Rodent eradications on Mexican islands: advances and challenges

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Abstract In Mexico, attempts had been made to eradicate rodents from nine islands by 2009, and eight of these were successful. Methods evolved from bait stations on small islands to aerial bait applications on islands that were larger and more complex. Six islands (5 to 82 ha) were treated with bait stations from 1995 to 2002. All of these attempts were successful except for Isabel Island (the largest). Three islands (17, 82 and 267 ha), including Isabel for the second time, were treated with the high-tech aerial broadcast technique between 2007 and 2009, which was the first time this technique was used in Latin America. Post-eradication monitoring has confirmed rodent absence and ecosystem recovery, which includes re-colonisation of seabirds and population increases in reptiles and seabirds. The experience and trust gained have made planning and funding possible for additional projects on bigger islands. Planning, permitting, funding, research, and execution have progressed following a focused, long term collaborative approach with multiple partners. About 30 Mexican islands still have one or two species of invasive rodents. New challenges include bigger islands (e.g., Guadalupe; 24,171 ha), tropical islands (e.g., Banco Chinchorro Atoll; 580 ha), and islands with endemic mammals including rodents (e.g., María Madre; 14,388 ha).

Keywords: Invasive rodents, *Rattus rattus*, *Mus musculus*, Mexican islands, eradication, bait stations, aerial broadcast, ecosystem recovery

INTRODUCTION

Rodents (*Rattus* spp., *Mus musculus*) are among the most harmful and widespread invasive species (Towns *et al.* 2006; Angel *et al.* 2009; Drake and Hunt 2009). They are responsible for the extinction of numerous species of terrestrial vertebrates (Harris 2009), suppress thousands of populations of seabirds (Jones *et al.* 2008), and have significant socioeconomic impacts (Reaser *et al*. 2007). On islands, invasive species such as rodents may establish more easily due to low species diversity and the presence of empty ecological niches (Pino *et al.* 2008).

During the last four decades, eradication techniques developed and tested in New Zealand (Veitch and Clout 2002; Towns and Broome 2003) have been applied successfully on hundreds of islands around the world (Howald *et al.* 2007). There are now numerous examples where eradicating rodents from islands has proved to be an effective way of facilitating the restoration of insular native communities, even in cases where active management beyond rodent eradication is needed (Mulder *et al.* 2009).

Mexico stands out on the American continent because of the high levels of success with the eradication of invasive species from insular ecosystems (Aguirre-Muñoz *et al.* 2008). Applied restoration projects started in 1995 with a couple of rat and cat eradications on small islands, and reached a total of 49 populations eradicated on 30 islands by 2010 (Aguirre-Muñoz *et al.* 2011). The invasive rodent eradications fall into two distinct periods. From 1995 to 2002 six small, dry islands were treated by hand laying bait in bait stations. Two projects were led by researchers of the Universidad Nacional Autónoma de México (UNAM); the rest by Grupo de Ecología y Conservación de Islas-Mexico (GECI) in conjunction with Island Conservation-USA (IC). The second period, which started in 2003, has involved three larger and more complex islands, including one in the tropics. These three were treated with aerially broadcast bait and three more are scheduled for treatment. The projects are part of a long term strategy led by GECI, with the support of key partners. Here we summarise the evolution of these Mexican achievements, and outline plans for the future.

ERADICATION METHODS AND RESULTS

Rodent eradications are particularly difficult (Towns *et al.* 2006). In Mexico, six islands were treated with bait stations: Rasa, San Roque, San Jorge (3 islands) and Isabel. Subsequently, three islands: Farallón de San Ignacio, San Pedro Mártir and again Isabel were treated by aerial broadcast of bait (Fig. 1). These islands were chosen based on the vulnerability of native species to rat predation, on cost and logistical feasibility (in terms of size, topography and native species), and on the level of reinvasion risk. Collectively they are important breeding areas for 19 species of seabirds, 12 species of reptiles, and one species of bat (Table 1). The way that these techniques were applied is described below and additional details are in Table 2.

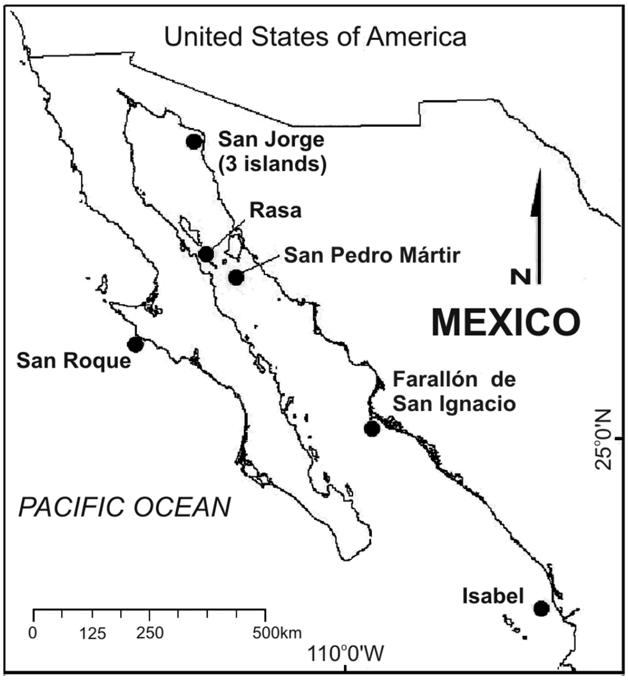

Fig. 1 Location of Mexican islands were rodent eradications have taken place up to 2009.

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Table 1 Breeding species of vertebrates on Mexican islands where rodent eradications have taken place up to 2009.

Species and common name	Rasa	San Roque	San Jorge	Farallón de San Ignacio	San Pedro Mártir	Isabel
Reptiles						
Aspidoscelis costata Western Mexican whiptail lizard						X
Aspidoscelis martyris San Pedro Mártir whiptail lizard					X	
Aspidoscelis tigris Western whiptail lizard				X		
Crotalus atrox Western diamondback rattlesnake					X	
Ctenosaura pectinata Spiny-tailed iguana						X
Lampropeltis getula nigritus Common kingsnake					X	
Lampropeltis triangulum Milk snake						X
Phyllodactylus homolepidurus Sonoran leaf-toed gecko				X		
Sceloporus clarkii Clark's spiny lizard						X
Urosaurus ornatus Tree lizard				X		
Uta palmeri San Pedro Mártir side-blotched lizard					X	
Uta stansburiana Side-blotched lizard	X	X				
Seabirds						
Anous stolidus Brown noddy						X
Falco peregrinus Peregrine falcon	X	X		X	X	
Fregata magnificens Magnificent frigatebird						X
Larus heermanni Heermann's gull	X	X	X	X	X	X
Larus livens Yellow-footed gull	X				X	
Larus occidentalis Western gull		X				
Pelecanus occidentalis Brown pelican		X			X	X
Phaethon aethereus Red-billed tropicbird			X	X	X	X
Phalacrocorax auritus Double-crested cormorant		X	X	X		
Phalacrocorax penicillatus Brandt's cormorant		X			X	
Ptychoramphus aleuticus Cassin's Auklet		X				
Puffinus opisthomelas Black-vented shearwater		E				
Thalasseus elegans Elegant tern	X	E	X			
Onychoprion fuscatus Sooty tern						X
Thalasseus maximus Royal tern	X	E	X			
Sula leucogaster Brown booby			X	X	X	X
Sula nebouxii Blue-footed booby			X	X	X	X
Sula sula Red-footed booby						X
Synthliboramphus craveri Craveri's murrelet	E	X	E		X	
Mammals						
Myotis vivesi Fish-eating bat	X		X	X	X	
Peromyscus maniculatus cineritius North American deermouse		Ex				

X = presently breeding, E = extirpated, Ex = extinct.

Table 2 Successful rodent eradications on Mexican islands up to 2009.

Island	Area (ha)	Species removed	Date of eradication*	Principal method	Ecosystem type	Reference
San Jorge (3 islands)	<25	*Rattus rattus*	2000	Bait stations	Arid	Donlan *et al.* 2003
Farallón de San Ignacio	17	*Rattus rattus*	2007	Aerial broadcast	Arid	Samaniego-Herrera *et al.* 2009
San Roque	35	*Rattus rattus*	1995	Bait stations	Arid	Donlan *et al.* 2000
Rasa	57	*Rattus rattus* *Mus musculus*	1995[1]	Bait stations	Arid	Ramírez-Ruiz and Ceballos-González 1996
Isabel	82	*Rattus rattus*	2009[2]	Aerial broadcast	Subtropical	Samaniego-Herrera *et al.* 2010
San Pedro Mártir	267	*Rattus rattus*	2007	Aerial broadcast	Arid	Samaniego-Herrera *et al.* 2009

*Work conducted by Conservación de Islas except when indicated otherwise.
[1]Project conducted by J. Ramírez-UNAM (Ramírez-Ruiz and Ceballos-González 1996).
[2]First eradication attempt (1995), conducted by C. Rodríguez-UNAM, failed (Rodríguez-Juárez *et al.* 2006).

Bait stations

Islands treated with this technique were three independent initiatives conducted by different institutions. The first two described below had important seabird nesting sites where researchers had established long term monitoring programmes that documented the negative impacts of introduced invasive rodents. The third one marked the beginning of a large scale island restoration program which now includes all Mexican islands.

1. Rasa Island. In 1995, a ship rat (*Rattus rattus*) and house mouse (*Mus musculus*) eradication was led by Jesús Ramírez (deceased) and collaborators of the Instituto de Ecología, UNAM, and Conservación del Territorio Insular Mexicano, A.C. Bait stations on a 25 m grid containing 50 ppm brodifacoum wax blocks were used; the stations remained for one year although consumption ceased after six weeks (Ramírez-Ruiz and Ceballos-González 1996).

2. Isabel Island. In 1995, a ship rat eradication was undertaken by C. Rodríguez and collaborators of the Instituto de Ecología, UNAM. Bait stations containing 50 ppm brodifacoum wax blocks were used; the bait stations were removed after just six weeks even though consumption rates of the baits had not decreased (Rodríguez-Juárez *et al.* 2006).

3. San Roque and San Jorge Islands. Unlike the above projects, eradications on these islands were part of a larger scale strategy of island restoration work. GECI, in conjunction with IC, started applied restoration work on Mexican islands in 1995 eradicating cats (*Felis catus*) and ship rats on San Roque Island. Brodifacoum wax blocks were used to eradicate rats in combination with 100 ppm bromethalin in a gel bait; stations remained for one year (Donlan *et al.* 2000). Later in 2000, ship rats were eradicated from all three San Jorge Islands. Bait stations on the biggest island were on a 25 m grid and contained 50 ppm brodifacoum wax blocks. On east islet diphacinone was used and on the west islet cholecalciferol was used. The bait stations on each island remained in place for one year (Donlan *et al.* 2003).

Aerial broadcast

Following the experience gained by working on small islands and with growing support of funders and partners, GECI then initiated more ambitious projects. Because Farallón de San Ignacio, Isabel and San Pedro Mártir islands are topographically complex, and the last two are medium sized (82 and 267 ha, respectively), a helicopter was used to disperse rodenticide broadly across each island. Although effectively employed elsewhere (e.g., Howald *et al.* 2007), this was the first use of aerial procedures in Latin America. Each rat eradication project included a two year pre-eradication and a two year post-eradication phase. In all cases the ship rat was the target species.

Farallón de San Ignacio and San Pedro Mártir islands were integrated into a single project due to their physical and ecological similarities. Both islands were treated in autumn 2007 using specially designed 25 ppm brodifacoum pellets manufactured by Bell Laboratories, USA (for additional details see Samaniego-Herrera *et al.* 2009).

Isabel Island is the most recent project. Although the previous attempt to eradicate rats from this island using bait stations failed, the aerial broadcast of baits in spring 2009 appears to have been successful. No rats have been detected following almost two years of monitoring. This eradication used the same Bell Laboratories bait described above but with the addition of a biomarker, which allowed monitoring of consumption by target and non target species, especially those scarcely or non present in previous eradications (e.g., iguanas, snakes, land birds; see also Samaniego-Herrera *et al.* 2010).

Additional research and activities

There was limited monitoring of native species on the islands treated with bait stations and the results remain unpublished. Existing information comprises changes in seabird populations on Rasa and San Roque islands (Table 3). Pre and post-eradication monitoring on the islands treated with aerial broadcast (Table 2) included reptiles, seabirds and bats on all islands (Table 3). On Isabel Island

Table 3 Examples of ecological benefits on native populations at Mexican islands after rodent eradications.

Island	Species	Changes recorded after rodent eradication
Farallón de San Ignacio	*Phaethon aethereus* Tropicbird	60% increase in number of nests after two years without rats. Percentages of egg-hatching success and development of juveniles also increased.
	Phyllodactylus homolepidurus Sonoran leaf-toed gecko	Changed from extremely rare to low abundance after two years without rats.
Isabel	*Ctenosaura pectinata* Spiny–tailed iguana	Population abundance increased.
	Onychoprion fuscatus Sooty tern	Nesting again after few years of extirpation.
Rasa	*Larus heermanni* Heerman's gull	Breeding success increased five times.
	Thalasseus elegans Elegant tern	Population (55,000 individuals in 1995) has increased to 200,000.
San Pedro Mártir	*Lampropeltis triangulum* Milk snake	"Reappeared" on the island after two years without rats.
	Synthliboramphus craveri Xantus´s murrelet	Nesting again after decades of extirpation.
San Roque*	*Phalacrocorax penicillatus* Brandt's Cormorant	Both nesting again after years of extirpation. Also several new records of seabirds in recent years.
	Ptychoramphus aleuticus Cassin's auklet	

* The project included both ship rat and cat eradication.
Sources: Velarde *et al*. 2005; Castillo 2009; Samaniego *et al.* in prep; E. Velarde pers. comm.

terrestrial crabs were also monitored. Details of the species involved, methods, and results will be provided elsewhere (Samaniego-Herrera *et al.* in prep).

Several biomarker trials have been associated with planed rodent eradications (Greene and Dilks 2004; Griffiths *et al.* 2008; Parks and Wildlife Service 2009; Wegmann *et al.* 2009). To the best of our knowledge, the 2009 rat eradication on Isabel Island was the first to use bait with a biomarker for the actual toxic bait application. This "large scale experiment" allowed us to test the palatability of baits across a wide range of native and introduced species of invertebrates and vertebrates. The results are part of a larger study, which include other insular ecosystems, so are not reported here.

All projects included environmental education as a tool for both project acceptance by local communities and authorities, and for reinvasion risk management. On seven of the eight islands the risk of reintroduction is low because the islands are not inhabited by humans, have no tourism, or no longer feature activities with a high risk of accidental introduction of invasive rodents (mainly guano mining). The exception is Isabel Island, which is inhabited by fishermen for most of the year and is regularly visited by small groups of students and tourists. Due to the higher risk of reintroduction, the authority with jurisdiction over this natural protected area, which is the Comisión Nacional de Áreas Naturales Protegidas (CONANP), enforces an environmental education campaign with a permanent prevention programme that includes checks of boats and gear for invasive species.

Along with the eradication projects and field monitoring, literature reviews and interviews were conducted to update our database of invasive rodent distribution on Mexican islands. Monitoring included standard trapping of small mammals in different habitat types and seasons when possible. Inputs from authorities, island users, and researchers included formal interviews and informal conversations. Most of the cases revealed from interviews were confirmed in the field, and the rest were backed by credible evidence.

DISCUSSION

Five of the six attempted eradications using bait stations were successful on islands <52 ha (Table 2), but the attempt failed on the largest island, Isabel (82 ha). Hasty implementation without first studying the behaviour and ecology of the target population (as well as potential native competitor species) were identified as the main cause of failure (Rodríguez-Juárez *et al.* 2006). We agree that insufficient planning and research, especially concerning land crab interference, and not the method, was the cause, especially since much bigger islands have successfully been cleared of rats with bait stations (Howald *et al.* 2007).

All three projects using the aerial broadcast of baits were successful. On the most recent one (Isabel Island), the second year of confirmation monitoring is about to be completed. As in New Zealand and elsewhere, the size and complexity of islands favoured a change of methods from bait stations to aerial broadcast procedures. Baits and techniques developed in New Zealand, which in turn were adopted in the USA, facilitated the several technical, logistical and legal aspects involved in these eradications. At the same time it is important to highlight that crucial requirements for aerial procedures, such as helicopters equipped with Differential GPS and permits to import the specific rodenticides required by the method, are difficult to obtain in Mexico. Therefore these will continue to be limiting factors for future projects until a facilitating legal framework for restoration projects is developed. This concern has been underlined in previous publications (Aguirre *et al*. 2005, 2008, 2009) and national forums attended by researchers as well as managers and government authorities (e.g., Encuentro Nacional para la Conservación y el Desarrollo Sustentable de las Islas de México, 2009).

The positive effects observed after rat eradications in Mexico include increased reproductive success and recolonisation of seabirds, as well as increases in the abundance of reptiles (Table 3). On Isabel Island, the eradication of the invasive house sparrow (*Passer domesticus*) was an additional but unplanned benefit; once common around human settlements, no sparrows have been recorded in almost two years of monitoring (Samaniego-Herrera *et al.* unpublished data).

Environmental education and re-invasion prevention programmes, combined with a low to moderate risk of reintroduction, have so far helped to prevent reinvasions by rats. The first projects were completed about 15 years ago and recent field monitoring confirms that the islands are still free of invasive rodents (Samaniego-Herrera *et al.* 2007). Moreover, these eight islands are now free of all invasive mammals as cats were also eradicated from some of them.

There are at least 30 more Mexican islands with either ship rats, house mice, or both species present (Table 4). There are also two invasive species that are native to an adjacent area: *Peromyscus eremicus cedrocensis* which is endemic to Cedros Island, was accidentally introduced to San Benito Oeste Island (50 km east of Cedros) in 2006 (Aguirre *et al.* 2009); *P. fraterculus*, which is native and common on the adjacent mainland, was probably introduced to Santa Catalina Island in the beginning of the 1990s (Álvarez-Castañeda *et al.* 2009). There are no confirmed records of brown rats (*R. norvegicus*) on islands although the species is present on mainland Mexico. Some of the remaining invaded islands are small and rodent eradication should be easily achievable with baits in stations or broadcast by hand. However, several islands are very close to either the mainland or to a larger island with invasive rodents, hence elevating the risk of reinvasion. Eradication must then be evaluated in a cost-benefit perspective, as management requires a metapopulation approach (Russell *et al*. 2009) and expensive prevention considerations must be taken into account. Regarding the islands on which aerial broadcast is the only option to eradicate invasive rodents, size is not the only challenge. Apart from human activities, tropical ecosystems, and the presence of native mammals, including rodents, are the biggest concerns; factors for which there is little experience worldwide (Wegmann 2008; Harris 2009; Varnham 2010). In preparation for future eradication projects we are conducting monitoring and research on topics such as species that indicate ecosystem recovery, the palatability of baits and the risks they pose to native species, and mitigation measures for those species at risk of primary and secondary poisoning.

The successes on all eight islands prove support for the initiative to scale up the rodent eradication programme at a national level. More than ever, rodent eradications in Mexico should constitute an inter-institutional effort and prioritisation analyses need to be developed. Funding must be secure in advance and include pre- and post-eradication studies and environmental education, and bio-security measures need to be applied in a serious and long term approach.

Table 4 Mexican islands with presence of exotic invasive rodents in 2010.

Island	Area (ha)	Species	Ecosystem type	Native mammals?
PACIFIC OCEAN				
Cedros	34,933	*Mus musculus* *Rattus rattus*	Temperate	Yes
Coronado Sur	126	*Mus musculus*	Desert	Yes
Guadalupe	24,171	*Mus musculus*	Temperate	No
Magdalena	27,773	*Mus musculus*	Desert	Yes
San Benito Oeste	364	*Peromyscus eremicus cedrosensis*	Desert	No
Socorro	13,033	*Mus musculus*	Tropical	Yes
GULF OF CALIFORNIA				
Alcatraz (Pelícano)	50	*Mus musculus*	Desert	No
Almagre Chico	10	*Rattus rattus*	Desert	No
Ángel de la Guarda	93,068	*Mus musculus* *Rattus rattus*	Desert	Yes
El Rancho	232	*Mus musculus* *Rattus rattus*	Desert	No
Granito	27	*Rattus rattus*	Desert	Yes
María Madre	14,388	*Rattus rattus*	Tropical	Yes
María Magdalena	6977	*Rattus rattus*	Tropical	Yes
María Cleofas	1963	*Rattus rattus*	Tropical	Yes
Mejía	245	*Mus musculus* *Rattus rattus*	Desert	Yes
Melliza Este	1	*Rattus rattus*	Desert	No
Pájaros	82	*Rattus rattus*	Desert	No
Saliaca	2000	*Mus musculus* *Rattus rattus*	Desert	Yes
San Esteban	3966	*Rattus rattus*	Desert	Yes
San Vicente	14	*Mus musculus*	Desert	No
Santa Catalina	3890	*Peromyscus fraterculus*	Desert	Yes
GULF OF MEXICO AND CARIBBEAN SEA				
Cayo Norte Menor	15	*Rattus rattus*	Tropical	No
Cayo Norte Mayor	29	*Rattus rattus*	Tropical	No
Cayo Centro	537	*Rattus rattus*	Tropical	No
Cozumel	47,000	*Mus musculus* *Rattus rattus*	Tropical	Yes
Holbox	5540	*Rattus rattus*	Tropical	No
Muertos	16	*Mus musculus*	Tropical	No
Mujeres	396	*Mus musculus* *Rattus rattus*	Tropical	No
Pájaros	2	*Mus musculus*	Tropical	No
Pérez	11	*Rattus rattus*	Tropical	No

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