

# High-impact Conservation: Invasive Mammal Eradications from the Islands of Western México

Islands harbor a disproportionate amount of the earth's biodiversity, but a significant portion has been lost due in large part to the impacts of invasive mammals. Fortunately, invasive mammals can be routinely removed from islands, providing a powerful tool to prevent extinctions and restore ecosystems. Given that invasive mammals are still present on more than 80% of the world's major islands groups and remain a premier threat to the earth's biodiversity, it is important to disseminate replicable, scaleable models to eradicate invasive mammals from islands. We report on a successful model from western México during the past decade. A collaborative effort between nongovernmental organizations, academic biologists, Mexican government agencies, and local individuals has resulted in major restoration efforts in three island archipelagos. Forty-two populations of invasive mammals have been eradicated from 26 islands. For a cost of USD 21 615 per colony and USD 49 370 per taxon, 201 seabird colonies and 88 endemic terrestrial taxa have been protected, respectively. These conservation successes are a result of an operational model with three main components: *i*) a tri-national collaboration that integrates research, prioritization, financing, public education, policy work, capacity building, conservation action, monitoring, and evaluation; *ii*) proactive and dedicated natural resource management agencies; and *iii*) effective partnerships with academic researchers in México and the United States. What is now needed is a detailed plan to eradicate invasive mammals from the remaining islands in the region that integrates the needed additional financing, capacity, technical advances, and policy issues. Island conservation in western México provides an effective approach that can be readily applied to other archipelagos where conservation efforts have been limited.

The 250+ islands of western México show patterns similar to those of islands worldwide (Fig. 1). They are well known for their high biodiversity, endemism, important seabird colonies, and relatively low levels of human disturbance (9–13). Historically, they have been protected from most human perturbations by aridity, isolation, and low human population densities on the adjacent mainland (14). Today, with the exception of the Baja California islands off the Pacific coast, which are in the process of being protected, all the islands of México are legally protected from many forms of land conversion (15, 16). Nonetheless, invasive mammals—primarily rats, cats, goats, pigs, donkeys, and rabbits—have been introduced to many of the islands of western México, causing population declines, a number of extinctions and extirpations, and significant damage to native vegetation (17–23).

Fortunately, invasive mammals can be permanently eradicated from islands. Eradication techniques have been developed in New Zealand and elsewhere during the past three decades, providing a powerful conservation tool (24). During the past decade, a collaborative effort between conservation nongovernmental organizations (NGOs), Mexican government agencies, and local individuals has resulted in the eradication of invasive mammals from the Pacific coast of Baja California, Gulf of California, and Revillagigedo island archipelagos in western México. For these islands we summarize: *i*) biodiversity patterns, *ii*) eradication successes, *iii*) the costs and benefits of those conservation efforts, *iv*) the general approach used to achieve those conservation gains, and *v*) the future of island conservation in this region. Island conservation in western México provides a model that may be applicable to other archipelagos. Given that invasive mammals are present on more than 80% of the world's major islands groups and continue to threaten a significant percentage of the earth's biodiversity (25, 26), it is important to disseminate potentially replicable, scaleable models to eradicate invasive mammals from islands.

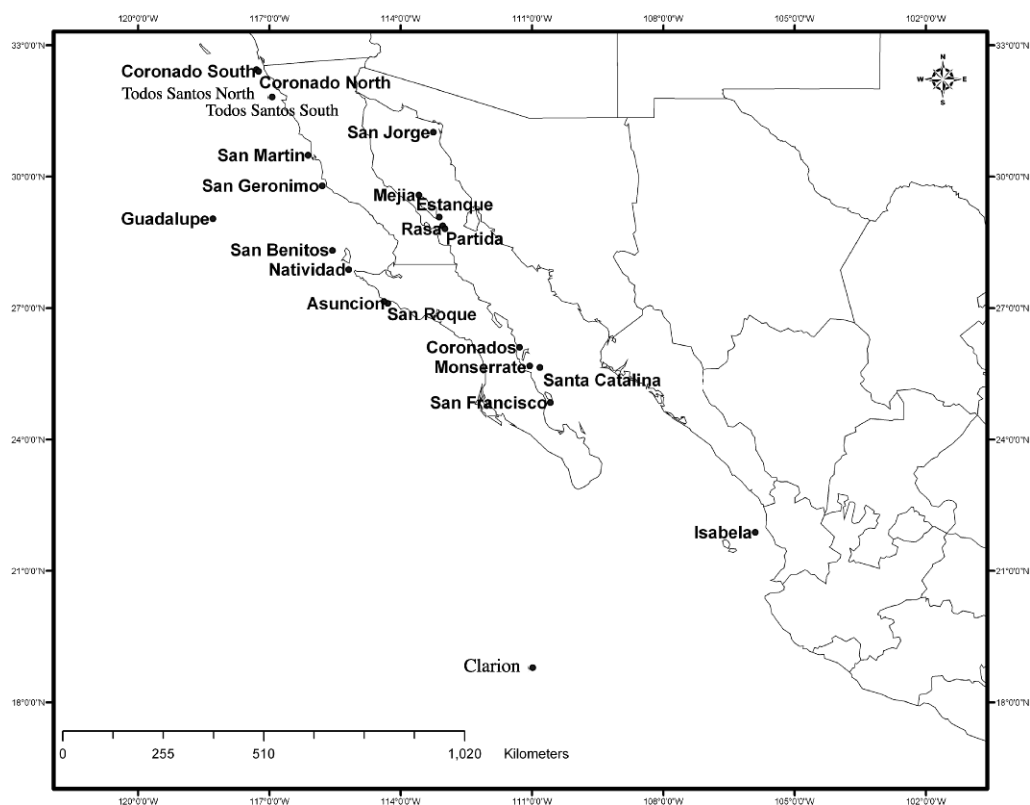
## INTRODUCTION

Although islands make up a small percentage of the earth's total area, they support a disproportionate share of global biodiversity (1). Unfortunately, islands have also suffered disproportionately in terms of extinction (2–4). For example, before the onset of anthropogenic impacts ca. 3000 years ago the islands of Oceania supported more than 2000 now extinct bird species—more than 20% of the extant avifauna worldwide (5). Invasive mammals are the primary driver of biodiversity loss on islands and a limited subset of feral mammals are responsible for a majority of insular diversity declines, including rats (*Rattus* spp.), cats (*Felis catus*), goats (*Capra hircus*), pigs (*Sus scrofa*), donkeys (*Equus asinus*), and European rabbits (*Oryctolagus cuniculus*) (6–8).

## ISLAND BIODIVERSITY PATTERNS

Islands make up approximately ~3% of land area worldwide, yet they harbor a relatively high percentage of biodiversity, including many endangered species. Of the mammal and bird species that are listed by the World Conservation Union (IUCN) worldwide, 83% of the documented historical extinctions have occurred on islands and 44% of the currently threatened taxa are insular (Fig. 2a). In México, biodiversity patterns are similar: islands make up a mere 0.2% of the total land area, but have suffered at least 50% of México's historic extinctions and hold 18% of the country's endangered mammals and birds (Fig. 2b). Virtually all of the extinctions and extirpations on islands in western México can be attributed to the impact of invasive mammals (18, 20, 22, 23). Because of

Figure 1. The islands of western México where invasive mammals have been successfully removed.



(A)

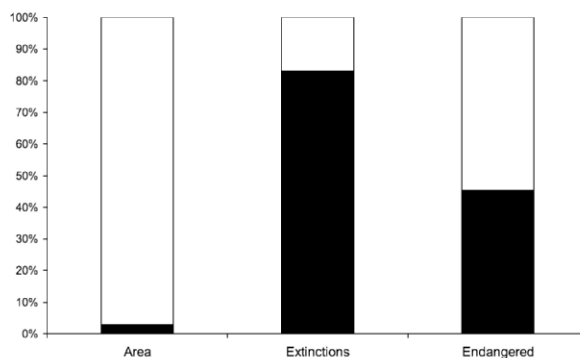
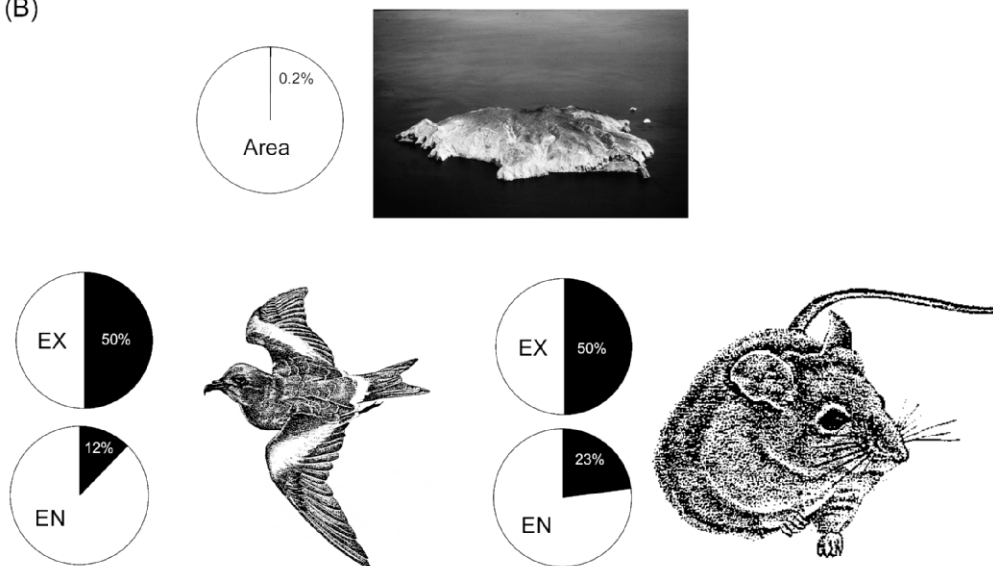


Figure 2. (A) Global percent comparisons of islands (black) versus continental (white) for total area, and extinct and endangered species of mammals and birds combined. (B) Percent comparisons within México between islands (black) and continental (white) for total area, extinct (EX), and endangered (EN) mammals, and extinct and endangered birds. Species data for both figures are from IUCN Red List ([www.redlist.org](http://www.redlist.org)). We classed Red List categories EX and EW as extinct, and CR, EN, and VU as endangered. México area data from Instituto Nacional de Geografía y Estadística.

(B)



**Table 1. Invasive mammal eradications in western México and the biodiversity protected. Invasive mammals have been removed from 26 islands in the region (BR = black rats, C = cats, D = donkeys, DG = dogs, G = goats, H = horses, M = house mice, Rab = European rabbits).**

Island	Area (ha)	Date	Non-native mammal			Endemic Species/Subspecies				Seabird breeding populations
			Removals	Failures	Present	Mammals	Reptiles	Birds	Plants	
Baja Pacific										
Todos Santos North	62	1999	C,Rab,D <sup>1</sup>			1	0	0	0	7
San Jerónimo	67	2000	C			1	0	0	0	8
Asuncion	68	1994	C			0	0	0	0	9
San Roque	79	1995	C,BR			0	0	0	0	12
Coronado North	79	1995	C			1	4	1	1	10
San Benito Middle	105	1998	Rab			0	0	1	1	15
Todos Santos South	127	1998	C,Rab			1	2	0	0	7
San Benito East	195	2001	Rab			0	0	2	3	15
Coronado South <sup>2</sup>	227	2003	C,G,D <sup>1</sup>			1	2	1	4	8
San Martin	298	2000	C			1	3	0	0	8
San Benito West	545	1998	Rab,G,D <sup>1</sup>			0	1	2	5	14
Natividad	1029	1999	C,G, <sup>1</sup> S <sup>1</sup>			1	0	0	3	10
Gaдалupe	26 469	2005	Rab, <sup>1</sup> D, <sup>1</sup> H, <sup>1</sup> DG		G, <sup>3</sup> C	0	0	4	34	9
Gulf of California										
San Jorge West	7	2000	BR			0	0	0	0	9
San Jorge East	9	2000	BR			0	0	0	0	9
San Jorge Middle	41	2000	BR			0	0	0	0	11
Rasa <sup>4</sup>	59	1995	BR, M			0	0	0	0	4
Estanque	105	1999	C			0	1	0	0	2
Isabela <sup>5</sup>	274	1996	C	BR		0	0	0	0	11
Mejia	328	2001	C			0	1	0	0	5
San Francisco	465	2000	C, G			2	0	0	0	1
Coronados	1003	1999	C			2	2	0	0	1
Monserate	1882	2001	C			1	2	0	0	2
La Partida	2029	2001	C			6	0	0	0	4
Santa Catalina	3080	2004	C			1	8	0	1	2
Revillagigedo										
Clarion	2928	2002	S,P	Rab		0	2	4	13	8
Total Protected	41 559					19	28	11	30	201

<sup>1</sup>Small populations were removed live in cooperation with island residents and governmental agencies. <sup>2</sup>Project conducted by Gustavo Arnoud of the Centro de Investigaciones Biológicas, Noroeste, with assistance from Island Conservation. <sup>3</sup>While goats are ecological extinct, the eradication campaign is still in progress (less than 200 goats remain). <sup>4</sup>Project conducted by Jesús Ramírez (deceased) of the Instituto de Ecología, Universidad Nacional Autónoma de México. <sup>5</sup>Project conducted by Cristina Rodríguez of the Instituto de Ecología, Universidad Nacional Autónoma de México with assistance from Island Conservation. See Rodríguez et al. (36).

those diversity patterns, the islands of western México are considered a national conservation priority (27).

## ERADICATION SUCCESSES

Three small islands with important seabird colonies were the genesis for invasive mammal eradications in México. In 1994/1995, the Mexican NGO Grupo de Ecología y Conservación de Islas (GECI) and the US-based NGO Island Conservation (IC), working with Jesús Ramírez, eradicated feral cats from Asunción Island and cats and black rats (*Rattus rattus*) from nearby San Roque Island (28). That same year Jesús Ramírez and colleagues from Universidad Nacional Autónoma de México eradicated black rats and house mice (*Mus musculus*) from Rasa Island, the world's most important nesting site for Heermann's Gulls (*Larus heermanni*) and Elegant Terns (*Sterna elegans*) (13).

From this beginning, a total of 26 invasive mammal populations have been removed from 13 islands off the Pacific coast of Baja California, 14 populations from 12 islands in the Gulf of California, and two populations from one island in the Revillagigedo Archipelago (Fig. 1, Table 1). Invasive predators (rats, cats, dogs) have been removed from 22 islands and invasive herbivores (donkeys, goats, sheep, and rabbits) from 10 islands. These conservation actions have protected 88 endemic populations from the impacts of invasive mammals (Table 1, Fig. 3).

Entire plant communities are now recovering from extensive overgrazing by invasive herbivores (19, 29). For example, on West San Benito Island, the single island endemic succulent *Dudleya linearis* was near extinction due to overgrazing by European rabbits; it is now recovering following rabbit



**Figure 3. Some of the island species protected by the eradication of invasive mammals on islands in western Mexico. Red-billed tropicbird (*Phaethon aethereus*) on the San Jorge Islands, the endemic San Martin Island alligator lizard (*Elgaria multicarinata ignara*), the endemic San Jeronimo deer mouse (*Peromyscus maniculatus jeroni*), Cassin's auklet (*Ptychoramphus aleuticus australe*) on the San Benitos Islands, the endemic San Benitos *Dudleya linearis*, the endemic Guadalupe Island pine (*Pinus radiata binata*), and the endemic Guadalupe rock daisy (*Perityle incana*).**



**Table 2. Measuring conservation impact and cost-effectiveness of non-native mammal eradications in western México.**

	USD-2005
Total expenditures (1994–2005) <sup>1</sup>	\$4 361 318
Cost per seabird colony protected	\$22 139
Cost per endemic terrestrial vertebrate protected <sup>2</sup>	\$49 560
Cost per hectare protected <sup>3</sup>	\$58

<sup>1</sup>Includes all expenditures (salaries, equipment, supplies, transportation, office space, policy work, and other costs) for Grupo de Ecología y Conservación de Islas and Island Conservation activities in México, and in the US and Canada in support of Grupo de Ecología y Conservación de Islas' projects. Also includes reported costs for Isabel Island from Rodríguez et al. (36). Does not include Rasa Island. <sup>2</sup>Species or subspecies. <sup>3</sup>Does not include *i*) the removal of rabbits, donkeys, and horses from Guadalupe Island, all of which were by-products of other campaigns or *ii*) Rasa Island (see Table 1).

eradication (Fig. 3) (28). Recent and ongoing goat removal efforts on Guadalupe Island have resulted in significant plant conservation gains—a total of 34 endemic taxa have been protected, including the rediscovery of four species that were thought to be extinct (29, 30). The endemic pine (*Pinus radiata* var. *binata*) and cypress (*Cupressus guadalupensis*) forests, habitats of the endemic Guadalupe junco (*Junco insularis*), are showing a dramatic comeback (Fig. 3). After a century without recruitment, thousands of pine and cypress seedlings are now present. Upon completion of goat removal from Guadalupe Island, the area of island habitat protected by invasive mammal eradications in México will triple (Table 1).

Eradication successes have also resulted in major conservation gains for seabirds in the region; more than 201 breeding colonies have been protected (Table 1). Many of these colonies represent species that breed on three or fewer islands or total less than 10 000 individuals (31–33). Invasive predators (i.e., cats and rats) have extirpated numerous seabird colonies in the region (e.g., Xantus' Murrelet, *Synthliboramphus hypoleucus*) and now that these predators have been removed, seabirds will likely recolonize the islands, as has been documented on islands to the north in California (20, 34).

During the past decade two eradication efforts in the region have failed, and these failures provide important insights for subsequent island conservation endeavors. In both projects, planning and consultation were limited and pre-eradication trials were not undertaken. In hindsight, the planning phase was particularly crucial because of the novel circumstances of the eradication attempts. Clarion Island is a subtropical island where feral pigs, sheep, and rabbits were targeted for removal. The size of the island (2928 ha) was much larger than any previous rabbit eradication campaign. Before Clarion Island, eradication campaigns led by GECI and IC took place on smaller islands where a small number of highly skilled hunter/trappers used a largely intuitive approach (35). This approach did not transfer well to Clarion, and the resulting under-planning led to insufficient budgeting. Although pigs and sheep were removed, the rabbit eradication campaign was stopped when techniques were not effective enough and funding ran out. Isabel Island is a tropical island where feral cats and black rats were targeted for removal. A team from Universidad Nacional Autónoma de México successfully eradicated cats, but the black rat eradication failed. This failure was likely because of poor timing of the eradication campaign in relation to rat reproductive biology, hasty project implementation, and unanticipated levels of bait uptake by native land crabs (*Coenobita compressus*), which are known to consume rodenticides (36). Bait uptake by land crabs, which are immune to most rodenticides, greatly complicates rat eradications on tropical islands and has been responsible for at least two other failures (37, Howald et al. unpubl. data). The failures of these two campaigns highlight the need for *i*) strategic planning, including consultation and in

some cases pre-eradication trials (38), and *ii*) flexibility to revise project needs when appropriate, such as methods, management, monitoring, evaluation, and budgets.

## ERADICATION COSTS AND BENEFITS

The eradication of 42 invasive mammal populations from 26 islands in western México at a cost ~USD4.3 million resulted in high conservation returns on investment (Table 2). Invasive mammals were removed at an average cost of US\$58 per hectare for each invasive species removed. Due to the cost effectiveness of this biodiversity protection and because many species co-occur in México and the United States (33), US government and private foundations have recently taken a trans-border approach to seabird conservation off the Pacific Coast of North America, funding eradication projects in México and, more recently, Canada (39, 40).

## CONSERVATION APPROACH

In the for-profit sector, organizations that specialize in a few complex operations often have an efficiency advantage over less specialized organizations (41). Such patterns are also likely to apply to the nonprofit sector, including conservation organizations (42, 43), particularly when highly specialized tasks such as eradicating invasive animals are involved. By specializing in eradications and applying a standardized, integrated, and heterarchical approach, GECI, IC, and Island Conservation-Canada (IC-Canada) have been able to increase efficiency and decrease costs with resulting gains for biodiversity. Perhaps more importantly, the steady accretion of shared expertise across three countries has enabled success in increasingly complex projects (37, 44).

The described conservation successes are a result of an operational model with three main components:

- a tri-national collaboration between three conservation NGOs (GECI, IC, IC-Canada) dedicated to eradicating invasive mammals from islands and preventing new introductions. These three groups applied a common approach that integrated *i*) research and prioritization, *ii*) public education, *iii*) policy work, *iv*) capacity building, *v*) on-the-ground conservation action, and *vi*) monitoring and evaluation;
- proactive and dedicated government agency partners in México; and
- effective partnerships with academic researchers in México and the United States.

GECI worked closely with these partners and its sister organizations (IC and IC-Canada) to leverage North American-wide economic, intellectual, and political resources to effectively fund and support science-driven conservation actions. Key stakeholders and agencies include *i*) universities (Universidad Nacional Autónoma de México, Centro de Investigaciones Biológicas del Noroeste, Centro de Investigación Científica y Educación Superior de Ensenada, University of California Santa Cruz); *ii*) government agencies (Secretaría de Medio Ambiente y Recursos Naturales, Secretaría de Gobernación, Secretaría de Marina, Armada de México, Instituto Nacional de Ecología, Comisión Nacional de Áreas Naturales Protegidas, Comisión Nacional de Biodiversidad, Procuraduría Federal del Medio Ambiente); and *iii*) local island users and community fishing co-operatives (Pescadores Nacionales de Abulón, Buzos y Pescadores de Baja California, California de San Ignacio, Abuloneros y Langosteros). This consortium initiated their efforts on smaller islands and used these experiences to build capacity and leverage successes for eradication campaigns on larger, more challenging islands.

Without buy-in from local island residents and users, the benefits of eradication campaigns are potentially short-lived because of the likelihood of intentional or unintentional reintroductions. Thus, many of the eradication campaigns in western México included environmental education campaigns with local fishermen and school children (see 45, 46). Whereas animal rights issues have caused challenges to eradications elsewhere (8), they were not a major issue for the eradications reported here. Environmental education campaigns that focused on the value of native biodiversity and the impacts of invasive mammals may have contributed to the lack of animal rights issues (45).

While the environmental education campaigns facilitate “bottom-up” support, working closely with governmental agencies provides “top-down” support from an island conservation policy perspective. Grupo de Ecología y Conservación de Islas is working with national government agencies to harbor more political support for eradication campaigns and protection of the region’s islands in general (47, 48). Both are critical to enable eradication campaigns and prevent reintroductions of invasive species in the long-term.

México has an existing legal infrastructure that affords protection for much of its insular natural heritage. Threatened species are protected by Mexican federal law under the Norma Oficial Mexicana NOM-059-ECOL-2001 (49), with specific protection provided by Article 87 of the General Law of the Ecological Balance and Environmental Protection and Article 85 of the General Wildlife Law. The islands of the Gulf of California have enjoyed legal protection since 1978, and have recently gained World Natural Heritage recognition by United Nations Educational, Scientific and Cultural Organization (16). The protected status of islands off the Pacific side of Baja California is rapidly changing. In 1988, Natividad, San Roque, and Asunción Islands were added to the Vizcaino Biosphere Reserve under the National System of Protected Areas. In 2005, Guadalupe Island and its surrounding islets and waters were designated as the Guadalupe Island Biosphere Reserve as a result of an initiative led by the Comisión Nacional de Áreas Naturales Protegidas in partnership with GECI. Currently, the Mexican Federal Congress has mandated a Biosphere Reserve designation for the remaining Pacific Islands. With sufficient resources, these new protected areas could provide both the legal framework and infrastructure for developing island management plans and facilitate the necessary enforcement of existing regulations to protect the insular biodiversity of the entire archipelago. Unfortunately, a lack of resources has inhibited the development of management plans for other protected islands.

Finally, a unique partnership between the IC and University of California Santa Cruz has fostered an integrated approach that combines on-the-ground science and conservation action. Island Conservation is physically housed at University of California’s Center for Ocean Health, which facilitates collaborations with academic staff and students (graduate and undergraduate) as well as other academic resources. Grupo de Ecología y Conservación de Islas, based in Ensenada, Baja California, is adopting a similar approach, building relationships with key Mexican academic institutions including Centro de Investigación Científica y de Educación Superior de Ensenada and Universidad Autónoma de Baja California. Whereas the process of targeting islands for eradications encompasses components that are opportunistic in nature, academic collaborations have helped facilitate a more systematic approach. For example, a regional island biodiversity database was developed to help prioritize eradication efforts in western México (28). Academic analyses of biodiversity patterns and conservation investments have highlighted previously

unrecognized conservation opportunities (33). Concurrent with eradication campaigns, targeted research on select islands also documents the biodiversity impacts of invasive mammals on the region’s island ecosystems and the conservation gains of eradication campaigns (18–21, 32, 44, 50). Such research not only helps guide decision-making for future conservation actions, but also aids in fundraising.

## THE FUTURE OF ISLAND CONSERVATION IN WESTERN MÉXICO

The islands of western México are celebrated laboratories of evolution and important centers of biodiversity (10–13, 51–54). Because of the efforts of multiple government, NGO, and academic institutions, the ability to remove invasive mammals from islands has vastly improved (24, 55–58), contributing to the island conservation gains in México outlined above. Invasive mammals can now be removed from large islands swiftly and cost-effectively (e.g., 59). All of the remaining islands in western México are now feasible conservation targets with respect to invasive mammal eradications. Goats are in the final phases of being removed from Guadalupe Island, one of México’s endemic hotspots. However, cats remain on Guadalupe, as well as on other islands with high biodiversity value, such as Socorro Island and the three largest islands in the Islas Marias Archipelago (60–62). Recent advances in techniques and technology make cat eradication on these large islands feasible (63, 64). Invasive rodent populations are still present on eight islands in the region, but many are within the size range where eradication would be straightforward and cost-effective with large conservation returns (58). Funding, rather than technical capacity and island size, are now the limiting factors in preventing extinctions on these and the remaining islands in western México (55).

Fortunately, local, national, and international support for the conservation of México’s islands is gaining momentum. What is now needed is a detailed, staged plan to eradicate invasive mammals from the remaining ~60 islands that integrates the needed financing, additional capacity, technical advances, and policy issues. With such a plan and the continued vision and determination of Mexican conservationists, México can continue to demonstrate feasible and cost-effective approaches to restore and safeguard the biodiversity of an entire suite of island archipelagos.

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