Italian Journal of Zoology

ISSN: 1125-0003 (Print) 1748-5851 (Online) Journal homepage: http://www.tandfonline.com/loi/tizo20

Diet of feral cats during the Scopoli's shearwater breeding season on Linosa Island, Mediterranean Sea

L. Ozella, M. Cecchetti & D. Pessani

To cite this article: L. Ozella, M. Cecchetti & D. Pessani (2016) Diet of feral cats during the Scopoli's shearwater breeding season on Linosa Island, Mediterranean Sea, Italian Journal of Zoology, 83:4, 589-599, DOI: 10.1080/11250003.2016.1237562

To link to this article: http://dx.doi.org/10.1080/11250003.2016.1237562

Italian Journal of Zoology, 2016, 589–599
Vol. 83, No. 4, http://dx.doi.org/10.1080/11250003.2016.1237562

Taylor & Francis
Taylor & Francis Group

Diet of feral cats during the Scopoli's shearwater breeding season on Linosa Island, Mediterranean Sea

L. OZELLA*, M. CECCHETTI, & D. PESSANI

Department of Life Sciences and Systems Biology, University of Torino, Italy

(Received 21 March 2016; accepted 8 September 2016)

Abstract
Feral cats (*Felis catus*) are considered to be one of main successful invasive species of island ecosystems. The introduced cats often negatively affect seabird populations due to the lack of anti-predatory strategies resulting from the absence of mammalian terrestrial predators during their evolutionary development. Linosa Island hosts the second largest colony of Scopoli's shearwater (*Calonectris diomedea*) of the species. In this study, we estimated the number of cats on Linosa Island and we evaluated their diet using a non-invasive method: scat analysis. Scat collection took place in the northern part of the island in the Scopoli's shearwater colony, where a feral cat colony lives permanently. We analysed a total of 188 cat scats, collected during the different stages of the shearwater breeding period. Introduced mammals were the most frequent preys: wild rabbits and black rats occurred in scats with the same frequency (28.72%). Birds were the second most frequent prey category found, primarily represented by the seabird Scopoli's shearwater (16.49%). The cats' diet varied seasonally in relation to prey availability and accessibility: shearwaters were mainly preyed upon during spring when they exhibited the greatest vocal activity and spent the most time out of their nests. Regarding the biomass, mammals were the dominant prey, and wild rabbits were the most consumed species. However, Scopoli's shearwater represented approximately one-third of the total biomass consumed. Consequently, the management of feral cats living in proximity of the seabird colony is strongly required, and the increase of "trap-neuter-release" (TNR) programmes is necessary in order to avoid uncontrolled gains in the cat population on Linosa Island. Since the cats have a crucial role in controlling the rat population (the main threat for shearwaters), before planning management strategies, the complex inter-relationship that exists between species must be taken into account.

Keywords: Felis catus, Calonectris diomedea, *seabird, invasive species, scat analysis*

Introduction

Cats (*Felis catus* Linnaeus, 1758) have been closely linked to the evolution of human society for thousands of years (Robertson 2008). In addition to "pet cats" (usually cats with an owner), there is another population of cats referred to as "feral cats"; these cats can roam freely and are not closely related to a particular household (Levy & Crawford 2004). Generally, feral cats gather in colonies: groups of three or more sexually mature cats, which live and feed together (Slater 2005). The home range size of feral cats varies according to availability and distribution of food (Liberg & Sandell 2000); thus, the size and stability of feral cat populations depend on a local combination of favourable environmental conditions that provide food and shelter (Ferreira et al. 2011). However, regular access to food provided by humans does not suppress the hunting behaviour of feral cats, and they may continue to kill even when prey populations are low (Turner & Meister 1988; Barratt 1997). Consequently, feral cats have a substantial impact on wildlife, even when they have no need to hunt to survive (Ferreira et al. 2011). Cats also hunt and capture prey even after having eaten nutritionally sufficient cat food, and they tend to play with their prey rather than consume it (Turner 2014). Feral cats feed on a wide variety of prey (Van Aarde 1980) and they are considered opportunistic and generalist carnivores (Fitzgerald 1988). Since their domestication, which took place around 9000 years ago from the Near Eastern wildcat (*Felis silvestris lybica* Forster, 1780) (Vigne et al. 2004; Driscoll et al. 2007; Serpell 2014), cats have been

*Correspondence: L. Ozella, Department of Life Sciences and Systems Biology, University of Turin, Via Accademia Albertina 13, Torino 10123, Italy. Tel: +39 0116704538. Fax: +39 0116704508. Email: laura.ozella@unito.it

accidentally or deliberately introduced into most of the terrestrial ecosystems of the world, including many remote islands (Fitzgerald 1988; Pearre & Maass 1998; Bonnaud et al. 2011). Cats were often introduced into island habitats to control previously introduced rodent and rabbit populations, but their opportunistic predator behaviour has affected a great variety of preys (Bonnaud et al. 2011). In insular ecosystems, cats become the most dominant predator and they have significant negative effects on native species (e.g. Courchamp et al. 2003; Nogales et al. 2004; Medina et al. 2011). Moreover, cats are successful invaders on islands because they can survive without access to fresh water, have high fecundity, and are extremely adaptable to new environments (Fitzgerald & Turner 2000; Say et al. 2002; Bonnaud et al. 2011). Feral cats on islands are dietary generalists, feeding on vertebrates (mainly mammals, birds and reptiles) and invertebrates (mainly insects), including endemic and endangered species (e.g. Nogales & Medina 2009; Bonnaud et al. 2011; Medina et al. 2011). Currently it is known that feral cats are present on at least 5% of the total 179,000 islands of the world (Nogales et al. 2013), and they are commonly considered responsible for the decline and the extinction of numerous species belonging to different taxa (Medina et al. 2011; Hervías et al. 2014). Native island species are particularly vulnerable to cat predation because of their lack of anti-predatory behaviour (Hervías et al. 2014). In particular, seabirds, mainly petrels and shearwaters, are often affected by introduced cats (Courchamp et al. 2003) due to their lack of defence against terrestrial predators, while they exhibit anti-predatory behaviours in respect to bird predators (Mougeot & Bretagnolle 2000; Rubolini et al. 2015).

For these reasons, feral cats are considered to be one of the 100 worst invasive species in the world (Lowe et al. 2000), and their active management is considered crucial in order to minimise their detrimental effects on insular wildlife (Nogales et al. 2013). Worldwide, feral cat eradication has been successfully carried out on 83 islands (Campbell et al. 2011). In Italy, the national law 281/91, concerning the management of pets and the control of feral cats, has introduced a no-kill policy for this species. Thus, "trap-neuter-release" (TNR) programmes have been carried out to control the increase of populations of feral cats.

It is important to know which species cats consume, to assess the impact of cats on conservation of biodiversity and to implement programmes for the control of cat populations (Hervías et al. 2014). Scat analysis is a non-invasive method widely used to study the diet of mammalian carnivores (Trites & Joy 2005; Medina et al. 2008); it does not require killing the animals, thus adhering to the no-kill policy of the Italian law.

This study was carried out on Linosa Island, a small island belonging to the Pelagie Archipelago (Italy), which hosts the world's second largest colony of Scopoli's shearwater (*Calonectris diomedea* (Scopoli, 1769)). The Scopoli's shearwater is a pelagic seabird that breeds in the Mediterranean, formerly classified as a subspecies of the Cory's shearwater but now considered to be a separate species (Sangster et al. 2012). The current conservation status of this seabird is "Least Concern", as indicated in the Red List of Threatened Species of the International Union for Conservation of Nature (IUCN), but the population trend appears to be decreasing (BirdLife International 2014). The main threats to the species include the impacts of invasive, non-native mammals and mortality from fisheries bycatch (Carboneras et al. 2013). The Scopoli's shearwater is a long-lived bird with low fecundity, which nests in individual burrows located on the ground in rock cervices (Warham 1990). During the incubation period, the adults spend several days fasting and incubating the eggs, and a few days after hatching, adults leave the chick alone and come back to feed it only once during the night (Cecere et al. 2013, 2014; Rubolini et al. 2015). Therefore, any assessment of the impact of introduced cats on this seabird requires a better understand of cats' feeding behaviour, particularly in response to the bird's breeding cycle.

The specific aims of the study were (1) to estimate the cat population present on the island; (2) to investigate the diet of a colony of feral cats which lives permanently near the colony of Scopoli's shearwater, by analysing their scats; (3) to evaluate the frequencies of prey categories, the niche-breadth, and the prey species biomass.

Materials and methods

Study site

The study was conducted on Linosa Island (5.43 km^2; Figure 1), located in the south-western Mediterranean Sea (35°52′N, 12°52′E), and belonging to the Pelagie Archipelago.

The climate on Linosa Island is semi-arid and, according to Köppen and Geiger (1930), is classified as BSh (steppe climate). Linosa hosts vertebrate species of particular conservation concern, due to Mediterranean endemism of species that are absent on the continent: the eyed skink (*Chalcides ocellatus*

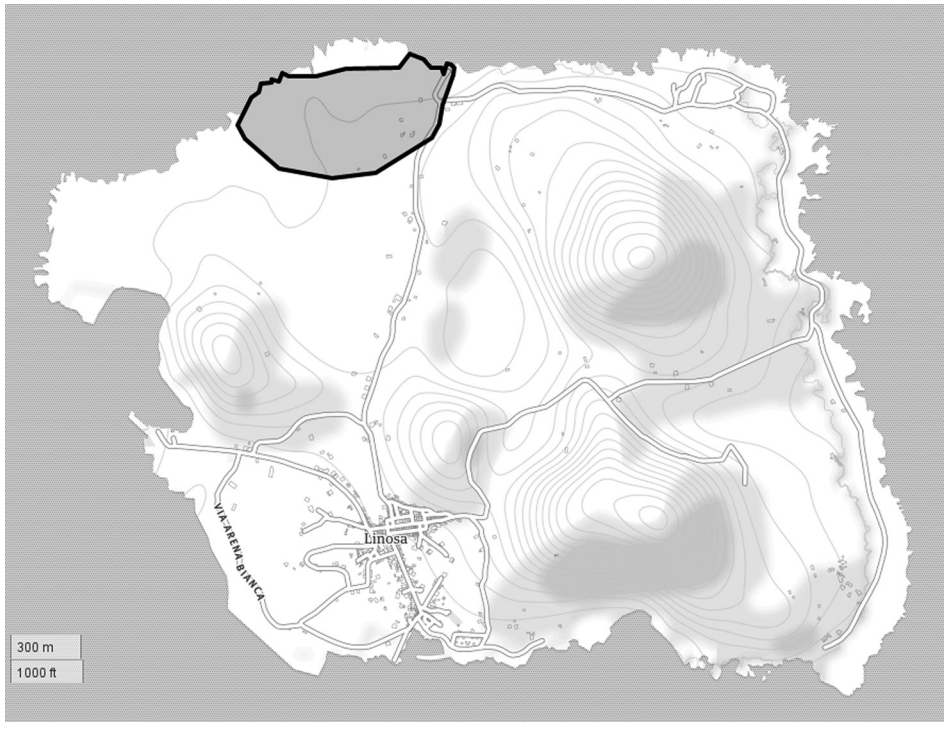

Figure 1. Map of Linosa Island; the site called "Mannarazza" where scats of feral cats were collected is highlighted in grey.

Forskål, 1775), the Filfola lizard (*Podarcis filfolensis* (Bedriaga, 1876)), the "big head" cricket (*Brachytrupes megacephalus* (Lefebvre, 1827)) and the Scopoli's shearwater (*Calonectris diomedea*). Regarding this latter species, Linosa hosts the second largest colony of Scopoli's shearwater in the world, with around 10,000 breeding pairs (Massa & Lo Valvo 1986). All non-flying mammals present on Linosa Island were introduced: cat (*Felis catus*), black rat (*Rattus rattus* (Linnaeus, 1758)), house mouse (*Mus musculus* Linnaeus, 1758) and wild rabbit (*Oryctolagus cuniculus* (Linnaeus, 1758)). Furthermore, different bird species use Linosa Island during migration periods as a stopping point, such as the spotted flycatcher (*Muscicapa striata* (Pallas, 1764)), the common stonechat (*Saxicola torquatus* (Linnaeus, 1766)), and the Eurasian collared dove (*Streptopelia decaocto* (Frivaldszky, 1838)).

Estimation of cat population

The estimation of the cat population on Linosa was conducted through direct observations and interviews with inhabitants. Direct observations were carried out by investigating all routes and paths of the island. For each cat, coat colour, gender, neutering status and other particularities useful for its recognition were noted. People who provide food to cats regularly are a common target group to interview; therefore, a "door-to-door" survey was proposed to them. The questions regarded the number of cats, their gender and how many cats were sterilised. Moreover, estimation of the feral cat population living near the Scopoli's shearwater colony was conducted, in the northern part of the island in a place commonly called "Mannarazza" (Figure 1), using the same method, i.e. direct observations and interviews with the inhabitants. These methods do not give us a precise and reliable estimate of the cat population, but allow an estimation of a range of likely orders of magnitude.

Scat collection and prey identification

The diet of feral cats was studied through scat analysis (e.g. Bonnaud et al. 2007; Faulquier et al. 2009; Hervías et al. 2014). Scat collection was carried out in "Mannarazza" (Figure 1) (24 hectares), the area where there is the largest concentration of nesting pairs of shearwater. Scats were collected throughout 1 year (from May 2014 to May 2015) during four sampling periods corresponding to the Scopoli's shearwater breeding cycle: (S1) 21 May–21 June (the shearwater incubation period); (S2) 21 July–18 August (the hatching of eggs and the chick rearing period); (S3) 9–20 November (absence of shearwater); and (S4) 20 April–20 May (the prospector arrival period). However, the distinct periods chosen

for sampling were strongly influenced by the possibility to reach Linosa, as the departure of the ship depends on the weather and sea conditions; thus, on more than one occasion, leaving the Sicilian harbour was not possible.

It was possible to collect unburied faeces, because many feral cats do not bury their faeces, to mark their territory; in addition, domestic cats also leave faeces exposed when they are away from home (Bateson & Turner 2014). All scats found were collected, excluding the old ones (dry and white). Samples were gathered in plastic bags and frozen at −20°C. Scats were washed under a stream of hot water with a 0.5-mm mesh size sieve in the laboratory, and divided into digested (faecal content) and undigested (hairs, feathers, bone fragments, teeth and arthropod chitin) material (Bonnaud et al. 2007). Each item of undigested material was identified and compared to reference collections to determine, if possible, the species eaten by the cats.

Analysis of cat diet and variation between sampling periods

According to Bonnaud et al. (2007), the cat diet was expressed as the percentage frequency of prey in scats (frequency of occurrence, FO%), which is the percentage of scats containing the remains of a particular prey species or food category. The Chi-square test was used to compare the consumption of different prey types by feral cats during the different sampling periods; the FO% for each food item was utilised for the test (Nogales & Medina 1996). Statistical analyses were carried out using R software, version 3.1.2 (R Core Team 2014), $p < 0.05$ was considered statistically significant. Levins' niche-breadth index (B) was applied to evaluate the niche breadth of the prey consumed (Krebs 1989) by feral cats; Levins' index is expressed as:

$$B = 1 \Big/ \Sigma(p_j^2) \tag{1}$$

where p_j is the frequency of each identified prey. To standardise the niche-breadth index we applied the following formula:

$$B_A = B - 1/n - 1 \tag{2}$$

where n is the total number of identified prey: a value of the standardised Levins' index (B_A) close to "0" indicates dietary specialization, and a value close to "1" indicates a generalist diet (Krebs 1989). B_A was calculated for each sampling period and for the total period.

Analysis of the prey biomass

The daily consumed biomass (DCB) of prey was estimated by counting the number of each prey (NI) ingested per day and per cat, and determining the mean body mass of each prey (MP) (Bonnaud et al. 2007). Thus, the equation applied for DCB was:

$$DCB = \Sigma NI \times MP \tag{3}$$

All identifiable items found in each cat scat were counted and compared to determine the number of individuals of each prey category present in each scat. If the items were not identifiable (as they were too small), all of these were considered to be part of a single prey category (Fitzgerald et al. 1991). As cats usually defecate one scat per day, the number of identified prey per scat corresponds to the number of individuals ingested per day and per cat (NI) (Bonnaud et al. 2007). The mean body mass of the possible prey species was obtained from the literature; these included house mouse, spotted flycatcher, common stonechat, Eurasian collared dove, Filfola lizard and "big head" cricket. These preys are relatively small, with low intraspecific variation in body mass, and are generally entirely ingested by cats (Bonnaud et al. 2007). The body mass of Scopoli's shearwater, rat and rabbit was estimated more precisely since their mass can vary substantially from one individual to another. It was estimated that cats eat 50% of an adult Scopoli's shearwater with a mean weight of 650 g (Becciu, unpub. data). Thus, a cat consumes 325 g of tissue per shearwater. Because the fragile cartilaginous bones of chicks can be completely digested by cats, the analysis of cat scats could not be used as method to understand the predation on shearwater chicks. The mean weight of rats in Linosa Island is 175 g (Stanzione, unpub. data). Feral cats principally prey upon juvenile rabbits and it was therefore assumed that the mean body mass for rabbits found in cat scats was 500 g, because this value corresponds to the limit between juveniles and adult rabbits (Keitt et al. 2002; Mukherjee et al. 2004).

According to Bonnaud et al. (2007), it was assumed that 546 g of prey tissue was the maximum biomass consumption per cat, per day, and, as a consequence, "when rabbit remains were present in scats with other prey species, the mass of rabbit tissue ingested was calculated so as not to exceed this maximum daily biomass: Rabbit biomass consumed = 546 g – sum (mass in grams of all other prey items present)" (p. 1076).

Results

Number of feral cats

The total number of feral cats sighted during the sampling periods on the entire Linosa Island was 299: 102 of them were identified through direct observations, and 197 through interviews with the inhabitants (Table I). The feral cats directly observed were 10 females and 23 males, and for 69 cats it was not possible to determine their gender; three cats were sterilised, nine were not sterilised and for 78 it was not possible to determine whether they were sterilised. Of these 102 cats directly observed, 14 were the feral cats inhabiting around "Mannarazza", near the monitored Scopoli's shearwater colony: five females (one sterilised) and nine males (one sterilised).

Of the 197 feral cats identified through interviews, 53 were females, 53 were males, and of the remaining 91 cats their gender was unknown; 44 of these 197 feral cats were sterilised, 118 were not sterilised and for 35 cats the interviewees did not have this information. However, an overlap between the number of cats directly observed and those identified through interview is entirely possible. Therefore, the density of cats could vary from 19 cats per km^2 (total overlap) to 55 cats per km^2 (no overlap).

Diet of feral cats and comparison between sampling periods

A total of 169 preys belonging to nine species were identified in 188 scats analysed (Table II). The sampling period S3 was a brief period compared to the

Table I. Estimation of the feral cat population on Linosa Island.

	Gender			Sterilized			
	Females	Males	Unknown	Yes	No	Unknown	Total
Cats colony in "Mannarazza" (direct observations)	5	9	0	2	12	0	14
Cats in Linosa Island (direct observations)	5	14	69	1	9	78	88
Cats in Linosa Island (interviews)	53	53	91	44	118	35	197

Table II. Composition of the feral cats' diet on Linosa Island in four sampling periods: (S1) 21 May–21 June; (S2) 21 July–18 August; (S3) 9–20 November; (S4) 20 April–20 May. FO% = frequency of occurrence of food items found in scats; N = number of scats. The standardised Levins' index (B_A) is indicated. Note the low number of scats collected in S3.

	S1 (N = 56)		S2 (N = 74)		S3 (N = 9)		S4 (N = 49)		Total (N = 188)	
Food items	N	FO%	N	FO%	N	FO%	N	FO%	N	FO%
Mammals	34	60.71	55	74.31	3	33.33	42	85.71	134	71.28
House mouse	0	0	2	2.70	0	0	2	4.08	4	0.02
Wild rabbit	16	28.57	24	32.43	0	0	14	28.57	54	28.72
Black rat	16	28.57	27	36.48	3	33.33	8	16.33	54	28.72
Unidentified	2	3.57	2	2.70	0	0	17	36.73	21	11.7
Birds	12	21.42	7	9.45	6	66.66	23	28.57	48	25.53
Scopoli's shearwater	10	17.86	5	6.75	3	33.33	13	26.53	31	16.49
Spotted flycatcher	1	1.78	0	0	0	0	0	0	1	0.53
Common stonechat	0	0	0	0	3	33.33	0	0	3	5.85
Eurasian collared dove	0	0	0	0	0	0	1	2.04	1	0.53
Unidentified	1	1.78	2	2.70	0	0	8	16.33	11	5.85
Reptiles	1	1.78	1	1.35	0	0	0	0	2	1.06
Filfola lizard	1	1.78	1	1.35	0	0	0	0	2	1.06
Arthropods	5	8.93	8	10.81	2	22.22	4	8.16	19	10.11
"Big head" cricket	5	8.93	8	10.81	2	22.22	4	8.16	19	10.11
Plant material	0	0	4	5.41	0	0	36	75.51	40	21.28
Anthropogenic refuse	7	12.5	1	1.35	1	11.1	6	12.24	15	7.98
Unidentified items	4	7.14	9	12.16	0	0	0	0	13	6.91
Levins' index (B_A)	0.48		0.36		0.20		0.54		0.48	

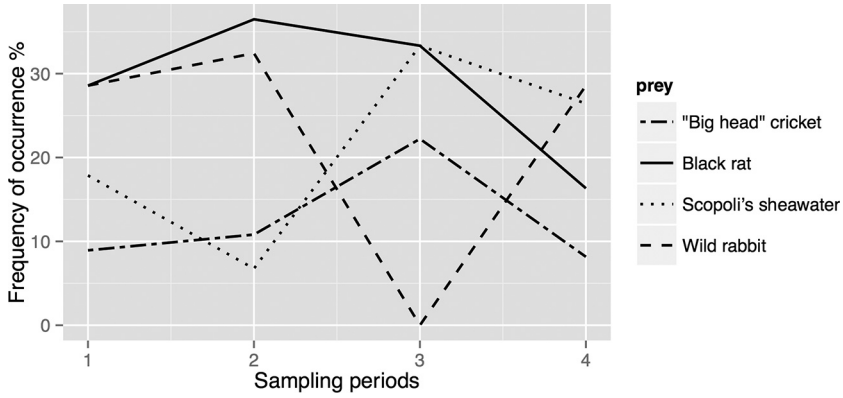

Figure 2. Frequency of occurrence of four prey items ("big head" cricket, black rat, Scopoli's shearwater and wild rabbit) in each sampling period: (S1) 21 May–21 June; (S2) 21 July–18 August; (S3) 9–20 November; (S4) 20 April–20 May. N = number of scats. Note the low number of scats collected in S3.

others, and only nine samples were collected. Consequently, S3 was only taken into account for the descriptive data analysis. Overall, mammals were the main group preyed upon (Table II): black rats and wild rabbits occurred at the same percentage (28.72%), while house mouse was found in only four samples. Birds occurred in 25.53% of scats (four bird species): Scopoli's shearwater was the most frequently preyed bird. In three sampling periods (S1, S2 and S4) mammal remains occurred in the majority of scats, while in S3 bird species were the most frequently encountered (Table II).

The frequency of occurrence of the four species most preyed by cats (wild rabbit, black rat, Scopoli's shearwater and "big head" cricket) is shown in Figure 2.

However, three sampling periods (S1, S2 and S4) were statistically compared because they have the same duration (one month) and similar sample numbers. The comparison between the consumption of the four species most preyed by cats showed a significant difference as regards the frequencies of rats between sampling periods (X^2 = 7.59, df = 2, p = 0.022): the rats were mainly preyed during S2 and less preyed during S4. Likewise, there was a significant difference as regards the frequencies of Scopoli's shearwaters between sampling periods (X^2 = 11.53, df = 2, p = 0.003): the shearwaters were most preyed during S4 and less preyed during S2. There was no significant difference as regards the number of wild rabbits (X^2 = 0.33, df = 2, p = 0.846), and "big head" cricket (X^2 = 0.39, df = 2, p = 0.819) between sampling periods. Considering all sampling periods, the standardised Levins' niche breadth (B_A) was 0.48. The B_A index was broader in S4 (0.58) and in S1 (0.48), and narrower in S2 (0.36) and S3 (0.20) (Table II).

Biomass of prey

Overall, the cats consumed daily a mean prey biomass of 225.9 g (standard deviation (SD) = 135.2, N = 188) ranging from 191.18 g (SD = 30.7, N = 9) in S3 to 260.37 g (SD = 105.09, N = 56) in S1 (Figure 3). Wild rabbits provided the predominant part of the biomass consumed (39.73%), even though rabbits were not found in the cats' scats during S3. Scopoli's shearwater represented the second most consumed prey (31%), especially in S3 and in S4. Black rat was the third most consumed prey (28.22%), especially in S2 and in S3, while in S4 the biomass consumed was lower (Table III and Figure 3). Other food items contributed only slightly to the daily biomass consumed by feral cats (Table III).

Discussion

Feral cats are successful invaders of island ecosystems (Bonnaud et al. 2011). Their opportunistic feeding behaviour makes them a highly adaptable species, also capable of surviving in inhospitable conditions, such as arid insular environments with no fresh water available (Courchamp et al. 2003; Nogales & Medina 2009). The introduced cats often negatively affect seabird populations, particularly petrels and shearwaters (Courchamp et al. 2003), due to the lack of anti-predatory strategies in these birds resulting from the absence of mammalian terrestrial predators during their evolutionary development (Van Aarde 1980).

In this study we estimated the number of cats on Linosa Island, a small southern Mediterranean island with a homogeneous semi-arid environment, and we evaluated their diet. Linosa Island hosts the

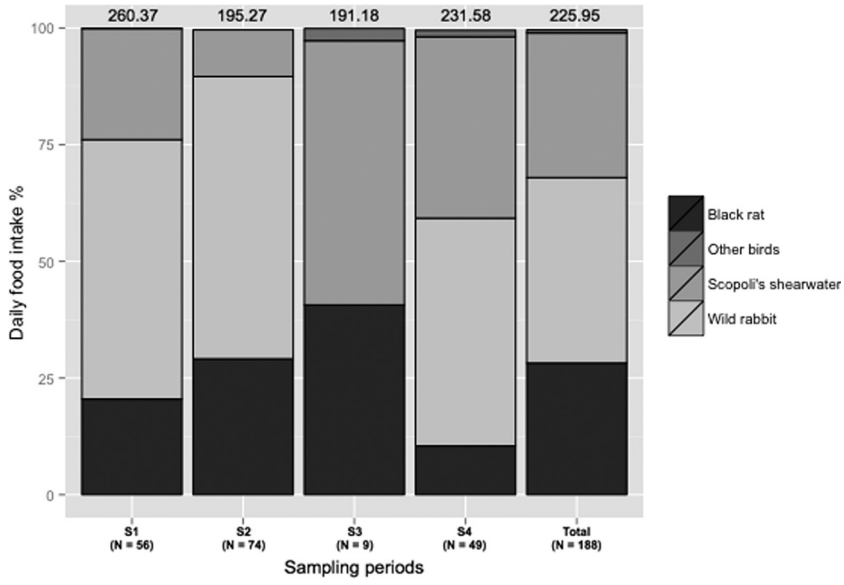

Figure 3. Percentage of biomass of total prey categories and in each sampling period: (S1) 21 May–21 June; (S2) 21 July–18 August; (S3) 9–20 November; (S4) 20 April–20 May. The percentage of biomass of invertebrates, reptiles and house mouse are not shown in this Figure, as they were too low (< 0.5%). The category "other birds" represents the sum of the percentage of biomass of spotted flycatcher, common stonechat and Eurasian collared dove. The mean daily prey biomass (g) is given above each bar. N = number of scats. Note the low number of scats collected in S3.

Table III. Percentage of prey biomass found in all cat scats (total) and in each sampling period: (S1) 21 May–21 June; (S2) 21 July–18 August; (S3) 9–20 November; (S4) 20 April–20 May. Mean weight of each prey species ingested by cats on Linosa Island is indicated. N = number of scats. Note the low number of scats collected in S3.

Food items	S1 (N = 56)	S2 (N = 74)	S3 (N = 9)	S4 (N = 49)	Total (N = 188)	Weight (g)	Reference
Mammals	76.08%	89.9%	40.67%	59.71%	68.3%		
House mouse	0	0.3%	0	0.45%	0.35%	25	Ruscoe & Murphy 2005
Wild rabbit	55.59%	60.49%	0	48.8%	39.73%	500[a]	Alterio & Moller 1997
Black rat	20.49%	29.11%	40.67%	10.46%	28.22%	175[a]	Stanzione unpub. data
Birds	23.85%	10.01%	59.23%	40.26%	31.622%		
Scopoli's shearwater	23.8%	10.01%	56.62%	38.86%	31%	325[a]	Becciu unpub. data
Spotted flycatcher	0.05%	0	0	0	0.022%	9.25	Snow & Perrins 1998
Common stonechat	0	0	2.61%	0	0.13%	15	Snow & Perrins 1998
Eurasian collared dove	0	0	0	1.4%	0.51%	165	Snow & Perrins 1998
Reptiles	0.039%	0.038%	0	0	0.028%		
Filfola lizard	0.039%	0.038%	0	0	0.028%	5.4	Scalera et al. 2004
Arthropods	0.031%	0.052%	0.1%	0.03%	0.05%		
"Big head" cricket	0.031%	0.052%	0.1%	0.03%	0.05%	0.85	Conti unpub. data

[a]See "Materials and methods".

second largest colony of Scopoli's shearwater in the world, with around 10,000 breeding pairs (Massa & Lo Valvo 1986). Firstly, we estimated the density of cats on the entire Linosa Island, and we hypothesised a density range from 19 to 55 cats/km^2. The density of cats has been reported for 28 islands worldwide (Nogales et al. 2004; Matias & Catry 2008). In 23 islands, the cat density was lower than 79.2 cats/km^2 (Nogales et al. 2004), in agreement with that observed on Linosa Island. Moreover, the density should increase in future because only a negligible number of cats were sterilised.

The scat collection took place in an area commonly known as "Mannarazza", located in the northern part of the island where there is the largest concentration of nesting pairs of shearwater and where 14 cats live permanently. According to several studies (e.g. Bonnaud et al. 2007; Medina et al. 2008; Faulquier et al. 2009) our results showed

that introduced mammals (rabbits and rats) constitute the most common prey for feral cats. Rabbit and rat are regular items in the diet of insular feral cats (Fitzgerald & Turner 2000; Medina et al. 2006), while the house mouse was consumed with a negligible frequency in our study. Different authors (Innes et al. 1995; Harris & Macdonald 2007) have suggested that interactions with black rats negatively influence the abundance of house mice. Competition between these rodents occurs because their diets overlap (Ruscoe & Murphy 2005). Moreover, black rats show predatory behaviour towards mice, without threat and display features (Bridgman et al. 2013).

In our study, the second most frequent prey category found in cat scats was birds, primarily represented by the Scopoli's shearwater. In general, birds represent an important prey item for feral cats on islands, more than on continents (Fitzgerald 1988), and seabirds are one of the most important groups preyed upon (Nogales & Medina 2009). Despite the fact that chicks can be cats' prey, in particular during the chick-rearing period (S2), when they stay alone for all of the day-time and part of the night-time, we did not consider the biomass of shearwater chicks consumed by cats, because they have fragile cartilaginous bones that can be completely digested, and thus it is not possible to detect them through scat analysis. Furthermore, the carcasses of chicks found near the nests were intact (in some cases without the head) and completely battered by scratches, demonstrating that in some cases cats also play with their prey rather than consume it (Turner 2014).

Predation upon Filfola lizard (the only reptile species found in scats) is very low, in accordance with other data obtained in similar semiarid habitat in the Canary Islands (Medina et al. 2008). Conversely, reptiles are frequently present in the diet of feral cats in tropical and sub-tropical islands (Fitzgerald 1988). According to a review by Bonnaud et al. (2011), the distance from landmass is positively correlated with predation upon birds, and negatively correlated with predation upon reptiles, in agreement with our results, as Linosa Island is far from the mainland (167 km away from Sicily (Italy) and 165 km from Tunisia). Regarding the predation upon invertebrates, we found one species of Orthoptera in cat scats, the "big head" cricket, with a relatively high frequency. Invertebrates appear frequently in the diet of feral cats on islands, and the consumption of invertebrates is related mainly to the feeding behaviour of kittens (Kirkpatrick & Rauzon 1986; Nogales & Medina 1996; Medina & García 2007).

Our results showed that the diet varied between sampling periods: the trophic niche breadth was wider in spring and narrower in summer. The lower value of the Levins' index obtained during the summer was probably due to the increased consumption of mammals with respect to the other prey items. The index was also low in November, but this result was probably affected by a limited number of faeces found during this sampling period: a semi-tropical cyclone with its epicentre on Linosa influenced strongly the duration of this sampling period, as well as the number of scats collected.

Cats hunt prey accordingly to their accessibility and relative abundance, and this behaviour facilitates the persistence of feral cat populations on the island with seasonal food resources (Pontier et al. 2002). Accordingly, our results suggested that the cats' diet changes seasonally, in relation to the availability and accessibility of prey. In particular, we found an opposite trend in the predation of Scopoli's shearwater and black rats during spring and summer; shearwaters were preyed mainly upon spring and to a lesser extent in summer. In spring, the shearwaters are at their most vulnerable and easiest to catch, as they exhibit their greatest vocal activity and spend the greatest time out of their nests (Bonnaud et al. 2012). Predation on these seabirds decreased in the summer, when the breeders reduced their activity and tended to stay inside the nest with their chicks (Bonnaud et al. 2012), and other species (e.g. rats) became more frequently consumed by the cats.

The daily biomass consumed by cats on Linosa Island (225.9 g) corresponds to the values obtained in other studies (Keitt et al. 2002; Bonnaud et al. 2007; Kutt 2012). Mammals constituted the major part of the biomass consumed, and wild rabbit represented the most-consumed species; therefore, introduced mammalian species should be considered the primary prey for the survival and persistence of cats. The Scopoli's shearwater is also an important prey, as it represents approximately one-third of the total biomass consumed. Consequently, control measures of feral cats are a desirable goal for the conservation of Scopoli's shearwater colony. The eradication of feral cats is considered a priority for the conservation of seabird colonies (Keitt & Tershy 2003), and it is generally the best option to reduce their negative impacts on native fauna (Bonnaud et al. 2010). Nevertheless, before planning management strategies, it must also be taken into account that cats have a crucial role in controlling rabbit and rat populations. The eradication of a super-predator like the cat may lead to an increase in secondary predation (e.g. by rats) that could, in any case, have negative effects on the seabird species, known as the "meso-predator release effect" (Courchamp et al. 1999). In Italy, national law 281 introduced a no-kill policy for

feral cats, and TNR is the only method available to control the cat population. Therefore, the local Veterinary Public Services should implement TNR programmes in order to avoid an uncontrolled increase of the cat population. Moreover, neutering of feral cats has additional benefits including the reduction of cat movements, and the improvement of their welfare and health. However, it is a very difficult management situation for the shearwaters with a no-kill policy for cats, and a cat- and rabbit-proof fence around the main colony is a possible solution. Another possible solution to manage the cat number could be to promote adoption: all the un-owned and unwanted island cats should be adopted on the mainland. This is a good option in the case of kittens and cats accustomed to people.

Acknowledgements

The field work was carried out in the framework of the Life project "Pelagic birds" (LIFE11-NAT/IT/000093). We thank Prof. Bruno Massa from Palermo University for his kind support and hospitality in the field station in Linosa. We are also grateful to *Ornis italica*, in particular to Giacomo dell'Omo and Paolo Becciu for the data concerning shearwaters.

References

Alterio N, Moller H. 1997. Diet of feral house cat *Felis catus*, ferret *Mustela furo* and stoats *M. ermine* in grassland surrounding yellow-eyed penguin *Megadyptes antipodes* breeding areas, South Island. New Zealand Journal of Zoology 243:869–877.

Barratt DG. 1997. Home range size, habitat utilization and movement patterns of suburban and farm cats *Felis catus*. Ecography 20:271–280. DOI:10.1111/eco.1997.20.issue-3.

Bateson P, Turner DC. 2014. Postscript: Questions and some answers. In: Turner DC, Bateson P, editors. Cambridge: Cambridge University Press. pp. 231–240.

BirdLife International. 2014. *Calonectris diomedea*. The IUCN Red List of Threatened Species. Version 2015.2. Available: http://www.iucnredlist.org. Accessed Sep 2015 03.

Bonnaud E, Berger G, Bourgeois K, Legrand J, Vidal E. 2012. Predation by cats could lead to the extinction of the Mediterranean endemic Yelkouan Shearwater *Puffinus yelkouan* at a major breeding site. Ibis 154:566–577. DOI:10.1111/ibi.2012.154.issue-3.

Bonnaud E, Bourgeois K, Vidal E, Kayser Y, Tranchant Y, Legrand J. 2007. Feeding ecology of a feral cat population on a small Mediterranean island. Journal of Mammalogy 88:1074–1081. DOI:10.1644/06-MAMM-A-031R2.1.

Bonnaud E, Medina FM, Vidal E, Nogales M, Tershy B, Zavaleta E, Donlan CJ, Keitt B, Le Corre M, Horwath SV. 2011. The diet of feral cats on islands: A review and a call for more studies. Biological Invasions 13:581–603. DOI:10.1007/s10530-010-9851-3.

Bonnaud E, Zarzoso-Lacoste D, Bourgeois K, Ruffino L, Legrand J, Vidal E. 2010. Top-predator control on islands boosts endemic prey but not mesopredator. Animal Conservation 13:556–567. DOI:10.1111/j.1469-1795.2010.00376.x.

Bridgman LJ, Innes J, Gillies C, Fitzgerald NB, Miller S, King CM. 2013. Do ship rats display predatory behaviour towards house mice? Animal Behaviour 86:257–268. DOI:10.1016/j.anbehav.2013.05.013.

Campbell KJ, Harper G, Algar D, Hanson CC, Keitt BS, Robinson S. 2011. Review of feral cat eradications on islands. In: Veitch CR, Clout MN, Towns DR, editors. Gland, Switzerland: IUCN. pp. 37–46.

Carboneras C, Derhé M, Ramirez I. 2013. Update on the population status and distribution of Mediterranean shearwaters. Report to Seventh Meeting of the ACAP Advisory Committee, 6–10 May 2013, La Rochelle.

Cecere JG, Catoni C, Maggini I, Imperio S, Gaibani G. 2013. Movement patterns and habitat use during incubation and chick-rearing of Cory's shearwaters (*Calonectris diomedea diomedea*) (Aves: Vertebrata) from Central Mediterranean: Influence of seascape and breeding stage. Italian Journal of Zoology 80:82–89. DOI:10.1080/11250003.2012.710654.

Cecere JG, Gaibani G, Imperio S. 2014. Effects of environmental variability and offspring growth on the movement ecology of breeding Scopoli's shearwater *Calonectris diomedea*. Current Zoology 60:622–630. DOI:10.1093/czoolo/60.5.622.

Courchamp F, Chapuis JL, Pascal M. 2003. Mammal invaders on islands: Impact, control and control impact. Biological Reviews 78:347–383. DOI:10.1017/S1464793102006061.

Courchamp F, Langlais M, Sugihara G. 1999. Cats protecting birds: Modelling the mesopredator release effect. Journal of Animal Ecology 68:282–292. DOI:10.1046/j.1365-2656.1999.00285.x.

Driscoll CA, Menotti-Raymond M, Roca AL, Hupe K, Johnson WE, Geffen E, Harley EH, Delibes M, Pontier D, Kitchener AC, Yamaguchi N, O'Brien SJ, McDonald DW. 2007. The near eastern origin of cat domestication. Science 317:519–523. DOI:10.1126/science.1139518.

Faulquier L, Fontaine R, Vidal E, Salamolard M, Le Corre M. 2009. Feral cats *Felis catus* threaten the endangered endemic Barau's petrel *Pterodroma baraui* at Reunion Island (Western Indian Ocean). Waterbirds 32:330–336. DOI:10.1675/063.032.0213.

Ferreira JP, Leitão I, Santos-Reis M, Revilla E. 2011. Human-related factors regulate the spatial ecology of domestic cats in sensitive areas for conservation. PLoS One 10:1–10.

Fitzgerald BM. 1988. Diet of the domestic cat and their impact on prey population. In: Turner DC, Bateson P, editors. Cambridge: Cambridge University Press. pp. 123–147.

Fitzgerald BM, Karl BJ, Veicht CR. 1991. The diet of feral cats (*Felis catus*) on Raoul Island, Kermadec Group. New Zealand Journal of Ecology 15:123–129.

Fitzgerald BM, Turner DC. 2000. Hunting behaviour of domestic cats and their impact on prey populations. In: Turner DC, Bateson P, editors. Cambridge: Cambridge University Press. pp. 151–175.

Harris DB, Macdonald DW. 2007. Interference competition between introduced black rats and endemic Galapagos rice rats. Ecology 88:2330–2344. DOI:10.1890/06-1701.1.

Hervías S, Oppel S, Medina FM, Pipa T, Díez A, Ramos JA, Ruiz de Ybáñez R, Nogales M. 2014. Assessing the impact of introduced cats on island biodiversity by combining dietary and movement analysis. Journal of Zoology 292:39–47. DOI:10.1111/jzo.2014.292.issue-1.

Innes J, Warburton B, Williams D, Speed H, Bradfield P. 1995. Large-scale poisoning of ship rats (*Rattus rattus*) in indigenous forests of the North Island, New Zealand. New Zealand Journal of Ecology 19:5–17.

Keitt BS, Tershy BR. 2003. Cat eradication significantly decreases shearwater mortality. Animal Conservation 6:307–308. DOI:10.1017/S1367943003003378.

Keitt BS, Wilcox C, Tershy BR, Croll DA, Donlan CJ. 2002. The effect of feral cats on the population viability of black-vented shearwaters (*Puffinus opisthomelas*) on Natividad Island, Mexico. Animal Conservation 5:217–223. DOI:10.1017/S1367943002002263.

Kirkpatrick RD, Rauzon MJ. 1986. Foods of feral cats *Felis catus* on Jarvis and Howland Islands, Central Pacific Ocean. Biotropica 18:72–75. DOI:10.2307/2388365.

Köppen W, Geiger R. 1930. Handbuch der Klimatologie. Berlin: Gebrueder Borntraeger.

Krebs CJ. 1989. Ecological methodology. New York: Harper Collins Publishers.

Kutt AS. 2012. Feral cat (*Felis catus*) prey size and selectivity in north-eastern Australia: Implications for mammal conservation. Journal of Zoology 4:292–300. DOI:10.1111/j.1469-7998.2012.00915.x.

Levy JK, Crawford PC. 2004. Humane strategies for controlling feral cat populations. Journal of the American Veterinary Medical Association 225:1354–1360. DOI:10.2460/javma.2004.225.issue-9.

Liberg O, Sandell M. 2000. Spatial organization and reproductive tactics in the domestic cat and other felids. In: Turner DC, Bateson P, editors. Cambridge: Cambridge University Press. pp. 83–98.

Lowe S, Browne M, Boudjelas S, De Poorter M. 2000. 100 of the world's worst invasive Alien species. A selection from the global invasive species database. Gland, Switzerland: The Invasive Species Specialist Group (SSC), IUCN.

Massa B, Lo Valvo M. 1986. Biometrical and biological considerations on the Cory's shearwater *Calonectris diomedea*. In: Medmaravis, Monbailliu X, editors. Berlin: Springer-Verlag. pp. 293–313.

Matias R, Catry P. 2008. The diet of feral cats at New Island, Falkland Islands, and impact on breeding seabirds. Polar Biology 31:609–616. DOI:10.1007/s00300-007-0396-6.

Medina FM, Bonnaud E, Vidal E, Tershy BR, Zavaleta ES, Josh Donlan C, Keitt BS, Corre M, Horwath SV, Nogales M. 2011. A global review of the impacts of invasive cats on island endangered vertebrates. Global Change Biology 17:3503–3510. DOI:10.1111/j.1365-2486.2011.02464.x.

Medina FM, García R. 2007. Predation of insects by feral cats (*Felis silvestris catus* L., 1758) on an oceanic island (La Palma, Canary Island). Journal of Insect Conservation 11:203–207. DOI:10.1007/s10841-006-9036-7.

Medina FM, García R, Nogales M. 2006. Feeding ecology of feral cats on a heterogeneous subtropical oceanic island (La Palma, Canarian Archipelago). Acta Theriologica 51:75–83. DOI:10.1007/BF03192658.

Medina FM, López-Darias M, Nogales M, García R. 2008. Food habits of feral cats (*Felis silvestris catus* L.) in insular semiarid environments (Fuerteventura, Canary Islands). Wildlife Research 35:162–169. DOI:10.1071/WR07108.

Mougeot F, Bretagnolle V. 2000. Predation risk and moonlight avoidance in nocturnal seabirds. Journal of Avian Biology 31:376–386. DOI:10.1034/j.1600-048X.2000.310314.x.

Mukherjee S, Goyal SP, Johnsingh AJT, Leite Pitman MRP. 2004. The importance of rodents in the diet of jungle cat (*Felis catus)*, caracal (*Caracal caracal*) and golden jackal (*Canis aureus*) in Sariska Tiger Reserve, Rajasthan, India. Journal of Zoology 262:405–411. DOI:10.1017/S0952836903004783.

Nogales M, Martin A, Tershy BR, Donlan CJ, Veitch D, Puerta N, Wood B, Alonso J. 2004. A review of feral cat eradication on islands. Conservation Biology 18:310–319. DOI:10.1111/cbi.2004.18.issue-2.

Nogales M, Medina FM. 1996. A review of the diet of feral domestic cats (*Felis silvestris* f. *catus*) on the Canary Islands, with new data from the laurel forest of La Gomera. Mammalian Biology 61:1–6.

Nogales M, Medina FM. 2009. Trophic ecology of feral cats (*Felis silvestris f. catus*) in the main environments of an oceanic archipelago (Canary Islands): An updated approach. Mammalian Biology 74:169–181.

Nogales M, Vidal E, Medina FM, Bonnaud E, Tershy BR, Campbell KJ, Zavaleta ES. 2013. Feral cats and biodiversity conservation: The urgent prioritization of island management. Bioscience 63:804–810. DOI:10.1525/bio.2013.63.10.7.

Pearre S, Maass R. 1998. Trends in the prey size-based trophic niches of feral and house cats *Felis catus* L. Mammal Review 28:125–139. DOI:10.1046/j.1365-2907.1998.00030.x.

Pontier D, Say L, Debias F, Bried J, Thioulouse J, Micol T, Natoli E. 2002. The diet of feral cats (*Felis catus* L.) at five sites on the Grande Terre, Kerguelen archipelago. Polar Biology 25:833–837.

R Core Team. 2014. R: A language and environment for statistical computing. Vienna, Austria: R Foundation for Statistical Computing. Available: http://www.R-project.org/. Accessed Jan 2015 15.

Robertson SA. 2008. A review of feral cat control. Journal of Feline Medicine & Surgery 10:366–375. DOI:10.1016/j.jfms.2007.08.003.

Rubolini D, Maggini I, Ambrosini R, Imperio S, Paiva VH, Gaibani G, Saino N, Cecere JG. 2015. The effect of moonlight on Scopoli's Shearwater *Calonectris diomedea* colony attendance patterns and nocturnal foraging: A test of the foraging efficiency hypothesis. Ethology 121:284–299. DOI:10.1111/eth.12338.

Ruscoe WA, Murphy EC. 2005. House mouse. In: King CM, editor. Melbourne: Oxford University Press. pp. 203–221.

Sangster G, Collinson JM, Crochet PA, Knox AG, Parkin DT, Votier SC. 2012. Taxonomic recommendations for British birds: Eighth report. Ibis 154:874–883. DOI:10.1111/j.1474-919X.2012.01273.x.

Say L, Devillard S, Natoli E, Pontier D. 2002. The mating system of feral cats (*Felis catus* L.) in a sub-antarctic environment. Polar Biology 25:838–842.

Scalera R, Capula M, Fornasari L, Zava B, Bombi P, Mariottini P, Bologna MA. 2004. Population structure, genetics and conservation of the Maltese wall lizard, *Podarcis filfolensis*, on Linosa Island (Reptilia, Lacertidae). Italian Journal of Zoology 71:153–159. DOI:10.1080/11250003.2004.9525552.

Serpell JA. 2014. Domestication and history of the cat. In: Turner DC, Bateson P, editors. Cambridge: Cambridge University Press. pp. 83–100.

Slater MR. 2005. The welfare of feral cats. In: Rochlitz I, editor. Dordrecht: Springer. pp. 141–176.

Snow DW, Perrins CM. 1998. The birds of the western Palearctic. New York: Oxford University Press.

Trites AW, Joy R. 2005. Dietary analysis from scat samples: How many scats are enough? Journal of Mammalogy 86:704–712. DOI:10.1644/1545-1542(2005)086[0704:DAFFSH]2.0.CO;2.

Turner DC. 2014. Social organization and behavioural ecology of free-ranging domestic cats. In: Turner DC, Bateson P, editors. Cambridge: Cambridge University Press. pp. 63–70.

Turner DC, Meister O. 1988. Hunting behaviour of the domestic cat. In: Turner DC, Bateson P, editor. Cambridge: Cambridge University Press. pp. 111–121.

Van Aarde R. 1980. The diet and feeding behaviour of feral cats, *Felis catus* at Marion Island. South African Journal of Wildlife Research 10:123–128.

Vigne JD, Guilaine J, Debue K, Haye L, Gérard P. 2004. Early timing of the cat in Ciprus. Science 304:259.

Warham J. 1990. The petrels: Their ecology and breeding systems. New York: Academic Press.