

Invasive Rodents on Tropical Islands: Eradication Recommendations from Mexico

Araceli Samaniego-Herrera

School of Biological Sciences, University of Auckland, Auckland, New Zealand, and Grupo de Ecología y Conservación de Islas, Moctezuma Ensenada, Baja California, México

James C. Russell

School of Biological Sciences, University of Auckland, Auckland, New Zealand

David Choquenot

Institute for Applied Ecology, University of Canberra, Canberra, Australia

Alfonso Aguirre-Muñoz

Grupo de Ecología y Conservación de Islas, Ensenada, Baja California, México

Mick N. Clout

School of Biological Sciences, University of Auckland, Auckland, New Zealand

ABSTRACT: Central to the growing field of island ecological restoration is the removal of invasive rodents. The lack of information on rodent tropical ecology is a limiting factor for the success of such eradication attempts on tropical islands worldwide. In Mexico, 14 successful rodent eradications have occurred, 6 of them on dry and wet tropical islands, and the others on temperate islands. All recent projects included research components in order to inform management strategies. Here we summarize the main research findings and management recommendations, using the case of Isabel Island to illustrate how efficacy and efficiency of conservation initiatives can be improved when informed by directed research.

KEY WORDS: invasive species, Isabel Island, Mexico, modelling, rat, *Rattus rattus*, restoration, rodent eradication, ship rat

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INTRODUCTION

There are 25 biodiversity hotspots (areas with exceptional concentrations of endemic species and unprecedented loss of habitat) at the global scale; 16 of these are in the tropics and 9 are mainly or completely made up of islands, including most tropical islands (Myers et al. 2000). Given the current biodiversity crisis (Thomas et al. 2004), investing in the conservation and restoration of tropical islands is an urgent matter.

The 500+ rodent eradications on islands worldwide (Howald et al. 2007, Parkes et al. 2011) reflects the high relevance given by the conservation community to this tool as an effective approach to restore island ecosystems (Towns et al. 2013). However, the limited achievements in the tropical islands mean that fewer efforts have been done to restore some of the most biodiverse portions of the planet. Furthermore, the apparent lower eradication success rate in the tropics, compared to temperate regions, has raised concern and highlighted gaps in knowledge.

The ~400 Mexican islands >5 ha (INEGI 2005) are among the richest insular territories, as Mexico is a megadiverse country with an important tropical area (Mittermeier et al. 1999). Most of these islands are protected and have low levels of human disturbance (Aguirre-Muñoz et al. 2011). Nevertheless, invasive mammals have caused at least 16 extinctions of vertebrates on Mexican islands and remain the main threat for many more (Aguirre-Muñoz et al. 2011). The need for a comprehensive restoration program was therefore clear, including research to fill in some of the gaps regarding the inherent challenges of working in tropical environments (Wegmann 2008, Varnham 2010, Griffiths et al. 2011). The Grupo de Ecología y Conservación de Islas (GECI) launched such a program about a

decade ago, incorporating large scale and complex experiments, taking advantage of real management projects and the significant investments involved. Among other outputs, this vision led to a doctoral thesis (Samaniego-Herrera 2014) with a strong applied conservation focus towards improving rodent eradications on tropical islands. This paper summarizes the main research findings and management recommendations of this doctoral research, illustrated by a case study: eradication of the ship rat (*Rattus rattus*) from Isabel Island.

RESEARCH UNDERTAKEN ALONGSIDE ERADICATION PROJECTS

The research in which the recommendations below are mainly based on was published as follows: Samaniego-Herrera et al. (2011) review the advances Mexico has made and the challenges it faces in relation to invasive rodent eradications, which assisted further research. An updated list of the Mexican rodent eradications conducted up to 2013 is shown in Table 1.

Samaniego-Herrera (2014) provides detailed information on the population dynamics of two invasive rodent species, house mice (*Mus musculus*) and ship rats, on tropical archipelagos. Also described are the diet and trophic niche of these insular populations, as well as monitoring of ground-dwelling invertebrates on islands with different invasion status (rat-infested, mouse-infested, or rodent-free). Finally, clear evidence of land crab vulnerability to invasive rats is presented, as well as seasonal patterns of land crab activity (crucial to assess interference with eradication procedures), updating and confirming the trends described by Samaniego-Herrera and Bedolla-Guzmán (2012).

Samaniego-Herrera et al. (2013) describe a novel

Table 1. Rodent eradications on Mexican islands up to 2013.

Island	Area (ha)	Species removed	Date of eradication*	Principal method	Ecosystem type
San Roque	35	<i>Rattus rattus</i>	1995	Bait stations	Temperate (arid)
Rasa	57	<i>Rattus rattus</i> <i>Mus musculus</i>	1995 ¹	Bait stations	Temperate (arid)
San Jorge (3 islands)	<40	<i>Rattus rattus</i>	2000	Bait stations	Temperate (arid)
Farallón de San Ignacio	17	<i>Rattus rattus</i>	2007	Aerial broadcast	Temperate (arid)
San Pedro Mártir	267	<i>Rattus rattus</i>	2007	Aerial broadcast	Temperate (arid)
Isabel	82	<i>Rattus rattus</i>	2009 ²	Aerial broadcast	Tropical (dry-wet)
Pájaros	2	<i>Mus musculus</i>	2011	Hand broadcast	Tropical (dry)
Pérez	11	<i>Rattus rattus</i>	2011	Hand broadcast	Tropical (dry)
Muertos	16	<i>Mus musculus</i>	2011	Hand broadcast	Tropical (dry)
Cayo Norte Menor	15	<i>Rattus rattus</i>	2012	Aerial broadcast	Tropical (wet)
Cayo Norte Mayor	29	<i>Rattus rattus</i>	2012	Aerial broadcast	Tropical (wet)
San Benito Oeste	400	<i>Peromyscus eremicus</i>	2013	Aerial broadcast	Temperate (arid)

* Work conducted by Grupo de Ecología y Conservación de Islas (GECI) except when indicated otherwise.

¹ Project conducted by J. Ramírez-UNAM.

² First eradication attempt (1995), conducted by C. Rodríguez-UNAM, failed (Rodríguez et al. 2006).

Spatial survey model that improves the confirmation process after an eradication operation, by providing an objective probability of eradication success and reducing the time to such declaration.

ERADICATION RECOMMENDATIONS

In Mexico, 14 islands, 6 of them tropical, have been cleared of invasive rodents (Table 1) and several more are scheduled for treatment. As the vast majority of the work has been conducted by the same Mexican organization (GECI), the experience gained has facilitated scaling up of projects and work on bigger islands – such as San Benito Oeste (364 ha) in the Pacific – and complex tropical islands – such as Banco Chinchorro (rainforest/mangrove archipelago) in the Caribbean, where the smaller islands have been cleared of rats and the largest (539 ha) is scheduled for an eradication operation in 2015. Intensive and extensive research (on target and non-target species), monitoring, environmental education and community engagement have accompanied most of these projects.

As rodent eradications on tropical islands are globally considered a major challenge, we aimed to contribute by sharing some lessons we have learnt in recent years. The following recommendations for future rodent eradications were derived from the implementation of eradications on different types of tropical islands (Table 1) and from the research conducted as part of those projects (see above). Our general approach for eradication operations consists of adjustments of New Zealand guidelines, especially from the NZ Department of Conservation (Broome et al. 2014) and the Pacific Invasives Initiative (PII 2011).

The Planning Phase

Justification of the Projects

Be clear about the need and urgency of restoring a specific island, in terms of local impacts but also considering how restoring habitat could enhance larger restoration goals. Despite the numerous examples of negative impacts caused by invasive rodents in most environments, there are some instances where rodent eradication has been regarded as ‘not urgent’ (e.g.,

Quillfeldt et al. 2008). However, larger restoration goals, such as restoring habitat for specific endangered species despite their original location, should be evaluated. Considering also the wide distribution of invasive rodents on islands and the limited resources for restoration, information on rodent population dynamics and local impacts is essential to inform prioritisation tools and to improve justification of particular projects (Ringler et al. 2014). Likewise, this information facilitates the selection of indicator species to be monitored (before and after the eradication), as well as several aspects of the implementation itself (e.g., season).

When planning management actions based on results from other tropical islands, keep in mind that the tropics is a very heterogeneous region. Rodent populations on tropical islands vary greatly, depending on factors such as climate and the presence of predators (Russell et al. 2011). Overall, rodent populations on wet tropical islands can be 10 times higher than the average density on temperate islands. Rodent abundance on dry tropical islands is also expected to be higher than on temperate systems but not as high as on wet tropical islands. For example, maximum ship rat densities varied from 66/ha on Cayo Norte Island (wet tropical) to 38/ha on Isabel Island (wet-dry tropical) and 19/ha on Pérez Island (dry tropical). On the other hand, rodents on islands with significant predators such as cats may be less abundant or have smaller body size, which may in turn limit their impacts. To avoid any indirect effects that may induce rodent population increases, eradication of all invasive mammal populations at the same time is desirable (Russell et al. 2011).

Regarding rodent population fluctuations, a decrease in capture success does not necessarily equate to a decrease in abundance, especially on islands with high densities of large land crabs (e.g., *Cardisoma* spp.). If the average body condition of rodents and the juvenile to adult ratio remain similar, the decline in capture rates may be due to a behavioural change. For example, ship rats on Cayo Centro appear to be more arboreal during the wet season, which makes them harder to trap, due to monopolisation of resources at ground level by large blue

crabs (*C. guanhumi*) that are superabundant during wet seasons.

Rodent diet and local impacts on native species vary according to the invasive rodent and the availability of resources. As documented for higher latitudes, impacts from rats on tropical islands are in general more severe than impacts from mice. In contrast with temperate regions, tropical islands clearly dominated by land crabs appear to have less potential to support other large invertebrates, which are more impacted by rodents (St Clair 2011). This means that rodent impacts on invertebrates may be concentrated on land crabs (the largest invertebrates), which in turn appear to differ in their vulnerability to rat predation (Samaniego-Herrera and Bedolla-Guzmán 2012).

Constraints

Start small, scale up, collaborate with others and share the results, successful or not. Traditionally, island size, topography, and native species are considered to be the main potential constraints for successful eradication. For temperate islands it seems that size is now mostly a financial issue, despite complex logistics, whereas for tropical islands there is a lag in terms of success of larger attempts. The largest temperate rodent eradication project, Macquarie Island (12, 875 ha) in 2011, was successful, whereas the largest tropical project, Henderson Island (3,700 ha) in 2012, failed. Until 2013, the largest successful tropical rodent eradication was conducted on Hermite Island (1,000 ha). More information on global eradication projects can be found online (Keitt et al. 2011).

Island topography and vegetation, especially on the perimeter, needs careful consideration. Mangrove islands have emerged as being especially challenging and require special treatment. Topography influences the details of the baiting technique employed (e.g., the direction of the flight lines of the helicopter distributing baits). The height and composition of the coast determine if special treatment is required along this area. Cliffs and rocky shores are generally treated with higher bait densities, as they are a primary rodent habitat. In contrast, on flat coral islands with wide beaches (e.g., Arrecife Alacranes) the perimeter habitat is of lesser concern. However, on flat islands with mangroves (e.g., Banco Chinchorro) the complexity of the perimeter habitat is a major concern. High ship rat activity was detected in mangrove areas located in permanent flooded terrain. However, Mexico has achieved success in eradicating ship rats and house mice in all of these ecosystems. Pre-operational planning supported by research, monitoring, and experimentation have been the key to success.

While assessing eradication feasibility, obtain substantial and recent information on native species and their fluctuations. For two main reasons, native species must be considered while deciding the eradication technique (ground or aerial) and the season for implementation: firstly, to minimise non-target impacts (e.g., disturbance and poisoning); secondly, to minimise interference with the operation itself (e.g., bait consumption by land crabs). The first aspect needs to be evaluated on a case-by-case basis, and information is

required on non-target species presence and basic population dynamics. The second aspect (interference) can be more easily generalised: Substantial interference by land crabs (to the point where rodent eradication has failed) has been documented (Wegmann 2008, Varnham 2010). However, the level of interference usually varies, depending on both season and type of land crabs. Even on islands in the wet tropics, land crab activity usually decreases during the dry season, as is the case on Banco Chinchorro. As for types of land crabs, it is important to note that Brachyuran land crabs are capable of consuming and removing larger quantities of bait per time unit than Anomouran (hermit) crabs. Also, in general, the larger the land crab species, the larger the capacity for bait consumption.

The Implementation Phase

Season for Eradication

Identify the dry season; ideally plan rodent eradication for the driest month. For New Zealand islands, winter is the preferred season for rodent eradication, as resources are low and consequently so are the numbers and the body and breeding condition of rodents (Broome et al. 2014). There is also the advantage of reduced impact on non-target species, as many of them are either absent or not breeding during winter. For tropical islands, where no real winter occurs and breeding may not cease, the end of the dry season is preferred for similar reasons. This is the approach GECI has been testing, so far with success on six tropical islands (including both dry and wet ecosystems). On dry tropical islands, environmental changes are more obvious (e.g., Isabel Island), but even on wet tropical islands (e.g., Banco Chinchorro) most of the following points apply. It can be summarized that during the dry season:

- 1) There is a higher probability of rodents having sub-optimal body condition and, for ship rats, spending more time at ground level. Rodent numbers and juvenile-to-adult ratios do not appear to change significantly throughout the year.
- 2) The availability of alternative food sources (other than bait) and fresh water for rodents generally decreases. Identification of nesting periods of small seabirds requires special attention so that they can be avoided. There are examples of successful eradications with little or no impact on non-target species on islands where large seabirds nest year-round.
- 3) Small invertebrates are generally less abundant, which means less bait fragmentation and consumption.
- 4) Land crabs are less active and, if conditions are dry enough, they will remain in their burrows even when rodent bait is laid on the ground. Field experiments on Banco Chinchorro have shown that even on wet islands the rate of bait consumption decreases significantly in the dry season. In addition, bait pellets remain in good condition for longer periods (e.g., weeks instead of days).

Bait Applications

Two bait applications can achieve rodent eradication as long as sufficient bait is laid on the ground. On tem-

perate islands, 2 bait applications about 1 week apart are recommended. For the tropics, a third application and/or a longer interval has been suggested and tested. However, for many cases and countries, the additional cost associated with a longer interval between bait applications or an extra application could be the difference between an operation being affordable or not. Therefore, it is crucial to analyze under which circumstances such baiting strategies are required for the tropics. Based on the rodent research and the successful eradications described in Table 1, it can be concluded that 2 bait applications 7-10 days apart can be sufficient to eradicate breeding populations of house mice or ship rats. In other words, the mere presence of juveniles and pregnant females at the time of baiting does not translate to eradication failure.

Furthermore, diet analysis on Alacranes Islands showed house mice and ship rats were feeding on a wide variety of items only days before their eradication. This means that all rodents, even pregnant or lactating females (certainly present), chose to eat bait although they had several alternative natural options available.

The Confirmation Phase

Rapid Confirmation of Rodent Absence

If feasible, confirm success immediately after the eradication operation. On small islands it is relatively easy and inexpensive to statistically assess rodent eradication success immediately after the baiting operation using the spatial-survey model described by Samaniego-Herrera et al. (2013). Since standard guidelines for the tropics are still being evaluated, the relevance of measuring the efficacy of the approach taken in each project is high. For the 6 Mexican rodent eradications conducted in the tropics between 2009 and 2012, being able to rapidly confirm success facilitated each subsequent project.

Indicator Species

Conduct research on rodent diet and impacts as well as on key native species. Information about rodent diets, obtained from classical diet analyses, stable isotope analyses, or molecular analyses, can all assist the selection of species indicators of ecosystem recovery. Stable isotope research results from Mexico confirmed that house mice and ship rats are generalist and opportunistic, consuming whatever resource is most readily available. In contrast with temperate islands, invertebrates (e.g., beetles), although consumed by both ship rats and house mice, were not a major component of the diet of rodents on tropical islands. This coincides with the overall moderate change in invertebrates found by pitfall trapping before and after the eradications. This may be partially due to the low diversity and abundance of large invertebrates, which in turn may be related to the dominance of land crabs. Land crabs, despite being abundant, can be dramatically impacted by rodents. However, it is not clear how vulnerability changes among crab species, life stages, and between seasons.

CASE STUDY: ISABEL ISLAND

Isabel Island was the first tropical island targeted for a

rodent eradication in Mexico. The first attempt was carried out in 1995 by a group of researchers familiar with the island but lacking experience in invasive species management. This attempt failed (Rodriguez et al. 2006). In 2009 a second attempt was carried out by GECEI, this time with success (Samaniego-Herrera et al. 2013). Details of the second attempt are described below, and a comparison of the approaches taken by each attempt is shown in Table 2.

Island Description

Isabel Island (82 ha) is located in the mouth of the Gulf of California, Mexico (21°51' N, 105°54' W). It is of volcanic origin, is topographically complex with cliffs and rocky beaches, has a maximum altitude of 85 m above sea level, and the main crater is now a hyper-saline lake. The island supports a rich vertebrate (reptile and avian) community and it is internationally recognized as an important seabird breeding site for 9 species (CONANP 2005), which justified its declaration as a National Park in 1980 and its inclusion as part of the World Heritage Site "Gulf of California Islands." Isabel Island is covered with tropical deciduous forest dominated by *Crataeva tapia* and *Euphorbia schlehtendalii*. It has two distinctive seasons: dry (December-May) and wet (June-November). As is typical for tropical island ecosystems, land crabs are present: in this case, the hermit crab *Coenobita compressus*, the red crab *Johngarthia planata*, and the Mexican crab *Gecarcinus quadratus* (Samaniego-Herrera and Bedolla-Guzmán 2012). Their presence affects the way rodent eradications can be conducted, as crabs are avid bait consumers.

Bait Application

Bait used was the rodenticide CI-25, developed by Bell Laboratories (Madison, WI) especially for ecological restoration purposes, and proven successful on several projects in North America (e.g., Samaniego-Herrera et al. 2011). CI-25 consists of green, unwaxed, compressed grain, 2-g extruded pellets containing 25 ppm brodifacoum (second-generation anticoagulant).

Because of the size and ruggedness of Isabel Island, the most feasible option for achieving eradication was to disperse bait pellets using the aerial technique (Towns and Broome 2003). Risks of failure are lowest if 100% of the island is treated aerially. However, due to a potential conflict with a research project on blue-footed booby (*Sula nebouxii*) behavior, a small percentage of the island had to be treated by hand broadcast. The effort reported for this includes on-site preparation work (delimitation of external polygons and transects to be walked for bait dispersion), hand broadcast, and clean-up work (pick-up of landmarks) (Table 3). At each of the 2 bait applications, 1 week apart, the island was approximately covered as follows: 90% aerially, 5% manually, and 5% not treated because it is a lake (Table 3). For the aerial applications, bait was broadcast by helicopter using a stainless steel spreader bucket (Helicopters Otago, Mosgiel, New Zealand). The helicopter (Bell 206 Jet Ranger from Aspen Helicopters, Oxnard, CA) was equipped with a DGPS. To track the aerial work, a 60-

Table 2. Comparison of two rat eradication attempts on Isabel Island, Mexico.

	First Attempt 1995	Second Attempt 2009
Main eradication technique	Bait stations	Aerial broadcast
Season for baiting	Wet	Dry
Land crab interference	High	Low
Pre-eradication research and monitoring	None	Extensive for target and non-target species
Experience of operators	Low	High
Expert consultation	Yes	Yes
Deviations from plan	Major	Minor, mitigated
Operational result	Failure	Success
Reference	Rodriguez et al. 2006	This study

Table 3. Details on bait utilized, effort required and surface covered during the rat eradication operation on Isabel Island on 1st and 7th May 2009 (first and second drop, respectively).

Aerial Broadcast	1 st Drop	2 nd Drop	Sum
Bait broadcasted (kg)	1,248.5	908	2156.5
Mean broadcasted rate (kg/ha)	13.01	7.6	20.61
Total helicopter flying time (hr:min)	2:10	1:40	3:50
Effective time broadcasting bait (hr:min)	0:27	0:31	0:58
Surface covered (%)	87.3	90	177.3
Hand Broadcast on Non-flying Zones	1 st Drop	2 nd Drop	Sum
Bait broadcasted (kg)	60	40	100
Mean broadcasted rate (kg/ha)	12	8	20
Total time required inside polygons (man-hr)	243	114	357
Effective time broadcasting bait (man-hr)	130	90	220
Surface covered (%)	7.7	5	12.7

Note: Surface covered by aerial and hand broadcast at each drop sums 95%; the remaining 5% corresponds to a lake that was not treated.

Table 4. Comparison of mean bait density in 4 monitoring sites, estimated by direct weighting on plots and by GIS, for each bait drop (1st and 7th May 2009) of the rat eradication operation on Isabel Island. Targeted bait density: 12 kg/ha and 8 kg/ha and, respectively.

Habitat	1 st Drop		2 nd Drop	
	Estimated by Plots (kg/ha)	Estimated by GIS (kg/ha)	Estimated by Plots (kg/ha)	Estimated by GIS (kg/ha)
Forest 1	12.46	12.51	7.48	6.79
Forest 2	10.65	12.39	6.51	5.76
Open ground 1	10.25	11.19	5.96	6.17
Open ground 2	11.99	10.99	7.56	7.83

-cm per pixel resolution QuickBird satellite multilayer image (DigitalGlobe™, Longmont, CO) was used and a GIS was built. When applying bait at the coastline, a deflector was used to avoid bait spread into the ocean. Because the intertidal zone represents prime habitat for rats, extra bait was spread by boat and by helicopter (above the islets) the day after each aerial drop. GIS estimations of bait deployed by helicopter were validated by on-ground sampling (Table 4), hours after the aerial baiting. The average bait application rate was 20.61 kg/ha (pooling drops), which was similar to the targeted rate of 20.0 kg/ha. This targeted rate was slightly higher than the usual for temperate islands, to compensate for the “crab factor,” (i.e., continuous interference through bait consumption) (Wegmann 2008). However, the interfer-

ence was minimal, proving that operating during the dry season improves efficiency of eradication procedures.

Timing of bait application was determined mainly by climate, as the end of the dry season corresponds with low activity for both seabirds and land crabs, and reduced rat-body condition (due to limited natural food). The eradication operation was carried out on the 1st and 7th of May 2009 (first and second bait drop, respectively). The total cost of the baiting operation was US\$268,421 (see Samaniego-Herrera et al. 2013 for cost breakdown).

Underwater monitoring (by diving) was conducted in the sub-littoral zone, simultaneously with aerial baiting of the island perimeter. The diving survey focused on assessing presence/absence of bait pellets and recording reactions of marine fauna to the pellets. Results yielded

<1 pellet/10 m², which sank immediately and disintegrated by wave action within few minutes. No marine animals were recorded as consuming pellets.

Rodent Monitoring

Prior to eradication, several monitoring techniques were applied to: 1) ensure the black rat was the only rodent species present; 2) obtain ecological information on the rat population; and 3) estimate spatial detection parameters from local rats. Three independent transects (280 m) were set on 6 occasions (2007-2009). Each transect included 15 trapping points 20 m apart, each including 3 devices: 1 Tomahawk trap (Tomahawk Live Trap LLC, Hazelhurst, WI), 1 Sherman trap (H. B. Sherman Traps, Inc., Tallahassee, FL), and 1 WaxTag[®] (peanut-flavored wax chew block, Pest Control Research, Christchurch, NZ). The total capture effort was 1,170 trap-nights and 585 tag-nights. All captured rats were humanely killed with the anesthetic Pentobarbital sodium. Ship rat was the only mammal species recorded. Prior to eradication, a total of 284 rats were caught. Capture success varied slightly between years and habitat types.

A 10 × 10 trapping grid with 20-m spacing was set in the middle of the forest in April 2009 to conduct a capture-mark-recapture study 2 weeks before the rat eradication. A total of 100 Tomahawk traps were opened and baited with peanut butter each afternoon, then checked and closed each morning for 6 days. Total trapping effort resulted in 600 trap-nights. Each day, all rats caught were measured and individually marked using numbered monel ear tags, then released at their capture site. Population parameters were estimated with the spatially explicit capture-recapture software Density 4.4 (Efford et al. 2004). Capture success resulted in an average of 51.8 ± 4.5 captures per day; 159 individuals were marked and released. Population parameters for April 2009 were: rat density = $38.4 \pm 3.2/\text{ha}$; $g_0 = 0.169 \pm 0.022$; $\sigma = 14.8 \pm 0.8$.

Finally, radio-telemetry was employed to monitor time to death during the actual eradication. One week before the first bait application, 14 adult rats (7 females and 7 males) were trapped in dispersed locations, fitted with radio-collars, and monitored daily. All individuals were recovered and dissected to confirm cause of death. The first rat died at Day 3 after the baiting, while the last one died at Day 11. Dissections confirmed poisoning as the cause of death in 100% of the rats.

Evaluation of the Eradication

Two approaches were used to confirm success of the rat eradication operation: the traditional “wait and see” approach (by conducting live-trapping within 24 months after the baiting), and a novel spatial-survey model to quantify the probability of eradication given no detection of rodents. The 99% (“high percentage”) of probability of success from the spatial-survey model coincided with the result of the “wait and see” approach (zero rat sign after 2 years), as both indicated that the 2009 rat eradication was successful. Details on both approaches were described by Samaniego-Herrera et al. (2013).

Lessons Learnt

On Isabel Island, rodent monitoring started with three types of detection devices as rodent species present was unclear. Once we were confident that *R. rattus* was the only species present, adjustments were made. Sherman traps were removed early in the project and Tomahawk traps used in a later phase. The use of WaxTags[®] for post-baiting absence confirmation allowed island-wide monitoring in a cost-effective way, reducing operational cost and increasing confidence in data when combined with Bayesian analysis.

Having non-flying zones without a solid ecological argument was considered by the restoration project team to be a high-risk practice. This restricted maneuverability of the helicopter, added time and complexity to the operation, required extra resources (especially staff and equipment), and created unnecessary disturbance around seabird colonies. However, the requirement of having such zones allowed documentation of the much slower capacity of the hand-broadcast technique per hectare when compared to the aerial technique (1,039 man-min/ha vs. 0.32 min/ha, respectively). Hand broadcast is only recommended as the main eradication technique when aerial procedures are not feasible (Broome et al. 2014) or for small and easily accessible islands where start-up aerial cost would be prohibitive (see examples in Table 1). Seabird monitoring conducted as part of the broader restoration project documented no major negative impacts in any of the colonies on Isabel Island, regardless of the baiting method. In other words, operational risk, resources, and seabird disturbance could be saved in future projects by treating 100% of the islands with aerial procedures.

An important application of the spatial-survey model for rapid assessment of an eradication operation, developed for the Isabel Island case, is the *a priori* prediction of the survey effort required to meet a target probability of success immediately following an operation. Since the Isabel Island operation, this spatial-survey model has been used in subsequent projects in Mexico, greatly increasing confidence during rodent eradications in the tropics. This also accelerates the evaluation of the adjustments made to each operation, creating a positive synergy and thus facilitating each future project.

Isabel Island represented the 8th successful rodent eradication in Mexico. The rigorous planning and confirmation procedures have given funders and authorities confidence of success, overcoming the “can’t-be-done” feeling left by the 1995 failed attempt. The accumulated experience has also facilitated the implementation of other recent projects, including 5 more on dry and wet tropical islands (Table 1). Operational details of these projects will be published elsewhere. The (ongoing) long-term research program on target and non-target species is providing inputs to improve both efficacy and efficiency of eradications in the tropics, as well as adding to the documented benefits of such actions for the recovery of tropical ecosystems. Finally, results are also facilitating the improvement of biosecurity measures, which is especially important on inhabited islands where risks are greater.

CONCLUSION

Investing in tropical island restoration is imperative for the conservation of global biodiversity. Overcoming the challenges of eradicating rodents from such islands is greatly enhanced by combining science and management. The results of extensive research and restoration actions on Mexican tropical islands, partly mentioned here, may contribute to the international initiative of improving success rates of eradication on such type of islands. Rodent eradications on tropical islands have inherent challenges which vary between dry and wet ecosystems. However, more and larger tropical islands can be cleared of rodents if directed research informs planning, implementation, and biosecurity strategies

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