Planning for the eradication of feral cats on Guadalupe Island, México: home range, diet, and bait acceptance

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Abstract Feral cats (*Felis catus*) introduced to new environments have caused the extinction of many vertebrate species, including six species of birds on Guadalupe Island, México. To save species from extinction and restore natural processes, cats have been eradicated from islands using a variety of techniques. Eradication campaigns have to be planned carefully; ideally supported by information about the population to be eradicated. Our study focuses on home range estimation (fixed kernel); bait consumption by feral cats and non-target species; and diet of feral cats on Guadalupe Island. Home range was 76 to 1098 ha (KE 95) and core areas 21 to 196 ha (KE 50). Feral cats and non-target species including Guadalupe junco (*Junco hyemalis insularis*), Guadalupe rock wren (*Salpinctes obsoletus guadalupensis*), western gull (*Larus occidentalis*), and house mouse (*Mus musculus*) consumed baits. Items most commonly found in diet samples were mice (66.5%) and birds (16.8%). Male cats were 2.9 ± 0.6 kg, and females 2.4 ± 0.9 kg. The results of this study will inform eradication decisions for Guadalupe Island, especially regarding the use of poison baits.

Keywords: Morphometrics, *Mus musculus*, *Junco hyemalis insularis, Salpinctes obsoletus guadalupensis, Larus occidentalis,* non-target species, birds, poison baits.

INTRODUCTION

Global extinctions recorded over the past six centuries have been dominated by insular species, and introduced mammals are recognised as the main cause (MacPhee and Flemming 1999; Aguirre *et al*. 2005). Since 1600, 27% of mammal extinctions in the world have been on oceanic and oceanic-like islands; 28 reptile taxa have become extinct (Honegger 1981; Alcover *et al.* 1998) and 90% of bird extinctions have been insular forms (Johnson and Statterfield 1990). The probability of extinction is 40 times higher for an insular species than for continental species (Johnson and Statterfield 1990). One of the most damaging introduced species on islands is feral cats (*Felis catus*), which have been responsible for numerous extinctions worldwide (Iverson 1978; Jehl and Parks 1983; Mellink 1992; Veitch 2001; Tershy *et al*. 2002). For example, on Mexican islands, cats are thought to be responsible for the extinction of at least 16 taxa of birds and mammals (Aguirre *et al.* 2011).

Birds that evolve in predator-free environments often lack defences against new species (Whitaker 1998; Blackburn *et al.* 2004), and rapidly succumb to pressure from predators such as cats. This could include a combination of lack of predator awareness behaviour and habits that make them more vulnerable, such as feeding and nesting on the ground (Simberloff 1995). Cats were introduced to Guadalupe Island, México, in 1885 as an attempt to control the house mouse (*Mus musculus)* introduced ten years earlier (Moran 1996). Instead, the cats exterminated six species of endemic birds: Guadalupe ruby-crowned kinglet (*Regulus calendula obscurus*), Guadalupe Bewick's wren (*Thryomanes bewickii brevicauda*), Guadalupe rufous-sided towhee (*Pipilo maculatus consobrinus*), Guadalupe northern flicker (*Colaptes auratus rufipileus*), Guadalupe caracara (*Caracara lutosus*) and the Guadalupe storm-petrel (*Oceanodroma macrodactyla*). The first extinction was just seven years after the cats were introduced (Jehl and Everett 1985). Cats also extirpated the red-breasted nuthatch (*Sitta canadensis*), white-throated swift (*Aeronautes saxatalis*), red crossbill (*Loxia curvirostra*) and red-tailed hawk (*Buteo jamaicensis*), as well as caused a decline of several populations of seabird species such as Xantus's murrelet (*Synthliboramphus hypoleucus hypoleucus*) and Cassin´s aucklet (*Ptychoramphus aleuticus*) (Keitt *et al.* 2005).

Globally, feral cats have been eradicated from 75 islands (Campbell *et al.* 2011). The techniques used have evolved from the more traditional such as trapping, shooting, and the use of hunting dogs, to the more sophisticated such as special delivery methods for poisons (Marks *et al*. 2006). Eradication requires careful planning, selection of techniques most appropriate to the site, and relevant knowledge of the ecology of the target species (Bonnaud *et al.* 2011). Eradication campaigns against cats need support from research on movements and bait acceptance so existing techniques can be improved (Nogales *et al.* 2004). Information that now informs decisions about how and when to implement eradications includes studies of the diet of feral cats on islands (Bonnaud *et al.* 2011), their home ranges (Smucker *et al.* 2000; Edwards *et al.* 2001; Molsher *et al.* 2005), and bait acceptance (e.g., Wickstrom *et al.* 1999; Algar *et al.* 2007).

Diet studies for feral cats have often tried to quantify the impact of cats on native species (Paltridge *et al.* 1997; Bonnaud *et al.* 2011). Such studies can also highlight the relevance of particular prey to the eradication campaign and thus the likely effectiveness of the eradication attempt (Fitzgerald *et al.* 1991). For example, eradications may be most likely to succeed when the main prey species is scarce (Veitch 1985). If cats are to be eradicated from Guadalupe Island, answers are required for two main questions: 1) which are the most common prey species, and 2) how do populations of these species fluctuate throughout the year? Studies aimed at answering these questions will also generate new information regarding cat diet on Mexican islands. So far, cat diet analyses are only available for two islands in the country (Arnaud *et al.* 1993; Espinosa-Gayosso and Álvarez-Castañeda 2006).

Baits used to attract cats to traps or poisons can vary in effectiveness (Wickstrom *et al.* 1999). In addition to the diet of cats on Guadalupe, we analysed the acceptance of baits successfully used elsewhere for feral cats and non-target species. Although poisoning of some non-target species may be unavoidable during an eradication, there may be ways that these effects can be minimised (Veitch 1985). The first step is to determine which species are potential non-targets.

We also investigated home range characteristics of feral cats, which can inform decisions about the optimum spacing of baits or traps (Edwards *et al.* 2001). Existing home range studies on cats show great variation between habitats and locations (islands or mainland) (Edwards *et al.* 2001; Harper 2004; Molsher *et al.* 2005; Schmidt *et al*. 2007).

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MATERIALS AND METHODS

Site Description

Guadalupe Island is 24,171 ha, rises to 1298 m, and is 260 km off Baja California Peninsula, México (Fig. 1). The island's climate is influenced by the cold California Current and characterised by wind, fog, and winter rainfall (León de la Luz *et al*. 2003). Average temperature is 17.2°C (Hastings and Humphrey 1969) and annual rainfall is 250 mm (Castro *et al*. 2005). The main island, islets and surrounding waters are included in the Guadalupe Island Biosphere Reserve, administered by the Mexican Federal Government's National Commission of Natural Protected Areas.

In total, Guadalupe has 139 species of birds (Quintana-Barrios *et al*. 2006), including 10 species of breeding seabirds (Luna Mendoza *et al*. 2005). The invertebrate fauna is very diverse, including 11 species of endemic land snails. There are no native amphibians, reptiles, or terrestrial mammals. Colonies of northern elephant seal (*Mirounga angustirostris)*, Guadalupe fur seal (*Arctocephalus townsendi*) and California sea lion (*Zalophus californianus*) are present (Moran 1996). After its discovery in 1602 (Moran 1996), sealers and goat hunters visited the island until the 20th century. The Mexican Navy and Local fishermen established permanent settlements on the island in the 19th and 20th centuries respectively.

Guadalupe has 223 plant species, including 39 that are endemic (Rebman *et al.* 2005; Junak *et al*. 2005). Pine, cypress, and palm forests, oak and juniper woodlands, as well as chaparral, grassland, sage scrub, and maritime desert scrub were the major habitat types before goat introduction (Oberbauer 2005). Now, only 6% of the forest remains, the chaparral no longer exists, and the grassland has increased from 1250 ha to 12,800 ha (Oberbauer 2005), due to grazing by feral goats and the introduction of weeds. The only remaining pristine habitat is scrub vegetation on the islets, which never had goats or other exotic mammals. As part of a restoration project, goat and dog eradication started in 2002. Dogs were eradicated in 2005 and the last Judas goats were removed in 2010 (Julio Hernández-Montoya pers. comm.). The only remaining introduced mammals are cats and house mice.

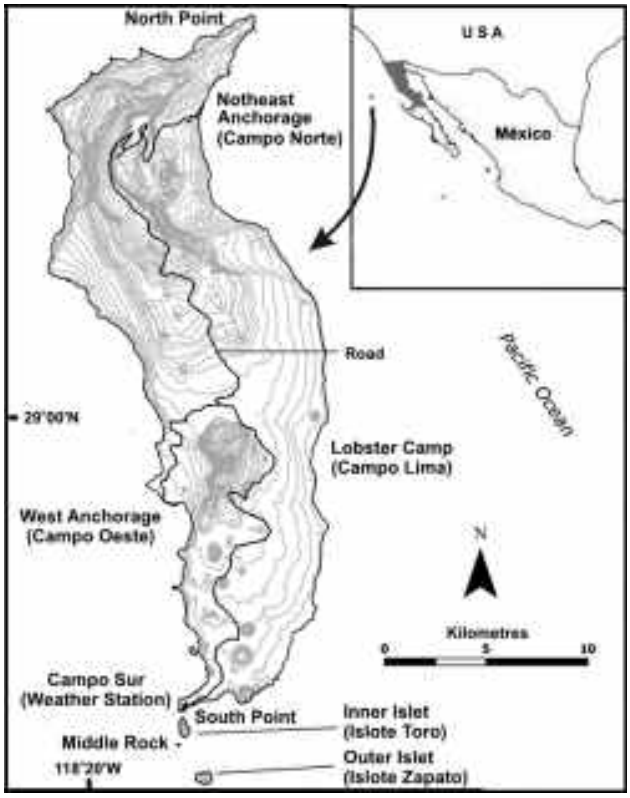

Fig. 1 Guadalupe Island. Location and significant features.

Feral cat population and biology

Home range

Estimates of home range size for feral cats were conducted from May to October 2009. Victor Oneida Soft Catch leg-hold traps (No. 1.5 Oneida Victor Inc. Ltd., USA) were set on trails or in caves (Veitch 1985; Wood *et al*. 2002) using fried fish, fried canned tuna or sardine as bait. Trapped cats were anaesthetised using 0.2-0.4 ml of 5-10 mg/kg zolazepam and tiletamine (Zoletil, Virbac) given intramuscularly (Virbac 2009) and fitted with mortality-sensitive VHF transmitters (Model TXE-311C, 31 gr, 163.499 – 163.959 Mhz, Telenax MX). Morphological attributes such as weight, sex, and age, were measured. Collared cats were released near their capture location and monitored daily using a Yagi folding antenna and a portable receiver (Model WTI-1000, Wildlife Track Inc. USA). Position, time of day, and bearing were recorded (Harper 2004; Molsher *et al*. 2005). Triangulation (Kenward 2001) was used to determinate approximate locations of collared cats. These data were then processed in software Locate III (Pacer Computing, Tatamagouche, NS, Canada). Cat positions were calculated with 95% confidence and incorporated into a Geographic Information System using ArcGis 9.2 (ESRI Inc., Leica Geosystems GIS Mapping, Microsoft Corporation, LizardTech Inc. and Independent JPEG Group) and displayed on a Quickbird image (DigitalGlobe Inc. USA) of the island. Home Range Tools (HRT) for ArcGis (Rodgers *et al*. 2007) were used to estimate the home ranges of feral cats. The Kernel Density Estimation (KDE) method was used, as recommended by Laver and Kelly (2008). Kernel (KE) 95% was used to estimate home range. Core area was calculated using KE 50%. The fixed kernel smoothing parameter was used (Edwards *et al.* 2001; Kenward 2001). Home ranges were calculated with ≥20 locations for each individual and core area with ≥10 locations (Harper 2004; Molsher *et al*. 2005).

Baits

Beef and chicken baits were made by local manufacturers, following the specifications for Eradicat developed by the Department of Environment and Conservation of Western Australia (Algar *et al.* 2002; 2007). Baits contained 80% meat and 20% fat with monosodium glutamate as a flavour enhancer. The baits were 60-70 mm long x 10-15mm diameter and 20g dry weight.

Bait take by feral cats and non-target species was evaluated. The major species of concern were the endemic Guadalupe junco (*Junco hyemalis insularis*), Guadalupe rock wren (*Salpinctes obsoletus guadalupensis*) and Guadalupe house finch (*Carpodacus mexicanus amplus*) as well as the native burrowing owl (*Athene cunicularia*), American kestrel (*Falco sparverius*), western gull (*Larus occidentalis*), mourning dove (*Zenaida macroura*) and western meadowlark (*Sturnella neglecta*). Bait take by house mice was also evaluated.

Bait uptake trails were established in cypress forest, scrubland, grassland, and on the coast. The habitats used were to enable different species to be targeted rather than for comparing habitats. In each habitat, three transects were established 200m apart with eight sand plots (stations) 100m apart along each (a total of 96 stations). Each station was cleared of vegetation and a 1m diameter of sifted dirt or sand was laid to record all animal tracks (Linhart and Knowlton 1975). One bait was placed in the middle of each station, alternating between beef and chicken (Kavanaugh and Linhart 2000). The sand plots were surveyed between

21 October and 13 November 2009 on three consecutive days. After animal tracks were recorded, the stations were then reset by raking over tracks and replacement of baits. Four cameras (Model Trophy Cam, Bushnell Corporation, USA) were used to record bait consumption; two placed on stations with beef sausages and two on stations with chicken sausage. Cameras were installed 30-50cm above ground in front of the stations (S. Robinson pers. comm.), set to record 20-30 seconds of video with a minimum interval of three minutes between recordings, and set for one night on each transect.

Bait consumption was also tested on 24 feral cats held in cages (160x110x110 cm) for four and seven days during October-November 2009. Cats were fed each day at the same hour with fresh meat. During the last day of captivity, three beef and three chicken baits were placed in the cages. Preference of consumption was recorded by direct observation and by the cameras (Marks *et al*. 2006), which were set to take videos every 20-30 seconds with a minimum interval of 10 seconds between shots (Clapperton *et al*. 1994).

Morphological attributes

Between June and December 2009, feral cats were captured at several places on the island using Victor Oneida Soft Catch leg-hold traps and Tomahawk Live Traps (Model 207, 81.3 x 25.4 x 30.5 cm, Tomahawk Live Trap Co. USA) baited as described above. Cats were anaesthetised using procedures described above and euthanized with a heart lethal injection using 0.5-1.0 ml of sodium chloride (Kelefusin, PiSA), at a dose of 40-70 mg/kg (Phillips *et al*. 2005; AVMA 2007). The sex and age (juvenile or adult by tooth wear following Logan *et al*. 1986), coat colour, weight (± 100g), and head-body length (± 10mm) were recorded.

Diet

Stomach contents and scats collected from cats captured were analysed and separated into four categories: house mice, birds, insects or plant material. Frequency of occurrence and relative frequency were calculated for each diet sample. Frequency of occurrence of each category was calculated by dividing the number of diet samples containing each category by the total number of diet samples analysed. Relative frequency was calculated by dividing the frequency of occurrence of each prey item by the total of frequencies of occurrence for all prey items (Smucker *et al.* 2000).

RESULTS

Feral cat population and biology

Home range

In total, 17 cats were caught over 129 trap-nights and transmitters deployed on 12 males (11 adults and 1 juvenile) and 5 females (2 adults and 3 juveniles). Of the cats with transmitters, eight were located more than 20 times over 2100 hours of tracking (Table 1). The average home ranges were 510.4 ± 353.8 ha for males and 226.5 ± 118.1 ha for females (Table 2).

Table 1 Home ranges and core areas (ha) for collared cats. Age = (A) adult; (J) juvenile.

Cat No	Age	Sex	No. places	Home range (ha) KE 95	Core area (ha) KE 50
G01	A	M	28	186	33
G02	A	M	25	495	105
G05	A	F	25	310	69
G09	A	F	31	143	27
G11	A	M	25	485	76
G12	J	F	26	76	21
G14	A	M	20	288	60
G17	A	M	20	1098	196

Table 2 Home ranges of adult feral cats on Guadalupe Island and other locations.

Location	Sex	n	Home range (ha) KE 95	Core area (ha) KE 50
Guadalupe Island [1]	M	5	510.4 ± 353.8	94 ± 62.7
	F	2	226.5 ± 118.1	48 ± 29.6
Australia [2]	M	3	103.1 ± 91.9	18.6 ± 13.9
New South Wales [3]	M	11	25-575	7-152
	F	4	126-310	11-68
Stewart Island [4]	M	8	1815 ± 360.3	
	F	3	1065 ± 241.6	

[1]This study; [2]Edwards *et al.* 2001; [3]Molsher *et al.* 2005; [4]Harper 2004.

Baits

On transects, 69.16% of the baits were consumed. There was no significant preference between beef and chicken baits ($t = -1.844$, $df = 8.79$, $P > 0.05$; Table 3).

Of the stations where baits were consumed, 28% had images showing the process of consumption. At stations where there was a combination of sign on the raked sand and images obtained from camera traps, there were visits by cats, Guadalupe rock wren, Guadalupe junco, western gull, and mice. Burrowing owls visited the stations but showed no interest in the baits. Tracks or images of Guadalupe house finch, American kestrel, mourning dove, and western meadowlark were not detected at the stations.

Of 24 cats held in captivity, 22 (91.7%) consumed at least one bait and 75% consumed at least three of the six baits offered. Chicken bait was preferred (62.5%) over beef bait (29.17%).

Morphological attributes

In total, 278 feral cats were captured (3548 trap-nights). The coat colour was 77.4% tabby, 21.4% black and 1.2% black and white (Table 4).

Diet

In total, 140 diet samples were analysed, 14.3% were from summer and 85.7% from autumn (Table 5).

The bird species most commonly found in diet samples were mourning dove, Leach's storm petrel (*Oceanodroma leucorhoa*) and Guadalupe Junco, but there was no further analysis of their relative contributions.

Table 3 Bait consumption by feral cats and non-target species.

Species	Bait	Consumption (%)
Cat	Chicken	78.21
	Beef	63.29
House mouse	Chicken	10.26
	Beef	25.32
Guadalupe rock wren	Chicken	5.13
	Beef	6.33
Guadalupe junco	Chicken	1.28
	Beef	1.27
Western gull	Chicken	5.13
	Beef	3.80

Table 4 Measurements of feral cats on Guadalupe and other islands.

Island	Sex	Weight (kg)	Max. (kg)	n	Head and body length (mm)	Max. (mm)	n
Guadalupe[1]	M	2.87 ± 0.58	4.6	141	489 ± 36.0	550	91
	F	2.35 ± 0.94	3.5	52	465 ± 28.8	530	34
Little Barrier[2]	M	2.95	4.1	18	473	530	21
	F	2.23	3.8	35	440	320	40
Cocos Islands[3]	M	3.38 ± 0.07	4.8	63			
	F	2.69 ± 0.06	3.7	76			
Macquarie[4]	M	4.3 ± 0.06	5.5	74			
	F	3.7 ± 0.09	5.8	54			

[1]This study; [2] Veitch 2001; [3]Algar *et al.* 2003; [4]Brothers *et al.* 1985.

DISCUSSION

In this study, our main interest was to assess the cats' minimum home range so that any eradication programme using baits would spread them at a density accessible to every cat. On Guadalupe, as in other studies, females had the smallest home ranges (Table 2). Home ranges on Guadalupe and Stewart Island (Harper 2004) were larger than those found on mainland Australia (Edwards *et al.* 2001; Molsher *et al.* 2005). The Guadalupe study was done during autumn, when food resources were abundant. During winter, which will be the best timing for eradication, food resources will be scarcer and in consequence we expect home ranges to be larger.

The size and weight of feral cats on Guadalupe are similar to those reported by other studies (Table 4). Considering the home ranges and morphometrics of cats on this island, we believe that eradication of feral cats from Guadalupe Island is possible using aerial broadcast poison baits at a rate of 100/km^2 to knock down the population (Algar *et al*. 2001, 2002), followed by a rapid response using traditional techniques of trapping, shooting, and hunting dogs.

Bait trails showed that baits similar in size and characteristics to Eradicat could work on Guadalupe Island. Eradicat cannot be imported to Mexico but a similar product can be manufactured. As we expected, bait consumption by house mice was high (Table 3). Interference by house mice will likely be less in winter but will have to be considered for the eradication.

Baits were consumed by three species of birds, which may result in non-target poisoning. Bait consumption by Guadalupe junco and western gull was expected but not the consumption by Guadalupe rock wren. Junco and rock wren are endemic species. The western gull is the only gull breeding on the island and may be an endemic race (Hubs 1960 cited in Jehl and Everett 1985). Mitigation measures required for these species, and further assessment for each non-target species, will have to be included in the eradication planning process. Potential mitigation techniques include the capture and temporary holding of non-target bird species (Howald *et al.* 2003, 2010) or development of encapsulated poison within baits that are unable to be consumed by these non-target species (Marks *et al.* 2006; Hetherington *et al.* 2007). These mitigation actions will require further testing and validation on site. Because the use of 1080 is banned in México, new toxins may need to be evaluated for use on Guadalupe. For example, para-aminopropiophenone (PAPP) may be suitable for the eradication of feral cats (Johnston *et al.* 2010; Eason *et al.* 2010).

Table 5 Cat diet. Frequency of occurrence and relative frequency of prey.

		Mice	Birds	Insects	Plants
Summer (n=20)	Freq of occurrence	63.6%	31.8%	--	4.5%
	Relative frequency	70.0%	35.0%	--	5.0%
Autumn (n=120)	Freq of occurrence	65.4%	15.4%	4.3%	14.8%
	Relative frequency	88.3%	20.8%	5.8%	20.0%

Cats held in captivity consumed chicken and beef flavoured baits but showed a preference for chicken, perhaps because of their higher fat content compared with beef baits. Nevertheless, chicken baits are more difficult to preserve and store than those made of beef, which limits the use of chicken baits in the field. Since beef baits were also accepted and consumed, particularly in the field trials, these baits should be adequate for a cat eradication programme. Other baits could be tested particularly those with at least some chicken or fish to enhance the odour attraction. Fish baits could be considered in the future, but some studies have suggested that they are less reliable for use in the field (Wickstrom *et al.* 1999).

On Guadalupe Island, house mice predominated in the cats' diet (64.4%) followed by birds (23.6%), and plant material (9.7%) (Table 5). Insects were only present during autumn (4.3%), but this could be due to a larger sampling effort. In summer, cats consumed almost exclusively mice and birds. In autumn, the percentage of bird consumption was lower and higher for plant material. The relative abundance of cats on Guadalupe declines during winter, which coincides with the collapse of the house mice population (Luna-Mendoza *et al*. unpubl. data) and the absence of seabirds. Eradication should thus be most effective in winter because the mouse population is probably regulating the abundance of cats. Seasonal or yearly mouse plagues have been reported by locals as the mice seem to be regulated by food availability after rain, when numbers increase, followed by population collapse during winter. It is also possible that vegetation changes after goat eradication are influencing mouse abundance. The seabird population on Guadalupe is seasonal and not large enough to sustain a large cat population.

Questions remain regarding the potential effects of cat eradication on the mouse population. Conceivably, there is potential for mesopredator (mouse) release, which could be more damaging to the natural value of the islands than the current impact of cats. Some studies suggest that the removal of cats (superpredators) increase mesopredator communities such as rats (*Rattus sp*.), which can then cause more damage to prey populations (Russell *et al*. 2009). The negative impacts of house mice on birds are much less known than the effects of rats, but some studies (Wanless

et al. 2007; Jones and Ryan 2009), suggest that mice could be a serious threat for seabirds. In contrast, Blackwell *et al*. (2003) suggests that ship rats (*R. rattus*) and house mice seem to be regulated more by food availability than by predator pressure. Under this scenario, the eradication of feral cats in Guadalupe might not affect the house mouse population. However, because the effects of house mouse eruptions due to cat removal are difficult to predict, the simultaneous eradication of house mice and cats should be considered.

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