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DIET AND HOME-RANGE OF THE FERAL CAT, *FELIS CATUS* (CARNIVORA: FELIDAE) ON SOCORRO ISLAND, REVILLAGIGEDO ARCHIPELAGO, MEXICO

DIETA Y ÁMBITO HOGAREÑO DEL GATO FERAL, *FELIS CATUS* (CARNIVORA: FELIDAE) EN LA ISLA SOCORRO, ARCHIPIÉLAGO DE REVILLAGIGEDO, MÉXICO

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ABSTRACT. Socorro is an oceanic island rich in biodiversity and endemisms. However, the island has been threatened by feral cats since 1957. The diet of this predator, determined through the analysis of stomach contents of 79 cats, consisted mostly of house mice (*Mus musculus*, 22.16%), endemic lizards (*Urosaurus auriculatus*, 15.09%), anthropogenic rubbish (15.09%), and insects (Orthoptera, 13.20%). The home range of the feral cat was identified through telemetry using four individuals with GPS/VHF radio-collars. The three males had a much larger average home range of 219.10 ha, as compared with 118.86 ha of the female. Knowing the home range of the Socorro Island feral cat is critical for the successful eradication of the island's invasive population. Thanks to this information, it is possible to calculate the trapping effort and the amount of bait needed per unit area to successfully carry out the ongoing eradication, contributing to the conservation of global biodiversity.
Key words: diet, *Felis catus*, feral cats, home range, Socorro Island.

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RESUMEN. Isla Socorro es una isla oceánica rica en biodiversidad y endemismos. Sin embargo, la isla ha sido impactada por el gato asilvestrado desde 1957. A través del análisis del contenido estomacal de 79 gatos se determinó la dieta de este depredador, la cual está constituida mayormente por el ratón doméstico (*Mus musculus*, 22.16%), la lagartija endémica (*Urosaurus auriculatus*, 15.09%), residuos antropogénicos (15.09%), e insectos (Orthoptera, 13.20%). Se identificó el ámbito hogareño de los gatos a través de telemetría, utilizando cuatro individuos con radio-collares GPS/VHF. El ámbito hogareño de los machos resultó de 219.10 ha en promedio, mucho mayor que el de las hembras que fue de 118.86 ha. Conocer el ámbito hogareño del gato asilvestrado de Isla Socorro es clave para la erradicación exitosa de la población de la isla. Gracias a esta información se ha podido calcular el esfuerzo de trampeo o la cantidad de carnada que deben ser empleadas por unidad de área durante la erradicación en curso, que es relevante para la conservación de la biodiversidad global.
Palabras clave: ámbito hogareño, dieta, *Felis catus*, Gato asilvestrado, Isla Socorro.

INTRODUCTION

Island ecosystems are vulnerable to introduced species, because these environments generally have a low biodiversity and high rates of endemism (Fritts & Rodda, 1998), especially oceanic islands (Kier *et al*., 2009). Approximately 75% of animal extinctions on the planet have occurred on islands and most of them have been caused by introduced species (Blackburn *et al*., 2004). Among predators, the domestic cat (*Felis catus*) is considered the introduced carnivore which has caused the largest number of extinctions and extirpation of native wildlife on islands of the world (Ebenhard, 1988; Nogales, 2004); it is also responsible for transmitting diseases to wildlife and human beings (Patronek, 1998; de Wit *et al*., 2017).

In Socorro, an oceanic island located on the Revillagigedo Archipelago in the Mexican Pacific (Fig. 1), cats have been present since 1957. Jehl & Parkes (1983) con-

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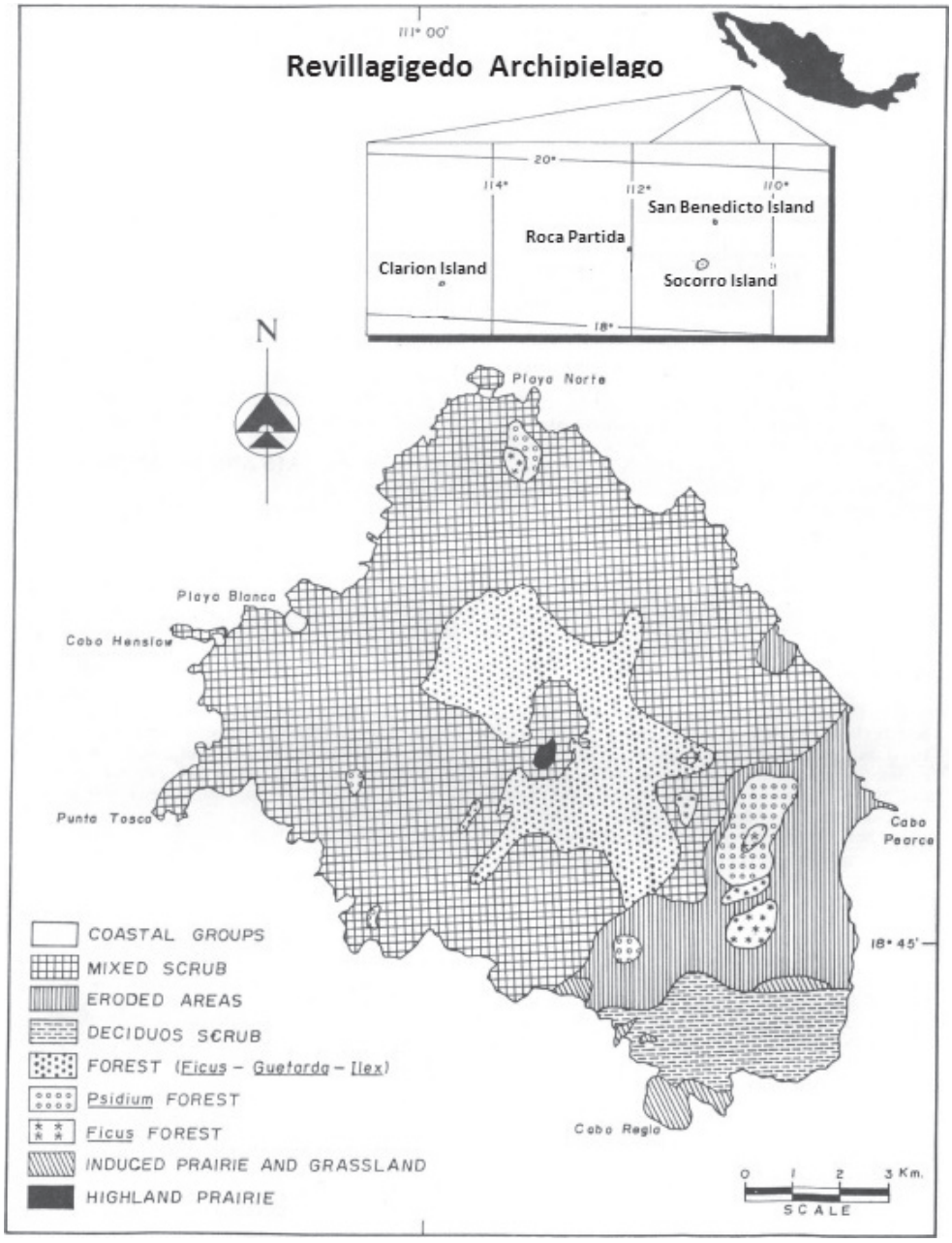

Figure 1. Localization of vegetation types in Socorro Island (Arnaud *et al.,* 1993).

sidered that this predator is responsible for the *in situ* extinction of the endemic Socorro dove (*Zenaida graysoni*). Cats are also a threat to the Socorro Blue Lizard (*Urosaurus auriculatus*; Arnaud *et al.,* 1994), and Townsend's Shearwater (*Puffinus auricularis*; Llinas-Gutiérrez, 1994). Cats have affected the Socorro Mockingbird (*Mimus graysoni*), which is critically endangered CR (IUCN extinction) (Castellanos & Rodríguez-Estrella, 1992), and have also reduced the distribution and abundance of other birds such as the Socorro Towhee (*Pipilo socorroensis* = *Pipilo maculatus socorroensis*) and the Socorro Wren (*Troglodytes sissonii*; Ortiz-Alcaraz, 2016).

The cat in Socorro Island was not the only anthropogenic introduction on the island; a second event was the introduction of an exotic rodent. This probably occurred multiple times and possibly but not necessarily in the or-

der presented. However, both anthropogenic events are important since it led to the establishment of cohabitation, with its consequent impact on the landscape. In the conservation literature, there are many cases where two or more anthropogenic events occur. For example, the now classic book on island biogeography by Whittaker *et al*. (1998) where they referred to these human-induced events as combined or additive; or Lomolino (1986) who referred to more than one anthropogenic event occurring as "interactive events"; and/or more recently Larrinaga and Santamaría (2013) where they referred to more than one anthropogenic event as a "combined impact" that negatively impacts the landscape life. Although it has been recognized for some time that anthropogenic events affecting landscapes can have more than one human-induced cause, a singular term is used to describe them, i.e. "anthropogeny". At present, there is no single word to express two or more human-induced events affecting environmental landscapes, even though many environmental impacts are influenced by more than one human induced event.

Given the large impact and distribution of exotic species on islands, their eradication is one of the best possible actions to support conservation efforts (CANTIM, 2012). In order to design and implement an eradication program, it is particularly important to examine the diet, home range and habitat use of invasive cats on Socorro Island.

METHODS

Study site. Socorro Island is a volcanic cone whose peak reaches 1,040 m asl and with a surface area of 140 km². The climate is tropical with an average annual temperature and precipitation of 24.6 °C and 404.7 mm, respectively. Vegetation varies from halophyte associations at sea level to forests at the higher elevations dominated by tropical shrubs and trees along the altitudinal gradient (Flores-Palacios *et al*., 2009; Fig. 1). The hurricane season extends from July to October (Coria-Benet, 1994). Freshwater is found in temporary puddles formed after tropical storms and year around in several caves. A Mexican Navy garrison was established on Socorro since 1957, it is located at the southern end of the island (Adem, 1960; Jehl & Parkes, 1982).

Eight endemic taxa of land birds breed on Socorro: Yellow-crowned Night-Heron, *Nyctanassa violacea gravirostris*; Socorro Red-tailed Hawk, *Buteo jamaicensis socorrensis*; Socorro Ground-dove, *Columbina passerina socorroensis*; Socorro Parakeet, *Psitacara holochlorus*; Socorro wren, *Troglodytes sissonii*; Socorro Mockingbird, *Mimus graysoni*; Tropical Parula, *Setophaga pitiayumi graysoni*; and Socorro Towhee, *Pipilo socorroensis* (= *Pipilo maculatus socorroensis*) (Brattstrom 1990); and an endemic lizard, *Urosaurus auriculatus*.

Specimen collection and prey identification. Cats were captured in November 2012, April 2013 and April 2014, for 21 days per month (the collection of samples of specimens was authorized by the Secretaría del Medio Ambiente y Recursos Naturales, permit SGPA/DGVS/03692/13, 04176/13, 04932/13). Ninety steel traps (Oneida Victor Soft Catch #1 ½) were used and were placed at different sites (Fig. 2), baited with an attractant made of seafood, tuna or fried sardines (Brothers, 1982). Trapping took place in the eastern portion of the island, where cat density was greater based on observed traces (excreta) and observations of individuals, and previous research (Arnaud *et al*., 1994). Traps were checked daily from 07:00 to 10:00 am. Those hard to reach areas were equipped with telemetry systems (ATS, mammal trap monitor Series M4000) to determine from distance whether they had been activated (Will *et al*., 2010).

Captured animals were euthanized without inflicting pain. They were injected first with an anesthetic (Xylazine-Ketamine), and subsequently with a lethal intracardiac- dose (Potassium chloride). To a lesser extent, night hunts were conducted with rifles of calibers .22, .222 and .243 equipped with a telescopic sight and lamp. Each individual had a humanitarian death, attending the normativity (DOF, 2001). Upon capture the gender, height, and age data were recorded of each trapped animal and their stomach contents were collected to determine diet. Stomach contents were placed in plastic bottles with Ethanol 70% and taken to the Laboratory of Animal Ecology of the Centro de Investigaciones Biológicas del Noroeste, in La Paz, Baja California Sur, where contents were identified by comparing the scales, bones, feathers and hair with a reference collection that is composed of biological material from the island. Diet results are expressed in frequency of occurrence and percentage.

Home-range data. To determine the home range of cats, in April 2012 four adult individuals (3 males and 1 female ranging from 2.7 to 3.5 kg), were captured in different locations distant from each other. They were equipped with GPS/VHF telemetry collars (G2C model 128A Sirtrack GPS datalogger, 135 g). The recorded information on the collars included ArcMap 9.3 program (ESRI Inc., Leica

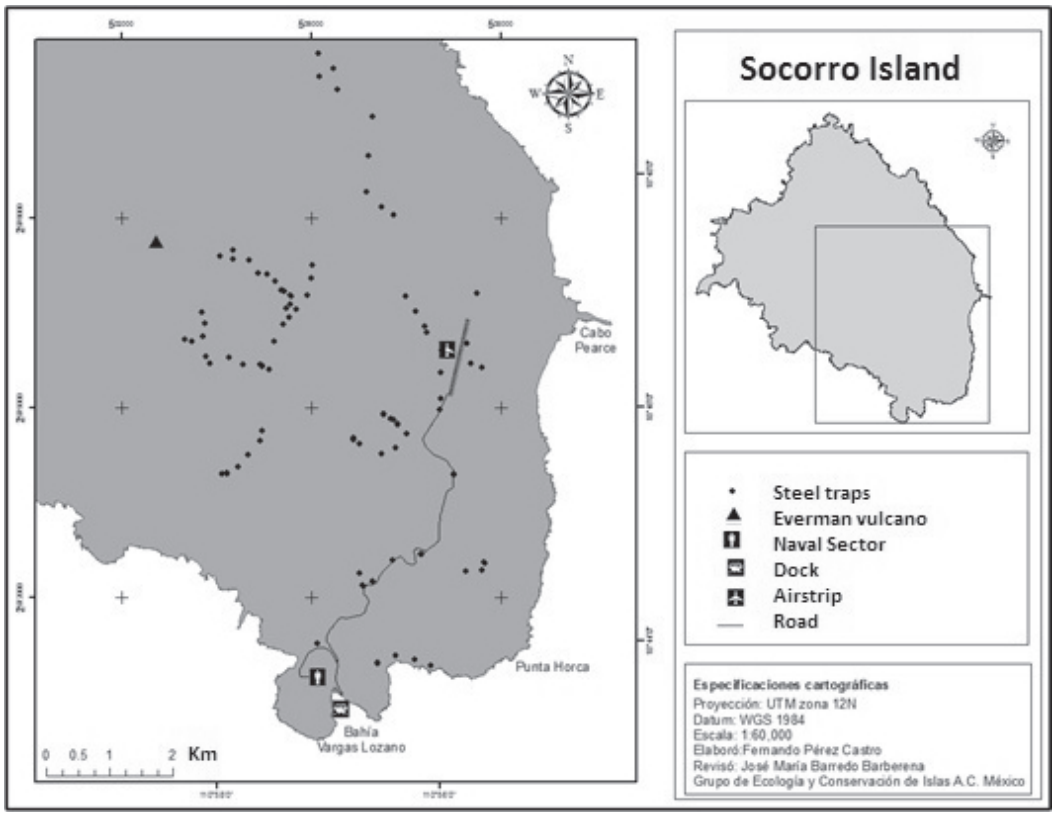

Figure 2. Localization of cat traps (Ortiz-Alcaraz, 2016).

Geosystems GIS Mapping, Microsoft Corporation, Lizard Tech Inc. e Independent JPEG Group), a geographic information system (GIS) allowing for the display of the obtained information in a Quickbird (2008) image of Socorro Island. For determining the home range of the cats a Home Range Tool (HRT) known as ArcGis (Rodgers *et al*., 2005) was used to calculate the Minimum Convex Polygon (MCP) at 95% of the utilization distribution, while the core area was defined and calculated at 50%.

RESULTS

Diet. Seventy nine cats were caught (51 in November, 2012; 15 in April, 2013; 12 in April 2014), of which 67 (84.8%) stomachs were obtained with their respective stomach contents and 12 (15.1%) were empty. Feral cats were feeding mainly on invasive house mice (*Mus musculus*), endemic Socorro blue lizards, endemic Socorro Ground dove, insects, scorpions, centipedes, plant materials and anthropogenic refuse (Table 1). House mice were present in 22.16% of the cats' stomachs. Endemic lizards, grasses and anthropogenic refuses were present in 15%, while grasshoppers were present in 13.20% (Table 1).

Home-range. The four individuals were radio-collared in April 2012. Male 01 (M01) was radio-tracked until August 2012 with 501 locations obtained; male 05 (M05) until June 2012 with 494 locations obtained; male 06 (M06) until September 2012 with 489 locations obtained. The 95% MCP of the locations was 175.28 ha for individual M01; 262.14 ha for M05; 219.88 ha for M06 and 118.86 ha for H02. Males had an average home range of 219.10 ha compared to 118.86 ha for the female. The home range of the female H02 overlapped at 100% with the male M06 (Fig. 3). The 50% MCP of the locations was 53.88 ha for M01; 108.48 ha for M05; 96.88 ha for M06 and 66.07 ha for H02.

DISCUSSION

Our research supported previous works showing that feral cats are a highly generalist predator that feed on prey ranging from small insects to birds and rodents (Turner

Table 1. Diet composition of feral cats (*Felis catus*) on Socorro Island, expressed in frequency occurrence (fo), and percentage of prey categories found in the stomach of cats in November 2012, April 2013 and 2014.

Food categories	Nov 2012 (n = 40)		April 2013 (n = 15)		April 2014 (n = 12)		TOTAL	
	fo	%	fo	%	fo	%	n	%
MAMMALS								
Mus musculus	27	20	10	20.8	10	34.4	80	21.16
BIRDS								
Columbina passerina	10	7.4	4	8.3	2	6.8	22	5.82
REPTILES								
Urosaurus auriculatus	25	18.5	4	8.3	3	10.3	56	14.81
FISH								
Unidentified	1	0.7					1	0.26
INVERTEBRATES								
Orthoptera	17	12.5	9	18.7	2	6.8	63	16.66
Lepidoptera	1	0.7	1	2			4	1.05
Coleoptera	4	2.9					15	3.96
Blattodea			1	2			1	0.26
Scorpions	4	2.9					8	2.11
Scolopendromorpha	4	2.9	3	6.2			7	1.85
Decapods (*Gecarcinus planatus*)	1	0.7					3	0.79
PLANT MATERIAL								
grass	22	16.2	5	10.4	6	20.6	33	8.73
FUNGI								
Unidentified	1	0.7			2	6.8		
ANTHROPOGENIC REFUSE								
plant fibers, plastic, organic material	17	12.5	11	22.9	4	13.7	73	19.31

& Bateson, 2000). Thus, the diet of the cats will change depending on prey availability. The most frequent prey of the feral cat on Socorro Island was an introduced rodent. This result is the same as those that have been reported throughout many other islands in the world, due to these poly-anthropogenic introductions (Fitzgerald *et al.,* 1991; Pointer *et al.,* 2002; Bonnaud *et al.,* 2007). Arnaud *et al.* (199) in the analysis of cat excreta also found a high percentage of house mice although at that time the distribution of the mice was concentrated in the south of the island (Arnaud *et al.,* 1994). Since then, invasive mouse distribution has moved to other regions of the island (López-Higareda *et al.,* 2014), perhaps making their availability to cats greater. The second most frequent prey category found in the stomach contents of the cat was the endemic Socorro blue lizard. In regards to this species, it is urgent to implement measures for its protection, because the cat has been preying on this endemic lizard species since it was first introduced. (Arnaud *et al.,* 1993). An eventual control of *M. musculus* without the prior eradication of cats could lead to greater short-term predation on Socorro blue lizards until the cat populations have decreased due to the absence of mice. The percent frequency of anthropogenic refuse in the stomach content of the cats captured was high, confirming that on Socorro Island the feral cat population is subsidized by human food sources.

We found that the diet of the feral cats also contained a high percentage of insects. This pattern has been reported previously for Socorro Island (Arnaud *et al.,* 1993) and in others sites throughout the world (Nogales & Medina, 1996). When this type of prey is locally abundant, they will be consumed in large numbers by feral cats (Berruti, 1986; Tidemann *et al.,* 1994). Birds were found to be represented in only the diet of one specimen, thus in a low percentage. This may be related to the fact that most of the cats caught were in low-lying areas in the southeast-

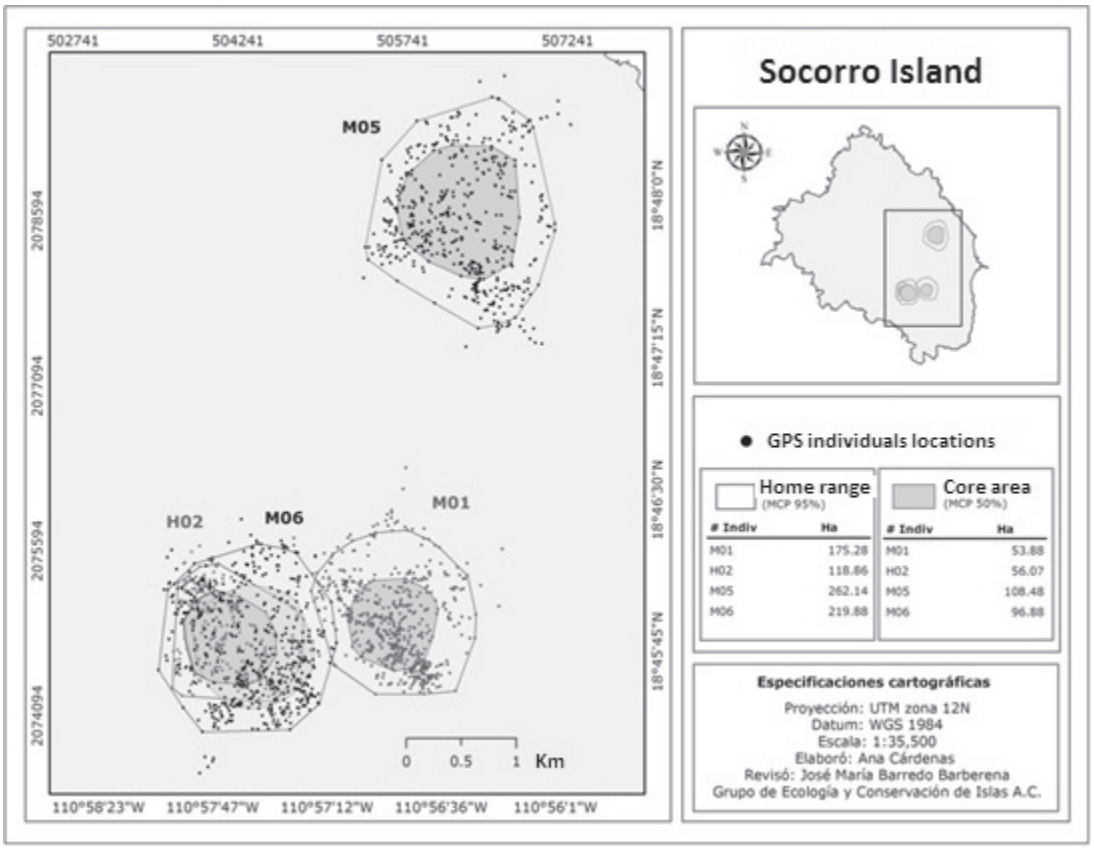

Figure 3. Home-range from spring-summer 2012 of cats with radio-collar.

ern part of the island, where birds are less abundant; our results are comparable to those reported by Arnaud *et al*. (1993) and Rodríguez-Estrella *et al*. (1991).

GPS collars placed on the feral cats allowed for the generation of a database of the locations of each cat collared at high acquisition rate during the study period. Our results of the home-range area of cats varied from 118 to 262 ha. In others studies, using radio-tracking the ranges varied from 490.2 to 1,571.4 ha (Pierce, 1987), 42 to 840 ha (Norbury *et al.,* 1998), and using GPS 178 to 2,486 ha (Recio *et al.,* 2010). Care must be taken when making comparisons, because differences in habitat configuration (topography and canopy structure) reduces the signal levels the transmitter sends and the ability of the receiver to decode signal in order to decode the actual location; this is known as fix success (Dussault *et al.,* 1999; D'Eon *et al.,* 2002; Di Orio *et al.,* 2003; Cain *et al.,* 2005; Hansen & Riggs, 2008). The relatively good fix success obtained in this research might be explained by the relatively small size of the Socorro cats which influences their behavior patterns by reducing their mobility in short temporal time scales which improves signal strength. Their small size allows them to utilize a great range of holes or cavities in the area as a shelter for resting, or as dens. These cavities are usually open to the sky and hence facilitating signal transmission. They also hide under the dense shrub vegetation probably also for shelter, resting or as a convenient hunting outpost for locating available nearby prey. It is evident from this study that any program executed should concentrate in mixed habitat areas, where both shelter and food are available.

Although our tests on habitat use showed consistent results, these results must be viewed with caution because of the small sample size used. To obtain a better understanding of the spatial ecology of the feral cats in Socorro Island, further studies with suitable sample sizes (including a greater emphasis on females whose smaller home ranges will determine the density of trapping, baiting and search efforts) and in different seasons are required, thus allowing for more efficient cat-control programs.

In concluding, we stress that these introductions of mice and cats (even if they constitute a predator-prey re-

lationship) are two separate anthropogenic events. One human induced event was the rodent introduction and the second was the cat introduction. These probably occurred multiple times and possibly but not necessarily in the order presented. However, both anthropogenic events are important since it led to the establishment of cohabitation, with its consequent impact on the landscape. In the conservation literature there are many cases where two or more anthropogenic events occur, such as in this paper with rodent-prey introductions. Many environmental impacts are influenced by more than one human induced event or polyanthropogenic events, as we suggest they should be referred.

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