A Review of the Desecheo Island Rat Eradication Project

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Reviewers: Derek Brown[1], Bernie Tershy[2]

1. Island Management and Pest Eradication Consultant, 102 Cullensville Road, RD1 Picton 7281 New Zealand.

2. Adjunct Professor, Coastal Conservation Action Lab, Center for Ocean Health, 100 Shaffer Rd. Santa Cruz, CA 95061

Executive Summary

An attempt was made in March 2012 to eradicate the ship rat *Rattus rattus* from 120 hectare Desecheo Island in Puerto Rico using aerially sown rodenticide bait containing brodifacoum, with supplementary use of bait stations. The eradication was deemed to have failed with the discovery of surviving rats several months later.

Review of eradication projects, successful or not, is critical to improving eradication practice so we commend the Desecheo project stakeholders for commissioning this important review. We were tasked with three objectives; analysing the possible reasons for the failure; assessing whether the strategy, design, planning and implementation were adequate to provide a reasonable probability of success; and what lessons can be drawn from the project toward a future eradication attempt on Desecheo. We were constrained by neither of us having visited Desecheo Island, and also by operating within a short timeframe. Thus, we were limited to examining available project documentation and conducting interviews with key project personnel. The review is as complete as possible given these constraints. It represents the authors' opinions based on the information available to us.

The project failure could have derived from a single factor or a 'perfect storm' of several overlapping issues. We consider the most likely causes of failure include: inadequate overall or localised bait rates and/or bait availability, accentuated by known non-uniformity of bait distribution particularly in the critical first bait application; unusually wet weather patterns promoting an abundance of alternative natural foods during bait application; or rat breeding during the operation causing either temporal and/or spatial unavailability of bait to juveniles emerging from natal nests, or more speculatively behaviour-related bait avoidance by some breeding females.

We examined the planning, design and implementation of the project. Bait rate evaluations did not allow sufficient margin for possible temporal or spatial variances over the island and did not focus on the 'extreme' results which needed to be catered for in eradication design. Data collected in previous years with different weather patterns could have been misleading on rodent density and breeding cycles and on bait competitor activity or abundance. Implementation strategy was significantly affected by maximum permissible bait rates and other regulatory requirements and was clearly less than ideal as a result, with identifiable concerns with both the comprehensiveness of the coverage and the bait rates. Critical review of some plans was insufficient, and where advice was received it was not always addressed. A more experienced project manager, and less diffused responsibilities within the project, may have increased the level of 'ownership' of the project's technical aspects. GIS analysis of the first application should have identified areas for re-treatment, and this information should have been acted upon.

A range of recommendations are provided, of relevance to any possible future eradication attempt on Desecheo and for tropical island rodent eradications in general. Development of best practice documents for tropical eradications would resolve many issues encountered here. Despite the identified shortcomings in planning and operational matters, the project came very close to succeeding. If due attention is given to the issues identified and recommendations made in this review, we consider that a second eradication attempt for *Rattus rattus* on Desecheo Island has a high probability of success.

Table of Contents

Review Objectives

The authors were contracted by Island Conservation on behalf of the project partners to independently review the Desecheo Island rodent eradication project and attempt to answer the following three questions:

- What factors most likely contributed to the unsuccessful eradication attempt?
- Were the strategy, design, planning and implementation of the eradication and biosecurity program adequate to expect a reasonable probability of success?
- What lessons can be learned and applied to a future eradication attempt on Desecheo Island, including identifying any additional research needs?

Review Constraints

The authors have not visited Desecheo Island and thus this review is based on examining available project documentation and conducting interviews with key project personnel. We were further limited by operating within a relatively short timeframe. The review is as complete as possible given these constraints, and represents the authors' opinions based on the materials and information available to us.

Background

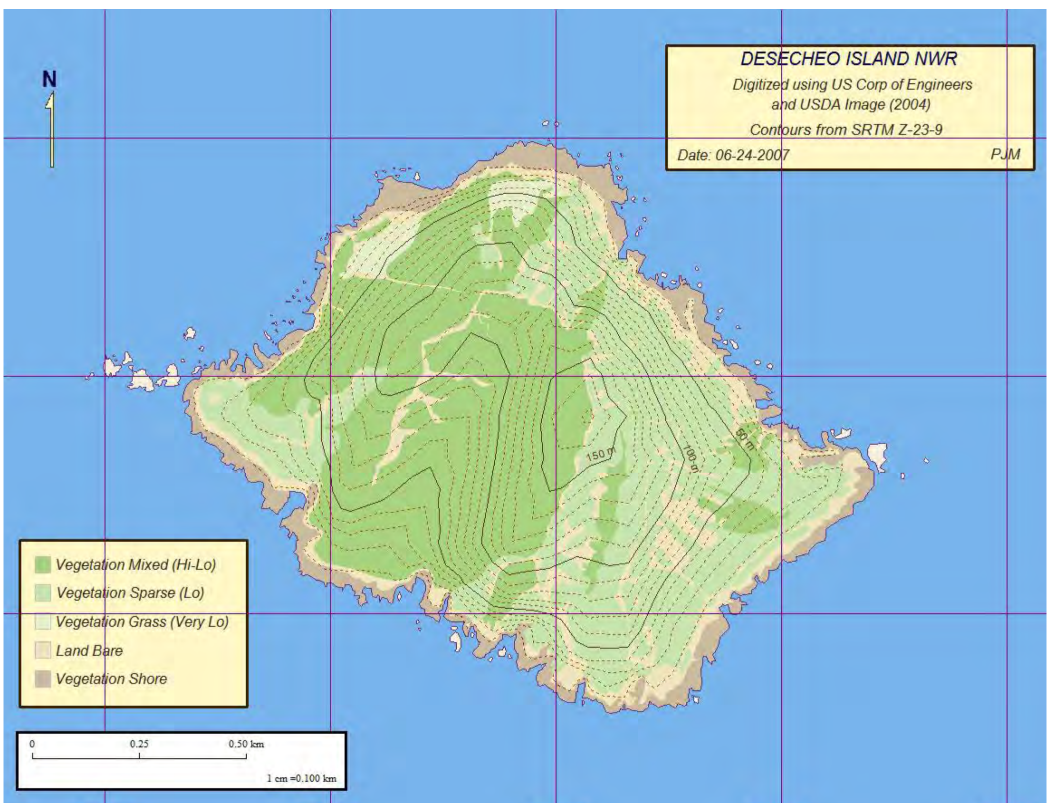
In 2012, the United States Fish and Wildlife Service (USFWS) Caribbean National Wildlife Refuge and Island Conservation (IC) undertook a project to eradicate rats (*Rattus rattus*) from Desecheo Island, Puerto Rico. The overarching goal of the project was to restore and protect Desecheo Island's historical seabird colonies, subtropical dry forest habitat and other native flora and fauna, and to support the mission of the USFWS to manage protected areas.

Desecheo is a 296 acre (~120 ha) semi-arid, uninhabited and steep island located 13 miles from the mainland of Puerto Rico. It was designated a National Wildlife Refuge in 1976 and is managed by the USFWS.

A rat eradication operation took place in March 2012, using a helicopter to aerially spread two island-wide applications of rat bait containing brodifacoum, supplemented by bait stations in some areas. A surviving rat was captured and killed 10 days after the second bait application. No rats were observed during a short site visit for reptile work in October 2012, but during fieldwork in March 2013 observations of surviving rats were made by the field team, and one rat was captured. Motion-detecting cameras at three geographically distinct locations also detected rats. DNA analysis has confirmed that the captured rat was part of the original population, not a new arrival. It is concluded that some rats survived the baiting efforts, and the eradication failed.

Review of eradication projects, whether successful or not, is critical to improving eradication practice. The project partners should be greatly commended for enabling a thorough and detailed external review of the Desecheo Island rat eradication project.

Desecheo is just one of several tropical rat eradication projects that have failed in recent times, including Wake Atoll in the central Pacific, Henderson Island in the Pitcairn Island group, and Enderbury Island in the Phoenix Islands of Kiribati. Cumulatively these results have taken the eradication community by surprise. Each operation can be analysed and criticised with the benefit of hindsight, but in light of the above, Desecheo must not be seen as an isolated case. Each of these islands eradication projects has its own unique circumstances, but there may be similarities that could be informative if each project is reviewed. Collectively it appears that eradication practitioners may not yet have identified (and therefore have been unable to address) some key aspects to maximising eradication success on tropical islands, and there is obviously more to be learned by everyone. We hope this review goes some way to assisting in the process by which the rodent eradication community as a whole develops and refines eradication best practice and methodology for future tropical island projects.



Map 1. Desecheo topography and vegetation.

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Review Objective 1. What factors most likely contributed to the unsuccessful eradication attempt?

There are just two possibilities for rats still being present on Desecheo Island:
1) the eradication attempt failed, or
2) the biosecurity program failed and rats re-invaded post eradication.

DNA comparison from rats caught before and a single rat caught after the eradication support a failed eradication. This finding is not conclusive because only one individual from Desecheo was analysed post eradication and no comparison was made with individuals from other potential source populations. While reinvasion cannot be entirely discounted, it is unlikely.

Eradication failure is therefore the logical conclusion.
There are only two possible reasons for eradication failure, either:

1. All rats **could not** eat a lethal dose of bait; or,
2. All rats **would not** eat a lethal dose of bait

These options can be further broken down into sub-categories which could explain why either of the above was not achieved on Desecheo:

1. All rats **could not** eat a lethal dose of bait because:

a. There was a gap in coverage. This could have been caused by

   (i) Gaps in the aerial application
   (ii) Gaps in the bait station operations
   (iii) Rats surviving in areas where bait could not reach them.

b. There was insufficient bait for all rats. Bait disappeared before some rats could access them (eaten by other rats or non-target species).

c. The rats had higher resistance than expected to the toxin in the bait.

d. The bait itself (or some of it) was not toxic enough.

2. Rats **would not** consume a lethal dose of bait because:

a. Some rats chose not to eat bait, or enough of it, either because of the palatability of the bait and/or the availability of natural or commensal food resources, and/or because of seasonal behavioural changes (e.g. breeding females)

b. For some rats there was a natural or learned aversion to bait stations.

This review focuses on these possible explanations and uses available evidence to identify the most likely contributors to eradication failure. This will answer the first review objective.

Detailed Examination of the Possible Causes

Gap in Coverage

<u>Gaps in the aerial application</u>

There were noted 'mishaps' in the first of the two aerial applications, where confusion led to the wrong-sized aperture disk being fitted into the bait bucket, meaning initial bait rates were much lower than desired. However, such instances have been relatively common-place in successful eradication projects, and on this project, GPS-linked monitoring quickly identified and remedied the problem. Interpretation of bait rates is made complicated and confusing here due to both 2D and 3D figures being used, a very unusual circumstance for eradication work. The first bait application achieved a 17.1 kg/ha (3D) average (~19.6kg/ha in 2D), as opposed to the 18 kg/ha (3D) target or the ~20kg/ha (2D) sow rate as stated in the Baiting Strategy. The second bait application was reportedly a lot smoother, achieving a 9.1 kg/ha (3D) average (or ~10.4 in 2D), very close to the 3D target of 9 kg/ha, and with no issues reported.

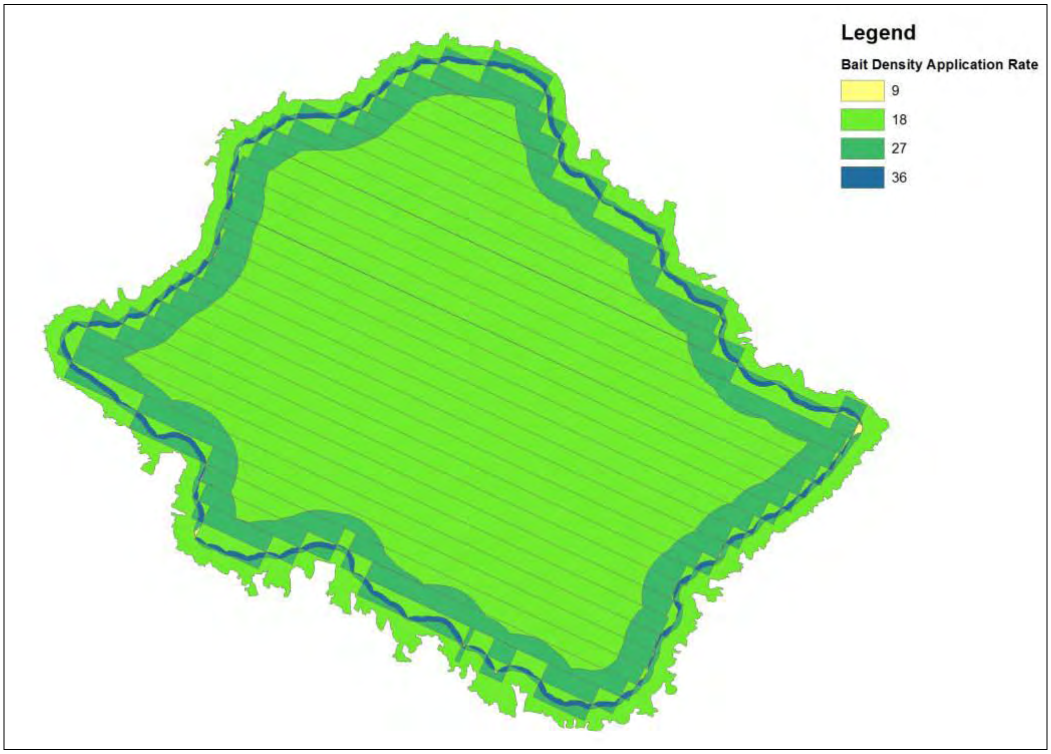
However, in the first application there were appreciable areas of the island that appeared to receive <9 kg/ha, *less than half the desired rate*, which is concerning. The most sizeable area (an estimate from the GIS map of ~200m x 40m) appears under-treated in the south-western section of the island, and there are multiple other smaller areas elsewhere on the island in a similar state . The actual coverage is represented in Map 3 below (Fig 9.4 from the Post-Operational Plan) and this can be compared with the idealised coverage as per Map 2 (Figure 6 from the Baiting Strategy Appendix B, of the Operational Plan).

The lack of apparent subsequent response to these perceived gaps is in contrast to the prescription in the Operational Plan: "*In cases where it is evident that a portion of the treatment area greater than 50 m^2 did not receive the required application rate, there will be supplemental, systematic broadcast by hand or helicopter to fill in the gaps*". The areas of under-treatment were not discovered until after the aerial bait application was completed. While the flight lines of baiting swaths were recorded and showed no gaps, the tracking system did not detect areas where swaths were not overlapping and therefore had only received 50% of bait intended. This was because the GIS manager used 'buffers' on the individual flight lines to detect any gaps, and did not look closely enough at the actual overlap of each swath. He admitted the mistake "*was a lesson*" for him. It was only when the GIS manager created the bait density map after operations had ceased for the day that the error became apparent. The issue was then informally discussed, but no decision was taken to fully treat the area with an additional application the following day. This was in our view an error in judgement, but there may have been few options available.

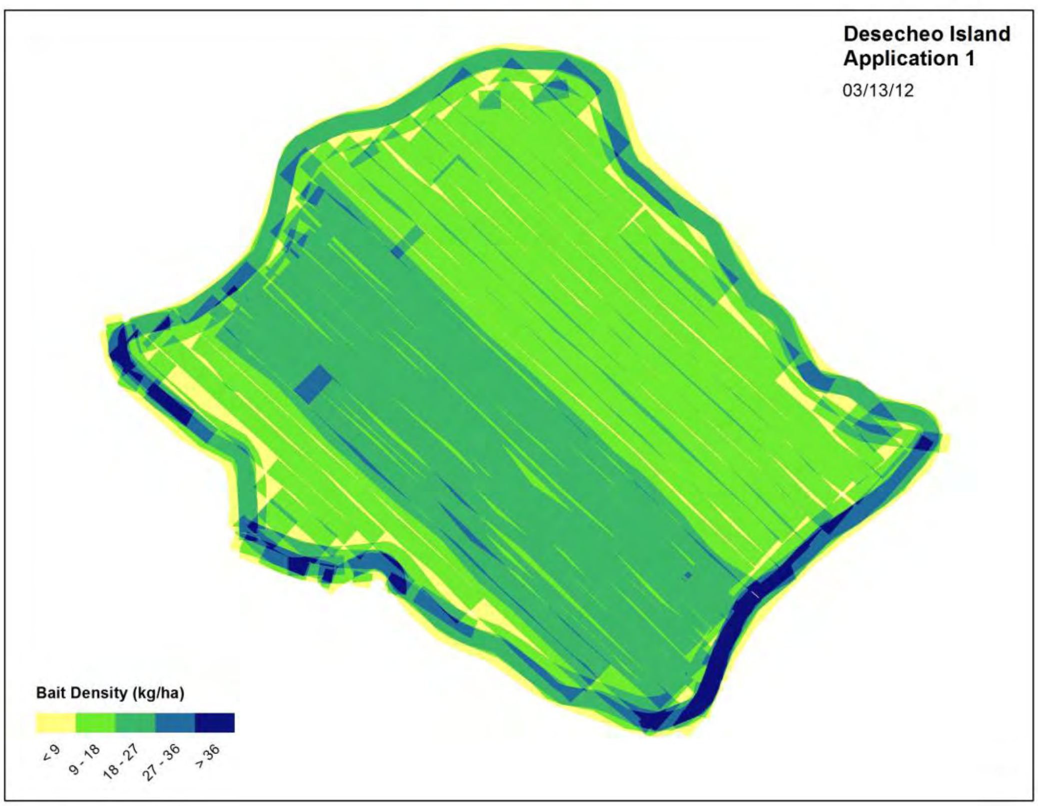
There was a small window between the maximum bait rate allowable (20kg/ha in 2D) and the bait used (~19.6kg/ha) which meant ~47.5kg was still available for use to redress (at least) the largest identified area of undersowing, either through GPS-guided hand-broadcast or aerial application. However, this highlights the issue of the current US regulations leaving very little leeway for immediate supplemental baiting where errors or undersowing are known to have occurred. In most other situations outside US jurisdiction, some of the bait intended for the second application or set aside as contingency could have been used to ensure comprehensive coverage of the island was achieved during the first bait application. For Desecheo, a total of 4584kg of bait was available for aerial application, but in the end only 3482.9kg was used, meaning that over 1100kg of bait was left unused, and this could have been used to address such problems but wasn't, largely due to regulatory constraints. If insufficient bait rates or areas of undersowing are (as we believe) a possible cause of operational failure, this could have had a fundamental effect on outcome of the project.

Also of considerable concern was the apparent starting and stopping of cross-island transects well inland of the coast (see Map 3, which clearly shows this). While this approach has been used successfully on a few other islands (e.g. Palmyra, Rat Island) these islands are notably different in topography and vegetation, and for Palmyra at least there could be much higher precision in placement of bait close to the coast. This approach is not standard practice elsewhere and nor do we believe it should be recommended practice, but accept that intention to comply with US regulations was the driving justification for this approach here. The steepness of some of Desecheo's coastal areas would have accentuated any possible 2D gap. While the original intent at Desecheo may have been to create desired overlap (see Map 2) this did not occur in practice. It appears the second coastal bait swath (desirably slightly further inland than the first) was flown by the pilot 'by eye' (as is always the case for coastal swaths) rather than via GPS-guidance. Here, it did not adequately buffer these areas as intended (as evidenced in Map 3). However, this should have been detected in subsequent GPS analysis and appropriately responded to. The stopping and starting of cross-island bait swathes well before the coast derived from operational methodology considered necessary to comply with regulations and ensure, as far as practical, bait did not enter the marine environment at the start and end of cross-island transects. The overall baiting rate restrictions also had a bearing in this decision because 'doubling up' of bait swathes in coastal area, meant that less would be available to spread elsewhere.

The project's draft baiting strategy was reviewed by the New Zealand Department of Conservation (DOC)'s Island Eradication Advisory Group (IEAG), a group with considerable experience in rodent eradication planning and implementation. In their review (IEAG 2011) they identified this issue and asked "*How will the coastal swath be connected with the cross island parallel swathes? There may be opportunity for gaps in bait coverage if these are not overlapped in some way*." The Baiting Strategy stated "*in order to minimize potential gaps in bait availability on the ground, the coastal swaths and interior swaths must overlap"*, but the first bait application clearly did not follow this edict.



Map 2. Idealised bait application rate map.
(*Figure 6 in the Baiting Strategy (Appendix B) of the Operational Plan*)



Map 3. Actual bait spread, Application 1. The yellow areas show where bait rates were less than half the planned rate. *(Fig 9.4 from Post-Operational Report).*

Best practice documents for eradicating rodents from islands have been developed by the New Zealand Department of Conservation, a world-leader in rodent eradications, specifically for their own operations on temperate-climate New Zealand islands. They have not been intended for use elsewhere, but the vast majority of principles and recommendations within them are applicable to all eradication projects, and in the current absence of any US or tropical equivalents are the most useful guides for best practice. While wording in the IEAG's eradication best practice document for New Zealand islands (Broome *et al.* 2011a) is unclear on this matter, the standard practice (and we believe implied best practice) of many previous eradications has been to apply bait on cross-island transects from coast to coast, to reduce the possibility of bait gaps caused by the inherent potential for errors from turning off the bait bucket's sowing too early.

While some operations have been successful using the approach applied on Desecheo, it is our view that attempts to comply with US regulatory requirements adds to the standard risk factors already present in eradication operations. We feel greater flexibility and allowances are needed within currently allowed maximum bait levels, for possible supplementary treatment in areas of concern because of the inherently higher risk of bait gaps using this approach. It is quite conceivable that in the instance of Desecheo, other possible events happened simultaneously to further compound any 'bait gap' issues. Such events could include a brief bait blockage or slowing in bait flow rate (caused by bridging of pellets); sowing without bait in the bucket; a momentary 'swing' of the bucket shifting the actual landing position of bait; or the still not entirely clear relationship between mapped coverage and actual coverage on the ground. Bait bucket 'swing' is caused by tight turns by the helicopter at the start or end of each line, and it is noted that sometimes this takes a few seconds to 'settle' to a steady orientation again. It is something that perhaps more attention needs to be paid to in future eradications (K. Broome *pers comm*). All these issues, if minor, would have been mitigated, or at least buffered, by a higher bait application rate.

Anecdotal observations from the island suggested that some steep sides of the valleys did not seem to have much bait (M. Pott *pers comm*), and these areas correlate to some degree with the woodland areas with high rat and crab densities and the associated risk of rapid bait disappearance. Figure 11.2 of the Post-Operational Report shows wide variance (and in some cases concerningly low) amounts of bait available within monitoring plots immediately after each bait application. This could be due to random variation but also suggests some unevenness of bait spread. There was some thought amongst interviewees that the perpendicular bait runs on Desecheo may have resulted in 'baiting shadow' on the lee face of the sharp narrow ridges, which could have contributed to localised lower densities of bait there. However, this effect should be counteracted by the next swath usually being applied from the opposite direction, but the 'on-ground' effect of swath orientation has rarely if ever been examined closely. The Desecheo Island operation is a rare example of an eradication project where aerial baiting lines ran *perpendicular* to many very steep topography faces. In New Zealand best practice documents, and in most eradication operations, inland 'cliffs' (cliffs are defined in best practice as areas over 50° slope) have bait applied by the usual cross-island lines then a *supplemental* application with the ideal *parallel* orientation (or contour flying for curved faces). Both baiting applications had a similar orientation of flight lines (only a 25° variation), which meant both applications applied bait at a roughly perpendicular angle to the steep valley faces. A small proportion of the island (<5ha, IC data) is over 50° but a high proportion of the island's area is over 30°. These areas had been identified beforehand as potentially problematic, and there had been some prior discussion of how these ridges were to be treated (e.g. IEAG 2011) but the suggested 'up-valley' supplementary sowing runs considered in early planning were not implemented largely due to the US regulatory restrictions on maximum bait rates - additional sowing in any area would mean these rates would be exceeded (K. Swinnerton *pers comm*). This appears to be a clear indication of how the restrictions on maximum bait rates or supplemental baiting prevented what should have been a standard procedure in eradications – where 'if at all in doubt' the area would either receive a pre-planned extra treatment, or it would be treated again with contingency bait.

The Post-Operational Report's Figure 9.5 shows that the second bait application had a much more even and comprehensive coverage than the first application. Thus we find nothing in the coverage in that application that may have contributed to the failure of the eradication. It may be considered that the thoroughness of the second application negated the known shortcomings of the first, and to an extent this is probably true. In our opinion, the problems with the first application probably significantly reduced both overall bait quantity and overall length of availability in some locations but the comprehensive coverage achieved during the second application could not rectify these issues of bait availability.

Many rat eradications (albeit largely in temperate climate zones) have succeeded with a single application of bait. It is thought that bait take by rats in a first or single bait application is accentuated by social or feeding interactions between individual rats – in effect a peer-induced encouragement to 'eat whatever they're eating'. Only more recently has a second application become standard, to reduce the possibility of any gaps in the first application. There has been an untested and perhaps widely held assumption that rats that missed accessing bait in a first drop will behave like the rats that didn't survive the first bait application, and therefore that the second application has a similar likelihood of attracting rats to the bait.

An alternate hypothesis is that any rats that survived the first bait drop are likely to be isolated from other survivors, and may radically alter their behaviour (e.g. reduced socially-induced responses, heightened neophobia, or restricted home ranges) in response to mass mortality, drop in rat density and the resulting increase in natural food availability per rat. While focusing on an invading rather than a surviving rat, Russell *et al*. (2005) support the possibility of such 'aberrant' behaviour – "*our findings confirm that eliminating a single invading rat is disproportionately difficult, not only because of atypical behaviour in the absence of conspecifics, but also because bait can be less effective in the absence of competition for natural food sources*". We accept this study is for an incursion not an eradication survivor, but the similarities and implications are too important to ignore – an isolated survivor cannot automatically be assumed to act the same way as all the rats in the first application. Papers like Russell *et al.* (2005) and Thorsen *et al*. (2000, highlighting difficulties in eradicating a new invasion of rats on an island in the Seychelles) indicate it may be generally a lot harder to target very low density of rats, and this possible factor should be evaluated more. To counter this, some evidence (e.g. Russell *et al*. 2008) suggests an isolated rat in incursion events [and by our interpretation possibly translatable to eradication events] can often - but critically not always - be enticed to a trap or poison (between only 36-71% of recorded instances depending on how data is interpreted), a very low figure compared to the 100% required for eradication.

There is no doubt that a second application has value as a safety measure, particularly in tropical situations where breeding may occur year-round, or where more than one rodent species exists. There is some scanty evidence that in some previous eradication projects that a second (or third) application of bait accounted for rats that survived the first application (e.g. Fregate Island, Seychelles P. Garden *pers comm*), but in prior successful eradications it is not usual to see rats surviving the first application. Our intended point is that the first application is absolutely critical to get right. There is clear evidence on Desecheo Island (from a live but moribund rat found 12 days after the 2nd bait application, and by possible bait station sign 15 or more days after the first aerial baiting) that some rats survived the first bait application.

There is a possibility (as identified on Wake Atoll) that bait sowing was being recorded when the bait bucket was in fact empty, but there is no evidence that this occurred on Desecheo Island. With multiple safeguards, such as overlapping every swath, and the double application there should be no 'gaps' in coverage, but it is feasible that a lower density of baits may result on the ground, with the potential for a pocket of land where bait disappears too quickly for *all* rats to gain access to a lethal dose.

The steepness of the coastal cliffs and the presence of sea caves and overhangs in some locations were also raised as a concern with respect to coverage. However, steep cliffs have been part of many successful eradication projects and have not presented a known issue before, and were treated by standard methodology here. The caves were assessed during the planning phase and most were tidal or very shallow and assessed as not able to provide a permanent home for rats (K. Swinnerton pers comm). It is possible that coastal 'caves' were not adequately treated, possibly partly due to restrictions on flight lines in order to minimise bait entering the water, or via attempts by the pilot to comply with the regulations. The pilot indicated he could not guarantee that bait entered some of the caves (P. Garden *pers comm*) but it is not clear to the reviewers how many caves were present or their nature (intertidal or not, etc.) so the relative risk is hard to assess. An alternative means of baiting the caves - hand-broadcasting through access by boat, which was used successfully by Island Conservation on Anacapa Island and other projects - had been discussed (S. Silander *pers comm*) but was thought not necessary, and operationally risky because of potentially rough sea conditions prevalent at that time of year.

<u>Gaps in the bait station operations</u>

A total of 161 bait stations were used, although 248 were initially considered necessary. However, the higher number was apparently based on an over-calculation of requirements on paper, and 'ground-truthing' found that only 161 bait stations were required.

Bait stations were used here as a supplement, not a replacement for aerial broadcast, so it is difficult to see any possibility of gaps in *total* coverage in areas where bait stations occurred. Given their distribution and the standard New Zealand DOC best practice of deploying baits stations on a 50x50m grid for *R. rattus*, we can assume that to the extent they were effective, they supplemented bait availability for about 25m on either side of the upper ridgelines.

Bait-take attributable to rats (on the basis of droppings or other diagnostic sign) from bait stations was appreciable, with all but 2 of the 161 stations visited by rats at some stage. Hermit crabs did pose a problem, and large numbers of hermit crabs were found inside bait stations, potentially preventing rat access to bait. However, crab activity was concluded in the post-operational report to be a learned behaviour and their use of bait stations seemed to accelerate as rat activity decreased. It could alternatively be attributed to disappearance of aerially-dispersed bait from elsewhere in the vicinity and the crabs increasingly concentrating on the few remaining sources. It should be noted that we find the statement that rats were somehow preventing crab access to the stations inconsistent with our own experience with hermit crabs on tropical Pacific islands.

The logic behind the use of bait stations and the subsequent ‘boundaries’ for bait station operations to supplement the aerial baiting seems unclear and based on quite limited information. The 2010 bait up-take trials had a result of 83% of bait taken in a single night in the ridgeline shrubland habitat, attributed in large part to consumption by ants. This uptake is higher than desirable, as it indicates insufficient bait could be available to all rats over subsequent nights. The need for bait stations at all, the boundaries of the area they were to occupy, and the basis for these decisions is not well explained in operational documents. It appears, though it is not clearly stated in planning documents, that bait stations were considered the best solution to ensure continued availability of bait to rats (rather than the more simple solution of applying extra bait aerially) because of legal constraints on the overall amount of bait per hectare allowable. This appears to have been an attempt to work around self-imposed limits on bait application rates that, although well-implemented, may not have been an appropriate mitigation.

<u>Rats surviving in areas where bait could not reach them.</u>

All areas were treated, and in some instances by two separate methods. Unlike some other recent operations, there were no baiting exclusion zones and bait coverage could therefore be comprehensive and relatively straightforward.

The small islets off the south-western coast had bait applied. Other islets that appear obvious from the map are apparently regularly washed over by waves and were not baited (R. Griffiths *pers comm*). The south western islets had breeding colonies of bridled terns on them during 2010 (Wolf *et al.* 2010) so portions of the rocks were clearly staying ‘dry’ for extended periods and therefore capable of holding terrestrial species such as rats, even if temporarily. Some anecdotal comments suggested the weather is rougher in winter months (including the period for the baiting operation), and as a consequence rats would not occur on the wave-washed islets. This may generally be correct, but does not take account of unexpected variability in conditions, and seemingly unusual conditions did occur immediately before the bait-spreading operation.

The delivery of bait to these southwest islets was not ideal. The Post-Operational

Plan states a single bag of bait per islet was dropped by helicopter, but project team members interviewed report a larger though unrecorded number of bags were delivered to each islet treated. If the bag is unbroken and bait is not spread, a single bag is like a single bait station which could be dominated by a single individual, preventing access by other individual rats. However it appears some bags sown 'burst' on impact, scattering bait somewhat, and the risk of domination of bait bags or piles by single rats lessens with the number of bags delivered and whether they stayed intact or not. Some bait bags could have been placed in an area where rats would not go (e.g. an open area of rock well away from protective cover, etc.). This is particularly true if rats survive on the islets by feeding in the intertidal zone and only forage on the top of the island when birds are nesting there. However, bait still appeared present after 10-plus days, after any dominant rat should have eaten bait and died by then, and any other rats would have had access to it. A repeat baiting of the islets was therefore not made during the second application.

While there is no evidence of rats surviving on the islets, the 'casualness' of the approach to baiting or of ensuring that there were no rats on these islets, and unsubstantiated assessments that they did not provide sufficient foraging habitat is not condoned by the reviewers. New Zealand best practice (Broome *et al.* 2011a) states "*It is critical that all potential rodent habitat is baited. Treat rock stacks above high water around an island even if it seems unlikely that there are any rats on them*". A reluctance to have bait fall into the marine environment may be responsible for the methods used on the offshore islets (as well as the coastline of the main island). The EA (USFWS 2011) states that "*Every reasonable effort would be made to minimize the risk of bait drift into the marine ecosystem.*" Some discussion with regulatory agencies may be beneficial as to the most precise possible definition of 'reasonable effort', so that regulations are complied with, but operational efficacy is maintained as high as possible.

There was a thought raised that some rats may have been spending most if not all their time up in the often very dense vines growing in the tree-tops, and consequently may not have had access to bait on the ground. While this cannot be ruled out, evidence from other locations (e.g. Palmyra, Howald *et al*. 2004), including previous eradications and radio-collar studies, suggest it would be a very unusual circumstance. For rats to live within them without venturing to the ground, the vines or connected trees would have needed to harbour a significant alternative food source that could sustain rats over a number of days. If the vines were dense, they should have trapped aerially-sown bait pellets within them which would have been available to arboreal rats. Conversely the vines could have prevented pellets reaching the ground for terrestrial rats. A 2013 post-eradication trip to the island showed appreciable rat activity within the vines, and it is thought rat nests were commonly made within the dense vine growth (C. Hanson *pers comm*).

Insufficient Bait, or Bait Not Available for Long Enough

A total of 11,606 lb (5,264 kg) of toxic bait was purchased which included 10,106 lb (4,584 kg) for aerial application (of which 10% was allocated for contingency in the event that bait was lost or spoiled) and 1,500 lb (680 kg) for bait stations.

The rat population on Desecheo was abundant, but regarded by interviewees as not appreciably different to other islands they were familiar with. Capture rates in trapping indices in visits in 2009 (156 trap-nights) were ~0.25 rats/adjusted trap night and in 2010 (140 trap-nights) ~0.55 rats/adjusted trap-night. The capture rate in 2010 was higher than the mean capture rates in Palmyra atoll in 2005 (mean 37% success) and 2008 (mean 44% success, Pott *et al*. 2010).

The bait is registered for a maximum application rate of 18kg/ha followed by a second application of 9kg/ha. If an application rate greater than this is required, then a separate EPA authorization submitted by USDA-NWRC (the bait registrant) is needed to allow it.

The substantial reduction of bait rates (halving in this instance, in accordance with the bait label for Brodifacoum-25D Conservation) for the second application of bait implies that rats are responsible for this large proportion of the bait consumption, but the relative uptake of bait between rats and non-target species has rarely been established. Theoretically, most if not all rats should have been removed by the first application, but the number of non-target consumers (especially crabs and other invertebrates) will remain largely the same. This substantial reduction between first and second applications has been a common practice in tropical eradications but perhaps this should be re-evaluated, to ensure that the bait rate in the second application meets targets for bait availability for any surviving rats.

Overall (2D) bait rates for the aerial application here were ~29kg/ha, but when supplemental bait station quantities are added, the overall bait rate was ~30.2kg/ha, based on the 3483kg sown aerially and 127kg actually consumed in bait stations over the 119.6ha treatment area.

In the 2009 trials, over a 1ha grid (with 1.25ha buffer) bait uptake rates differed remarkably between the 3 grassland plots (one in the baited grid, but two in the buffer area which may have been exposed to immigrant rats) and the 6 woodland plots (each plot 25m^2), with bait disappearance being higher in the woodland plots. At four days after the inert bait application at 18kg/ha, only 1 out of 7 woodland plots had any bait remaining (1/120 pellets, Swinnerton & McKown 2009). The trials were appropriately designed with 20m-wide buffer areas also treated, to eliminate hermit crabs or ants 'swarming' onto small bait plots. As an indicator of what was taking the bait, subsequent trapping within the baiting grid caught 33 rats with a capture rate of ~0.25 rats/adjusted trap night, and a very similar number of traps were triggered by hermit and land crabs.

In the 2010 trials, where the maximum permissible bait rates were used, of 18kg/ha and 9kg/ha for first and second bait applications respectively, the bait had variable disappearance rates. Of concern though, was that bait had entirely disappeared from one of the 10 'lowland woodland' plots within the first night following the first application. Following the 2nd bait application, four of 10 plots had all bait gone after one night. While this was later attributed to possible macaque interference, there is no mention of this factor in the reports, and the potentially spurious data was included in analysis. If this were indeed the case, with macaques still present on the island during the bait operation, intensive localised bait take by them should have been another consideration in determining bait rates. The 'upland grassland' plots had generally less dramatic bait take but none of the six plots there had any bait remaining at all after four nights (*sourced from raw data MS Excel spread sheets, Island Conservation*). It should be stressed that these were small samples, restricted by the size and accessibility of suitable study areas. Had 90% confidence intervals been calculated for the entire island, they would have indicated that other plot-sized sections of the island would have bait available for even less time than the shortest plots. The all-too rapid disappearance of bait from some plots should in hindsight have been 'a red flag' with regard to bait rates (M. Pott *pers comm*),

A clear appreciation of the impact the baiting restrictions can be seen from a statement from the Post-Operational Report (IC 2013): "*Because of the steep topography, bait needed to be applied at an approximate rate of 20 kg/ha followed by 10 kg/ha in order to achieve the required bait density on-the-ground. However, because of the legal restrictions and the higher bait density where flight lines were anticipated to overlap, we aimed to sow between 18 kg/ha and 20 kg/ha for the first application. Desecheo is a small island and its shape has a high perimeter to area ratio meaning that our intended overlap along the coast would have had a significant impact on the average application rate across the island. To give us some room for flexibility we opted to separate the coastal deflector runs into two applications of 10 kg/ha. In the event that we baited the interior of the island too close to 20 kg/ha we could reduce our application rate on the second coastal application, thus ensuring that the entire island was baited and we met our average application restrictions".* It is abundantly clear from that statement that: 1) the implementing agency would have preferred higher bait rates overall; and that 2) actual methodology was adapted from the preferred methodology to suit this imposition.
Point 1 was reinforced by several project staff interviewed, and point 2 acknowledged.

Bait monitoring transects post-application (IC 2013) showed un-eaten bait remained available in most of the 12 monitoring transects (each of 25m x 1m, five selectively placed in the woodland valley and seven in grassland habitats) for many days after the baiting. On average, 60% of bait had gone by 3 nights after the first application, but on average 24% was still left just prior to the second bait application. However, in one woodland monitoring transect *all* bait had gone within 3 nights after the first application and within 2 nights after the second application. This very rapid localised disappearance of bait should perhaps have raised concerns and perhaps also some response actions in terms of prioritised monitoring for such areas or supplemental baiting, e.g. via use of bait stations, though we acknowledge the challenges faced with the latter action under the US regulations. We also acknowledge there is no currently defined 'minimum desirable period' for which bait remains available to rats, but suggest 2-3 nights is too low. Bait monitoring in eradications is very desirable from a learning perspective, but for eradication purposes should not be overly concerned with averages, but should focus on the *worst case* scenarios. These should be determined from confidence interval extrapolations based on a sample of plots. Thus, the worst case scenario is invariably even worse that the worst sample plot.

It is also noted that none of the bait-uptake monitoring transects during the operation covered the identified 'weak points' in baiting coverage at the start or end of cross-island transects or the relatively large area of under-application near the western coast. Despite the known issue of areas where under-sowing had occurred, the monitoring team did not receive any instruction to investigate such areas, which in hindsight could have been seen as a high priority.

Relatively more aerially-broadcast bait remained in the ridgeline areas than in woodland transects, perhaps due to the availability of alternative bait in the bait stations. However it could also perhaps have resulted from ant control measures there, or from a change of ecological conditions between the trials in 2009/10 and the operation in 2012 which could have altered populations of bait-consuming species such as ants and crabs.

The Environmental Assessment (USFWS 2011) suggested that hermit crabs *Coenobita clypeatus*, at a recorded maximum density of 833/ha (and an average of 696/ha) would be "*significant consumers of bait*", but the baiting rates on Desecheo Island were surprisingly low in view of this. The average crab density stated above is higher than the average densities (albeit for a different range of crab species) recorded for any natural forest type on Palmyra Atoll and comparable to the 574 crabs/ha in coconut palm forest there (Howald *et al*. 2004), where it was thought that anything between 3.34 and 47.7kg of bait per hectare was required to satisfy crab consumption alone. However, the crab monitoring here was led by staff experienced with Palmyra, so it is assumed direct comparisons could be made, but the difference in the overall bait rates between the two projects is significant. The density of land crabs *Gecarcinus ruricola* was not evaluated due to their being nocturnal (Pott *et al.* 2010). They were considered uncommon, but underestimation of their number or effect may have contributed to rapid bait disappearance.

Some concern was raised over the 13% difference in planar island area (c.120ha) and the 3-D surface area (c.133ha), and that bait calculations were based on the lower figure. Consequently, bait would be at a lower than expected rate 'on the ground' than for rates based on trials using surface area (3-D) calculations. This was overcome by applying for a supplemental approval for overall bait quantities to reflect the 3-D dimensions of the island.

It seems that the process in finding the bait rate necessary to undertake an eradication here was somewhat flawed, and relied too heavily on results from field trials that were limited in scale by physical constraints, and did not factor the 'worst case scenarios' into the calculations, while (intentionally or not) seemed to attempt to find the minimum amount needed without factoring in desirable safety buffers into such calculations. The best practice approach would be to take an approach of asking what bait rate would guarantee the bait is available to all rats for as long as necessary (currently undefined but suggested as at least four nights per application) to ensure eradication. An analogy presented by one interviewee is apt – 'rather than try to find the minimum-sized hammer *likely* to crack a nut, use the one you know will be *sure* to do the job'.

We also note that most other projects (especially outside the US) have not had to scientifically justify bait rates to regulatory authorities, and instead set conservative (i.e. generous) bait rates largely on the basis of prior experience of the conservation managers and expert peer review, rather than having to justify rates around a seemingly arbitrarily set bait label maximum. If eradication is the intent (i.e. 100% of rodents are to be targeted, and no less is acceptable), bait rates need to be set at a level that by definition must *always* err on the side of caution, i.e. be above - with an appropriate margin for safety to allow for variance - the minimum considered necessary for *all* portions of the treatment area.

In a failed eradication, all bait deployed is wasted (e.g. a contaminant introduced into the environment with at the most short term benefits). In a successful eradication, only bait left on the ground after all rats have died is wasted. Baiting rates that are too low will obviously cause an eradication to fail. Baiting rates that are 'just high enough' leave little if any room for operational error, ecological changes or just bad luck. Baiting rates that are higher than strictly necessary can buffer against small planning errors, operational errors, unanticipated ecological conditions and bad luck. Higher baiting rates can thus dramatically increase the probability of eradication success and therefore reduce wasted bait.

Rainfall in Jan, Feb and March 2012 at the two closest rainfall stations was well above average. Some (but not all) project members interviewed thought the island greener with more rainfall in 2012 than in the same months in 2009 and 2010. Photo-points or comparable photos between years could possibly demonstrate the extent of this. Increased rainfall may have altered natural food availability and rat population cycles, making prior monitoring results poor predictors of rat behaviour at the time of the baiting implementation.

Any nursing female rat would have had access to bait over two different baiting periods for a total of perhaps ≥6 days (based on average bait availability in the poorest performing plots, see Fig 11.3 in the Post-Operational Report), although some areas of the island probably had even poorer bait availability. Possible low bait availability would be exacerbated by any increase in neophobia associated with pregnancy and lactation. While the vast majority of rats appear to die within 3-4 days of consuming bait, it is possible a few nursing females that consumed bait remained alive long enough to wean their young. The timing between bait drops has been developed for that reason, but is based on analysis of limited data from temperate locations, rather than tropical islands. For example, it has been suggested that survival of 'orphaned' rat pups is higher on tropical islands than for temperate islands where cold increases calorific demands and the risk of hypothermia. It is therefore possible that some orphaned / newly weaned rats did not have access to bait because by the time they became independent the bait within their foraging range had been eaten by other consumers.

On the basis of the results here and other recent failures, some discussion in the wider eradication community has already been aired about lengthening the period between bait drops, or adding a third bait application, for tropical island rat eradications. The length of bait availability was suggested by IC (2012b) as a potential cause of failure for the Henderson Island project failure. With similar circumstances prevailing, this may also be a possibility for failure of the yet-to-be reviewed Enderbury Island rat eradication project.

Resistance to Toxins

There is no reason to expect brodifacoum resistance on Desecheo Island as there is no history of rodenticide use, and significant brodifacoum resistance has not been recorded in other populations of *R. rattus*, even those with a long history of brodifacoum-based control.

Bait Toxicity

Bell Labs' Brodifacoum 25 bait has a proven track record, and has been used in numerous successful eradications, e.g. numerous islands in the Galapagos, Anacapa, Rat Island, Palmyra Atoll, 3 small islands in Pohnpei, Tahanea (French Polynesia), Isabel, San Pedro Martir (Mexico) and several islands in the Caribbean, and Allen Key in the Bahamas.

It has two versions, 25-W and 25-D, intended for wet and dry conditions. Little difference in formulation is known, only that the 25-W has a slightly different manufacture process with an agent added to prolong the baits' condition in damp or rainy conditions. Conservation 25-D, the formulation used here, has been more widely used (in 31 operations), with 21 confirmed successes, 8 yet to be confirmed, and two failures, Congo Cay in the US Virgin Islands and Desecheo Island, a success rate of >91% where the outcome is known (IC unpub data).

Bell Lab's analyses identified no quality issues in the 25-D used in any previous eradication. Their samples of bait intended for Desecheo averaged 29.3ppm, (C. Reikena, e-mail to M. Pott and G. Howald), more than meeting the stated label concentration of 25ppm. An independent test was carried out by the Puerto Rican Department of Agriculture and the sample showed a 33ppm concentration of the toxin (IC 2013).

Brodifacoum levels in the other bait (Pestoff 20R) used extensively and generally successfully in rat eradication projects are 20ppm, at least 25% lower than the Bell 25-D.

In addition to the 'active' bait, 700 lbs (317 kg) of non-toxic bait was purchased for the bait bucket calibration trials. This was packed into paper sacks (as opposed to pails and bulk bags for the toxic bait), to avoid confusion and any mixing of active and non-toxic bait in the field. Furthermore, bait-bucket calibrations were done off island, so there was little chance that inert bait was accidentally used in the operation.

Overall, we feel it is highly unlikely that bait toxin loadings are a possible cause of failure here.

Bait Aversion

Bait up-take trials in 2010 using a non-toxic version of the Bell 25-D bait (containing a biomarker) showed that 100% (70 out of 70) rats took the bait (USFWS 2011). This indicates a very high palatability of the bait to Desecheo Island rats at a time when natural food resources were considered low.

It is feasible that intra-specific interactions may have limited access of some individuals to bait, but this scenario would be faced in all rodent eradications, and would only be an issue if bait was not spread widely enough and in sufficient abundance (i.e. bait gaps or insufficient bait – see relevant sections).

There is some anecdotal evidence to suggest rats may take a day or two to overcome initial neophobia or unfamiliarity with bait (e.g. *R. exulans* noted running past quantities of freshly sown bait to feed on natural food on Enderbury Island (R. Pierce *pers comm*), and initially avoiding placebo bait in trials on Henderson Island in 1997 (G. Wragg *pers comm*). If some individual rats take longer to attune to the new food source there is a risk, where bait rates are too low, that bait within their foraging range will disappear before they can find a lethal dose.

It is feasible that ant activity on a bait pellet (especially any chemical residues left by the ants) may lower that individual pellet's palatability to rodents. To our knowledge, this has not been evaluated in eradication scenarios. Where significant ant densities occur, it is possible that not only appreciable quantity of bait is eaten by ants, but the amount of remaining bait that is *palatable* to rats is also reduced.

There is no direct evidence to suggest some rats disliked or intentionally avoided bait, but there are some suggestions they either could not access it (bait gaps and/or bait abundance in localised areas), or they chose not to eat it for whatever reason (possibly but not categorically due to breeding-related behaviour) favouring naturally available foods instead. It is possible (and in our view probable) that higher than average rainfall in 2012 and the subsequent on-set of breeding by some rats changed the *relative* palatability of the baits and the willingness of a very few individuals toward taking bait.

While a review of the failed Henderson Island project (IC 2012) suggested that, with few exceptions, rodent bait is more palatable than natural foods, there is growing evidence that this may not be entirely the case. In one of the cited cases, a natural food (coconut) was preferred over commercial bait (Alifano and Wegmann 2010) though this did not compromise the outcome of that project, while bait uptake trials on Wake Atoll (Wegmann *et al.* 2009) showed some rats clearly not taking inert bait pellets when they were freely available to them. Furthermore, toxicology trials on Wake (Mosher *et al.* 2007) showed that for some rats there was a "*preference of the chow [commercial rat food] over the rodenticide*" and that this "*was a major contributing factor in the lower-than-expected mortality rates*". All of these indicators caution against making assumptions about the attractiveness of rodenticide baits to *all* rodents at *all* times.

Bait Station Aversion

Bait stations were installed a minimum of 15 days before deployment of bait, which is helpful to overcome potential neophobia.

J.T. Eaton™ Safe-Tee plastic rodent bait stations were used because of their light weight design, which allowed the field team to carry them easily across the island during deployment and demobilization. Puerto Rico pesticide laws prevailed here with regards to what was permissible in terms of design. Selection of bait station should always be primarily on their appeal to rats (or conversely, lack of 'deterrent factor'). Other considerations should *always* be secondary to the proven effectiveness of the particular design in prior rat eradications. Most if not all commercial varieties of bait stations must by their nature be able to be accessed by rodents, but they also incorporate features necessary in standard situations (e.g. human safety, designed for commensal use, cost vs. efficiency factors, incorporation of a specific type or shape of bait, etc.) that do not apply in most eradication situations. It is of less concern if, say, 0.1% of rats in 'control' situations do not enter bait stations due to some deterrent factor in their design, but it is absolutely critical in eradication situations that *all* rats willingly enter the bait station.

A general weakness in bait station-based eradication is the assumption that if *some* or *most* rats enter a specific design and 'set-up' of bait stations, then *all* rats will. On Desecheo, some bait stations were nailed to trees above ground, and some were not. No data is available on difference in visitation rates or bait consumption between these (and any differences could also be attributed to habitat difference at the sites where the two different presentations were used). However, this generalized weakness is less significant on Desecheo Island where bait stations were used only as a supplement to aerial broadcasting.

The additional value of bait stations on Desecheo was in documenting presumed rat activity post aerial bait-spreading. Ten stations with rat activity were detected on 24-25 March (1-2 days after the second aerial bait application i.e., a minimum of 6-7 days and maximum of 11-12 days after the first aerial bait application). This should have registered some concerns, though it is possibly still within what could be considered a 'normal' period for rat activity following bait application. What should have registered concern and triggered a thorough analysis of options, was the observation that some bait stations ("*less than three*") were possibly still active by the 28-29th of March, ≥15 days after the first bait drop. This 'sign' was usually of droppings, and although each station was cleaned at replenishments, it is not wholly clear if sign was recent or had been missed being removed at earlier checks. However, in the absence of definitive information, the worst case scenario in eradications should always be assumed. All rats should ideally have had access to the first aerial bait application, and it should have been extremely concerning if there were still survivors (as indicated by possibly fresh sign at bait stations) 15 or more days post bait drop.

Options for response may well have been 'can't do anything' but could also have included tracking tunnels to define the area of problem, supplemental bait stations (as did occur at one site on Desecheo), supplemental hand-spread of bait, deployment of traps, etc. The very least that should have been seen is some documented evidence of the *recognition* of a possible issue, and some discussion of what could be done (if anything).

Natural Food Resources & Behaviour

A small number of macaques were present on the island during the rat eradication, the remnants of a previously much larger population reduced through an on-going eradication program. We considered the possibility that the presence of macaques (a definite food competitor and a possible predator) on Desecheo had somehow influenced rat behaviour, with rats for instance finding refuge in dense vine-lands or altering foraging behaviour to avoid interaction with the macaques. While this is possible, macaques are diurnal and unlikely to have significant impacts on rat behavior at night. Furthermore, the bulk of the macaque population had been removed, well before (and probably several generations of rats before) the rat eradication attempt.

Feral goats were recently eradicated from Desecheo, with the bulk of the population removed by 2006, but with the last animal not being removed until 2009. It is probable that the ecosystem recovery associated with goat removal had not fully manifested itself by the time of the 2009 and 2010 fieldwork, but would have been appreciably more advanced by 2012. Positive environmental changes such as recovery of flora, better flowering and fruiting of certain species, re-development of humus or topsoil layers, and resultant increase in invertebrate populations could be expected from the goat eradication. Such responses could have compounded the differences between pre-operational monitoring and the conditions during the rat eradication operation.

Biology of rats and the timing of the eradication operation were discussed in the Environmental Assessment (USFWS 2012), where they stated quite correctly that: "*rat eradication from an island is more likely to be successful if intensive baiting takes place when the rat population is declining in response to annual food shortages. At this time, rats are typically more food stressed and therefore more likely to eat the bait presented (Macdonald et al. 1999). The probability of eradication success is also increased if the bait application takes place when rats are not breeding*".

The period from January to March was considered ideal for baiting due to the increased chances of dry weather necessary for bait application, the need to avoid hurricanes and tropical storms which would severely disrupt operations, the assumption that rats would be more likely to eat bait because natural food would be more limited, and because field trials in February and March 2009 and 2010 demonstrated that rat reproductive activity appeared to be low.

On the eradication team's arrival at Desecheo Island on February 19th 2012, initial impressions were that the island's vegetation was greener than observed during the same period in 2009 and 2010. Several interviewees commented on the 'greenness' of the island in contrast to previous years and according to one interviewee the "*full bloom*" of fruiting occurring immediately prior to the baiting. A retrospective analysis of weather data for Puerto Rico indicated that precipitation recorded at the Rincon station (the closest point to Desecheo) from January to March was above the annual average, and in February 2012 precipitation was 2.9 times higher than the 34-year average and the third highest rainfall for the month of February since 1968 (IC 2012). However, one member of the field team did not think the island was markedly different between 2010 and 2012.

This greening of the island contributes to concerns that more food resources (not only vegetation but also flowers, fruit and invertebrates) may have been available for rats and that rats could have been breeding during the operational period. The field trials in a similar time of year in 2009 and 2010 detected no females in breeding condition, nor any newly weaned juveniles.

During the eradication attempt there is evidence (IC 2013) of breeding with 'opportunistic' necropsies of a small number of rats (n=6) found dead during the 2012 operations showing one female rat with three embryos, and a male and the same female showed subjectively significant abdominal fat (body condition and food resources are strongly tied to when rats initiate breeding).

The field monitoring team on the island at the time of baiting observed few if any small juvenile rats, and while we acknowledge the possibility of year-round breeding (with seasonal peaks and troughs) it appears breeding had not been widely occurring for any prolonged period beforehand. The project's Operational Plan clearly says "*The operation would coincide with the dry season (January to April) on Desecheo when food will be limiting for rats and minimal breeding in rats occurs*". This statement suggests that intensive breeding events were not normal for the island during that period, based on all the evidence to that point. Effects of breeding status of rats on eradication prospects are currently unclear, but Island Conservation are undertaking a concurrent database review of all tropical eradications which may shed some further light on this. Effect of breeding status may relate not just as to whether breeding is or isn't occurring, but possibly to the relative *intensity* of breeding activity, the abruptness and extent of environmental changes that encourage breeding, or the stage of the breeding cycle of individual females.
The field monitoring team on the island at the time of baiting did not observe many if any small juvenile rats, so it can be assume breeding was only just underway or 'imminent' during the operation but had not been widely occurring for any prolonged period beforehand.

The island had notable alternative food resources for rats during bait application. The populations of the three lizard species on the island were appreciable, and it is recorded that rats on Desecheo actively stalk and kill the *Anolis* lizards there (McKown 2010). Two species of lizards are likely to be a year-round food supply (K. Swinnerton pers comm) may have provided a sought-after protein source for breeding rats. A proportion of *Bursera* trees also had their small fig-like fruit at that time of year (M. Pott *pers comm*) offering a potentially significant food source at the time of the operation.

The IEAG (2012) considered that for the failed Henderson Island project "*atypical rainfall in 2011 leading to a range of ecological changes which combined to allow survival of rats*" was a high likelihood for reason for the failure. It is possible this is also a leading option for the failure of the Enderbury Island project, but this project has yet to be formally reviewed.

Conclusion – What Caused the Desecheo Failure?

We cannot say conclusively what caused the failure of the Desecheo Island rat eradication. It may have been a combination of the factors examined, or even something we have not thought to consider. After reviewing the available documents and interviewing project participants, we feel the failure to eradicate rats on Desecheo was most likely due to:

- An overall bait application rate that was at best barely adequate and possibly inadequate to make sufficient bait available to all rats for at least 4 days per application, as apparently intended. A higher bait application rate could have buffered operational errors or bad luck. Instead, errors and bad luck were exacerbated. The most significant factors are recorded below.

- The different climatic conditions experienced on the island immediately prior to the bait drop in comparison to previous years. This above normal rainfall appeared to promote a flush of vegetative growth compared to previous years (when monitoring to determine bait rates occurred), which may have led to more natural food being available, and could have initiated possibly seasonally atypical intensity of rat breeding. Potential behavioural and foraging changes in breeding females may have resulted in either the emergence of possibly orphaned young rats from the natal nest after bait availability had ceased , or speculatively, a very few individual females choosing not to take bait.

- Some small errors or omissions in bait coverage in the first bait application that may have created localised shortages of bait and potential gaps in bait coverage or accessibility to some rats in certain areas.

- Non-standard aerial bait application methodology (e.g. perpendicular rather than parallel baiting along inland steep faces; stopping and starting cross-island bait swaths well before the coast, non-broadcast on islets; almost unidirectional treatment and no supplementary treatment of steep inland areas, etc.).

It must be stated that the eradication attempt here appeared to come very close to achieving success. Whatever the cause of the failure was, it was not a 'catastrophic' failure. The evidence suggests there were very few survivors, and they or their progeny took some time to become apparent.

In some past (successful) eradication experiences, similar circumstances may have been in force and pure luck may have been the difference between success and failure here, as the margins between the two in eradications are infinitesimally small, e.g. two non-pregnant rats surviving of the same sex = success, one pregnant rat or two rats surviving of opposite sexes = failure.

Review Objective 2. Were the strategy, design, planning and implementation of the eradication and biosecurity program adequate to expect a reasonable probability of success?

The Project Design and Planning Process

An appropriate sequence of planning and project process was followed, with a number of necessary or desirable tasks being carried out, including:
- a rodent control options paper

- biomarker studies
- bait uptake studies
- DNA collection
- an environmental assessment and public consultation process
- an internally-reviewed operational plan
- external review of the baiting strategy by members of the IEAG
- pre-eradication ‘readiness checks’
- post-operational bait availability and bait degradation monitoring
- on-site presence of staff until c.6 weeks after the first bait application
- immediate post-operational review
- longer term post-operational review

Several aspects of planning were thorough and overall a tremendous amount of effort was put into planning and project preparation, as much or more than most eradication projects. However, there were aspects of the planning process that could have contributed to the eventual failure, or at least should be improved in future projects to maximize likelihood of success.

The Project Manager was not full-time during the planning phases of this project, and concurrent work may have restricted input into planning and evaluation of technical strategies for this project.

Feasibility Study

No comprehensive ‘feasibility study’ was completed for this project. Such a study should have listed and examined issues pertinent to maximizing the likely success of eradication. A feasibility study is the first ‘investigative’ opportunity that outlines issues such as non-target species bait take, any difficult bait treatment areas, a summary of rodent ecology and distribution and other factors that will influence later operational planning.

Some aspects of what a feasibility study would normally entail were achieved elsewhere (e.g. bait rate and uptake and acceptance trials). However, these were not critically reviewed until very late (i.e. too late) in the planning process and only by internal (IC) personnel.

Reviews and Readiness Checks

The degree of external review of this project appeared limited, especially from experienced specialists in aerial bait application. Some public response was noted in the Environmental Assessment (USFWS 2011) but only one from an independent experienced rat eradication practitioner, who did not have aerial baiting experience. Only the draft baiting strategy was reviewed by the IEAG but they saw no other documentation, and made a comment “*…we are not in a position to answer…*” with respect to some questions because of this lack of overall information.

There was no apparent formal documented response to the few reviews and internal readiness checks that were undertaken in relation to this project – some recommendations and responses to questions did not seem to make it through to the final version of the operational plan (e.g. questions raised by IEAG on ants and *Gecarcinus* land crabs). However, this situation is not unique to Desecheo, and it is suggested all future projects should have a process to either 'accept' review or readiness check comments or to 'decline and explain why the advice is not accepted' within the final version of the Operational Plan or an appropriate internal document.

It is possible that some of the planning issues reflected the relative inexperience of the project manager in managing rat eradication projects. Some constraints were to an extent 'dictated from above' (e.g. maximum bait quantities, restrictions on how/where bait is applied to reduce bait entering the water) and the project manager may not have had sufficient technical eradication experience to fully appreciate the potential effects such constraints could have on the outcome.

While more experienced personnel within IC (and outside the agency) were engaged in some aspects of the planning to provide their collective wisdom through mentoring and reviews, the input appears to have been somewhat piecemeal, with various people drawn in for singular tasks. As a possible consequence, there may have been no one experienced practitioner that had the complete 'big picture' view of the project. A more desirable approach would have been a 'beginning-to-end' mentoring process with a single designated mentor, which would have helped both the project manager and mentor to more fully appreciate the intricacies of this particular project. It was only very late in the process when an experienced person read through the trial data that it was realized bait rate calculations may not have been ideal. By then, a rapid decision had to be made on whether to postpone the project for a year (potentially very costly, perhaps almost as much as carrying on) or to proceed and do what little was possible in the timeframe through supplemental label applications to marginally increase the bait rate.

We consider that for what appeared to be a relatively straightforward operation, the overall extent of review was probably more than for many other similar eradication projects. It should also be noted that most eradication experience (especially for aerial operations) has been derived from temperate or 'dry tropical' island projects, and that relatively speaking, within the eradication community there is collectively a lower degree of experience to draw upon for wetter-climate tropical island projects.

It is important to develop more people with skills in rodent eradication, especially at the project manager level, but it is also important that they are mentored in this process. It would be interesting to know how much time was able to be devoted by more experienced managers within IC to provide advice and feedback *throughout* the planning and operational process. In contrast to this, there was also a suggestion that 'ownership' of the project was not allowed to fully rest with the project manager.

Island Conservation had been undergoing a re-evaluation and restructuring before this operation, with new people in new positions, and as a consequence the ability for internal review and guidance at the time was not ideal (G. Howald *pers comm*). This perhaps should have triggered consideration of delaying projects such as this which had a high technical component to them.

The Operational Strategy

The operational strategy was based on prior field investigations and prior knowledge of past rat eradications.

The project seemingly chose to proceed on the basis of compliance with the regulatory conditions applying *at that time*, rather than seek to modify the conditions through supplemental applications. Consequently, some planning did not conform to established New Zealand eradication best practice principles that are designed to maximize prospects for success, and which are generally applicable in all eradication situations. These include the maximum permissible quantity of bait allowed under normal 'label' restrictions (or in this case the slightly increased rate as per the supplemental label). This bait application rate may have been possibly adequate on the basis of previous years' data-collection, but may not have been sufficient to cater for the changed environmental circumstances faced in 2012, nor did it allow any real flexibility to deal with special areas via re-treatment or supplemental bait application. A decision was made to press ahead taking these baiting constraints on board, rather than delay the whole project at least a year to go through the process of a supplemental bait application to increase overall bait rates. It should be noted the project had already been delayed a year because of the lengthy NEPA process (US Federal Environmental Assessment) and the necessary translation of large amounts of documentation into Spanish, and yet another delay may have been wished to be avoided.

Use of bait stations as a supplementary baiting tool was clearly a reaction to maximum bait limits. The more appropriate 'best practice' response would be to change the bait limits unless there was perfect knowledge (not demonstrated here) of where bait shortage was going to be a problem.

The operational decision of starting and ending of cross-island baiting swaths inland of the coast created an added risk of baiting gaps or lower than planned bait rates in localized areas. The potential for gaps in such areas is reduced in standard application methodology by the 'safety buffering' of these swaths by the coastal swaths.

It is not clear to us how much discussion was had between agencies on these issues, nor how hard IC or other stakeholders fought for best practice to over-ride such impositions. If the pressure to 'modify' best practice to something less desirable is too great, then strong consideration should be given in future to delaying the project to resolve such issues or even abandoning the project rather than take unnecessary extra risks.

Implementation

The Incident Command Structure for Desecheo appeared very straightforward and logical, and the technical aspects of the bait-spreading operation were dominated by specialist staff from IC, some with considerable eradication experience. In contrast to Wake Atoll, it appears that in general, staff were allocated primarily on the skills and experience suited to that particular position, and tasks and responsibilities were not limited by any maximum number ceiling. It appears that Desecheo had a surplus of staff in some quarters at least, partly due to a desire for training purposes and gaining of experience, which is much more desirable in eradication projects than the situation on Wake, where resources were over-stretched.

The project was hampered by physical separation between the aerial baiting team and the monitoring team on the island, further compounded by poor communications technology and protocols between the two camps. The on-island team seemed to have little idea what was happening with regard to the bait application, and key information such as areas of under-sowing of bait were not relayed to the island team until 4-5 days after the first bait application.

Communications between the bait loading team and the baiting command team were not ideal, with one key player attempting to play a role in both. This did not work because he was 'contaminated' by bait residue after loading and was not able to enter the 'clean' environment where the GPS tracking records were viewable. An easily accessible 'low light' room where digital & GIS data can be displayed to all participants would facilitate discussion, analysis and review during eradication operations.

Many aspects of the project went very well, and the team is to be commended on their efforts. Most of the operational team appeared to admirably fulfill their allotted tasks and the failure to eradicate rats should not be any reflection on their efforts, skills or dedication.

Biosecurity

We cannot comment on the biosecurity program or planning to any degree. It does appear that suitable biosecurity measures within the projects' own field operations were carried out, and biosecurity issues are highly unlikely to be a possible reason for failure.

Conclusion – Objective 2.

The lack of a comprehensive feasibility study was an oversight, but for such a relatively straightforward eradication it may not have been thought necessary. A feasibility study could have created more initial focus on fundamental issues such as necessary bait rates, how to apply bait to certain areas such as islets, steep faces and high ant density areas, and greater consideration of phenology and alternative food resources for rats. However it is easy to be critical in hindsight, and both authors are guilty of not realising the importance of some of these factors leading up to their own failed eradications.

The bait uptake trials appeared to be carried out well, but the interpretation of the results and derivation of bait rates needs to be improved in future, to take account not only of the upper extremes of bait uptake, but their 90%- 95% confidence intervals and added safety margins on top of that (depending on the agency's tolerance for failure), rather than the average values.

The design of the operation was compromised by the very strong justifications required to obtain regulatory approval to exceed bait label limits, and the subsequent internal decision to press ahead with the largely self-imposed limits on bait quantities, rather than a costly delay the project, potentially for several years, while stronger scientific evidence to support a higher bait rate was obtained and submitted. This was quite possibly a reasonable option at the time, given the cost of postponing could have been almost as great as continuing with the operation, but earlier recognition of the issues could have circumvented the problem altogether.

The decision to proceed with less-than-ideal bait rates resulted in unusual strategies such as supplementary use of bait stations being employed, and the negating of any possible supplemental treatment of areas of possible concern. The baiting strategy may not have given sufficient attention to the coverage on very steep ridge flanks. In locations outside of US jurisdiction and regulations, contingency bait or planned extra baiting swathes would in all probability have been used for an additional treatment for such areas.

Regulations relating to avoidance of bait entering the water caused a strategy that heightened risk of bait gaps or shortages between ends of ‘across-island swaths and the coastal swaths.

The baiting strategy may not have given sufficient attention to the coverage on very steep ridge flanks. Contingency bait or planned extra baiting swathes could in all probability have been used for an additional treatment for such areas if the total application rate had not been constrained.

The first bait application did not go entirely to plan, and the potential under-application of bait in some areas was not picked up quickly enough, nor was responded to adequately either in re-treatment or in monitoring.

Review Objective 3. What lessons can be learned and applied to a future eradication attempt on Desecheo Island, including identifying any additional research needs?

No eradication project goes strictly according to plan. There are lessons to be learned from all eradication projects, successful or not.

Some key points that we think should be taken from the Desecheo operation are:

1. IC should focus on project design that maximizes the likelihood of eradication success while minimizing short-term negative impacts to threatened and endemic native species. They should then focus on how to change, or get exemptions to existing regulations and constraints in order to implement those projects. Where efficacy has been compromised to conform to existing regulations, IC should only conduct projects if they are widely understood to be pushing a particular identified boundary.

2. Where product labels and regulations are open to interpretation, or to conditional variances, IC should interpret them and seek any permissible variances in such a way as to maximize the probability of eradication success.

3. Existing eradication best practice documents, built upon many years of experience, have been developed specifically for temperate islands in New Zealand. While many of the principles within these documents are applicable to tropical eradications, these (or something similar) need to be used as a basis to develop specific tropical island versions of eradication best practice. Such best practice documents then need to be used in the development of future operational plans and baiting strategies. Subsequently, any deviations from such best practice principles should be more openly acknowledged and/or justified within planning documents and wherever possible rectified through supplementary actions that can fit within the regulatory framework.

4. Compliance with restrictive regulations and island manager-imposed conditions is a necessity, and while it is not our role to question the regulations, the acceptance of such restrictions where they may cause deviation from eradication best practice principles should be acknowledged by operational planners and stakeholder agencies as potentially seriously compromising the prospects for a successful outcome. The current constraints, whether regulatory or self-imposed, severely restrict any operational 'flexibility' for possible re-treatment or supplementary treatment of areas where practical coverage was doubtful or inadequate.

5. Determination of the ideal bait rate needs to be improved, to incorporate margins of error within any trials. Development of a best practice methodology for bait rate determination on tropical islands is recommended, and this should have large enough plots distributed across habitat types and should use Confidence Intervals,

or another statistical approach to estimate highest bait uptake rates. Average bait uptake rates should not be used to calculate application rates – by necessity, translation of monitoring data needs to allow for the higher confidence levels required to maximise the prospect of success in rat eradication. Eradication planning needs to be acknowledged as requiring as close to 100% confidence levels as possible, significantly higher than the standard scientific confidence levels in most statistical analyses. Bait rates should also allow for possible variance of populations of rats and non-target species within and outside trial plots, and from year to year.

6. The success or failure of eradication projects should be attributable to one person and the organization that employs her or him. That one person should ideally be experienced (or closely mentored though the entire process) and should take the project from feasibility right through planning, permitting and implementation.

7. It is recommended that for all eradication projects, vital components of the planning process need to be critically reviewed by independent eradication experts, and that specific individual experts are involved in as much of the process from start to finish, and are provided with as much information as possible to maximise their appreciation of the specific circumstances of that island, and therefore maximising the value of their contributions, and also perhaps their relative accountability if that information eventually proves wrong. There also needs to be greater demonstrated response to reviews of project documents and methodology.

8. There should be greater awareness in future of year-to-year climate cycles and variation, and to the possible vegetative responses (and subsequent rodent breeding and population level responses), to further refine the optimum times to undertake eradication on individual tropical islands. Simple actions such as use of data-loggers, photo-points, satellite imagery or nearby weather station data may provide valuable information to assess the longer term climate patterns and how the 'current' status relates to it. This factor, which may have contributed significantly to the failure here, is also a principal suspect for the failure of eradications on Henderson and Enderbury Islands, and knowing what we now know in hindsight, it is probable we would want to avoid a second eradication attempt on these islands during similar climatic events. If unusual environmental conditions are in place at the time of planned baiting, this needs to be given stronger consideration in whether to proceed or postpone the operation. In relation to this, data collected from previous years should not be assumed to be directly applicable to others, especially if environmental conditions are noticeably different between years. Managers should be prepared to make the tough decision to defer the eradication if the situation doesn't appear 'normal'. Information was not available at the time, but with the benefit of hindsight accrued from Henderson, Enderbury and this project, postponement of the Desecheo project could have been considered based on January and February rainfall data from the two closest weather stations.

9. Collectively we have made the almost unquestioned assumption that the bait types used for rat eradications have universal acceptance in rodent populations. This is based on undoubtedly high quality products and the extremely high success rates

when such bait has been used on temperate islands and seemingly also on 'arid' tropical islands. There is now some growing circumstantial evidence to suggest it is not as universally accepted in situations where abundant natural food resources occur, and more research is required into bait acceptance for tropical island eradications. Bait palatability needs further research, especially where abundant alternative food resources occur and when rat breeding is occurring. The possible effect of ant activity on bait palatability to rodents also warrants investigation, and simple and inexpensive preference trials could be conducted between ant-tainted and fresh bait palatability to rats.

10. More investigation is highly desirable on the risks of undertaking eradications when rat breeding is occurring. Research is particularly needed on the behaviour of female rats when pregnant and nursing young – including foraging range, potential 'fixation' on particular foods, the possibility of increased neophobia and avoidance of 'new' foods including the types of bait used in eradication projects.

11. Modelling and field research are needed to determine the ideal time interval between baiting applications for tropical island situations, and/or a re-evaluation occurs of the ideal length of time bait should remain available for.

12. Analysis, display and sharing of GIS bait coverage data needs to take place in near-real-time. This will allow any 'areas of concern' to be identified much sooner in analysis of GPS bait coverage maps, and a more formal response process initiated and recorded. Monitoring transects or plots should also be initiated wherever practically possible in areas with light or dubious bait coverage, and these need to receive monitoring priority.

13. Greater post-operational monitoring, detection and response measures should be built in to tropical island eradication operational planning in future. This is especially apt for smaller and relatively accessible islands such as Desecheo. Monitoring and rapid response should be part of normal biosecurity measures, but focused post-operational monitoring where use of indicator devices and alternative control options could feasibly detect earlier, and possibly deal with any surviving rodents before they can re-establish a viable population (currently unproven in eradication scenarios but proven in incursion events). The additional cost could be worthwhile if it helps identify causes of any future failures, and in some circumstances could feasibly mean the difference between failure and success.

Conclusion

An apparent underlying problem in this project (and the Wake Atoll failure) was a philosophy of working within constraints imposed by regulatory and partner organizations, rather than an intense and singular focus on what is needed for a successful eradication.

It seems that initial feasibility research and planning should be free of constraints other than non-target impacts, and should work within developed best practice principles. Once this ideal plan is developed, the implementing agency should work to sell it to regulators and partners and, if they can't achieve that, either do not undertake the eradication or do it with the understanding that the operation has an experimental component and a higher associated risk factor. The current working model seems set up for future failures, as there is an effort to work within constraints rather than attempt to remove, remedy or mitigate those constraints.

Based on our analysis of available documents, we feel that a second *R. rattus* eradication attempt on Desecheo Island has a high probability of success if sufficient bait application rates are used over the entire island (including shorelines, areas above MHWS and adjacent islets), best practice principles are applied, bait application is analysed, displayed and discussed in near real time, supplemental baiting is possible where required, and the eradiation takes place in a year with < average rainfall in Dec-Mar with no evidence of a large-scale breeding event for rats.

All future tropical island rodent eradications should be able to draw upon the lessons learned from failed operations such as Desecheo, Wake, Henderson and Enderbury, and hopefully avoid repeating any identified errors, including underestimating factors such as rat breeding status or plant phenology that may influence the outcome. Commonalities between the failed projects will hopefully be examined, but cannot yet be stated with certainty here. Both Wake and Desecheo are currently in the review process, the Enderbury project is soon to be reviewed, and Henderson has been completed by two agencies with two appreciably different conclusions (IC 2012b, and IEAG 2012 - see ‘Insufficient Bait’ and ‘Natural Food Resources’ sections above).

Established New Zealand best practice principles (in the current absence of any more appropriate tropical alternative) need to be given more focus in preparation of operational planning, and this best practice needs to be revised and built upon for tropical islands as the knowledge base grows.

In view of several recent tropical eradication failures, and in the process of this review, it is apparent that the eradication community has generally assumed tropical island rat eradications, particularly using aerial broadcasting - a generally quite recent endeavour - will have a similar success rate to the previous and continuing extremely high success rate of eradications on temperate islands. While there have been some outstanding successes on tropical islands (e.g. Palmyra, Midway, Cocos in Guam, McKean and Birnie in the Phoenix Islands, and various islands in the Galapagos, Seychelles, Mauritius and the Caribbean) even some of these have been ‘a close-run thing’ (e.g. a juvenile rat found 29 days after baiting on Palmyra, and healthy live rats caught and killed post-baiting on Birnie at a time when they should have been showing signs of poisoning). A project can be successful even if two or three rats survive if they are all of the same or distanced geographically, while it would be a failure if chance has both sexes surviving in closer proximity. We cannot entirely exclude simple ‘luck of the draw’, and there is no doubt an element of luck involved in distinguishing between the ‘close-run’ successes and the narrow failures (which we deem Desecheo to be). However, best practice has developed over the years to minimise the potential for luck to have a bearing on outcome.

To progress the technology and capability for rat eradications, some risks need to be taken. Because of this, it is important to accurately document each project, and wherever possible to work within best practice principles, so that if a project does fail, the possible causes of failure are much fewer and more identifiable, and the resultant potential improvements can be far more targeted.

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Appendix 2. List of People Interviewed for this Review.

Island Conservation:

Kirsty Swinnerton

Madeleine Pott

David Will

Richard Griffiths

Chad Hanson

Gregg Howald

US Fish and Wildlife Service:

Susan Silander

Appendix 3. The Interviewees Thoughts on Reasons for Eradication Failure.

We asked all seven project participants interviewed what, in their view, were the main reasons for the failure of the operation on Desecheo Island. Each respondent could give as many reasons as they liked.

Table 1. Factors identified by 7 project participants interviewed, that were the likely cause of failure.

Likely Main Factor(s)	No. of Respondents
Not enough bait / too many rats	6
Bait not out for long enough, or insufficient baiting interval	4
Bait gaps	1
Rat breeding	3
Alternative natural foods	2

The Authors

Derek Brown is a New Zealand-based independent consultant with 30 years of experience in island restoration, threatened species management and pest eradication. Formerly with the New Zealand Wildlife Service and Department of Conservation, he has been directly involved in the implementation of more than 20 eradication projects, involving 70^{+} islands and 11 species of invasive animals. He has contributed on many other projects, providing advice, training, reviews and audits, and has developed numerous feasibility studies, operational plans, restoration plans, and biosecurity documents and has helped develop eradication best practice documents and a web-based eradication resource kit.

Bernie Tershy is an Adjunct Professor in Ecology and Evolutionary Biology and co-Director of the Coastal Conservation Action Lab at the University of California Santa Cruz. He is has published over 70 papers on the conservation and ecology of marine and island species. Bernie received his B.S. in biology from the UC, Santa Cruz, M.S. in marine sciences from Moss Landing Marine Labs, and a Ph.D. in neurobiology and behavior from Cornell University.