; Ds, dry desert; Ds, dry steppe; W, wet; D, dry; O, overall; IZ, isoclimatic zone; *n*, total number of samples analysed.

information is available on the actual intermediate host of these cestodes, but their cysticercoids have been extensively reported in several poikilothermic animals (Witenberg, 1932; Roca, 1985). In Gran Canaria, the endemic Boettger's wall gecko (*Tarentola boettgeri*) is the only reptile included in the diet of cats, reported to be infected with either cestode (Roca *et al.*, 1987, 1999; Santana-Hernández & Rodríguez-Ponce, 2019). The population density of this gecko decreases with altitude (from sea level up to 750 m), with higher densities in the Dd areas (Mateo, 2002) – a fact which could account for the higher prevalence of cestodes in cats from Dd zones on the island. In addition, by preying on geckoes, two species of *Diplopylidium* are being transmitted to another important invasive species on Gran Canaria, the California Kingsnake (*Lampropeltis californiae)* (Santana-Hernández *et al.*, 2021). Hence, the life cycle of *Diplopylidium* spp. highlights the urgent need to control invasive species such as feral cat colonies and their co-invasive parasites to preserve Gran Canaria's fragile biodiversity.

However, added to the benefits of paratenic/invertebrate host usage, environmental resistance is a key feature for the survival of parasites. *Ancylostoma*, for example, is clearly sensitive to desiccation and sunlight, which explains its higher prevalence in Tc–Ds areas in contrast to Dd areas, where the action of the paratenic host may have a crucial role in their survival. Similarly, the use of land molluscs by lungworms is evidently limited to areas with higher densities of these animals, such as Ds and higher areas, with superior humidity to Dd areas. Thus, it suggests more benevolent climatic conditions for egg and larvae to survive.

Despite these patterns, mean temperature and precipitation in a specific location seemed to have a stronger influence on parasite prevalence than seasonal fluctuations in this study. The only recorded seasonal fluctuation was the prevalence of *C. felis* and *Giardia* spp. during the wet season. This high humidity could suggest more benevolent conditions for protists to survive. Similar patterns have been described by other authors, but no further conclusions have been formulated (Barutzki & Schaper, 2011).

In conclusion, islands similar to Gran Canaria could be used as model ecosystems to evaluate the influence of climate on parasite communities in wildlife and with further sampling, the potential consequences of climate change on parasitic biodiversity.

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Conflicts of interest. None.

Ethical standards. The authors assert that all procedures contributing to this work comply with the ethical standards of the relevant national and institutional guides on the care and use of laboratory animals.

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