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Feral cats threaten the outstanding endemic fauna of the New Caledonia biodiversity hotspot

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ABSTRACT

Feral cats (*Felis catus*) are one of the most successful and harmful invasive predator species, leading to dramatic loss of biodiversity across the globe. Our study assessed feral cat predation in a major biodiversity hotspot: the New Caledonian archipelago. We focused on the consequences of this predation for the outstanding endemic fauna found throughout the rich range of New Caledonian natural habitats. We analyzed > 5300 cat scats sampled from 14 selected sites representing the 4 main natural habitats, with 4 to 6 sampling sessions per year over > 4 years per habitat. Our study reveals previously unreported patterns of cat predation on both alien and endemic species. Throughout the archipelago, cats prey strongly upon squamates, flying foxes and petrels. Feral cat prey included at least 44 native vertebrate species, 20 of which are IUCN Red-listed threatened species. This study adds some 44.4% to the number of IUCN threatened species vulnerable to and preyed upon by feral cats on the world's islands. New Caledonia, while it represents only 0.12% of the total area of islands worldwide (Australia included), hosts 30.8% of IUCN threatened species known to be predated by feral cats. This study recommends prioritizing management and conservation strategies by focusing actions on maquis mosaic and humid forest habitats, where feral cats pose the greatest threat. To limit the impact of feral cats, we recommend conducting targeted management actions on sites key to threatened species conservation, and preventing arrival or promoting eradication on islets.

1. Introduction

Biological invasions are one of the main threats to world biodiversity, especially on islands. Invasive species are considered the primary cause of island biodiversity loss (Clavero and Garcia-Berthou, 2005; Sax and Gaines, 2008; Tershy et al., 2015). Alien mammal predators have been responsible for most species extinctions on islands worldwide (Blackburn et al., 2004; Doherty et al., 2016b). The domestic cat (*Felis catus*), is one of the most widespread introduced predators on islands (Courchamp et al., 2003; Medina et al., 2011). Its life history traits, early domestication with companion animal status, and value as a rodent catcher have promoted its extensive, human-mediated dispersal on islands (e.g. Driscoll et al., 2007; Hu et al., 2014). In addition, introduced cats' high reproductive success, rapid geographical spread and generalist predator behavior particularly threaten native fauna, especially in their feral form (e.g. Medina et al., 2011; Turner and Bateson, 2014). Of invasive mammalian predators, feral cats have proven to be the most damaging species for insular fauna. They currently threaten 430 different species (birds, mammals and reptiles) with extinction and are implicated in the recent extinction of 63 species (40 bird, 21 mammal and 2 reptile species), i.e. 26% of recent extinctions (Doherty et al., 2016b). Furthermore, Doherty et al. (2015a) for Australia and adjacent islands and Bonnaud et al. (2011) for the rest of the world's islands, listed 16 and 29 IUCN Red-listed threatened vertebrate species respectively, in the diets of feral cats. Strong variations exist in the feral cat diet, mainly explained by biogeographic and bioclimatic factors, along with prey availability (Bonnaud et al., 2011; Doherty et al., 2015a; Medina et al., 2011). Bonnaud et al. (2011) and Doherty

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et al. (2015a) showed that feral cats on islands feed on a wide range of prey, including medium-sized and small vertebrates (birds, reptiles, marsupials, rodents, bats, frogs, fish, and both medium-sized and large exotic mammals) and invertebrates (Bonnaud et al., 2015; Hilmer et al., 2010; Turner and Bateson, 2014). Introduced mammals (rodents and lagomorphs) generally constitute staple prey that can facilitate the establishment and expansion of abundant feral cat populations, indirectly increasing predation risk for native species through a so-called "hyper-predation" mechanism (e.g. Courchamp et al., 1999; Ringler et al., 2015).

Located in the southwest Pacific Ocean, the New Caledonian archipelago is typical of sites that facilitate invasion. Originally, native apex predators only included squamate and bird taxa. The early introduction of the Polynesian rat (*Rattus exulans*) by the first Austronesian settlers, followed in around 1860 by the European introduction of other commensal rodents (particularly the Black rat *Rattus rattus*), provided ideal conditions for the establishment and rapid spread of feral cat populations (e.g. Doherty et al., 2015b). In the biodiversity hotspot of New Caledonia, terrestrial species richness and endemism rates reach outstanding levels (Mittermeier et al., 2011; Myers et al., 2000). It is notable that 98 of the 108 terrestrial squamates, 6 of the 9 native mammals (bats) and 24 of the 111 nesting birds are strictly endemic, some of them micro-endemic (Barré et al., 2009; Bauer et al., 2012a, 2012b; Hand and Grant-mackie, 2011; Sadlier et al., 2012, 2013, 2014a, 2014b, 2014c, 2014d; Whitaker and Sadlier, 2011).

Cats were introduced around 1860 (Pascal et al., 2006) and can now regularly be observed in a wide range of habitats throughout the archipelago, even in its most remote and elevated areas. However, several papers have pointed out the complete absence of feral cat studies in this hotspot, stressing the urgent need to investigate this potentially important conservation topic (Bonnaud et al., 2011; Nogales et al., 2013). This paper addresses a number of issues pertaining to the feeding ecology of feral cats and their impacts on the exceptional terrestrial fauna of the New Caledonian biodiversity hotspot. To assess feral cat diets, we conducted intensive 6-year feral cat scat sampling at the scale of the archipelago. This enabled us to explore the composition of the feral cat diet and to determine the relative importance of different prey items according to habitat type (4 main habitat categories) and season (2 categories). Particular attention was paid to identifying prey taxa, so as to better understand the nature and the extent of feral cat impact at the different study sites and in the different habitats. We especially focused on IUCN Red-listed threatened species that are prey to the feral cat, in order to provide suitable evidence-based management and conservation recommendations concerning this invasive alien top-level predator.

2. Materials and methods

2.1. Study sites and sampled habitats

Of the 36 biodiversity hotspots, New Caledonia is the smallest formed of a single archipelago (Mittermeier et al., 2011). This hotspot (21° 30′ S, 165° 30′ E) with 270000 inhabitants, located in the southwest Pacific Ocean 1210 km east of Australia, covers 18,576 km^2 and is composed of a main island (16,664 km^2) and various satellite islands (Lifou, Maré, Ouvéa, Isles of Pines, Art, Pott, Tiga) (Dubois et al., 1973). The New Caledonia archipelago is, characterized by a large variety of habitats with a mountainous topography and marked climatic and geological contrasts (Isnard et al., 2016). Each habitat harbors very unique species assemblages, and rates of endemism for flora and fauna are especially high because of its geographical isolation and particular ultramafic soils (Grandcolas et al., 2008; Isnard et al., 2016).

The climate is subtropical with average annual temperature varying between 21.9 °C and 24.1 °C. Due to dominant winds from the southeast, the eastern coast is wet, with 2500–4000 mm of rain per annum, while the western coast is drier, with 1200 mm of rain per annum. There are two main seasons: a hot, wet season (November–April), a cold, dry season (May–October), defined by calculating the average of monthly precipitations recorded by 50 stations between 1971 and 2000 (Wet > 120 mm/month; Dry < 120 mm/month) and the average of monthly temperatures at 5 stations between 1980 and 2010 (Hot > 23 °C; Cold < 23 °C) (Meteo France). Due to its mountainous topography, the archipelago has a wide range of ecosystems (ranging in altitude from 1 m a.s.l. to 1625 m a.s.l.).

These climatic contrasts lead to markedly different habitats, each characterized by typical vegetation types. We thus considered 4 major habitats representing a wide range of climatic conditions and vegetation. The "Dry forest" is composed of sclerophylous and mesic forest on sedimentary rocks. The "Humid forest" is composed of rain forest on metamorphic rocks. The "Maquis mosaic" is composed of maquis shrubland and rainforest on serpentine soils (A.1). The "Limestone forest" is composed of rainforest on calcareous soils (Isnard et al., 2016).

2.2. Cat diet study

2.2.1. Sampling design and sampling effort

Feral cat diet was studied through scat analysis (e.g. Bonnaud et al., 2007). We collected feral cat scats from 14 different areas in the 4 main types of habitat listed above, between 2011 and 2016 (Fig. 1, Table 1). Scats were collected along paths and rural roads used by cats (Turner and Bateson, 2014; Recio et al., 2015). Scats from each study site (Fig. 1) were collected along the same selected paths in all sampling sessions (3–6 sampling sessions per year; 3–14 sampling sessions per site). Because all scats found were collected, it was assumed that each sampling set reliably represented the feral cats' diet between two successive sampling sessions. During the 6-year sampling period, 5356 feral cat scats were collected across all the habitats and study sites. Cumulatively, this represents a total of 2435 km-sessions (mean effort ± Standard Deviation: 608.8 ± 751.0 km-sessions per habitat), with a total sampling length of 267 km (mean sampling length 66.7 ± 64.7 km per habitat). An average of 1339 ± 1327 scat samples were collected from the different habitats, with a mean of 2.7 ± 1.3 scats found per km per session. Thus, despite the uneven sampling effort in the different habitats and sites, our sampling can be considered robust and significant (n > 100 for all habitats and n > 100 for most sites) (Bonnaud et al., 2011). Each cat scat was georeferenced, stored in individual Ziploc bags, and frozen until it was analyzed.

2.2.2. Determination of prey remains

Scats were washed under water over a 0.5-mm sieve to sort prey items (hair, bone fragments, teeth, squamate jaws and scales, bird feathers, bat claws, and arthropod chitin fragments). The prey items were examined under binocular microscope, compared to reference material and assigned to one of the eight following prey categories: (1) introduced rodents, (2) bats, (3) birds, (4) squamates, (5) arthropods, (6) fishes, (7) plant materials and (8) anthropogenic refuse (Bonnaud et al., 2007). Differential degradation of prey remains during the digestion process can cause the loss of some diagnostic characteristics (i.e. shape, size, color), leading to differing levels of prey group identification (Zarzoso-lacoste et al., 2016). To deal with these identification difficulties, we systematically used a large reference collection that proved particularly useful for squamates (scale patterns, jaws, head bones), flying foxes (hair, claws, teeth) and seabirds (feathers, claws, beaks) (A.2).

Based on scat analysis, two different diet indexes were used: (i) Frequency of Occurrence (%FO), the occurrence of each type of prey per scat (Bonnaud et al., 2007); and (ii) Minimum number of individual prey for squamates. To determine feral cat predation on each prey group, we examined each group's occurrence in the cat diet according