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ORIGINAL PAPER

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The diet of feral cats (*Felis catus* L.) at five sites on the Grande Terre, Kerguelen archipelago

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Abstract Assessing the impact (direct or indirect) of introduced predator species on native seabird populations is a clear management priority, particularly so in the simple sub-Antarctic ecosystems where these effects may be dramatic. We evaluated the diet of introduced feral cats (*Felis catus* L.) on the Grande Terre, Kerguelen archipelago, by analysing 149 scats from 5 sites. Overall, rabbits (*Oryctolagus cuniculus*) were the primary prey (72.6%), followed by house mice (*Mus musculus*) (11.6%) and birds (all species confounded, 14.9%). However, the proportions of the three prey species varied among sites, reflecting the spreading pattern of cats onto the Grande Terre. Birds were consumed much less frequently in this study (7.3%, all sites pooled but one) compared to a 1976 study in the same area (66.3%), suggesting that cats had a strong impact on the native avifauna.

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Introduction

Sub-Antarctic islands are important breeding sites for seabirds, most of which have not evolved to cope with mammalian predators (Lack 1968; Johnstone 1985; Warham 1990). The domestic cat, *Felis catus*, has been commonly introduced to sub-Antarctic islands (Johnstone 1985). Cats are generalist predators that readily adapt to different prey items (Fitzgerald and Turner 2000). The presence of cats in sub-Antarctic ecosystems is thus generally viewed as negative, because they reduce the abundance of some native bird species (Jones 1977; Johnstone 1985; Bloomer and Bester 1992; Fitzgerald and Turner 2000). In particular, cats have caused serious declines or extinction of several burrowing petrel species that breed on these islands (Jones 1977; van Aarde 1980). It is essential that management aims for the eradication of cats to allow the recovery of seabird populations. However, eradication of cats could lead to negative effects when prey like rabbits (*Oryctolagus cuniculus*) or rodents were also introduced (Pech et al. 1995). The complex inter-relationships that exist between the native and introduced species, as well as the size and inaccessibility of some islands, increase the difficulty of defining the best management strategy (Pech et al. 1995; Courchamp et al. 1999).

The domestic cat was introduced to the Kerguelen archipelago in 1951 (Lesel 1971) to control the alien rodents (*Rattus rattus*, *Mus musculus*) and rabbits at the research station of Port-aux-Français. Introduced by sailors in the nineteenth century, rabbits are now dispersed throughout the archipelago (Chapuis et al. 1994; Roue 1995). By 1977, an estimated 3,500 cats consumed approximately 1.2 million birds every year (Pascal 1980). Cats are now widely distributed over the main island (Roue 1995). A long-term study of cat ecology began in 1994. Genetic data (D. Pontier, unpublished data) associated with estimates of population density based on line-transect methodology showed that the population had now reached an equilibrium, with around 7,000 individuals (Say et al. 2001).

In order to manage cats, their impact must be understood. This paper describes the diet of cats at five different sites in the Kerguelen archipelago. Assessing the diet of cats is an important step for understanding their ecology, behaviour, and impact on native fauna. Although it is not possible to infer the impact of feral cats on prey populations from dietary studies, a comparison of the results of this study with those of a previous one conducted at the time when the cat population was increasing exponentially both locally and in distribution (Derenne 1976), might indicate broad-scale changes in the availability of prey species and provide qualitative information on the deleterious effect of cats on bird-prey species in the Kerguelen archipelago.

Materials and methods

Study area

The Kerguelen archipelago (48°28′–50°S, 68°28′–70°35′E) consists of a 6,600-km^2 island partly covered by an ice-cap, called "Grande Terre", and over 300 secondary islands and islets for a total surface of 7,200 km^2. The mean annual temperature is 4.6°C (Météo-France, 1951–1999 record) with annual rainfall <800 mm in the eastern part of the Grande Terre and very windy conditions. We collected samples in five sites on the eastern part of the Grande Terre (Fig. 1): (1) the French scientific station Port-aux-Français (site A), which was established in 1950, (2) the 1930–1932 farmer settlement of Port-Couvreux (site B), (3) the Norwegian whaling station of Port-Jeanne-d'Arc (site C), on the southeastern part of the Grande Terre (Jeanne d'Arc peninsula), which was built in 1920 and used until 1930, (4) Ratmanoff (site D) on the Courbet peninsula, and (5) Sourcils Noirs (site E, on the Jeanne d'Arc peninsula), which was characterised by the highest diversity of nesting bird species, including an especially large colony (ca. 1,100 pairs) of black-browed albatrosses (*Diomedea melanophris melanophris*) and numerous pairs of light-mantled sooty albatrosses (*Phoebetria palpebrata*). The pairwise distances between sites range from 20 to 140 km, following the coastline. The five sites included the same type of short vegetation (mosses, tussock grass *Poa cookii*, *Azorella selago* and *Acaena magellanica*) but differed in terms of number of prey species available (Pontier et al. 1999). No estimate of bird densities was available.

Data collection

We collected 149 scats from cats captured in baited (with fish) cages between 1 November 1998 and 1 November 1999. An equivalent number of scats were collected in winter and in summer for each site. The present work is part of a wider ecological study based on observations and capture-mark-recapture of live cats, so it was not possible to analyse stomach contents. Each scat was washed in water and the contents separated out using two sieves, the first of 1-mm and the second of 0.5-mm mesh. Feathers, hair, claws, paws and bones were obtained from the first sieve. Remaining feathers, hair and bones were examined and sorted by eye and binocular microscope. Mammals were identified by comparing microscopic characteristics of the hair with those of published reference collections (Keller 1981; Debrot et al. 1982). Birds were identified by feather characteristics, using our own reference collection. The different cleaned prey-type remains of each scat were then oven dried and weighed using an electronic balance (± 0.01 g). Although the diet of feral cats can show seasonal variations (because of seasonal breeding in seabirds), this aspect was not considered in the present study because the number of scats collected per site was too low. We compared the general patterns of the diet in the different sites. Because we had only one or two scats per individual, we did not take individuals into account in further analyses.

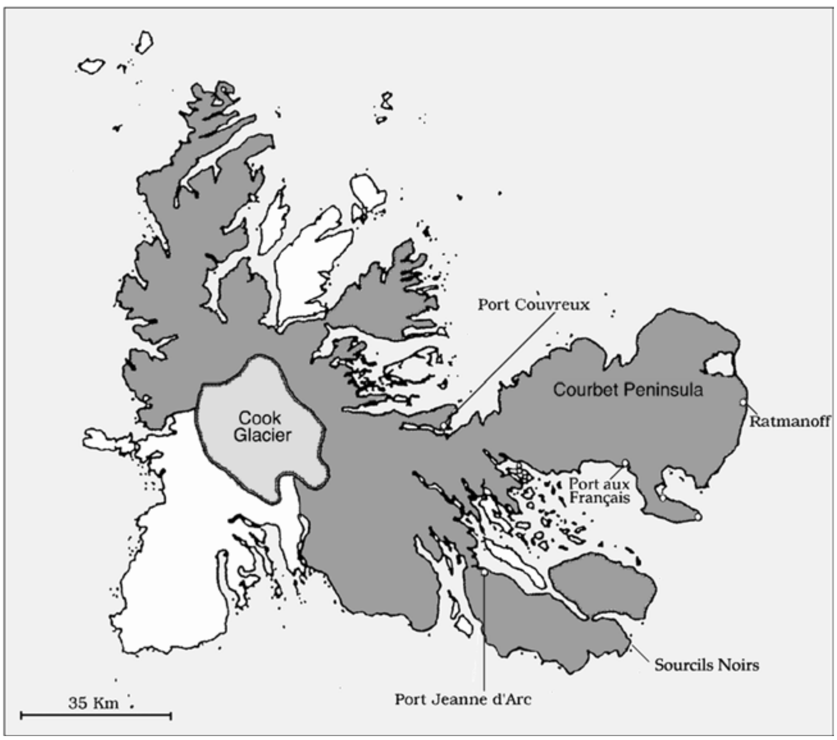

Fig. 1. Location of the sampled sites on the eastern part of the Kerguelen archipelago (Grande Terre). The centre of the main island is occupied by an ice cap. The *streaked lines* denote the distribution range of cats on the Grande Terre

Statistical analyses

The results of scat examinations were analysed in two different ways: (1) we calculated the frequency of occurrence (±SE) of prey items in the scats, i.e. the percentage of the total number of scats that contained a particular prey item for each site across seasons. The prey species found in scats are listed in Table 1; (2) we performed a centred Principal Component Analysis on a table, with scats in the rows and the percentage of the total weight of each prey found in scats in the columns (called %PCA after de Crespin et al. 2000). This table has a row total equal to 1 (i.e. 100%). This analysis shows the spread of the scats for each site and the differences between sites. The first %PCA plane is used for representation purposes. Preys are represented according to Gabriel's (1981) proposals (biplot presentation). The position of each prey on the %PCA plane is equivalent to the position of a scat containing 100% of the corresponding prey species. Each scat is at the centroid of the preys, with each prey species being given a weight equal to its proportion in the scat. The higher the proportion of a given prey in a scat, the closer the scat will be to the prey species position. The average profile for the whole scats and the average profiles for the five sites are also represented on the %PCA plane. Each average profile is at the centroid of the preys, with each prey being given a weight equal to its average proportion in the corresponding profile. Each prey is linked to the whole scat centroid by an arrow whose length is proportional to the relative abundance of this prey (de Crespin et al. 2000). From each site, centroid lines are drawn in the direction of each scat found in this site. For clarity, the length of the line is half the distance between the scat and the centroid. The greater the distance, the higher the difference between the average profile and the scat. When the lines depart from a site in various directions with relatively important lengths, it means that the scats found on this site noticeably differ in their proportions of prey species, reflecting important variations in the diet. Computations and graphical displays were performed with ADE-4 (Thioulouse et al. 1997) and R-softwares (Ihaka and Gentleman 1996).

Results

Diet composition

A total of 15 different prey species were recorded in the diet (Table 1). The frequency of occurrence of mammals (rabbits and house mice) and birds (all species pooled) by site is summarised in Table 2. Rabbits were the single most-important prey item at all but one site (see Tables 1, 2). White-headed petrels (*Pterodroma lessonii*) and Antarctic prions (*Pachyptila desolata*) were the bird species most frequently found in scats, followed by white-chinned petrels (*Procellaria aequinoctialis*) (see Table 1). Other birds occurred infrequently, except for South Georgian diving petrels (*Pelecanoides georgicus*). Prions and other petrel species could not be distinguished in some scats. In these scats, they were therefore pooled into an "undetermined petrels" category (see Table 1). However, this category occurred in a site when the two types of species were also frequently found separately. The great-winged petrel (*Pterodroma macroptera*) was consumed at sites B and E only.

Spatial variation in cat diet

The first two principal components of %PCA explained 58.3% and 13.4% of the total variability, respectively,

Table 1. Occurrence (in percentage) of prey species in the scats of *Felis catus* on the Grande Terre from 1 November 1998 to 1 November 1999. See Materials and methods for site abbreviations

Prey items	A (*N*=59)	B (*N*=10)	C (*N*=25)	D (*N*=10)	E (*N*=45)	All sites (*N*=149)
Mammals						
Felis catus	1.7	0.0	0.0	20.0	2.2	2.7
Oryctolagus cuniculus	93.2	100	100	50.0	80.0	87.9
Mus musculus	8.5	0.0	24.0	70.0	68.9	32.9
Birds						
Pygoscelis papua	0.0	0.0	0.0	20.0	4.4	2.7
Eudyptes chrysolophus	0.0	10.0	0.0	0.0	4.4	2.0
E. chrysocome	0.0	0.0	4.0	0.0	0.0	0.7
Pelecanoides georgicus	1.7	0.0	0.0	0.0	11.1	4.0
Pterodroma lessonii	0.0	10.0	24.0	20.0	40.0	18.1
Pterodroma macroptera	0.0	20.0	0.0	0.0	4.4	2.7
Lugensa brevirostris	0.0	0.0	4.0	0.0	2.2	1.3
Procellaria aequinoctialis	0.0	0.0	0.0	20.0	20.0	7.4
Halobaena caerulea	0.0	0.0	0.0	0.0	8.9	2.7
Pachyptila desolata	5.1	0.0	16.0	20.0	31.1	15.4
Oceanites oceanicus	0.0	0.0	8.0	0.0	6.7	3.4
Undetermined petrels	1.7	10.0	8.0	0.0	13.3	6.7
Chionis minor	0.0	0.0	12.0	0.0	2.2	2.7

Table 2. Percentage of the total weight of each prey item found in the scats of cats on the Grande Terre for each of the five sites from 1 November 1998 to 1 November 1999. See Materials and methods for site abbreviations

	Birds, all species (%)	*Oryctolagus cuniculus* (%)	*Mus musculus* (%)	*Felis catus* and undetermined prey (%)
A (*N*=59)	7.06±0.03	88.27±0.04	3.31±0.02	1.36±0.01
B (*N*=10)	0.63±0.00	99.37±0.00	0	0
C (*N*=25)	3.20±0.01	89.81±0.04	6.95±0.03	0
D (*N*=10)	25.10±0.04	31.44±0.12	38.36±0.12	5.10±0.05
E (*N*=45)	32.57±0.05	45.79±0.05	21.55±0.04	0.09±0.00
Mean	14.90±0.02	72.63±0.37	11.56±0.02	0.91±0.00

and were sufficient to illustrate the main structure of diet composition among sites (Fig. 2). Birds were closer to the general centroid than rabbits and mice, which were both at equivalent distances from it. This implies that birds were less represented in scats than rabbits and mice. All bird species arrows were nearly parallel, therefore having a similar importance in the diet of cats. Three sites, A, B and C, were very close to rabbits' position (see Fig. 2), although some lines indicated variations from the average profile. In site A, a low proportion of scats contained bird remains whereas in most of the scats collected at site B, rabbits were exclusively represented. In contrast, sites D and E exhibited the largest variability in prey consumed, with a more balanced proportion between house mice and rabbits. The number of lines departing from site E to birds showed a significant diversified consumption of bird species in this site. The site D position, being closer to house mice than to rabbits, indicated a higher proportion of mice in scats than rabbits (in agreement with results in Table 2). In conclusion, three types of sites could be identified: site B, characterised by a very low variability in diet composition, the most abundant prey consumed being rabbit; sites A and C, where rabbits dominated, with from time to time birds and house mice eaten; and sites D and E with a more balanced diet among birds, rabbits and house mice.

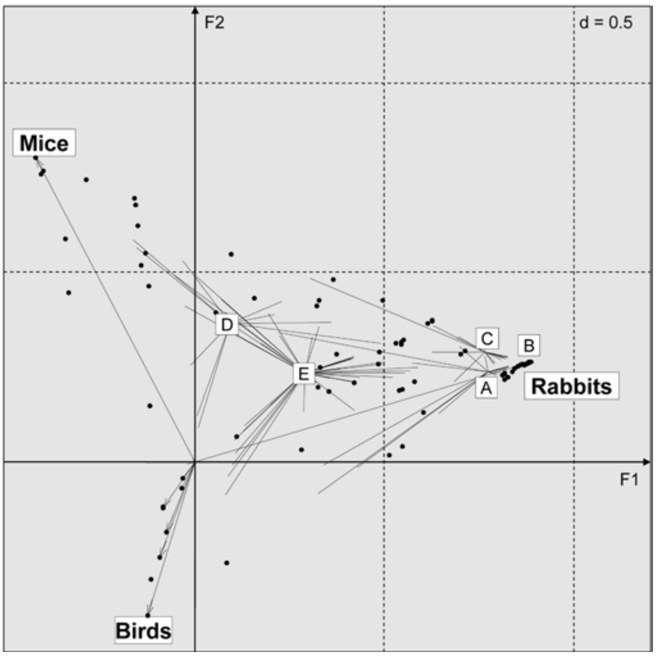

Fig. 2. Biplot of prey and scats obtained from a %PCA (first factorial plane, $N = 149$). The position of each prey category (birds, rabbits, house mice) is equivalent to the position of a scat containing 100% of the corresponding prey. Scats (*dots*) are positioned proportionally to their percentage of each prey item by averaging; length and direction of lines departing from each site (*A* Port-aux-Français; *B* Port Couvreux, *C* Port Jeanne d'Arc; *D* Ratmanoff; *E* Sourcils Noirs) are related to the profile of the diet in each site. See Materials and methods and Results sections for further details. The scale ($d = 0.5$) gives the size of the grid

Discussion

Our results show that the diet of feral cats differed markedly among sites on the Grande Terre. Rabbits were the most common dietary item (about 90% throughout the year) in sites A, B and C, whereas in the other two sites (D and E), rabbits, mice and birds were similarly represented (about 30%). Among birds, Antarctic prions represented the major prey of cats in all sites with the exception of Port-Couvreux, where their presence at this site has never been recorded (D. Pontier, personal observation). This species is the most abundant petrel on the eastern part of the Grande Terre (Weimerskirch et al. 1989). The cat remains found in two scats (in both cases the distal part of the paws) are most likely to be the result of scavenging rather than predation (Furet 1989; Fitzgerald and Turner 2000). In addition, the site where bird diversity in the diet was lowest (site A, Port-aux-Français) was where cats were first introduced (in 1951), before spreading throughout the Courbet Peninsula (Pascal 1980). At Sourcils Noirs (site E), where we found the remains of the highest number of avian species, the first scats of cats were only found in 1975 (Pascal 1980).

Thus, the difference in diet we observed among sites probably reflects the opportunistic behaviour of cats which helped them adjust to changes of prey availability with time (van Aarde 1980; Bloomer and Bester 1992; Fitzgerald and Turner 2000), and thus the duration of the presence of cats in the area. Our hypothesis is also supported by the strong difference between our results and those of Derenne (1976) obtained in the same area (except Sourcils Noirs): in 1976, 66.3% of stomachs examined contained birds and 35.0% contained rabbits whereas in 1998–1999, scats consisted of 7.3% of birds and 84.2% of rabbits (all sites pooled but Sourcils Noirs). Rabbits were present equally during the whole study period (Roue 1995). Despite the fact that the data obtained from stomach contents are not directly comparable to those obtained from scats (although Copson and Whinam 2001 found similar results comparing the two methods in the feral cats from Macquarie Island), the large difference strongly suggests: (1) that bird availability is now lower than in 1976, and (2) that cats could have a strong impact on the Kerguelen avifauna in a relatively short period of time (less than 50 years), as observed at other sub-Antarctic localities (van Aarde 1980; Bloomer and Bester 1992).

The eradication of cats in sub-Antarctic islands is a desirable goal for the conservation of seabirds (Johnstone 1985). However, cats were introduced on the Kerguelen archipelago to control other introduced mammals (pest rodents and rabbits), and it is possible that they have an important role in controlling rabbit populations (Courchamp et al. 1999). Eradicating cats could cause an increase in the abundance of mammalian prey species like rabbits and rats (*Rattus* spp.) which, in turn, could have adverse consequences on the biotic and abiotic environment. Rabbits can modify both vegetation and soils (Chapuis et al. 1994; Pye et al. 1999). Rats prey on birds, eating eggs and chicks (Atkinson 1989). Although they are not present on the main island at Kerguelen, the problem is well known on other sub-Antarctic islands (Johnstone 1985; Pye et al. 1999). In addition, the area of the locality where the introduced predators have to be controlled may represent a limiting factor and/or determine the type of method that should be used. Thus, eliminating alien mammals on small islands (rats: up to 31 km^2, Taylor et al. 2000; Micol and Jouventin 2002; cats: up to 290 km^2 on Marion Island; Bloomer and Bester 1992; rabbits: up to 8 km^2 on Saint-Paul Island; Micol and Jouventin 2002; T. Micol, unpublished data) is feasible. However, the much larger area of the Grande Terre (6,600 km^2) precludes total eradication. Nevertheless, it should be possible to reduce the impact of cats and rabbits locally (see, e.g., previous studies on rats, by Seto and Conant 1996; Bried and Jouventin 1999) although control measures should be repeated from year to year. Besides, the Kerguelen archipelago also comprises several small islands (a few square kilometres) where the eradication of introduced cats and/or rabbits has either been achieved (Verte and Guillou Islands), is in progress (Cochons Island) or planned (Australia Island) (Chapuis et al. 2001). Therefore, priority should be given to such operations, which represent, at least for the moment, a cheaper and more efficient solution, and which will rapidly increase the number of refugia available to the native avifauna.

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