

Feral Cats *Felis catus* Threaten the Endangered Endemic Barau's Petrel *Pterodroma barau* at Reunion Island (Western Indian Ocean)

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Abstract.—Cats (*Felis catus*) were probably introduced to Reunion Island (Western Indian Ocean) in the seventeenth century and feral populations are now spread over all anthropogenic and native habitats. The diet of feral cats living in the breeding habitat of Barau's Petrel (*Pterodroma barau*), an endemic and threatened seabird of Reunion Island, were studied. Results from the analysis of 217 scat (333 prey items) showed that Barau's Petrel were the most common prey of feral cats, followed by introduced rodents. Numerous dead birds at breeding colonies that had been killed by cats were found, 58% of the birds were adults. Given the high sensitivity of the population growth rate of a long-lived seabird to any additive mortality of adults, these results are particularly worrying. As this species is also threatened by massive light-induced mortality of fledglings, it is highly likely that this population is declining. A control of cats at breeding colonies is urgently needed to save this species from extinction. *Received June 28 2007, accepted February 28 2008.*

Key words.—Tropical island, endemic seabird, conservation, alien mammal, cat predation, extinction risk, tubenose.

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As obligate island-nesting seabirds lack behavioral, morphological and life-history defences against predators, they are particularly vulnerable to introduced mammals such as cats or rats (Schreiberg and Burger, 2002). Cats have been introduced to most islands of the world and are known to prey on petrels, shearwaters and prions (Procellariidae) including large species like the Black Petrel *Procellaria parkinsoni* (Imber 1975). Cats have caused the decline of numerous seabird populations all over the world, and the extinction of some endemic species (e.g. the Guadalupe Storm-Petrel *Oceanodroma macrodactyla* from Pacific Mexico, McChesney and Tershy 1998). Regarding cats, Moors and Atkinson (1984) wrote, that "No other alien predator has had such a universally damaging effect". To help mitigate this problem, cats have been eradicated successfully on at least 48 islands during the last 30 years (Nogales *et al.* 2004).

Barau's Petrel (*Pterodroma barau*) is a recently described endemic seabird of Re-

union Island (Western Indian Ocean, Jouanin, 1963). The species breeds colonially in burrows from September to April on the highest mountains of the island (Barré *et al.* 1996; Probst *et al.* 2000). Most of its breeding biology is unknown as colonies are hard to reach. Although the present population is estimated at between 3,000 and 5,000 breeding pairs (Le Corre and Safford 2001), the species is considered as "Endangered" (IUCN, 2004) because of habitat destruction, poaching, light-induced mortality and predation by introduced mammals (Probst *et al.* 2000; Le Corre and Safford 2001; Le Corre *et al.* 2002). Indeed, many species of mammals have been introduced to Reunion Island since human colonization. Feral cats (*Felis catus*), Black Rats (*Rattus rattus*), Norway Rats (*Rattus norvegicus*), House Mice (*Mus musculus*), Asian House Shrews (*Suncus murinus*) and Common Tenrecs (*Tenrec ecaudatus*) are now widespread across all habitats, from the coast to the highest mountains of

the island. Cats were probably introduced in the early seventeenth century and are now present at all Barau's Petrel colonies. However, although their impact is thought to be severe (Probst *et al.* 2000), no study has attempted to quantify their predation on petrels.

The goal of our study was to determine the diet of feral cats at Barau's Petrel colonies in order to estimate the additive mortality of Barau's Petrel induced by feral cats. We also propose action plans for the conservation of this endemic seabird.

METHODS

Study Area

Reunion (21°S; 55°N) is a mountainous volcanic island covering 2,512 km² in the tropical south-west Indian Ocean. The study area lies from 2,300 to 3,000m above sea level and includes the two main summits of the island, Piton des Neiges (3,069 m) and Grand Bénare (2,896 m) (Fig. 1). The former is an extinct shield volcano that holds the most important breeding colonies of Barau's Petrel (four main colonies) whereas the latter supports smaller colonies. These two massifs are largely cliffs, ridges, bare rocks and volcanic scree devoid of vegetation; however, the slopes and ledges are covered by mountain shrubland and thickets. The climate is extremely wet, with frequent frosts in winter and a mean annual temperature of 10°C (Météo France). The area is uninhabited apart from a mountain refuge near "Le Piton des Neiges", that is used for recreation and tourism. The study area is within a Nature Reserve (since January 2001) in order to prohibit access to colonies by visitors and to regulate intrusive activities such as climbing and helicopter flights which may affect colo-

nies of Barau's Petrel (Le Corre and Safford 2001). The three sites studied were: 1) Grand Bénare, (hereafter called GB) with low burrow density (about 100 pairs in 25 ha); 2) the western slope of Piton des Neiges (PN) with high burrow density (about 900 pairs in 30 ha); and 3) the Plateau of Piton des Neiges (PL) with no breeding sites but adjacent to an inaccessible colony. The surface areas were calculated with GIS software (MapInfo, 2002).

Cat Predation

Fieldwork was conducted between June 2003 and June 2006. Each site was visited several times during the breeding season (between November and May) but sampling effort was concentrated during the chick rearing period (February to April). Cat scats and the carcasses of birds killed by cats were collected and marked on a map (GPS coordinates). In sites GB and PL, we sampled cat scats both on colonies and on paths that access to the colonies. In the laboratory, each scat was washed in water and the contents strained with a sieve of 0.5 mm mesh. Hairs, feathers, bones, claws, jaws, insect chitin and beaks obtained in this way were examined and sorted (Nogales *et al.* 1988). Each item was identified using our reference collection and the minimum number of prey of each species was counted. Mammals were distinguished and counted on the size, shape, and characteristics of bones, jaws and teeth with the assistance of a binocular microscope. However, bones of Black (*R. rattus*) and Norway Rats (*R. norvegicus*) could not be distinguished and were listed in the same category (*Rattus* spp.). Birds were identified by feathers characteristics (shape, color), size and shape of claws and beaks. However, the different species of passerines could not be distinguished. We assumed that bird remains in a scat came from a single bird, except when two beaks were found (Keitt *et al.* 2002). Waste material and vegetation were also extracted from scats.

Results for the analyses of scats are given in occurrence (O) and in frequency (F) as defined by $O_i = S_i/S$, where O_i is the occurrence of prey category I , S_i is the number scats containing items of the prey category I , S

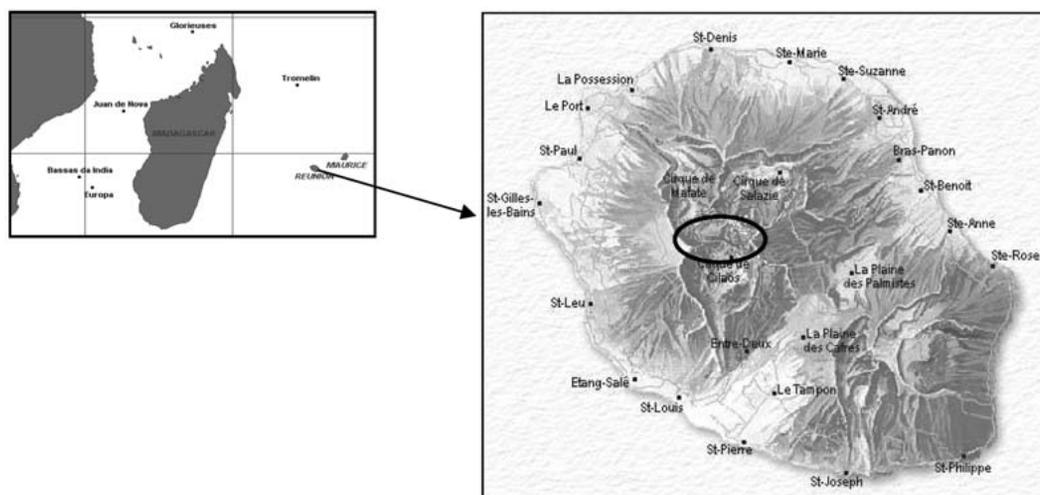


Figure 1. Location of Reunion Island in the Indian Ocean and the study area on Reunion Island.

is the total number of scats; $F_i = P_i/P$, where F_i is the frequency of prey category i , P_i is the number of prey found in the scats and P is the total number of prey found in the scats. We also determined the mean number of each prey per scat (n). As cats defecate one scat per day (Apps, 1983), this value gives the mean number of prey killed by a cat per day. To estimate the number of petrels killed by cats during one breeding season (N), we assumed a breeding season of seven months or 210 days (t) from prospecting for burrows (September) to fledging (April-May). Therefore, the total number of petrels killed during the breeding season is:

$$N = t \times n \text{ petrels} \times c$$

where c is the number of cats present at the colonies (unknown, so the calculation will be made using several hypothesis of cat population sizes) and n petrels is the mean number of petrels per scat. Birds found dead at the colonies and killed by cats were analysed to determine their age. We used biometrics, aspects of the feathers, presence of down and skull ossification to determine whether these dead birds were either adults or fledglings.

Chi-square tests ($P < 0.05$) were used to compare the diet of feral cats at the different sites, with four prey categories: petrels, rats, mice and "others". Means are given \pm SD.

RESULTS

Diet Composition

A total of 217 cat scats containing the remains of 333 prey items were collected at the three sites. Barau's Petrel were the main prey and were present in 54% of the scat and represented almost 37% of the prey items identified (Table 1). The second and third most important prey were rats (31% of occurrence and frequency of 22%) and mice (23% and 22%, respectively). Tenrecs, passe-

rines, shrews and insects were rarely found in scats (less than 10% for each) and accounted for less than 7% of the identified prey items.

Within each colony, we separated the scats collected from the path accessing the colony and the scats collected on the colony into two different samples (GBp and PNp for the paths and GBc and PNC for the colonies). There was no significant difference in prey frequencies between the two colonies GBc and PNC ($\chi^2_3 = 1.2$; $P > 0.05$; $N = 93$). However, there were significant differences between the paths (GBp + PNp) and the colonies (GBc + PNC) ($\chi^2_3 = 36.4$; $P < 0.05$; $N = 125$; Fig. 2), and between the paths and site PL which is next to a colony ($\chi^2_3 = 30.7$; $P < 0.05$; $N = 124$) as well as between the colonies and site PL ($\chi^2_3 = 17.1$; $P < 0.05$; $N = 185$).

On the colonies, Barau's Petrel was the main prey item, followed by mice or rats, and the percentages of the other species were negligible (Fig. 2). On the paths, the main prey was mostly rats and mice, with Barau's Petrel accounting for only 8% of the prey items. The site PL was intermediate.

Quantification of Predation

The mean number of petrels killed by a single cat was 0.57 ± 0.55 individuals per day (Table 1). We collected 93 Barau's Petrel carcasses at breeding colonies, among which 64 were found at the site PNa (which holds the largest Barau's Petrel colony). We aged 70 of these 93 birds. 41 (58%) were adults and 29

Table 1. Occurrence and frequency (%) of prey items in 217 scats of feral cats collected at Barau's Petrel breeding habitat.

Prey items	Occurrence (%)	Frequency (%)	Mean number/scat \pm SD
Birds			
<i>Pterodroma barau</i>	54.38	36.94	0.57 ± 0.55
<i>Passerines</i>	12.90	8.71	0.13 ± 0.35
Mammals			
<i>Rattus</i> spp.	31.34	22.22	0.34 ± 0.54
<i>Mus musculus</i>	22.58	21.62	0.33 ± 0.79
<i>Suncus murinus</i>	2.76	2.40	0.04 ± 0.23
<i>Tenrec ecaudatus</i>	9.68	6.31	0.10 ± 0.30
Insects	2.76	1.80	0.03 ± 0.16
Vegetation	50.69	/	
Waste material	3.23	/	

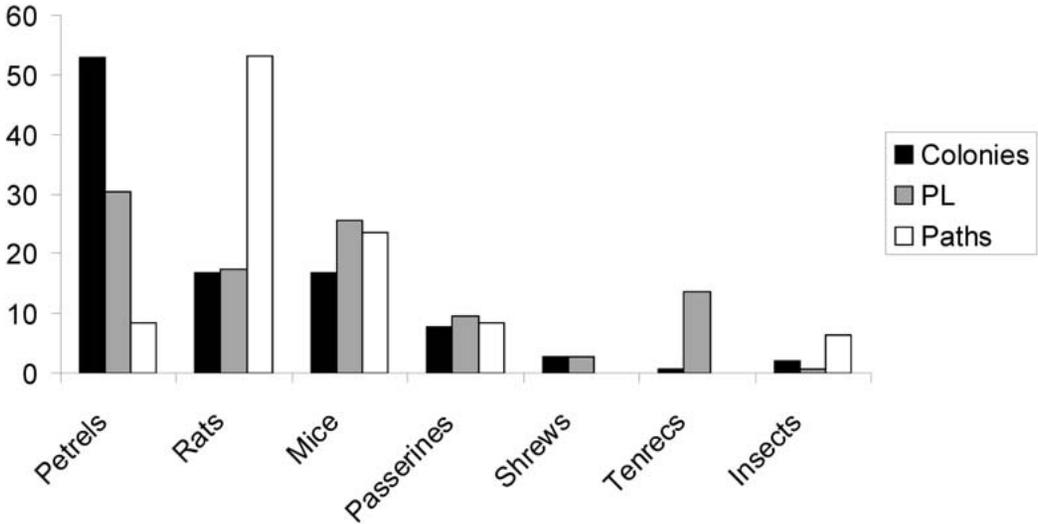


Figure 2. Diet composition (in prey frequency) of feral cats at the three sites (Barau's Petrel colonies, Planèze of the Piton des Neiges (PL) and main paths that give access to the colonies).

(42%) were fledglings. Thus, we obtained 0.24 fledglings and 0.33 adults killed by a cat per day. Assuming that fledglings stay 90 days at the colonies and adults stay 210 days, the average numbers of birds killed by one cat during the whole breeding season would be about 22 fledglings and 70 adults.

Estimating the number of cats present at colonies is difficult because of their discreet and nocturnal behavior and the rough topography of the sites. However, our results suggest that as few as ten cats could kill as many as 900 petrels each year.

DISCUSSION

Diet Composition

Feral cats living in breeding habitats of Barau's Petrel prey mostly on this threatened and endemic seabird, as 57% of their scats contain remains of this bird. Both adults and fledglings are killed by cats. The vulnerability to feral cats is due to the fact that petrels are easy to see and catch given they are large, numerous, clumsy and noisy at their colonies, breed in burrows and have evolved no aggressive anti-predator defences. Moreover, both cats and petrels are active at night (Alterio and Moller 1997). Therefore, on Re-

union Island, cats prey mainly on seabirds, as they do on other islands such as Marion (Bloomer and Bester, 1990) and Natividad Islands (Keitt *et al.* 2002).

Rats and mice are eaten frequently, whereas shrews and tenrecs are caught occasionally, and this may reflect their respective abundance in these mountainous habitats. All these mammals have been introduced to Reunion Island, and predation by introduced mammals has been frequently observed on other islands (Turner and Bateson 2000). Rats represent the main rodent prey of cats both in occurrence and frequency. Cats are an opportunistic predator, which means they can adapt their diet to the availability of resources (e.g., Pontier *et al.* 2002). Thus, when petrels are absent from their breeding colonies (from May to August), rodents may form the principal prey of cats or cats might move to lower elevations where alternative prey are more abundant. For example, at the PNp site, which is located lower than the colony (PNc), there are no petrel burrows, and rats and mice are the main prey.

Quantification of Predation

Although data are still lacking on the number of cats present at the colony, an ap-

proximate estimate of the number of petrels killed annually in the two colonies gives a minimum of 920 birds per year, assuming a conservative value of only ten cats in this area (55 ha). Around 1,000 pairs of Barau's Petrel breed in the two studied colonies (100 at GB and 900 at PNa). Using these figures and assuming that these colonies hold 5,000 birds (breeders, non breeders and fledglings), we estimate that the minimal predation rate by cats in this study area could be 18.4%. Furthermore 58% of the birds found dead and presumably killed by cats were adults. Such a high additive mortality of adults is of major concern because Barau's Petrel populations, as long-lived seabirds, are sensitive to changes in adult survival (Keitt *et al.* 2002). Moreover such intensive cat predation also results in a lower breeding success because both parents share parental care equally (Cooper *et al.* 1995). This result also suggests that relatively few cats might kill hundreds of petrels per year (Martinez-Gomez and Jacobsen 2004).

Our study was implemented mostly during the incubation and chick rearing periods and does not include the period when petrels are displaying on the ground and prospecting for burrows. At this stage, ground-nesting seabirds are especially vulnerable to predation by cats and other predators (Warham 1996; Bonnaud *et al.* 2009). Consequently, our estimates are probably conservative as there are likely more petrels killed by cats at the beginning of the breeding season.

Conservation

The Barau's Petrel population is already small and fledglings are endangered by massive seasonal light-induced mortality (Le Corre *et al.* 2002). Between 300 and 800 fledglings are found stranded as a result of urban light attraction (Le Corre *et al.* 2002, authors' unpublished data) and would die without the rescue campaigns conducted by the Société d'Etudes Ornithologiques de La Réunion (SEOR) since 1996. Our study raises concerns that the cumulative effects of both light induced mortality on fledglings

and cat predation on adults and chicks might lead to the extinction of this species.

Mountain habitats of Reunion Island also support a small population of the other endemic species of petrel, the Mascarene Petrel (*Pseudobulweria aterrima*). This critically endangered seabird, also threatened by light (Le Corre *et al.* 2003) and is probably one of the rarest seabirds in the world (Attié *et al.* 1997). Even though its exact nesting-sites remain unknown, the Mascarene Petrel could also be threatened by cat predation. Reunion Island is the only island in the world which holds two species of endemic petrel. Both are endangered and our study confirms that cats pose a very serious threat to at least one of them and possibly to the other. Such results stress the immediate need to establish conservation procedures to reduce the feral cat population and so limit their harmful effects on petrels. Removing cats from seabird colonies has been shown to drastically reduce predation rates over short temporal scales (Peck *et al.* 2008).

Cats have been successfully eradicated from numerous small (<10 km²) islands (Nogales *et al.* 2004; Cooper *et al.* 1995; Veitch 2001), but few attempts have been implemented on large islands. The largest island where cats have been eliminated is the subantarctic Marion Island (290 km²) (Bestler *et al.* 2000). Although the latter study demonstrates that large-scale clearance of cats can be achieved, a complete eradication on the much larger and inhabited Reunion (2512 km²) is unlikely to be achievable. A more restricted mountain-top control, permanent in order to counteract immigration from below, will be necessary. This may be achieved through permanent poison baiting and trapping, as already done in the Madeira to save Zino's Petrel (*Pterodroma Madeira*) (Zino *et al.* 2001), and in mainland New Zealand (Saunders and Norton 2001).

The eradication or control of an introduced top predator (e.g., a cat) may lead to the release of its main prey. If this prey is another alien mammal (e.g., a rat) which also kills native birds, then the unwanted result of cat control or eradication may be that native birds continue to decline as a conse-

quence of increased rat predation (the so-called "mesopredator release" effect, Courchamp *et al.* 1999; Rayner *et al.* 2007). However, life history parameters of the prey and differential predation of the introduced predators should be taken into account when considering the trophic interactions between cats, rats and seabirds (Le Corre 2008). Cats kill both adults and chicks whereas rats kill only eggs and chicks; and, in long-lived animals, population growth rate is more sensitive to changes in adult survival than changes in reproduction rates. Furthermore, rats are currently rare at the Barau's Petrel colony (Fontaine 2006) and we suspect that this is not because of a top-down control by cats, but, rather, a bottom-up control by food resources available for rats between two seabird breeding seasons. Thus, we believe it is more urgent to control or eradicate cats at breeding colonies of the Barau's Petrel, even if there is a minor risk of an increase of the rat density, because this increase will have less demographic impact than the current impact of cats. However, if a year-round cat control campaign is implemented at the Barau's Petrel colonies, this should be accompanied by the long-term monitoring of rats and mice, and eventually lead to additional controls of these alien rodents.

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