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Trophic habits of feral cats in the high mountain shrublands of the Macaronesian islands (NW Africa, Atlantic Ocean)

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Feral cats *Felis catus* Linnaeus, 1758 have contributed to the extinction of numerous native species on islands, which are clearly sources of global biodiversity. We studied the diet of this introduced predator in the Madeira and Cape Verde archipelagos, which harbour important colonies of endangered seabirds in the high mountain habitats, and compared the results with those obtained in the same habitat in the Canary Islands, Macaronesian archipelago. On Madeira, 461 prey were identified from 143 scat groups. Mammals, overall mice, constituted the basic diet appearing in 95% of cat scats. On Fogo (Cape Verde), 657 prey items were obtained from 145 scats, and mammals were also the most important prey, reaching a frequency of occurrence of 88%. Although introduced mammals were the main prey category on all Macaronesian islands, we observed variation in feral cat diet among these islands. Birds were more frequently consumed on Madeira, lizards on Tenerife (Canaries) and invertebrates on Fogo. No specific differences were observed in relation to La Palma. We suggest that the diet composition on these islands varies according to the respective availability of the different prey types.

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Key words: non-native cats, Macaronesia, Madeira, Canaries, Cape Verde, diet, mountain environments

Introduction

Feral cats *Felis catus* Linnaeus, 1758 have become a top predator in the food chains on islands where they were introduced (Nogales *et al*. 1992), contributing to the decline and extinction of numerous native species worldwide (Lever 1994, Tershy *et al*. 2002). From continents (Dickman 1996) to islands of continental origin

(Taylor 2000, Bonnaud *et al*. 2007, Phillips *et al*. 2007) and, above all, oceanic islands (Fitzgerald and Veitch 1985, Konecny 1987, Tidemann *et al*. 1994, Medina and Nogales 2009), the negative effects of feral cats have been reported on a great variety of prey including mammals, birds, reptiles and invertebrates (Fitzgerald and Turner 2000, Courchamp *et al*. 2003).

The diet of feral cats on islands is mainly composed of other introduced mammal species such as rabbits *Oryctolagus cuniculus*, rats *Rattus* spp. and mice *Mus musculus* (see review of Fitzgerald and Turner 2000). However, the predatory behaviour of feral cats can change in relation to the abundance or availability of these main prey species (Malo *et al*. 2004, Harper 2005), in turn altering the predation pressure upon the frequently endangered indigenous species. In this respect, dietary studies have been used globally to interpret and quantify their impact upon endangered species (Paltridge *et al*. 1997), particularly on islands where the presence of one predator only has been sufficient to induce the extinction of the endemic prey (Courchamp *et al*. 1999).

Madeira (Madeiran archipelago) and Fogo (Cape Verde archipelago) are the islands in Macaronesia where two threatened bird species, the Madeira petrel *Pterodroma madeira* in Madeira and the Fea's petrel *Pterodroma feae* in Fogo occur (BirdLife International 2008a, b). They breed in high mountains that are covered with a specific high mountain shrubland. The diet of feral cats had not been studied there before, except of a preliminary study by Cook and Yalden (1980) on Deserta Grande (Madeiran archipelago). The study of the possible ecological effect of feral cat populations upon the Madeira and Fea's petrels would contribute to the knowledge on the influence this predator exerts on the breeding success and stability of burrowing petrel populations on oceanic islands (Veitch 2001, Bester *et al.* 2002, Pontier *et al.* 2002). Furthermore, we expect that the absence of rabbits on Fogo should cause significant modifications in the dietary composition and feeding ecology of this predator (Molsher *et al*. 1999, Harper 2005).

Thus, the aim of this contribution was to (1) study the diet of feral cats in the high mountain shrublands on Madeira and Fogo islands; (2) compare this data with the findings of previous studies carried out in the same habitat in the Canary Islands; and (3) assess their general impact on the native and endemic fauna of the high mountain areas of the Macaronesian archipelagos.

Study area

Macaronesia comprises the archipelagos of the Azores, Madeira, Salvages, Canaries and Cape Verde (Fig. 1). The altitude and orientation of the islands give rise to highly heterogeneous environments characterized by an altitudinal progression of vegetation belts (del Arco-Aguiar *et al*. 2006). One of the most interesting habitats, due to its great number of endemic plant species, is high mountain shrubland, which is only present in the highest islands. It is present in all the Macaronesian archipelagos, although scarcely in the Azores; being important on Tenerife, La Palma (Canary Islands), Fogo (Cape Verde Islands) and Madeira.

This study was conducted on Madeira island (Madeira archipelago; 32°73'32"N, 17°01'68"W) and Fogo island (Cape Verde archipelago; 14°56'17"N, 24°25'59"W). On Madeira the high altitude vegetation is above 1300 m a.s.l. It consists of shrub species of the genus *Erica* with a high ground cover of many endemic herbaceous plants, eg *Viola paradoxa* and *Armeria madeirensis*. In many areas, historically used by humans, introduced species eg *Cytisus scoparius* are present in high densities (Sequeira *et al*. 2000, Capelo *et al*. 2004). At least 12 bird species, one reptile *Lacerta dugesii*, one endemic bat subspecies *Nyctalus leisleri verrucosus* and several introduced mammals (rabbits, rats and mice) are distributed over this habitat (Oliveira 1999, Borges *et al*. 2008, Teixeira and Jesus 2009).

The study on Fogo island was focused on the upper parts of a great volcanic caldera called Bordeira. The vegetation in this area, located at approximately 2000 m a.s.l., is characterized by endemic shrubby plant species eg Artemisia *gorgonum*, *Lavandula rotundifolia*, *Echium vulcanorum*, *Tornabenea bischoffii* and *Helianthemum gorgoneum* (Borges *et al*. 2008). The native fauna on this island has been less studied than in the rest of the Macaronesian archipelagos. One native bat *Hypsugo savii*, 20 birds and 8 reptiles (4 gecko species – genus *Tarentola* and *Hemidactylus* and 4 skink species – *Mabuya* spp.) have been recorded on this island (Arechavaleta *et al*. 2005). Occurrence of rabbits, rats or mice was not documented on Fogo, however, rats and mice appeared in the cat diet analysed in this study.

Methods

The diet of feral cats was studied based on scat analysis (Delibes 1980, Trites and Joy 2005). To reduce the chance of sampling domestic or stray cats, which are likely to differ substantially in their diet, sampling areas were placed as

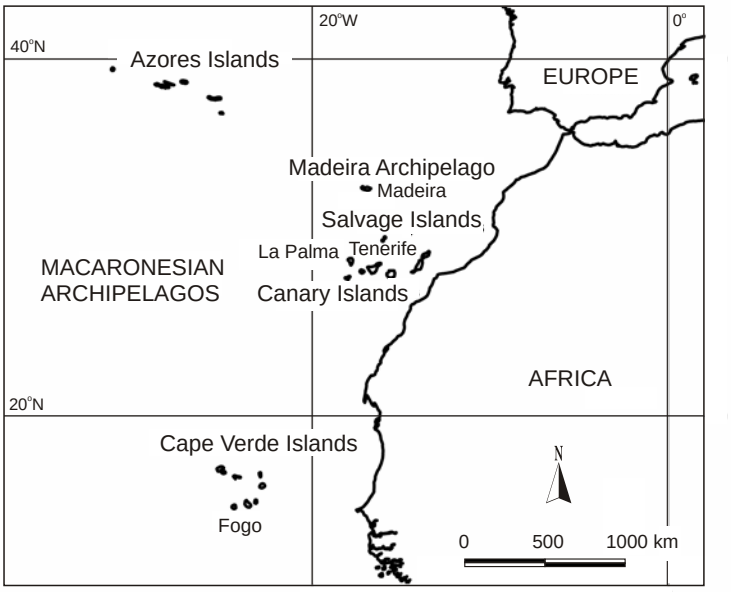

Fig. 1. Location of the studied islands in the Macaronesian archipelagos.

far as possible from human settlements. In most cases the distance exceeded 10 km, except on Fogo where it was 2 km, however, the collection sites were at a considerably different altitude (> 1000 m) and separated by an inaccessible steep cliff.

A total of 143 scats were collected in two different localities (Areeiro and Paul da Serra, 850 ha) on Madeira between 2001 and 2006, while on Fogo a total of 145 scats were collected during 2007 at one wide locality (Bordeira, 150 ha). Before analysis, scats were stored individually in aluminium cooking foil, recording location and date.

In contrast to other mammal predators, feral cats frequently bury their faeces (Bradshaw 1992), so it is very difficult to assign an exact date when faeces were deposited. So, the collected material probably represented all seasons because scats remain unaltered over a long period before disintegrating (Medina and Nogales 2007). Scats were broken up at the laboratory after previous saturation in water. Prey items were identified at a magnification of 16× to species level whenever possible using hairs, bones, feathers, arthropod exoskeletons compared to reference collections. Although it was difficult to quantify the number of individuals from scats, because the same prey may appear in more than one dropping (Delibes 1980), the minimum number of prey individuals was estimated by bone remains, especially jaws and teeth. Carrion was identified by the presence of large bones and fly larvae. The ingested biomass was estimated from weights obtained from bibliographic resources. In the case of invertebrates, only those prey weighing more than 0.05 g were considered, so as to avoid the presence of other indirect prey previously ingested by lizards (Medina *et al*. 2006, Medina and García 2007). For large prey such as rabbits, which constitute more than the daily food intake by cats, the total biomass applied was 170 g (Fitzgerald and Karl 1979), a weight widely used in several feral cat studies (see Nogales and Medina 2009). The number of prey, frequency of occurrence, relative frequency (number of individuals from the same species or taxonomic group × 100 divided by the total number of prey) and percentage of biomass (biomass of the same species or taxonomic group × 100 divided by the total consumed biomass) were the measures used to express diet composition. To overcome possible bias from these measures (Fitzgerald and Turner 2000), an index of relative importance (hereafter IRI) was calculated (Risbey *et al*. 1999, Hart *et al*. 2002). The IRI was measured for each food category, except for food scraps and plant material, using the formula:

$$\mathrm{IRI} = F\,(N + W)$$

where N is the relative frequency, W is the biomass percentage and F is the percentage frequency of occurrence (Pinkas 1971, see also Martin *et al*. 1996, for derivation of formula substituting mass per volume).

We compared the relative frequency of each prey type between islands using χ^2-tests. The analysis compared a certain prey item with the total number of the other prey identified (Medina *et al*. 2006). A standardized Levin's niche-breadth index was applied to evaluate the niche-breadth of the relative frequency of consumption by feral cats; values close to "0" indicate dietary specialization while those close to "1" show a broad diet (Krebs 1989). The Morisita index of similarity (Krebs 1989), using the relative frequency, was calculated to evaluate the feral cat diet overlap between the high mountain shrublands of the different Macaronesian islands.

Lastly, data of feral cat diet in the high mountain shrublands of Tenerife and La Palma were obtained from the previous research by Nogales *et al*. (1990) and Medina *et al*. (2006), respectively, and were appropriately standardized for comparison (see Nogales and Medina 2009).

Results

Feral cats diet on Madeira

The analysis of the 143 scat groups of feral cats from this island revealed a total of 461 prey items. Mammals constituted the basic diet of feral cats (86.2% of the total biomass consumed; Table 1). *Mus musculus* was the most important food item among mammalian prey. Birds were the second most frequently eaten group followed by reptiles, represented by one lizard species *Lacerta dugesii*. Although the invertebrates were taken more frequently than birds and reptiles their biomass consumed was the lowest. The IRI of invertebrates was higher than the IRI of reptiles. Nevertheless, their presence in scats was significantly related to reptile remains (χ^2 = 18.43, df = 1, $p < 0.001$). The Levin's niche breadth index was at medium level (B = 0.55).

Table 1. Diet of feral cats *Felis catus* on Madeira and Fogo. N – number of prey, RF – relative frequency, F – frequency of occurrence, B – percentage of biomass, IRI – index of relative importance.

Prey	Madeira (n = 143)					Fogo (n = 145)				
	N	RF	F	B	IRI	N	RF	F	B	IRI
Mammals	247	53.6	95.1	86.2	13294.9	273	41.6	87.6	57.6	8689.9
Oryctolagus cuniculus	40	8.7	27.3	37.0	1247.6	–	–	–	–	–
Mus musculus	154	33.4	50.3	13.0	2333.9	237	36.1	78.6	25.9	4873.2
Rattus spp.	53	11.5	35.7	36.2	1702.9	36	5.5	24.1	31.7	896.5
Reptiles	61	13.2	22.4	4.0	385.3	139	21.2	41.4	6.4	1142.6
Gekkonidae	–	–	–	–	–	43	6.5	16.6	2.0	141.1
Lacertidae	61	13.2	22.4	4.0	385.3	–	–	–	–	–
Scincidae	–	–	–	–	–	96	14.6	40.0	4.4	760
Birds	45	9.8	31.5	9.6	611.1	36	5.5	24.8	35.5	1016.8
Passeriformes	38	8.3	26.6	3.1	303.2	7	1.1	4.8	0.7	8.6
Non Passeriformes	7	1.5	4.9	6.5	39.2	17	2.6	11.7	20.4	269.1
Pterodroma feae	–	–	–	–	–	11	1.7	7.6	13.2	113.2
Numida meleagris	–	–	–	–	–	1	0.2	0.7	1.2	1.0
Invertebrates	108	23.4	16.8	2.8	398.2	209	31.8	46.2	0.50	1492.3
Orthoptera	101	21.9	14.7	0.3	326.3	100	15.2	26.2	0.33	406.9
Acrididae	2	0.4	0.7	0.003	0.3	54	8.2	15.2	0.2	127.7
Gryllidae	1	0.2	0.7	0.002	0.1	35	5.3	12.5	0.1	67.5
Tettigonidae	98	21.3	14.7	0.3	317.5	11	1.7	4.1	0.03	7.1
Coleoptera	6	1.3	2.1	0.003	2.7	92	14.0	30.3	0.15	428.7
Curculionidae	3	0.7	1.4	0.001	1.0	8	1.2	5.5	0.003	6.6
Tenebrionidae	–	–	–	–	–	5	0.8	3.4	0.002	2.7
Cerambycidae	–	–	–	–	–	68	10.4	26.2	0.14	276.1
Staphylinidae	1	0.2	0.7	0.001	0.1	1	0.2	0.7	0.001	0.1
Coleoptera indet.	2	0.4	1.4	0.001	0.6	2	0.3	1.4	0.001	0.4
Lepidoptera	–	–	–	–	–	17	2.6	6.2	0.01	16.2
Hymenoptera	1	0.2	0.7	0.001	0.1	8	1.2	4.1	0.003	4.9
Seeds	–	–	25.9	–	–	156	–	9.7	–	–
Plant material	–	–	31.5	–	–	–	–	23.4	–	–
Rubbish	–	–	–	–	–	–	–	0.7	–	–
Carrion	–	–	–	–	–	–	–	0.7	–	–

Feral cats diet on Fogo

The feral cat diet on Fogo was described from 145 scats containing a total of 657 prey items. Mammals (mice and rats) were the most important prey appearing in 87.6% of scats (Table 1). Although the contribution of invertebrates to the total consumed biomass was practically insignificant, both the number of prey and frequency of occurrence make them the second most important prey for feral cats on this island (Table 1). No relationship between the presence of invertebrates and reptiles in each scat was found ($\chi^2 = 0.02$, df = 1, $p = 0.96$); therefore invertebrates were directly consumed, not being indirect prey eaten first by reptiles. The presence of reptiles and birds is also noteworthy, comprising a similarly important part in the diet. Fea's petrel was the bird species most frequently consumed. The feral cat niche breadth was intermediate (B = 0.47).

Comparison of the diet in the high mountain Macaronesian shrublands

The IRI of the main prey categories (mammals, birds, reptiles and invertebrates) shows a variation in the feral cat diet among the various Macaronesian islands (Fig. 2). Frequency of occurrence or relative frequency of mammals varied significantly for the four islands considered ($\chi^2 = 53.9$, df = 3, $p < 0.001$). Mammals were more important on Madeira and La Palma than on the other two islands. Rabbits were consumed more often on La Palma and Tenerife ($\chi^2 = 53.5$, df = 2, $p < 0.001$); rats were significantly less important on La Palma ($\chi^2 = 39.3$, df = 3, $p < 0.001$), while on Fogo and Tenerife the predation upon mice was higher in the former ($\chi^2 = 112.9$, df = 3; $p < 0.001$). Birds were more significantly preyed on in Madeira than Tenerife ($\chi^2 = 39.0$, df = 3, $p < 0.001$), while on Fogo and La Palma the percentage of consumed birds were similar ($\chi^2 = 0.1$, df = 1, $p = 0.79$). Predation upon reptiles was highest on Tenerife ($\chi^2 = 166.9$, df = 3, $p < 0.001$), the lowest being on Madeira. No difference was found in the number of reptiles preyed on in Fogo and La Palma ($\chi^2 = 3.2$, df =1, $p = 0.08$). The highest contribution of invertebrates to the feral cat diet was on Fogo island ($\chi^2 = 74.7$, df = 3, $p < 0.001$). On Madeira, this taxonomic group was more important than on the two Canary Islands ($\chi^2 = 8.7$, df = 2, $p = 0.01$), where no statistical differences were observed (Tenerife and La Palma, $\chi^2 = 0.5$, df = 1, $p = 0.49$).

The Morisita index showed a variable trophic overlap between islands; in the case of Tenerife and Fogo the index indicates that the cats presented a clearly different diet (Table 2). Levin's index of niche breadth in Tenerife was 0.15, while for the rest of the islands it was at medium values (Madeira: 0.55, La Palma: 0.44 and Fogo: 0.47).

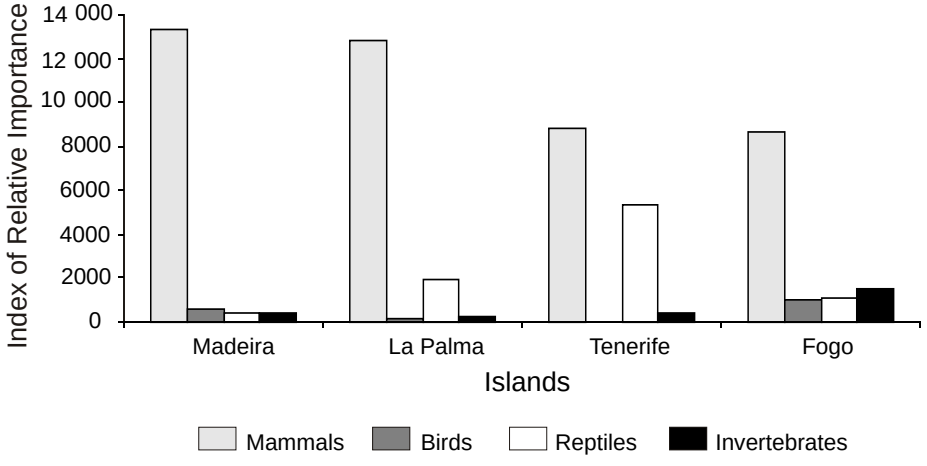

Fig. 2. Index of relative importance (IRI) for the main groups preyed on by feral cats *Felis catus* in the high mountain shrublands of the Macaronesian islands.

Table 2. Overlap of the feral cats' diet in the high mountain shrubland on different Macaronesian islands. Morisita index of similarity was applied using the relative frequency.

Islands	Tenerife	La Palma	Fogo
Madeira	0.59	0.78	0.86
Tenerife	–	0.61	0.17
La Palma	–	–	0.61

Discussion

Feral cat diet on Madeira and Fogo islands

The diet of feral cats on Madeira and Fogo islands follow a similar pattern to those recorded for many other islands where this predator has been introduced, characterized by a large biomass consisting of introduced mammals (mainly rabbits and mice), when present (Fitzgerald and Turner 2000).

On Madeira, mice were the most important mammal prey in terms of numbers of individuals eaten, however rabbits contributed much more to biomass as reported for temperate latitudes (Fitzgerald and Turner 2000). On islands, birds constitute the second greatest component of the diet (Nogales and Medina 2009), higher than on continents (Fitzgerald and Turner 2000). Nevertheless, seabirds were not consumed by cats because a small population of burrowing petrels *Pterodroma madeira* is distributed over the study area (BirdLife International 2008b). Reptiles presented the lowest relative frequency and also a low biomass due to the small size of lizards *Lacerta dugesii* (snout-vent length SVL $\approx$ 7–10 cm, Speybroeck 2007). A similar case was observed on Fuerteventura (Canaries), where a small lizard *Gallotia atlantica* is present and preyed on by cats at a low frequency (Medina *et al*. 2008). Lastly, predation upon invertebrates was in accordance with the general patterns observed in previous studies: high number of species and low biomass (Pearre and Maass 1998).

Despite the total absence of rabbits on Fogo (Arechavaleta *et al*. 2005), mammals were also the most important prey. Mice were the most frequently consumed prey, although on islands where rabbits are absent, rats were most commonly consumed (Dilks 1979, Fitzgerald *et al*. 1991, Fitzgerald and Turner 2000). On the other hand, when rabbits and rats are absent on some islands, cats highly predate upon birds (Fitzgerald and Veitch 1985). Nevertheless, in the present study, birds hardly contributed to the cat diet, probably because they were relatively scarce (BirdLife International 2008a). In fact, the second most important prey group were invertebrates followed by reptiles, both in number of prey and frequency of occurrence (Table 1). The predation upon large invertebrate species such as Acrididae (Orthoptera) and Cerambycidae (Coleoptera) has previously been described (Nogales and Medina 2009).

The medium values of Levin's niche breadth obtained for the diet was probably caused on both islands by the high predation upon mammals; these values were similar to those obtained in the Canary Islands (Nogales and Medina 2009).

Comparison of the feral cat diet in the high mountain shrublands of different islands

The proportion of introduced mammals in the feral cat diet in the high mountain shrublands, varied considerably among Macaronesian islands, probably in relation to prey availability (Fitzgerald and Turner 2000). While in the Canaries, rabbits were more frequently consumed (Nogales *et al*. 1990, Medina *et al*. 2006), on Madeira and Fogo mice were the most important prey. Rabbits were scarce during the study period on Madeira due to a myxomatosis outbreak and are completely absent in Fogo (P. Oliveira, unpubl., Arechavaleta *et al*. 2005). Previous studies have also shown that when these lagomorphs are rare or absent, feral cats mainly predate upon other mammal species (Fitzgerald *et al*. 1991, Alterio and Moller 1997, Murphy *et al*. 2004, Bonnaud *et al*. 2007), according to their ability to modify its behaviour to prey availability (Molsher *et al*. 1999, Malo *et al*. 2004, Harper 2005).

Birds were more frequently preyed on in Madeira than on Tenerife. The greater pro-

portion of predation upon birds takes place on oceanic islands where there is a high abundance of ground-nesting seabirds (Taylor 2000, Courchamp *et al*. 2003). However, most identified birds preyed on in Madeira were land species as they are relatively abundant on this island (P. Oliveira, unpubl.). Chicks in nests are easily captured by cats climbing trees and juvenile land birds are a fairly easy prey for feral cats due to their smaller size and poorer capacity to fight back. Contrary to this, on Tenerife the high predation upon other prey types, such as rabbits and lizards, could have resulted from low availability of birds in this ecosystem (Nogales *et al*. 1990).

Reptiles were found to constitute a high proportion of feral cat diet at low latitudes (Fitzgerald and Turner 2000), probably as a consequence of their high numbers and large body sizes of species living there. Nevertheless, although the number of species on each island studied decreases with latitude (Arechavaleta *et al*. 2005, Martín *et al*. 2005, Borges *et al.* 2008), the percentage of reptiles in the diet did not vary in the same way, being higher on Tenerife than on the rest of the islands. So, the proportion of reptiles consumed in the high mountain shrublands of Macaronesia seems to be probably related to their relative abundance on each island (Fitzgerald and Turner 2000).

Insects were the second most important prey for feral cats on Fogo, where the IRI reached its highest value for this item. Insects have been shown to constitute an important prey item of cats at low latitudes and in warm seasons (Pearre and Maass 1998). Furthermore, Fogo is the southernmost island of Macaronesia and is characterized by its dry climate. There, the cats' diet included a high proportion of large insect species, similarly as it was found in the xerophytic shrublands of the Canary Islands (Medina and García 2007, Medina *et al*. 2008, Nogales and Medina 2009). These xeric habitats harbour relatively impoverished communities and feral cats may be eating insects to obtain more water per food item ingested (Konecny 1987).

The overlap and specialization of feral cat diet between islands were different due to the high consumption of lizards and invertebrates on Tenerife and Fogo, respectively. Diet overlap and niche breadth was shown to decrease in seasons of low prey productivity or availability (Pearre and Maass 1998).

Conclusions

Our study have shown the low frequency of endangered species such as the Madeira and Fea's petrels in feral cat diet on Macaronesian islands, however, we cannot conclude that this predator is not threatening these species. Actually, we need quantitative data on population trends of endangered species to provide evidence for any impact of feral cat predation (eg Jones 2001, Hughes *et al*. 2008, Peck *et al*. 2008). Furthermore, the presence of introduced mammals, both predators (cats, rats) and prey (mice, rabbits), must be taken into account in order to prevent negative results in the conservation of endangered species, because of the hyperpredation process and mesopredator release effect (Courchamp *et al*. 1999, 2000). This is especially important in cases, as in these archipelagos, where the presence of rats, probably one of the most invasive species worldwide (Jones *et al*. 2008), and their influence on the endangered species could be compensated by the mitigating effect of feral cats (Dickman 1996, Rayner *et al*. 2007, Hughes *et al*. 2008). These effects should be considered in any control or eradication programmes of feral cats on islands, which aim at conservation of the native threatened fauna (Bergstrom *et al*. 2009).

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