Feral Cats and Biodiversity Conservation: The Urgent Prioritization of Island Management

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A great part of the Earth's biodiversity occurs on islands, to which humans have brought a legion of invasive species that have caused population declines and even extinctions. The domestic cat is one of the most damaging species introduced to islands, being a primary extinction driver for at least 33 insular endemic vertebrates. Here, we examine the role of feral cats in the context of the island biodiversity crisis, by combining data from reviews of trophic studies, species conservation status reports, and eradication campaigns. The integration of these reviews permits us to identify priority islands where feral cat eradications are likely to be feasible and where cats are predicted to cause the next vertebrate extinctions. Funding agencies and global conservation organizations can use these results to prioritize scarce conservation funds, and national and regional natural resource management agencies can rank their islands in need of feral cat eradication within a global context.

Keywords: biodiversity, conservation, diet, Felis catus*, insular environments*

Islands harbor a disproportionate amount of Earth's biodiversity and are characterized by the presence of a great number of endemic plant and animal species (MacArthur and Wilson 1967, Carlquist 1974, Myers et al. 2000, Kier et al. 2009). Invasive predator species, particularly mammals, are one of the primary extinction drivers on islands (Groombridge and Jenkins 2000, Courchamp et al. 2003, Blackburn et al. 2004). Reviews of the impact of mongooses (*Herpestes* spp.; Hays and Conant 2007), rats (*Rattus* spp.; Towns et al. 2006, Jones et al. 2008), and feral cats (*Felis silvestris catus*; Medina et al. 2011) on islands all note significant impacts on native mammals, birds, and reptiles.

Since domestication from the African wildcat (*Felis silvestris lybica*) some 9000 years ago (Driscoll et al. 2007), the domestic cat (figure 1) has established feral populations on many of the world's islands, even in the most remote oceanic archipelagoes (Ebenhard 1988, Courchamp et al. 2003, Hilton and Cuthbert 2010). Feral cats are usually a superpredator in the trophic network of islands (Fitzgerald 1988, Courchamp et al. 1999). This generalist and opportunistic predator has a strong and direct effect on a great variety of native prey, including birds, mammals, reptiles, and invertebrates (for a review, see Bonnaud et al. 2011 and the references therein). Native mammalian carnivores are usually rare on islands because of their low dispersal ability over sea (except bats). Because island vertebrates are often not adapted to coexist with mammalian carnivores (Stone et al. 1994), introduced mammals on islands can have severe impacts on native populations. Introduced mammals (rodents and lagomorphs) are often the most common prey on the islands where feral cats are present; however, when they are available, other native vertebrates (mostly birds and reptiles) are important components of feral cats' diet on islands (Bonnaud et al. 2011). The presence of alternative, abundant, year-round prey can facilitate the survival of and sustain large feral cat populations that can have an exacerbated impact on native species through a superpredator effect (Courchamp et al. 2000). Therefore, even if native species are a lesser component of feral cat diet on islands, presumably because of the lower relative or absolute abundance of native species, and when introduced rodents and lagomorphs are present, feral cats still represent a threat to native island species (Nogales et al. 2004).

A meta-analysis of 72 diet studies (based on scat, gut, and stomach contents) revealed that at least 248 species were preyed on by feral cats on 40 worldwide islands (27 mammals, 113 birds, 34 reptiles, 3 amphibians, 2 fish, and 69 invertebrates; for more detail, see Bonnaud et al. 2011). Impacts of feral cats on endangered species have primarily been inferred from dietary studies (Fitzgerald 1988, Fitzgerald and Turner 2000). These studies are useful in

BioScience 63: 804–810. ISSN 0006-3568, electronic ISSN 1525-3244. doi:10.1525/bio.2013.63.10.7

Figure 1. (a) Feral cat predating a fan tail fly-eater (*Gerygone flavolateralis*, Passeriformes) captured in the Island of Pines (New Caledonia). Photograph: Fabrice Brescia, Institut Agronomique néo-Calédonien. Some species rendered* critically endangered *by feral cats: (b)* Cyclura carinata *(Caicos Bank, Caribbean Sea); photograph: Joseph Burgess. (c)* Pterodroma phaeopygia *(Floreana, Galápagos Islands); photograph: Alan Greensmith,* www.ardea.com. *(d)* Dipodomys insularis *(San José, Baja California); photograph: Troy L. Best, American Society of Mammalogy.

understanding the impact of introduced mammals on insular biotas, but the quality of most diet analyses (especially prey identification and their quantification) limits their applications. Despite their utility in understanding trophic ecology and biological invasion, dietary studies are limited as an indicator of impacts on threatened species that are generally rare and unlikely to turn up in feral cat diet studies with samples sizes typical of those that have been published (Sinclair et al. 1998, Towns et al. 2006, Bonnaud et al. 2011).

Feral cats have been known to drive numerous extinctions of endemic vertebrates on islands (Veitch 2001, Nogales et al. 2004) and were included in the list of the 100 worst invasive species (Lowe et al. 2000); feral cats are the most widespread and probably the most damaging of the four carnivores on that list. At least 175 vertebrate taxa (25 reptiles, 123 birds, and 27 mammals) are threatened by or were driven to extinction by feral cats on at least 120 islands (Medina et al. 2011). By comparison, 179 vertebrate species were found in the dietary studies reviewed in Bonnaud and colleagues (2011), of which 29 (16%) are listed on the International Union for Conservation of Nature's (IUCN) Red List of Threatened Species. Feral cats on islands contributed to at least 14% (33 species: 2 reptiles, 22 birds, and 9 mammals) of all 238 vertebrate extinctions recorded globally by the IUCN. Furthermore, feral cats threaten 8% (38) of the 464 species listed as *critically endangered* (see Medina et al. 2011 for more details). A meta-analysis of the threatened native species most affected by feral cats suggested that their impact was greatest on endemic species, particularly mammals, and that this was exacerbated by the presence of nonnative prey species (see Medina et al. 2011).

Island prioritization

Negative impacts of feral cats on island biodiversity can be reduced and, sometimes, eliminated. Feral cats have been successfully eradicated from 83 islands worldwide (Campbell et al. 2011), saving many species from imminent extinction. Eradication involves a unique action that results in the complete removal of the target species; although the costs are generally high (Oppel et al. 2010), the benefits accumulate in perpetuity if reintroduction is prevented.

Feral cats have been eradicated from islands in all oceans, with Australasia and the Pacific coast of Mexico being the most active regions. Marion Island (which has an area of 290 square kilometers [km^2]) is the largest island on which feral cats have been eradicated, and eradications on much larger islands, such as Dirk Hartog (620 km^2), in Western Australia, are planned (Algar et al. 2011). Feral cat eradications failed in 19 campaigns, which represent 22% of the attempts to date. Although island size influences the outcome of feral cat eradication campaigns, other factors, such as funding and social issues, also appear to hinder their implementation (Oppel et al. 2010, Campbell et al. 2011).

We aim here to provide global priorities for insular cat population management, including eradication, by collectively analyzing the three global reviews of feral cats on island ecosystems. We focus on diet (Bonnaud et al. 2011), impacts on endangered vertebrates (Medina et al. 2011), and eradication campaigns conducted to eliminate impacts on *critically endangered* native (CR) species (Campbell et al. 2011). The timely management or eradication of feral cats on priority islands could arguably avoid several imminent insular vertebrate extinctions (Brooke et al. 2007). We also discuss difficulties in assessing the direct impact of feral cats on the population declines and extinctions of endangered species. Only mammal, bird, and reptile species were considered, because they are the most widely represented groups on islands and probably the most affected by feral cats. Furthermore, there is little information about the impacts of cats on invertebrates and even fewer assessments. Despite the limitations of our simplified prioritization exercise, it is a useful step forward to help institutions and conservationists working with island species prone to a high risk of extinction.

Large-impact islands for feral cat eradication

We prepared a list of prey species of feral cats on islands and their conservation status using Bonnaud and colleagues (2011) and Medina and colleagues (2011). To identify islands where feral cat eradication should have a large conservation impact, we updated Medina and colleagues' (2011) short list of CR species threatened by feral cats, which was collated from more than 500 published papers and gray literature, with those from the 2012 IUCN Red List. We then combined this list with our existing knowledge of the presence of feral cats on islands with CR species. Despite the limitations of the IUCN list, we think that this exercise provides a useful tool for conservation initiatives.

We filtered the islands for their feasibility of eradication, following two criteria for which precedents have been set: those whose area was smaller than the largest island from which feral cats have been eradicated to date (i.e., Marion, 290 km^2; Campbell et al. 2011; see table 1) and those whose human population was lower than the most populated island on which feral cat eradication was successfully carried out (i.e., Ascension, 900 inhabitants; Campbell et al. 2011; see table 2). Filtering our list using these two criteria, we identified 12 islands where feral cat eradication is probably feasible and urgently needed to prevent extinctions. These islands support 14 CR species (3 reptiles, all iguanas; 9 birds [4 seabirds and 5 land birds]; and 2 mammals, all rodents) (table 2; figure 1). Two islands (Socorro and Floreana) each harbor two CR species, and the remaining 10 islands (6 in the Pacific Ocean, 3 in the Caribbean Sea, and 1 in the Subantarctic region) support a single CR species. The islands' areas range between 3.5 and 254 km^2, with eight islands smaller than 100 km^2 and two larger than 200 km^2. All of the islands with available information also have other introduced mammals (mainly rats, mice, and dogs). The human population of inhabited islands ranges from 30 to 674 inhabitants. Unfortunately for some threatened island species, our assessment for needed feral cat eradications came too late to prevent their extinction.

Apart from the species included in this last island-filter selection (table 2), 11 islands that harbor 11 CR species (table 1) are beyond the human population range for which cat eradication is currently feasible. Therefore, we recommend that their respective management be based on the control of their feral cat populations, especially in those zones in which CR species are present. Moreover, species endemic to a single island should in particular be prioritized above those that occur on more than one island.

Conservation and management considerations

Most feral cat populations are likely derived from pet cats that breed unchecked, escape, or are intentionally released into the wild. On islands with human inhabitants, which normally have domestic animals, eradication campaigns are more difficult to implement than are those on uninhabited or sparsely inhabited islands (Oppel et al. 2010). Working with local communities and integrating sustainable biosecurity measures to prevent reintroductions will be key components of successful island feral cat management strategies. Consequently, it is crucial to obtain detailed analyses of social, cultural, and economic issues to increase the possibility that local communities support eradication plans (Oppel et al. 2010). Furthermore, social factors play a large role in the implementation of feral cat eradication, and some people (e.g., cat lovers, animal rights organizations) may be opposed to this conservation practice in certain regions. Specifically, legislation, spay and neuter programs, identification by microchipping, registration of pets, and the prohibition or control of importation will become more common as inhabited islands are targeted for eradications of feral invasive species that are also kept as pets.

Although feral cat eradications often have strong positive impacts on native biota, some negative effects can also occur (Zavaleta et al. 2001). The eradication of feral cats can sometimes increase the impact of other invasive omnivores, such as rats (Rayner et al. 2007) and mice (Caut et al. 2007), or herbivores, such as rabbits (Bergstrom et al. 2009, but see Dowding et al. 2009). Therefore, where this

Table 1a. **Critically endangered *(sensu 2012 International Union for Conservation of Nature Red List of Endangered Species categories) reptile species affected by the predation of feral cats (*Felis silvestris catus*).**

Native species affected	Animal group	Island	Region	Island size (in km²)	Species category	Other introduced predators	Population
Brachylophus vitiensis	Iguana	Matacawa Levu	Fiji, Pacific Ocean	25	Native	Rats	Less than 2000
Ctenosaura bakeri	Iguana	Útila	Bay Islands, Caribbean Sea	41	Native	Rats, dogs	2500
Cyclura carinata	Iguana	Pine Cay	Caicos Islands, Caribbean Sea	3.5	Native	Rats, dogs	Less than 50
Cyclura lewisi	Iguana	Grand Cayman	Cayman Islands, Caribbean Sea	196	Endemic	Rats, mice, dogs	44,021
Cyclura nubila caymanensis	Iguana	Cayman Brac	Cayman Islands, Caribbean Sea	38	Native	Rats, mice, dogs	Less than 2000
	Iguana	Little Cayman	Cayman Islands, Caribbean Sea	28.5	Native	Rats, mice, dogs	Less than 170
Cyclura pinguis	Iguana	Anegada	British Virgin Islands, Caribbean Sea	38	Endemic	Rats, dogs	200
Gallotia simonyi	Lizard	El Hierro	Canary Islands, Atlantic Ocean	269	Endemic	Rats, mice	10,960
Gonatodes daudini	Gecko	Union Island	Saint Vincent and the Grenadines, Caribbean Sea	8	Native	Opossum, snakes	3000

Note: Only those islands smaller than 290 square kilometers (km²) have been included.

Table 1b. **Critically endangered *(sensu 2012 International Union for Conservation of Nature Red List of Endangered Species categories) bird species affected by the predation of feral cats (*Felis silvestris catus*).**

Native species affected	Animal group	Island	Region	Island size (in km²)	Species category	Other introduced predators	Population
Acrocephalus luscinius	Land bird	Saipan	Marianas Islands, Pacific Ocean	115	Native	Rats, monitor lizards, brown tree snakes	48,220
Aphrastura masafuerae	Land bird	Alejandro Selkirk	Chile, Pacific Ocean	33	Endemic	Rats, dogs	57
Camarhynchus pauper	Land bird	Floreana	Galápagos Islands, Pacific Ocean	173	Endemic	Rats, dogs	138
Cyanorhamphus cookii	Land bird	Norfolk Island	Australia, Pacific Ocean	35	Endemic	Rats	2300
Diomedea amsterdamensis	Seabird	Amsterdam	Indian Ocean	55	Endemic	Rats, mice, dogs	35
Gallicolumba erythroptera	Land bird	Rangiroa Atoll	French Polynesia, Pacific Ocean	79	Native	Rats, mice, dogs	Less than 2000
Mimus graysoni	Land bird	Socorro	Revillagigedo Islands, Pacific Ocean	132	Endemic	Mice	30
Oceanodroma macrodactyla	Seabird	Guadalupe	Baja California, Pacific Ocean	254	Native	Rats, mice, dogs	100
Pomarea whitneyi	Land bird	Fatu Hiva	French Polynesia, Pacific Ocean	80	Endemic	Rats	584
Pseudobulweria macgillivrayi	Seabird	Gau	Fiji, Pacific Ocean	136	Endemic	Rats	3000
Pterodroma phaeopygia	Seabird	Floreana	Galápagos Islands, Pacific Ocean	173	Native	Rats, mice, dogs	138
Puffinus auricularis	Seabird	Socorro	Revillagigedo Islands, Pacific Ocean	132	Native	Mice	30
Sephanoides fernandensis fernandensis	Land bird	Robinson Crusoe	Chile, Pacific Ocean	93	Endemic	Rats, mice, dogs, coatis	674

Note: Only those islands smaller than 290 square kilometers (km²) have been included.

Table 1c. **Critically endangered *(sensu 2012 International Union for Conservation of Nature Red List of Endangered Species categories) mammal species affected by the predation of feral cats (*Felis silvestris catus*).**

Native species affected	Animal group	Island	Region	Island size (in km²)	Species category	Other introduced predators	Population
Dipodomys insularis	Rodent	San José	Baja California, Pacific Ocean	194	Endemic	Unknown	Less than 2000
Dipodomys margaritae	Rodent	Santa Margarita	Baja California, Pacific Ocean	231	Endemic	Dogs	Uninhabited
Peromyscus interparietalis	Rodent	San Lorenzo Sur	Baja California, Pacific Ocean	32	Native	Rats, mice	Uninhabited

Note: Only those islands smaller than 290 square kilometers (km²) have been included.

Table 2. **Critically endangered *(sensu 2012 International Union for Conservation of Nature Red List of Endangered Species categories) reptile, bird, and mammal species affected by the predation of feral cats (*Felis silvestris catus*).***

Islands	Species name	Common name
Pine Cay	*Cyclura carinata carinata*	Turks iguana, Caicos rock iguana
Little Cayman	*Cyclura nubila caymanensis*	Lesser Cayman iguana
Anegada	*Cyclura pinguis*	Anegada ground iguana
Alejandro Selkirk	*Aphrastura masafuerae*	Mas afuera rayadito
Floreana	*Camarhynchus pauper*	Galápagos medium tree finch
	Pterodroma phaeopygia	Galápagos petrel
Amsterdam	*Diomedea amsterdamensis*	Amsterdam albatross
Socorro	*Mimus graysoni*	Socorro mockingbird
	Puffinus auricularis	Townsend's shearwater
Guadalupe	*Oceanodroma macrodactyla*	Guadalupe storm-petrel
Fatu Hiva	*Pomarea whitneyi*	Fatuhiva monarch
Robinson Crusoe	*Sephanoides fernandensis fernandensis*	Juan Fernandez firecrown
Santa Margarita	*Dipodomys margaritae*	Margarita island kangaroo rat
San Lorenzo Sur	*Peromyscus interparietalis*	San Lorenzo mouse

Note: Only those islands smaller than 290 square kilometers and with a human population of fewer than 900 inhabitants have been included.

is possible, feral cat eradication should be integrated into multispecies eradication campaigns, which would not only limit secondary effects but could also reduce implementation costs. We understand that these multieradication plans could present some complexity, but they are certainly worth developing. When the eradication of all introduced predators is not feasible, several studies have indicated that, at least for some species, the overall effects of eradicating only the top predator are typically positive (Russell et al. 2009, Bonnaud et al. 2010, Campbell et al. 2011).

On the basis of our previous experience with feral cat eradication on islands (Nogales et al. 2004, Campbell et al. 2011), we recommend, if it is feasible, that rodents, rabbits, feral cats, and possibly other invasive species (e.g., mongoose) be targeted simultaneously for eradication, which will provide substantial cost savings compared with conducting a series of single-species eradications (Griffiths 2011) and would minimize the risks of unintended consequences to conservation targets. Where simultaneous eradication is not possible, managers should carefully plan the sequence in which invasive species will be removed, so that the removal of one invasive species will not complicate or prevent the removal of subsequent invasive species. Where multispecies eradications are not feasible, decisions to target feral cats should be made on the basis of cost–benefit analyses and with consideration of the potential for unintended outcomes. Managers may benefit from ecological and dietary studies of feral cats and food-web models to help predict potential outcomes (e.g., Zavaleta et al. 2001, Russell et al. 2009).

Aerial broadcast baiting techniques, more humane toxins, and other methodological advances are making feral cat eradications increasingly feasible on larger and more complex islands. Detecting and removing the last feral cats in an eradication campaign and confirming eradication can, in some instances, be the most expensive phase. Applied research and management tools are needed to increase the efficacy and reduce the cost of feral cat eradications. Feral cat eradications can cost between $4 and $431 per hectare (based on a survey of nine eradication programs), depending on the methods selected, the presence of human inhabitants and nontarget species, the remoteness of the island, and the competency of the implementers. Even at the upper end of this investment range, feral cat eradication can still be a cost-effective strategy for preventing species extinctions on islands.

Feral cat eradications have led to rapid positive effects on native species (Drake et al. 2011), especially seabirds (Cooper et al. 1995, Bester et al. 2002, Keitt and Tershy 2003, Hughes et al. 2008, Ratcliffe et al. 2010, Smith et al. 2010). Nevertheless, at least 38 IUCN-listed CR species (10 reptiles, 25 birds, and 3 mammals) are still threatened by feral cats on 41 islands (Medina et al. 2011). Five IUCN-listed CR species have already benefited from feral cat eradications (1 reptile [*Cyclura carinata* on Long Cay, Caicos Bank], 3 birds [*Phoebastria irrorata* on Isla de La Plata, Ecuador; *Pterodroma axillaris* on Mangere Island, New Zealand; and *Zosterops modestus* in the Seychelles], and 1 mammal [*Peromyscus pseudocrinitus* on Coronado Island, Baja California, Mexico]). In the same way, at least eight IUCN-listed *endangered* species have benefited from feral cat eradications (Richards 2007, Bellingham et al. 2010, Medina et al. 2011).

Conclusions

Feral cats are major drivers of extinctions on islands (Moors and Atkinson 1984). This link between species invasions and extinction or endangerment of native species is now widely accepted. Nevertheless, further work is needed in order to better understand the processes through which native island species are pushed toward extinction by feral cats and the resulting population declines. This is urgently needed in understudied regions in which numerous threatened endemic species are present (e.g., the Caribbean, Indonesia, Japan, French Polynesia, New Caledonia). This knowledge will help managers prioritize and determine the sequence of the removal of invasive species.

A detailed, data-driven prioritization of islands where feral cat eradication will have the largest conservation impact will be highly useful (Brooke et al. 2007). If the costs of

feral cat eradication are also included, this prioritization process can facilitate immediate conservation actions and the efficient use of conservation funds (Brooke et al. 2007). Effective education or social marketing programs are important tools for increasing the sensibility of stakeholders to the impact of feral cats on islands and to the benefits of feral cat eradication for native and endangered species. We identified at least 13 CR vertebrate species on 12 islands where feral cat eradication appears to be feasible and where imminent extinctions may be prevented. Furthermore, studies on the impacts of feral cats on a broader suite of species (e.g., invertebrates) would be desirable, and a similar exercise for other invasive species will further help prioritize islands requiring the eradication of feral cats within a global context.

Acknowledgments

This work was supported by several European Union projects: CGL-2004-0161 BOS, cofinanced by the Spanish Ministry of Science and Education and the French institutions the Fondation pour la Recherche sur la Biodiversité (under its DREAMS project), the French National Research Agency (under its ALIENS project), and the Ministère du Développement Durable (under its Ecotropic program); EB was supported by a Conseil Régional de Provence–Alpes–Côte d'Azur PhD fellowship. Five anonymous referees gave useful comments and suggestions that greatly helped improve the manuscript.

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