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# FERAL SHEEP ERADICATION AT SOCORRO ISLAND, MEXICO: A MANDATORY STEP TO ENSURE ECOLOGICAL RESTORATION

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## SUMMARY

Domestic sheep have been introduced to numerous islands worldwide; they became feral and caused indiscriminate impacts on ecosystems. On Socorro, a tropical Mexican island in the Pacific Ocean, feral sheep caused soil compaction and erosion, loss of vegetation, habitat destruction, landscape alterations, and species extinction. In response to these biodiversity threats, feral sheep were removed from Socorro Island. In 2009, 1257 sheep were dispatched using aerial hunting over 35 hours of flight time. To locate remaining herds, twelve sheep

were captured and equipped with radio-collars (Judas sheep). From March 2010 to April 2012 eradication continued using terrestrial hunting; 505 sheep were dispatched at this stage. The use of Judas sheep and detection dogs were critical in locating the last remaining sheep. A systematic monitoring program conducted during two years confirmed eradication success. In June 2014, Socorro Island was declared free of feral sheep. To date (November 2015), a remarkable ecosystem recovery has been recorded.

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## Introduction

Insular ecosystems have unusually high rates of endemic species present in their environments. Islands are important breeding grounds for a variety of birds and marine mammals. Mexican islands are known for their high biodiversity richness (Aguirre-Muñoz *et al.*, 2005, 2011). Despite their ecological significance, many islands around the world receive serious impacts derived from human activity (Johnson and Stattersfield, 1990). Approximately 75% of all animal extinctions have occurred on islands, the majority being caused by introduced species (Diamond, 1989; Groombridge, 1992). Feral species are among the main causes of biodiversity loss and ecological disequilibrium in many environments (Courchamp *et al.*, 2003; Blackburn *et al.*, 2004; Aguirre-Muñoz *et al.*, 2008),

even the primary cause of extinctions (Baillie *et al.*, 2004; Reaser *et al.*, 2007). In particular, the settlement of herbivores like feral sheep (*Ovis aries*) has caused important ecological impacts on insular ecosystems. In 1869, 100 sheep were introduced to Socorro Island for ranching (they supplied food to boaters and fishermen); over time, without humane care, sheep became feral, successfully adapting to island conditions (Levin and Moran, 1989; Álvarez-Cárdenas *et al.*, 1994; Brattstrom, 2015). Since its introduction, feral sheep has caused great modification to the natural habitat. Erosion rates and loss of vegetation coverage derived from the sheep presence were documented along the southern-central region of the island (León de la Luz *et al.*, 1994; Maya-Delgado *et al.*, 1994). Particularly, a shrub land

environment with *Psidium socorrense* and *Guettarda insularis*, both endemic species, was severely disturbed. Constant overgrazing resulted in the abundance of paths formed by the trampling of sheep on the soil, which triggered different erosive processes and put native flora and fauna at risk (Figure 1). Among the most significant changes on the original floral composition has been an increase in the presence of graminacea species and scrub species as well as a reduction of the area covered by the native flora. Sheep are particularly efficient in the propagation of introduced plant species (they carry seeds in coat and excret). The change in native vegetation has been observed in every habitat that sheep occupied (SEMARNAT, 2004). Nearly 30% of the original soil and vegetation on Socorro Island was lost due to

erosive processes caused by feral sheep (Ortega-Rubio *et al.*, 1992). This degradation problem was alarming since the erosion rate for deforested areas on Socorro Island was estimated at 20 to 90 tons/ha/year (Arnaud *et al.*, 1993; Maya-Delgado *et al.*, 1994; Ochoa-López *et al.*, 1998).

Similarly, areas covered by introduced vegetation have a negative effect on local natural processes, since native fauna species depend on native plants for food, shelter or nesting. Arthropods are rare on disturbed areas (Jimenez *et al.*, 1994). Vertebrates were negatively affected due to habitat loss; for example, the Socorro Blue Lizard (*Urosaurus auriculatus*) and the endemic birds Socorro Mockingbird (*Mimus graysoni*) and Socorro Wren (*Troglodytes sissonii*) were less abundant in eroded areas (Martínez-Gómez *et al.*,

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**KEYWORDS / Environmental Restoration / Eradication / Exotic Fauna / Feral Sheep / *Ovis aries* / Socorro Island /**

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## ERRADICACIÓN DE BORREGO FERAL EN ISLA SOCORRO, MÉXICO: ACCIÓN REQUERIDA PARA LOGRAR SU RESTAURACIÓN ECOLÓGICA

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### RESUMEN

Borregos domésticos han sido introducidos en numerosas islas alrededor del mundo; éstos se vuelven ferales y provocan impactos indiscriminados en los ecosistemas. En Isla Socorro, una isla tropical mexicana en el Océano Pacífico, los borregos ferales causaron la erosión y compactación del suelo, pérdida de vegetación y destrucción de hábitat, alteraciones del paisaje, y la extinción de especies. En respuesta a estas amenazas a la biodiversidad, los borregos fueron erradicados de Isla Socorro. En 2009, 1257 borregos ferales fueron sacrificados durante la fase de cacería aérea, con 35 horas de vuelo. Un total de 12 borregos fueron capturados y

equipados con radio-collares (borregos Judas); una vez liberados sirvieron para localizar las manadas remanentes. De marzo 2010 a abril 2012 se continuó con la erradicación mediante cacería terrestre; 505 borregos fueron sacrificados en esta etapa. El uso de borregos Judas y perros de muestra entrenados fue fundamental para la localización de los últimos borregos. Con el fin de confirmar la erradicación se llevó a cabo por dos años un programa de monitoreo sistemático. En junio 2014, Isla Socorro fue declarada libre de borregos ferales. A la fecha (noviembre 2015) se ha registrado una mejoría notable del ecosistema.

## ERRADICAÇÃO DE CARNEIROS FERAIS NA ILHA SOCORRO, MÉXICO: UM PASSO OBRIGATÓRIO PARA GARANTIR A RESTAURAÇÃO ECOLÓGICA

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### RESUMO

Carneiros domésticos foram introduzidos em numerosas ilhas em todo o mundo; tornaram-se ferais e tiveram impactos amplamente indiscriminados sobre os ecossistemas. Em Socorro, uma ilha tropical mexicana no Oceano Pacífico, os carneiros ferais causaram a compactação e erosão do solo, perda de vegetação e habitat, mudança da paisagem, e extinção de espécies. Em resposta a estas ameaças à biodiversidade os carneiros ferais foram retirados da Ilha Socorro. Em 2009, 1257 ovinos foram sacrificados durante 35 horas de vôo de caça aérea. Doze ovinos foram capturados e equipados com rádio co-

leiras (carneiros Judas) para localizar os rebanhos restantes. Entre março 2010 a abril 2012, continuo a erradicação com caça terrestre e 505 carneiros foram sacrificados nesta fase. O uso de "carneiros Judas" e cães de detecção foram fundamentais para localizar os últimos carneiros. Para confirmar o sucesso da erradicação um programa de monitoração sistemática foi realizado nos dois anos seguintes. Em junho 2014, Ilha Socorro foi declarada livre de carneiros selvagens. Até a presente data (novembro 2015) se registra uma recuperação notável do ecossistema.



Figure 1. Loss of vegetation (left) and soil (right).

2001; Martínez-Gómez and Jacobsen, 2004), but highly abundant in areas where the floral composition remained unaltered (Galina *et al.*, 1994; Rodríguez-Estrella *et al.*, 1994). Feral sheep contributed, along with feral cats (*Felis catus*), to the extinction from the wild of the endemic Socorro Dove (*Zenaida*

*graysoni*), with the last remaining specimens now kept only at zoos in Mexico, USA and Germany.

The removal of feral species has showed to be an achievable task in many islands of the world (e.g., Veitch and Clout, 2002; Veitch *et al.*, 2011). With funds from both Mexican

(CONANP, CONABIO and INECC) and USA (USFWS) governments, and national (Alianza WWF-Fundación Carlos Slim) and international (American Bird Conservancy, Packard and Marisla Foundation) donors, and with the invaluable logistic support from the Mexican Navy (*Secretaría de Marina*;

*Armada de México*), the Mexican civil society organization Grupo de Ecología y Conservación de Islas, A.C. (GECI) completed the feral sheep eradication on Socorro Island by 2012. In this paper we report the methods used to achieve this significant restoration project.

### Methods

#### Study site

Socorro Island (13,200ha; 1,040masl) is located in the Revillagigedo Archipelago (Figure 2), 460km west from Los Cabos, Baja California Sur and 694km west from Manzanillo, Colima (18°47'N, 110°58'W). It harbors 118 native vascular plants, 30 of which are endemic (León de la Luz *et al.*, 1994). Socorro's fauna includes 103 bird species (terrestrial, marine, wading and

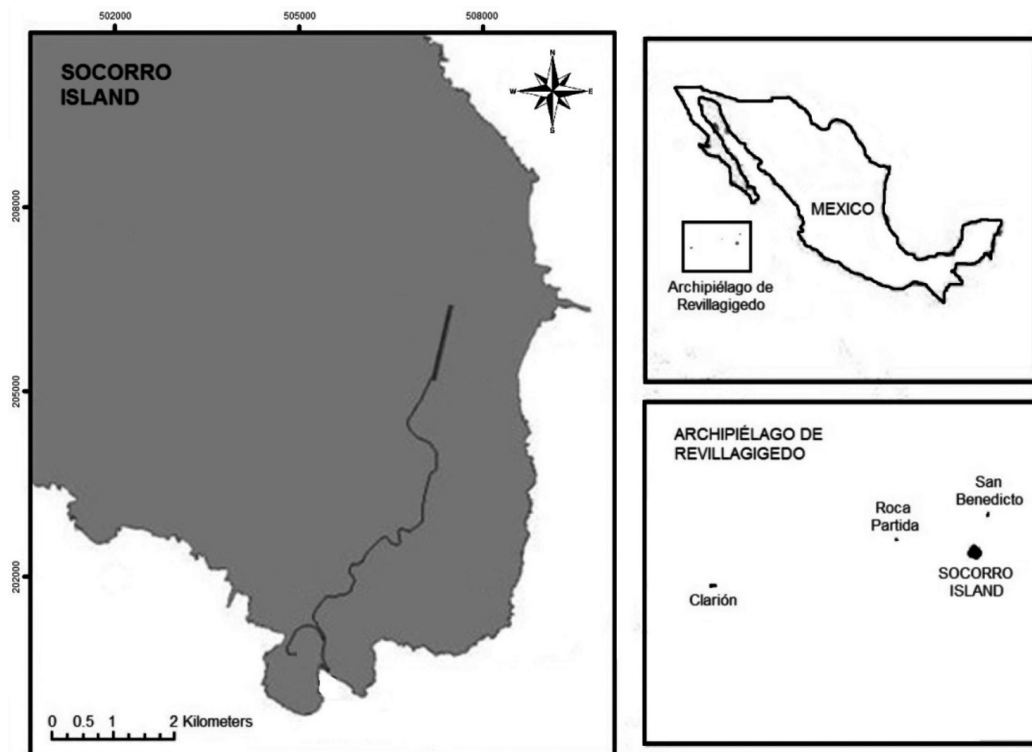


Figure 2. Location of Socorro Island.

migratory); eight of the terrestrial birds are endemic to the island. Also, two terrestrial reptiles are present, one being endemic (SEMARNAT, 2004). The island is permanently inhabited by military personnel (40-50 people) stationed at a Naval Base located in the southernmost part of the island.

Based on the experienced gained around the world (e.g., Campbell and Donlan, 2005) and in Mexico (Aguirre-Muñoz *et al.*, 2011) in the eradication of ungulates (mainly goats and sheep), we selected aerial hunting aided with global positioning systems, geographic information systems (GIS), terrestrial hunting and trapping as main eradication methods. Judas animals and specialized hunting dogs were also used for localizing remaining sheep.

#### *Feral sheep monitoring*

In 2002, GECEI began with a feral sheep monitoring program on Socorro Island to assess eradication feasibility; herbs location and major distribution areas were determined. It was concluded that eradication was

possible and that aerial hunting was the best method. During October 2005, several flights aboard a Beechcraft Bonanza aircraft were made over the island. This allowed to identify the main areas where sheep were distributed. At the same time, land surveys were conducted by foot and in motorized vehicles (ATV's). Mexican Navy officers guided these surveys. The locations of the sheep herds were recorded into a GIS.

#### *Aerial hunting*

The aerial hunting campaign, using a single turbine helicopter (model MD369D), took place between April 20 and 29, 2009. Twelve gauge semi-automatic shotguns (Winchester SX3) equipped with near-range scopes (Sightmark SM13003), and semi-automatic .308 rifles (Benelli R1) were used. Guns permits from the Secretariat of National Defense were obtained and hunting was supervised by Mexican Navy personnel on the island. Two hunters were hunting simultaneously during the flights, one

behind the pilot and another next to the pilot. Manual counting devices were used to register the number shot. Also, a GPS was used in order to record the flight trajectories and the areas where the highest numbers of sheep were found. All flights were done between 07:00 and 11:00, and between 16:00 and 19:00, when sheep have a higher activity. During the first two flights we covered the whole island in order to identify the main herds of sheep. For the subsequent 25 flights, hunting efforts were concentrated in areas with the higher densities of sheep (east zone of the island). Flights were done at an average speed of 42km/h and average height of 35m.

#### *Judas sheep*

During the hunting flights 12 live animals were captured, to be used as Judas sheep (Taylor and Katahira, 1988). These animals were neutered and fitted with radio-telemetry collars. The captured animals were taken to Socorro's Naval Base and kept in a barn prior to

their sterilization. The latter was done by GECEI's personnel, previously trained on Guadalupe Island by experts from the Galápagos Islands National Park. Sheep were kept for observation three days prior to their liberation. The animals were equipped with radio-telemetry collars (Telenax Mexico), with frequencies between 164 and 168Mhz. These Judas sheep were deployed back to the sites where they were captured.

#### *Terrestrial hunting and trapping*

From February 2010 to April 2012, 4 to 7 experienced hunters (with gun permits) carried out this stage of the project. Every hunter had a handheld GPS to record their hunting tracks. Rifles with telescopic sights (Leupold VX-1), caliber .222, .243 and .308, as well as 12 gauge shotgun with cartridges 00 buck were used. Periodically, Judas sheep were located to locate herds. Simultaneously, leg hold traps (Oneida Victor Soft Catch # 3) and snare traps were used on identified trails; both types of traps were checked daily. Traps were used to capture remaining sheep in places where previously hunted; thus, hunting efforts focused on new areas of the island.

#### *Hunting dogs*

As the last stage of the eradication, we used two hunting dogs (Beagle and Foxhound) to track down the last sheep herds. Dogs were fitted with GPS collars to record their locations and movements. The dogs were rented; they were trained for localizing of sheep and goat. Two dogs worked simultaneously during 2h periods with 30min rest.

## **Results and Discussion**

#### *Feral sheep monitoring*

Both aerial and ground surveys confirmed the description made in 1992 by Álvarez-Cárdenas *et al.* (1994) that

sheep were present in the east zone of the island (in an area of ~6000ha). Patches of *Bumelia*, *Ficus*, *Psidium* and *Guettarda* are abundant in this area. However, due to the rebuilding of the island's airstrip and to ground hunting done by the Mexican Navy for local human consumption, sheep were congregating in higher areas of the island. The areas frequented by sheep were wide open spaces, with scarce vegetation, but further away from human presence.

### Aerial hunting

A total of 35 hours of flight were done in one week for the aerial hunting stage, in which the majority of the island was covered (Figure 3). During this period, 1,257 individuals were dispatched. The total amount of flight hours and the sheep dispatched are detailed in Figure 4. The average flight time was 1h 20min. We stopped hunting when sheep were difficult to localize, and

few animals were dispatched in an hour of flight. Aerial hunting is a highly effective method to use in invasive species eradications (Campbell and Donlan, 2005). The technique allows hunters to access animals that otherwise would have been completely inaccessible by foot, considering that their location was confined to cliffs or canyons. The effectiveness of this technique is backed up by the results, since it only took 35h of flying time to dispatch a large part (~70%) of the sheep population.

Sheep were mainly present at least 1km away from the main trails and the airstrip. The rest of the hunting sites were located >2km away from the Navy Base. The distance from the trails made it very difficult to carry back the hunted sheep for human consumption. Nevertheless, certain areas with little or no vegetation allowed the use of the helicopter to carry back some sheep. Approximately 75 sheep were recovered and given to the Mexican Navy personnel. The Mexican Navy carries food to Socorro Island every two weeks for its personnel, so sheep did not represent their source of meat. They were

convinced of the ecological impacts caused by sheep and cooperated with this project.

The tropical climate of the island allowed the carcasses to decompose rapidly. Land invertebrates, aided by the microbial array present in the soil, were capable of fully decomposing one adult sheep in two weeks. The high irradiance rates of the tropical sun avoid for the carcasses to become a source of infection on the island. Furthermore, the decays enrich the soil of the area. GEI personnel carried out an on-foot survey, the day after the last hunting effort, in order to verify the state of the carcasses; they were beginning to dry out.

### Ground hunting and trapping

Ground hunting was concentrated on sites identified by air with the greatest abundance of sheep traces (Figure 5). A summary of hunting and trapping efforts is shown in Table I; 505 sheep were dispatched through ground hunting, in 9 months over a period of two years (March 2010 to April 2012). Judas sheep were most effective when there was a greater amount of remaining sheep, because it increases

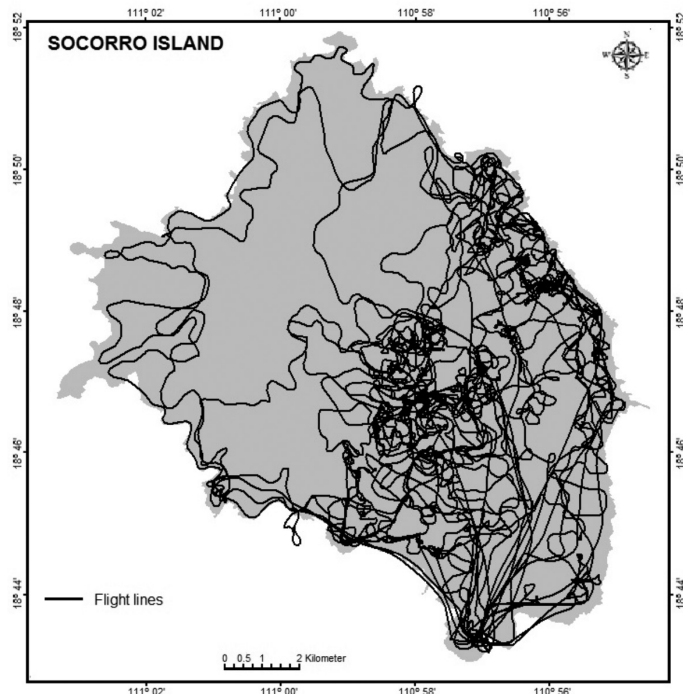


Figure 3. Helicopter flight trajectories on Socorro Island.

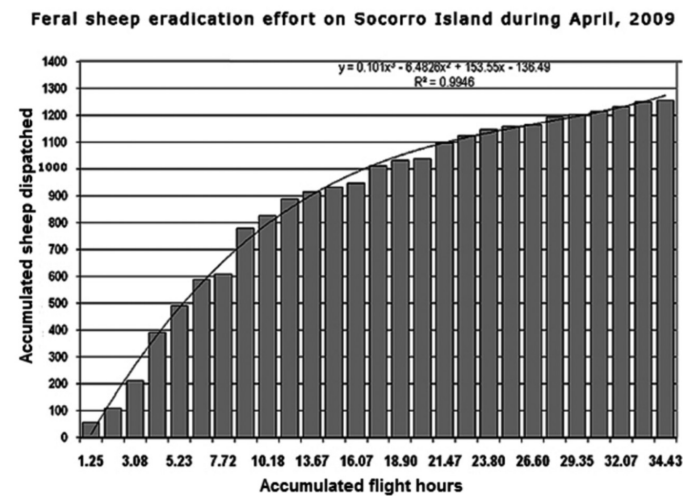


Figure 4. Amount of sheep dispatched by hours of flight (total accumulated).

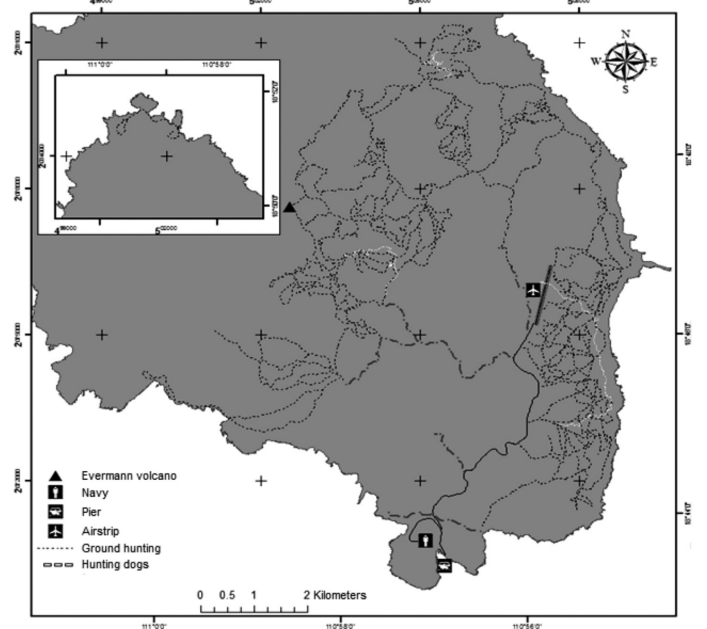


Figure 5. Hunting tracks (black line) and use of dogs (white line), from 2010 to 2012.

TABLE I  
GROUND HUNTING EFFORT

Year	Months	Personnel	Hours/hunter	Distance (km)	Sheep with Judas	Traps/Night	Captured sheep	Hours/dogs	Dispatched sheep
2010	Mar-Apr	7	1323	815	53	900	41	-	355
	Jul	6	588	460	18	-	-	-	48
2011	Apr	5	512	433	11	650	8	-	67
	Ago-Sep	4	728	644	4	-	-	-	25
	Nov-Dec	4	420	385	-	-	-	49	8
2012	Apr	4	240	216	-	-	-	-	2
		Total	3811	2953	86	1550	49	49	505

possibility of aggregation. Hunting dogs were only used to locate the last ten remaining animals, which were difficult to locate for hunters.

A total of 1762 sheep were dispatched from Socorro Island in a 3-year eradication campaign (April 2009 to April 2012). After aerial hunting, it took two years to dispatch 30% of the sheep population by terrestrial hunting, due to difficult logistics because of the distances, topography and size of the island. During the following two years (May 2012 to December 2014), a total of 14 expeditions of 21 days each were carried out to find traces of sheep (footprints and feces) on the island; no traces of sheep were recorded. Conventionally, islands are declared free of invasive species after two or three years without evidence of exotics (Rejmanek and Pitcairn, 2002; Regan *et al.*, 2006). Socorro Island was declared free of feral sheep in June 2014. This project had an approximate cost of US\$ 500,000. This amount does not include the contribution in-kind from the Mexican Navy: maritime transportation, accommodation, use of heliport and vehicles; and the costs of the two consecutive years for confirmation of the absence of sheep (US\$ ~200,000). Compared with other islands where goat or sheep have been eradicated (Van Vuren, 1992), feral sheep eradication on Socorro Island can be considered highly effective as it was completed in three years, when similar projects take 3-5 years, and even decades, to conclude (Campbell *et al.*, 2005). Moreover, the

methods used reduced project cost, which was of US\$ 38/ha, while other projects of sheep eradication, such as that on Santa Cruz Island, California, had a cost of US\$ 80/ha, due to capture and transport of sheep to the continent (Faulkner and Kessler, 2001).

Since the sheep eradication project was concluded vegetation began to recover passively. Comparison of satellite images from 2008 and 2013 show that vegetation has recovered in 1450ha. Results from a field assessment of vegetation showed an average of 21% of vegetation cover in 2009, at the most impacted sites by sheep, while in 2014 average vegetation cover reached 79%.

### Conclusions

The aerial hunting method showed to be an ideal technique for the eradication of sheep from Socorro Island. It enabled the eradication team to dispatch a high number of animals in few days of work, while allowing the hunters to complete difficult access areas. The use of Judas sheep and hunting dogs were crucial for concluding eradication. Therefore, these techniques can be used on other islands in Mexico and other countries.

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transportation of staff and equipment from the Manzanillo Harbor in Colima to the island, accommodation and use of the heliport and other facilities. The support of the Mexican federal government agencies SEMARNAT, DGVS, CONANP, SEGOB, SEDENA and the granting of all needed permits were key for the success of the program. Donors were: Mexican (CONANP, CONABIO, INECC) and United States (USFWS) governments, Alianza WWF-Fundación Carlos Slim, American Bird Conservancy, Packard and Marisla Foundation. We thank support from CONACYT Natural Protected Areas Network (RENANP).

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