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STATUS OF *DIPODOMYS INSULARIS*, AN ENDEMIC SPECIES OF SAN JOSÉ ISLAND, GULF OF CALIFORNIA, MEXICO

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The islands of the Gulf of California are considered protected natural areas by the Mexican government. However, mammals in these islands face major threats and possible extinction because of the introduction of exotic species. *Dipodomys insularis* is endemic to San José Island, and has been declared a critically endangered species by the World Conservation Union. Surveys undertaken since 1989 had been unsuccessful in documenting the presence of this species, leading to the conclusion that extinction may have occurred because of the presence of feral cats on the island. After 15 years of unsuccessful surveys, we rediscovered *D. insularis* in 2005. Kangaroo rats were captured at 5 locations on the island within a total area of less than 30 km^2. Fecal analyses showed that *D. insularis* is not a usual prey item of feral cats. A discriminant function analysis allocated 99.29% of the heteromyid upper incisors recovered from scats to *Chaetodipus spinatus* ($P > 0.97$), whereas only 2 incisors (0.71%) were allocated to *D. insularis*. The actual extent of damage to the native biota caused by the introduction of cats remains unknown.

Key words: Conservation, Heteromyidae, rodents, threatened

Although less than 20% of the world's fauna is restricted to islands, 75% of all recorded animal extinctions have occurred in insular habitats since the year 1600 (World Conservation Monitoring Centre 1992). This considerable reduction of biota on the islands is primarily the result of introduction of nonnative species, which has been considered to be the 2nd most significant cause of biodiversity loss after reduction and fragmentation of the habitat (Vitousek et al. 1997). Because insular ecosystems evolve in the absence of drastic competition, herbivory, parasitism, or predation, introduced species have a major impact on island biotas (Courchamp et al. 2003).

The Gulf of California is a reservoir of relict, endemic species and relatively intact ecosystems. The islands of the Gulf of California have been protected natural areas since 1978 (Secretaría del Medio Ambiente y Recursos Naturales 2000). Within this reserve, only those activities that are considered to have low impact on the environment are allowed (e.g., ecotourism). However, other activities have been conducted on the islands since the establishment of protected areas, such as extraction of guano and gypsum, goat grazing, permanent settlements, establishment of fisherman camps, and ship anchoring (Álvarez-Castañeda and Cortés-Calva 1996; Tershy et al. 1997). Native biota on islands in the Gulf of California and northwestern México are facing great threats because this area alone has experienced the highest number of extinctions in México (Álvarez-Castañeda and Ortega-Rubio 2003). Among the mammals that inhabit islands of the Gulf of California, rodents have been the most affected by the introduction of domestic cats (Nogales et al. 2004). In the past decade, rodent extirpations and extinctions on the islands of northwestern Mexico include *Peromyscus maniculatus cineritius* from San Roque Island, *Chaetodipus baileyi fornicatus* from Montserrat Island, *Peromyscus pembertoni* from San Pedro Nolasco Island, *Neotoma bunkeri* from Coronados Island, and *Neotoma anthonyi* from Todos Santos Island (Álvarez-Castañeda and Cortés-Calva 1996, 1999), all presumed to be the result of the introduction of feral cats (Álvarez-Castañeda and Cortés-Calva 1999).

San José Island (total area 194 km^2) is the 3rd largest island in the Gulf of California after Tiburón and Ángel de la Guarda (Lawlor et al. 2002). The vegetation is mainly desert scrubland (Rzedowski 1978); mean temperature varies between 19°C and 38°C, and mean annual precipitation is <200 mm. The island supports 4 native rodents, including 2 heteromyids (*Chaetodipus spinatus bryanti* and *Dipodomys insularis*) and 2 murids (*Neotoma lepida perpallida* and *Peromyscus fraterculus cinereus*), all of which are considered endemic taxa and listed as threatened by the Mexican government (Norma Oficial Mexicana 2002). The island fauna also includes the San José brush rabbit (*Sylvilagus mansuetus*), the ringtail (*Bassariscus astutus insulicola*; both considered as threatened in the Mexican endangered species list), and the mule deer (*Odocoileus hemionus peninsulae*).

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Exotic mammal species present on San José Island include feral cats, goats, and donkeys (Secretaría del Medio Ambiente y Recursos Naturales 2000; Wood et al. 2002). There is a permanent human settlement, Palma Sola (Fig. 1, site 3), on the northern part of the island, with a population of approximately 70 people whose primary activities are cable fishing and ranching. Although there are no reports of domestic cats or dogs on the island (Secretaría del Medio Ambiente y Recursos Naturales 2000), we recorded 4 dogs living in the Palma Sola settlements with at least 200 goats, 15 sheep, and 3 cows in a stable. Goats are allowed to graze upon native vegetation without control, which has led to the establishment of a reproductively active feral population.

Dipodomys insularis has been reported to be of critical status or at the edge of extinction (Álvarez-Castañeda and Ortega-Rubio 2003), and currently is considered a critically endangered species by the World Conservation Union (2004). There are no estimates of population density for *D. insularis* in the literature or evaluations of its distribution on the island. The last known specimen was collected by Troy Best in 1989 in the southwestern part of the island (T. Best, pers. comm.). During the past decade, Álvarez-Castañeda and Ortega-Rubio (2003) conducted unsuccessful surveys on the same area involving a total trapping effort of >4,000 trap-nights (Álvarez-Castañeda and Ortega-Rubio 2003; Fig. 1). Other surveys, with an effort of about 5,000 trap nights, were performed by the group of Fernando Cervantes, but these surveys were more directed to collecting *S. mansuetus* (F. Cervantes, in litt.). Recently, a possible skull of *D. insularis* was reported from scat of *B. astutus insulicola* (Rodríguez-Estrella et al. 2000). The scat was found on the northeastern part of the island, in a mountainous area with, apparently, little habitat that is suitable for *D. insularis*.

The absence of *D. insularis* during the last 15 years prompted us to make a final survey to establish with certainly the current status of this species. Our work is part of an ongoing program conducted by our institution, Centro de Investigaciones Biológicas del Noroeste, to assess the status of rodents on the islands of the Gulf of California. The survey for *D. insularis* was conducted with the hypothesis that this species has very specific microhabitat requirements (e.g., vegetation cover, slope, and soil structure) that previous fieldwork had failed to recognize.

Materials and Methods

We located potential occurrence areas for *D. insularis* on San José Island (Fig. 1) using satellite imagery generated by LandSat 7 literature review, and preliminary data taken by one of us (STA-C) on the island. We conducted 3 surveys in search of the species; the 1st on the eastern side of the island (site 1) in the area where the *D. insularis* skull was found in scat of *B. astutus* (Rodríguez-Estrella et al. 2000) and 2 others within the entire potential distribution area for *D. insularis* in other parts of the island (sites 2–12). The latter includes 2 regions: an arroyo on the northern part of the island, which covers the sites of Palma Sola, El Mangle and Los Ostiones (sites 2–4), and a slope located on the southwestern part of the island (sites 5–12; Table 1; Fig. 1), which covers previous collection areas of the species (Best and Thomas 1991).

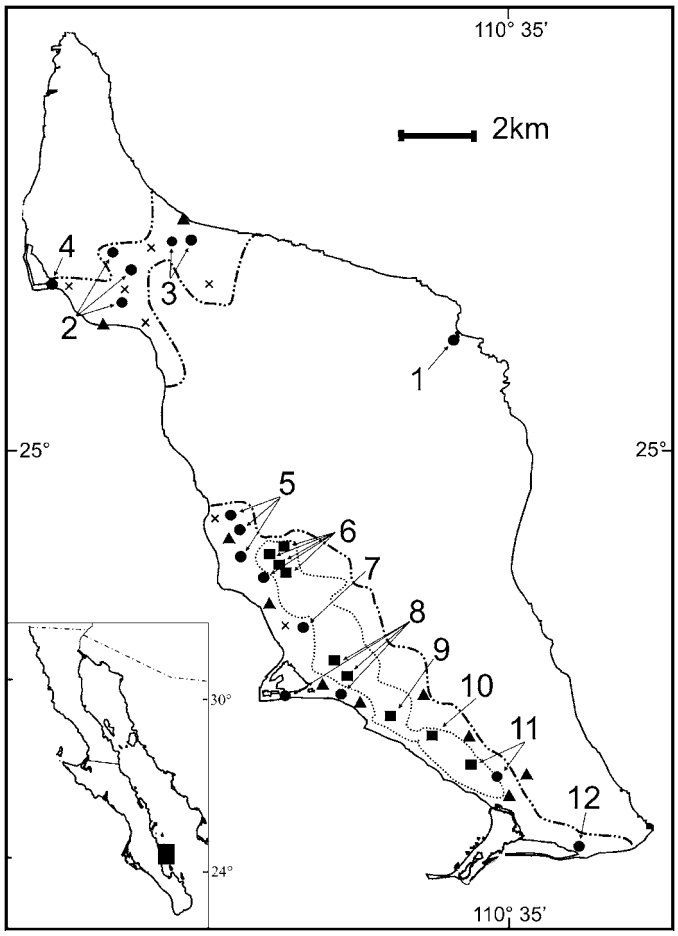

Fig. 1.—Map of San José Island, Baja California Sur, Mexico. Triangles show sites previously surveyed by Centro de Investigaciones Biológicas del Noroeste during 1995–2005; circles show sites surveyed during this work; squares show sites where *Dipodomys insularis* was found. The potential range of *D. insularis* based on preferred microhabitat is outlined with a dotted line; the potential range based on physiographic characteristics is outlined with a dashed dotted line. X = areas where goats were observed. Numbered localities are described in Table 1.

Over a period of 4 months (March–June 2005) trapping was conducted along 53 transects, each consisting of 40 Sherman live traps (H. B. Sherman traps, Inc., Tallahassee, Florida) involving a total sampling effort of 2,120 trap-nights. Traps were baited with rolled oats and trap sites were located in the entire potential area where suitable habitats for *D. insularis* were found, primarily riverbeds and flat areas (Fig. 1); we selected areas with sandy soil and low vegetation cover, which are recognized as preferred habitat features for *Dipodomys* (Bowers et al. 1987; Bradley and Mauer 1971; Price 1978; Price et al. 1984; Reichman and Price 1993; Rosenzweig 1973; Shier and Randall 2004). We followed the recommendations of the American Society of Mammalogists (Animal Care and Use Committee 1998) for handling the specimens.

Microhabitats where *D. insularis* was captured were characterized by measuring slope, soil type, number of burrows, and plant diversity (Wilson et al. 1996). Plant cover was estimated with photographs taken at a height of 6 m over each trap station with a Nikon Coolpix 2500 digital camera. We also observed the presence of natural predators (e.g., snakes [*Crotalus enyo enyo*, *C. mitchelli mitchelli*, *C.*

TABLE 1.—Habitat characteristics of survey localities on San José Island, Baja California Sur, Mexico. Localities are shown in Fig. 1 by site number. Sample size (n) is number of transects per site. Soil types: peb = pebbles, sand = sand, arroyo = arroyo area, comp = compacted soil, stony = stony, salt = salty aridisol; type at each site is indicated by ×. Environmental variables include slope, elevation above sea level (Elev), and percentage of plant cover (Plants).

						Soil types								
Site	Locality	Latitude (N)	Longitude (W)	n	Habitat	Peb	Sand	Arroyo	Comp	Stony	Salt	Slope (°)	Elev. (m)	Plants (%)
1	El Angelito	25°00′	110°35′	8	Rocky			×		×		4.0	18	18.5
2	El Mangle	25°01′	110°41′	4	Disturbed			×	×			2.1	16	24.0
3	Palma Sol	25°02′	110°40′	3	Disturbed			×	×			3.5	10	15.0
4	Los Ostiones	25°02′	110°39′	1	Dunes		×					0.3	5	12.0
5	Dos Arroyos	24°57′	110°39′	2	Riverbed		×	×		×		6.3	35	18.1
6	Punta Arena	24°57′	110°38′	8	Open flat	×	×					4.3	133	18.9
7	Salina north	24°56′	110°38′	3	Riverbed		×	×		×		5.7	57	13.5
8	Salina south	24°55′	110°37′	9	Open flat	×	×					2.4	41	17.9
9	Amortajado II	24°54′	110°36′	3	Open flat	×	×					3.8	42	18.6
10	Amortajado I	24°54′	110°35′	3	Open flat	×	×					3.4	56	21.3
11	El Rinconcito	24°53′	110°34′	5	Open flat	×	×					2	21	17.8
12	El Estero	24°52′	110°32′	2	Riverbed						×	1.4	14	13.8

ruber lucanensis, *Pituophis melanoleucus bimaris*, and *P. vertebralis*] and the ringtail). To assess the potential impact of introduced species, we recorded the presence of feral goats on the potential occurrence area of *D. insularis* and collected scats of feral cats in the distribution area of *D. insularis*. Scats were assigned to cats, rather than to other species on the island, by their form and size. Scats often were found in groups or latrines, unburied, as a sign of a territorial boundary (Land Protection 2003). Scats collected within an area of 2 m were considered as a single sample, often consisting of 5 or more droppings. A total of 48 samples were analyzed to determine prey items.

Because cats crush the skull and body parts of their prey in order to feed, most bones recovered from scats are incomplete or broken. However, upper incisors are more durable and also present morphological characteristics that are distinctive for the small mammals present on the island. The most apparent characteristic for distinguishing between families is the anterior surface of the upper incisor, which is smooth in murid rodents and has a double crest of enamel in heteromyids (Wahlert 1993). Because *C. spinatus* has thinner upper incisors than does *D. insularis*, we performed a discriminant function analysis to distinguish teeth of *C. spinatus* and *D. insularis*, using incisor width as the discriminate variable. We measured incisor width of specimens from the mammal collection of Centro de Investigaciones Biológicas del Noroeste to determine base values for *C. spinatus* ($\bar{X} = 1.21 \pm 0.079$, $n = 18$) and *D. insularis* ($\bar{X} = 1.63 \pm 0.068$, $n = 8$). Incisor width was measured to the nearest 0.01 mm on the midbase of the curve using a digital caliper. Only complete incisors were measured. This technique has been previously used to distinguish heteromyid taxa (Carrasco 2000).

Shannon–Wiener and Shannon evenness indices were calculated for the vegetation from each of the localities based on data obtained from digital photos.

RESULTS

Twenty-one *D. insularis* were captured at 5 sites of the 12 surveyed sites, with capture frequency ranging from 0.8% to 2.9% (Table 2). *D. insularis* appears to have a linear range that stretches along the most level terrain on the southwestern side of the island (Fig. 1), where it was found at a minimum distance of 72 m from the beach (site 11) to a maximum distance of 1.8 km (site 6), where it occurred at an altitude of 146 m above sea level. *C. spinatus* was the most abundant rodent species and was captured at all sites, with trap success ranging from 3.7% to 32.5% (Table 2). *P. fraterculus* was found at 4 sites (trap success 0.32–2.5%) and *N. lepida* was found at only 1 site (trap success 2%).

The structure of the microhabitat in which *D. insularis* was found was classified based on vegetation cover and soil structure characteristics (Table 1). Sites of occurrence (sites 6 and 8–11) had similar plant diversity, with vegetation cover ranging from 17.8% to 21.3% with intervening bare desert pavement, and slopes from 2° to 4.3° (Table 1). The Shannon–Wiener and Shannon evenness indices show that the diversity and evenness of localities in which *D. insularis* occurred are very homogeneous. Within its range of occurrence, sites where *D. insularis* was recorded did not differ significantly from sites where it was not trapped, either with respect to plant cover ($t = -1.48$, $d.f. = 2, 9$, $P = 0.17$) or slope ($t = 0.158$, $d.f. = 2, 9$, $P = 0.87$). Dominant plants at sites of occurrence were Adam's trees (*Fouquieria diguetii*), ashy limberbush (*Jatropha cinerea*), cardon cacti (*Pachycereus pringley*), cholla (*Opuntia cholla*), copal trees (*Bursera hindsiana*), elephant trees (*Bursera microphylla*), goatnut (*Simmondsia chinensis*), palo verde (*Cercidium peninsulare*), sour pitaya (*Stenocerus gummosus*), and wild plums (*Cyrtocarpa edulis*). *D. insularis* was not found in areas with high densities of sour pitaya. Burrows of *D. insularis* were primarily associated with elephant trees. At occurrence sites, surface substrate consisted of pebbles 0.5 cm in diameter and a lower cover of small-grain sand. These microhabitat characteristics were only found on the southwestern side of the island (sites 6–11). Native snakes (*C. enyo enyo* and *P. melanoleucus bimaris*) were observed in *D. insularis* microhabitat, whereas the presence of ringtails was not recorded.

Relative abundance of heteromyid rodents was based only on transect captures and does not reflect actual population size. However, these data are informative means of comparing sites of capture between heteromyid species (Fig. 2). For *D. insularis* the percentage in the optimal habitat was 1.89%

TABLE 2.—Relative abundance, presence of nonnative species, and ecological indices for rodent species at sites on San José Island, Baja California Sur, Mexico. Relative abundance is expressed as percentage trap success; localities are as shown in Fig. 1 with site number. Species are *Chaetodipus spinatus bryanti* (*C. spinatus*), *Neotoma lepida perpallida* (*N. lepida*), *Peromyscus fraterculus cinereus* (*P. fraterculus*), and *Dipodomys insularis* (*D. insularis*.). Presence of nonnative species was determined by observation or by tracks in the localities. Indices: Shannon–Wiener index for the vegetation (H′) and the Shannon evenness index (E′).

Site	Locality	Relative abundance (%)				Nonnative species	H′	E′
		D. insularis	*C. spinatus*	*N. lepida*	*P. fraterculus*			
1	El Angelito	0.0	12.0	2.0	2.5	Cat	1.6	0.6
2	El Mangle	0.0	9.5	0.0	0.0	Cat, goat, cow	1.9	0.6
3	Palma Sol	0.0	32.5	0.0	0.8	Cat, goat, cow, donkey, sheep	1.4	0.5
4	Los Ostiones	0.0	22.5	0.0	0.3	Cat	2.0	0.6
5	Dos Arroyos	0.0	18.7	0.0	0.0	Cat, goat	2.5	0.7
6	Punta Arena	2.9	12.2	0.0	0.0	Cat	2.4	0.7
7	Salina Norte	0.0	24.1	0.0	0.0	Cat, goat	2.5	0.7
8	Salina Sur	1.9	24.4	0.0	0.0	Cat	2.6	0.8
9	Amortajado II	0.8	5.0	0.0	0.0	Cat	2.6	0.8
10	Amortajado I	1.6	5.8	0.0	0.0	Cat	2.3	0.7
11	El Rinconcito	1.0	3.7	0.0	0.0	Cat	2.6	0.8
12	Estero	0.0	6.2	0.0	0.0	Cat	2.5	0.7

(0.83–2.90%). *C. spinatus* was present at all collection sites (Table 2; Fig. 2). The percentage of *C. spinatus* in all the islands was 15.9% (5–32.5%). The capture percentages of *C. spinatus* and *D. insularis* seemed to be related, but the correlation was not statistically significant (F, $d.f. = 2, 4$, $r^2 = 70$, $P = 0.076$).

Goats were ubiquitous on the northern side of the island (at Palma Sola and El Mangle) where locals allow them to forage freely. We observed donkeys foraging on the northern portion of the island were their scats were abundant. Paths formed by movements of cattle on the northern side of the island were common. We also observed groups of 12–15 goats with young at sites 5 and 7, which are areas where *D. insularis* potentially could live (Fig. 1). Feral cats were not directly observed; however, scats were most abundant on the western side of the island (sites 5–12).

Fecal analysis showed that cats prey upon all rodents of the island as well as the San José brush rabbit (Table 3). We recovered a total of 274 heteromyid incisors that could be measured and used in the discriminant function analysis. The analysis had a strong discriminate force (Wilks' lambda ≈ 0.12792). Posterior probabilities allocated 99.29% of the sample to *C. spinatus* ($P > 0.97$). Only 2 incisors (0.71%) were allocated to *D. insularis* ($P = 0.5998$ and 0.98187, respectively). Because these 2 incisors were extracted from the same sample, we assume they came from the same individual.

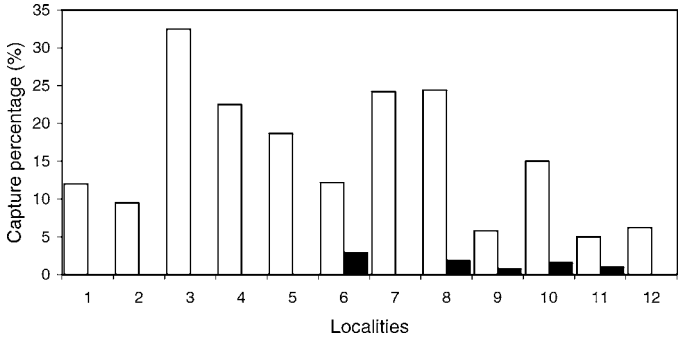

FIG. 2.—Trap success for heteromyids at sites on San José Island, Baja California Sur, Mexico. Localities are ordered as in Table 1 and Fig. 1. Black bars are *Dipodomys insularis* and white bars are *Chaetodipus spinatus*. Values are based on trapping with Sherman live traps for 2,120 trap-nights.

DISCUSSION

Chaetodipus spinatus was the most abundant rodent species on the island. It exhibited no habitat preferences, but was most abundant at a disturbed site (site 1) and was the only species captured in riverbed and sand dune areas with very low vegetation cover (sites 4, 5, 7, and 12).

Because our surveys were directed specifically to find *D. insularis*, the habitat requirements of which are different from those of murid rodents, the capture rates for murids were low. Of our survey localities, only site 1 met habitat requirements for *N. lepida* and *P. fraterculus*. However, individuals of *P. fraterculus* also were captured at El Mangle, Palma Sola,

TABLE 3.—Number of individuals (n) and frequency of occurrence of small mammal species identified from scats of feral cat on San José Island, Baja California Sur, Mexico.

Species	*n*	Occurrence (%)
Heteromyidae		
Chaetodipus spinatus	136	85.5
Dipodomys insularis	1	0.6
Muridae		
Peromyscus fraterculus	9	5.6
Neotoma lepida	2	1.3
Leporidae		
Sylvilagus mansuetus	11	6.9

and Punta Arena, which may indicate that the species is broadly distributed on the island.

Dipodomys insularis occurred only on the southwestern coast of San José Island in an area of less than 30 km^2. This area is flat and has a homogeneous vegetation cover except where dry riverbeds cross it. All the sites where *D. insularis* was found share the same basic microhabitat of low vegetation cover and small-grain soil. The species was not present if soil was smooth, as in riverbeds, or where the vegetation cover was too low. *D. insularis* appears to occur at densities comparable to those of *Dipodomys merriami* (Brown and Harney 1993), but because our data are limited additional studies are needed to accurately estimate population size.

At the sites where *D. insularis* was found it coexists with *C. spinatus*, the latter occurring at higher densities. From our data, we cannot determine if there is competition between the 2 species. *D. insularis* is absent where large riverbeds cross the island, places where *C. spinatus* is the only species captured. This may reflect a difference in foraging behavior—quadruped species forage on uniformly distributed seeds whereas saltatorial heteromyids forage on seed aggregates (Bowers 1982). More studies are needed to better understand the coexistence of heteromyid rodents on the island.

We surveyed the area, site 1, where scats of *B. astutus* had been found to contain remains of *D. insularis* (Rodríguez-Estrella et al. 2000). We did not trap *D. insularis* at this site, nor did we find any suitable habitat for the species. The nearest potential habitat is about 6 km northwest of site 1, on the Palma Sola ranch, and the closest known localities are about 10 km south across the highest elevation points on the island (Fig. 1). We consider the identification of the skull as *D. insularis* questionable. However, the ecology of *Bassariscus* on the islands of the Gulf of California is poorly known and there are no data on its home range or rates of movement.

Fecal analysis showed that feral cats mainly prey upon *C. spinatus*. In addition, 10 individuals of *P. fraterculus* were identified from scats, and *N. lepida* was retrieved from 2 scats; this despite the fact that the scats were collected from the area where *D. insularis* was found, areas in which murids were rare or absent. Fecal analysis indicates more intense predation on *S. mansuetus* than *D. insularis*; both are critically endangered species (World Conservation Union 2004). We do not know the extent to which feral cats have damaged the native biota of San José Island since their introduction. There was no other evidence of feral cats except for scats, occasional tracks, and diggings around our traps, and the total number on the island is unknown. Although cats do not appear to prey heavily on kangaroo rats, their eradication would benefit all potential prey species on the island.

Feral goats cause severe damage to native vegetation and are starting to invade the area where *D. insularis* occurs. This situation could affect food resources and vegetation structure and thus affect the presence of native granivores such as the *D. insularis*.

Failure to document *D. insularis* over a period of 15 years might be due to the lack of surveys in suitable microhabitat or to factors that have caused a population decline followed by a recent recovery. However, this example provides insight into the difficulties of determining extinction events in the wild. The rediscovery of *D. insularis* from San José Island opens the possibility of finding other species of mammals presumed to be extinct from other islands of the northwestern part of México. In the present case, Álvarez-Castañeda and Ortega-Rubio (2003) did not consider *D. insularis* to be extinct despite the absence of records over a 15-year period because of the size of San José Island, the great variation in habitats present, and the need of a thorough survey of the island.

Resumen

Las islas del Golfo de California están consideradas como un área natural protegida por el Gobierno de México. A pesar de esto, durante años la introducción de especies no nativas ha causado que las especies de mamíferos de las islas estén amenazadas o se encuentren ya extintas. *Dipodomys insularis* es una especie endémica de isla San José y ha sido declarada como críticamente en peligro por la World Conservation Union. Se ha buscado a esta especie desde 1989, llegando a considerarse como extinta a causa de la presencia del gato feral. Después de 15 años de bùsqueda infructuosa, se encontraron 21 ejemplares de *D. insularis* con un esfuerzo de captura de 2,120 trampas-noches. *D. insularis* fue capturada en 5 diferentes localidades de la isla en un área aproximada <30 km^2. El análisis de la dieta de los gatos ferales demostró que *D. insularis* no es una presa usual. El análisis de discriminates usado para distinguir entre los taxa de heterómidos de la isla, demuestra que el 99.29% de los incisivos encontrados en las excretas son de *Chaetodipus spinatus* ($P > 0.97$), y solamente dos incisivos (0.71%) fueron asignados a *D. insularis*. El efecto que están causando las especies introducidas en la biota nativa todavía es desconocido.

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