Wake Atoll Rat Eradication Review

Final Draft
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Wake Atoll, with Peale Island in the foreground and Wake Island behind
(*Photo courtesy of Rory Stansbury*, *Island Conservation*)

Executive Summary

An attempt was made in May 2012 to eradicate two rat species from Wake Atoll (comprising three individual islands) in the central Pacific using a combination of techniques. The project appears successful in eradicating *Rattus tanezumi*, and removing both rat species from one of the three islands (Peale), but has been unsuccessful for *Rattus exulans* on the linked Wake and Wilkes Islands.

All eradication projects, successful or not, can provide significant learning opportunities. We commend the Wake Atoll eradication stakeholders for initiating this review. We were tasked with three objectives; analyzing 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 Wake. This review represents the authors' opinions based on the materials and information available to us. It is limited by our lack of familiarity with Wake Atoll and by operating within a relatively short timeframe. The review's conclusions come from examining available project documentation and conducting interviews with key project personnel. The review is as complete as possible given these constraints.

In our experience, the project was one of the most complicated rat eradications yet attempted. The cause of failure in such a complex project cannot be precisely determined, and could have derived from a single factor or a 'perfect storm' of several overlapping issues. We consider the most important contributing factors include: bait gaps or localized shortages in bait availability created by inadequately designed baiting methodology in commensal and intertidal environments and complicated combinations (and integration) of various baiting methodologies, all exacerbated by known application errors or difficulties, and by low overall bait rates with insufficient buffer; bait preference/aversion issues coupled with availability of alternative natural or commensal foods; rat breeding during the operation causing temporal or spatial unavailability of bait to juveniles emerging from natal nests (or speculatively, behavioral avoidance of bait by some breeding females); poor understanding of habitats such as underground and abandoned structures; and insufficiently understood interactions between the two species that may have provided inadequate bait accessibility for *R. exulans*.

We examined the planning, design and implementation of the project. From initiation, the planning and associated research did not adequately address some of the key issues and the general complexities of the project - the feasibility study did not identify many issues of concern which had a consequent flow-on effect through the planning; more heed was warranted for concerning results related to bait acceptance and toxicology in early trials; and prior mapping of infrastructure (underground and abandoned structures) and testing of techniques for treating the *Pemphis* habitat were significant planning oversights. Bait rate evaluations did not allow for possible variances across the atoll and did not focus on the 'extreme' results and appropriate safety buffers which need to be catered for in eradication design. There were identified shortcomings in adherence to pre-operational agreements and task-lists. Lack of a single operational manager diffused responsibilities, and divisions in roles between agencies probably led to shortfalls and lack of integration in planning, and a lack of 'ownership' of the project. Critical review of some plans was insufficient, and where advice was received it was not always adequately addressed. The concerted effort, resources and optimized environment required to maximize the chances for eradication may not have been fully appreciated by some partner agencies or individuals within them. Communications between agencies and individuals could have been better in this regard.

A range of recommendations are provided, of relevance to possible future eradication attempts on Wake Atoll, and largely applicable to tropical island rodent eradications in general. Development of best practice documents for tropical eradications would resolve many issues encountered here. Despite the complexities and identified shortcomings in planning and operational matters, the project eradicated one rat species and came close to overall success. There is now only one rat species present, and we consider a second attempt to eradicate *R. exulans* on Wake Atoll would have a high probability of success if the issues identified in this review are addressed, best practice principles are developed and applied, and suitable baiting methodology and verification measures are determined in advance for all habitat types.

Contents

Background

Wake Atoll is a ~696 hectare[1] (c. 1720 acre) collection of three separate islands (Wake 526ha, Peale 95ha and Wilkes 76ha). Wake and Wilkes are linked by a vehicle access causeway, and therefore need to be treated as a single entity. Wake and Peale separated by a 50m gap of shallow lagoon.

An attempt was made in May 2012 to eradicate two species of rat, *Rattus tanezumi* (the Asian house rat) and *Rattus exulans* (Pacific rat) from Wake Atoll in the north-western Pacific Ocean. *R. tanezumi* was apparently successfully eradicated from all three islands. *R. exulans* eradication failed on Wake Island itself, and therefore the linked Wilkes Island will also be quickly recolonized, if anecdotal evidence to suggest both rat species were eradicated there is correct. The apparently successful eradication of *R. tanezumi* from all three islands is a key assumption made in this review. If *R. tanezumi* is subsequently found to have survived the eradication, the findings of the review and assessment of probable causes may need to be revised.

This was a co-operative venture between the US Air Force's 15th Airlift Wing (15 AW), Pacific Air Forces (PACAF), together with the United States Fish and Wildlife Service (USFWS) and Island Conservation (IC). The overarching goal of the project was to restore and protect Wake's natural habitat, protect native flora and fauna, and safeguard mission-supporting infrastructure used by the Department of Defense.

Wake Atoll is an active US Air Force installation that is inhabited year round by more than 100 people including military staff and a rotation of supporting contractors. Because of this, implementation of the rat eradication included measures to address those parts of the rat populations that were commensal with humans and the constant threat of arrival of new invasive species due to regular air and sea traffic.

Aerial baiting for eradication started 13 May 2012 (the first application) and concluded May 23 with the second application. Because of numerous exclusion zones, imposed by attempts to comply with federal regulations and by site-specific requirements of the USAF, the entire area could not be treated by aerial application, so a combination of hand-broadcasting of bait, and bait stations inside and outside buildings was used to cover the aerial exclusion zones and buffer areas. The hand-broadcasting and bait station operations occurred concurrently with the aerial operation, and most bait stations were maintained periodically until November 2012. Approximately 590ha was covered by aerial spread of bait, 32ha by hand-broadcasting only, c.11ha by a combination of aerial and hand broadcast, 4.2ha by bait stations, with 59.5ha (runway and taxiing, and bunded fuel storage areas) not baited at all (D. Will *pers. comm.*).

A *juvenile R. exulans* was found inside a bait station on 1 June 2012, 19 days after aerial baiting commenced. A reliable report of a live rat was made 25 June 2012, and another in a separate location on 30 June. Some site-specific responses occurred to target these rats. Three to four months later more observations of surviving rats were made (see Fig 1). Since then increasing numbers of rats sighted or caught on the island have confirmed that the eradication was unsuccessful for at least one of the rat species present. To date all rats that have been caught (>100) have been identified as *R. exulans* based on morphometric measurements (and the five samples that were DNA tested were all *R. exulans*), and no surviving or re-establishing rats have yet been detected on Peale Island. Based on limited sampling, it appears that the eradication of *Rattus tanezumi* was successfully completed, but *Rattus exulans* survived and is rapidly repopulating Wilkes and Wake islands.

[1] Areas derived from 2011 satellite imagery (D. Will, Island Conservation)

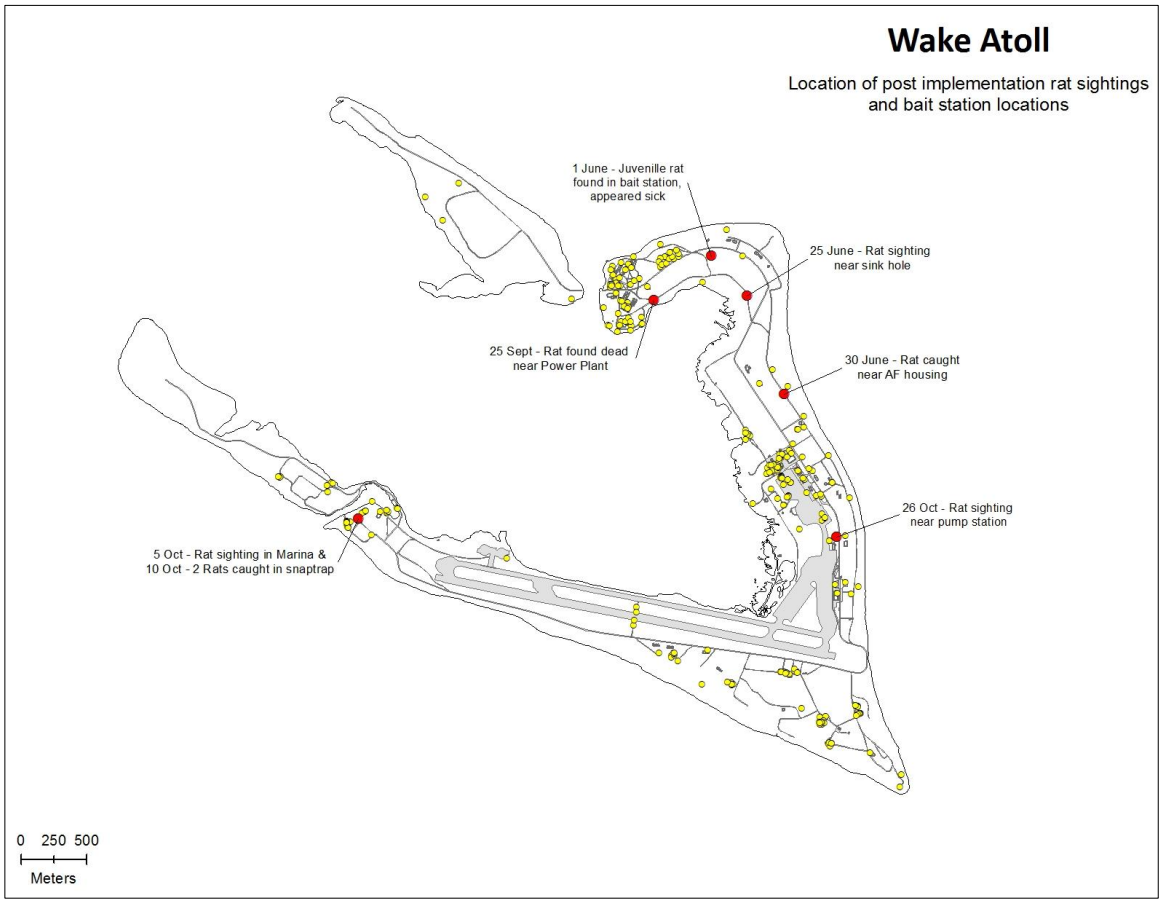

Fig 1. Rat sightings in the first five months post-baiting.
(*Map courtesy D. Will, Island Conservation*).

Review of failed projects is critical to improving eradication practice. The project partners should be commended for commissioning an external review of the Wake project and for enabling a thorough and detailed review of the project.

Wake Atoll is only one of several recent failures in tropical rat eradication projects including: Desecheo (Puerto Rico, target species *Rattus rattus*), Henderson (Pitcairn group), Teauau (French Polynesia), and Enderbury (Phoenix Islands, Kiribati), all with the target species *R. exulans*. Cumulatively these results have taken the eradication community somewhat by surprise. Each of these islands has its own unique circumstances, but there may be similarities that may be informative if each project is reviewed individually and collectively. Each operation can be analyzed and criticized with the benefit of hindsight, but in light of the above, Wake Atoll must not be seen as an isolated case. Collectively it appears that eradication practitioners have not yet identified (and therefore have been unable to address) some key aspects to maximizing 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, including a possible second attempt at rat eradication on Wake Atoll.

Review Objectives

We independently reviewed the Wake rodent eradication project in an attempt to answer three questions:

1. What factors contributed to the unsuccessful *R. exulans* eradication attempt from Wake and Wilkes islands?

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

3. What lessons can be learned and applied to a future eradication attempt on Wake Atoll, including identifying any additional research needs?

The review is limited by the reviewers' lack of familiarity with Wake Atoll. A limited timeframe and budget constraints did not allow a site visit. We were limited to examining project documentation and conducting interviews with key project personnel. The review is as complete as possible given these constraints.

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

There are only two possibilities why *R. exulans* is still present on Wake Atoll: they survived the eradication (a failure in the eradication), or arrived post eradication (a breach in post-operation biosecurity).

DNA voucher specimens were taken from both species prior to the eradication (Alex Wegmann *pers. comm.*). DNA analysis has been conducted on five rats caught post-baiting (between 30 June and 8 Nov 2012), and all were identified as *R. exulans* and all considered as "*likely a resident survivor*" (unpublished data from EcoGene). While a re-invasion (breach in biosecurity) cannot be entirely discounted, it seems very unlikely given these circumstances.

A failure in the eradication attempt is therefore the logical conclusion. The only possible reason for an eradication failure can be broken down into two very simple scenarios, either:

1. All rats **could not** eat a lethal dose of bait (or a lethal dose via secondary consumption of other bait consumers)
2. All rats **would not** eat a lethal dose

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

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 hand-broadcasting applications
(iii) Gaps in the bait station operations
(iv) Spatial or temporal errors in merging or overlapping between bait application type zones (aerial, hand, bait station)

b. There was insufficient bait for all rats because it was eaten by other rats or non-target species before all rats were able to consume a lethal dose.

c. The rats had higher tolerance than expected to the toxicant in the bait. This is a proven possibility through genetic predisposition, or theoretically possible but currently unproven through prolonged prior use of rodenticides.

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

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

a. For some rats there was a bait aversion acquired from previous control efforts on the island.

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

c. There was an inter-species competition that excluded some *R. exulans* either physically or behaviorally from accessing bait, particularly from bait stations.

d. Some rats chose not to eat bait, or enough of it, because of the palatability of the bait and/or the availability of natural or commensal food resources, and/or because of seasonal behavioral changes (e.g. breeding females confined to nests or with smaller home ranges).

This review uses the evidence available to identify the most likely contributors to *R. exulans* eradication failure on Wilkes and Wake Islands. This will address the first review objective, and will provide information to guide the latter two review objectives.

Detailed Examination of the Possible Causes of Failure.

Gap in Coverage

The locations of the surviving rats may give an indication of where problems in the eradication arose. All indications are that both *R. exulans and R. tanezumi* were successfully eradicated from Peale Island where there were few if any commensal rats, there were fewer anthropogenic food sources and one bait application technique predominated. *R. exulans* survived on Wake and Wilkes islands, but the locations of rat detections within these islands is unlikely to provide useful information because of the small size of these islands in relation to rat dispersal distances, the difficulty of detecting rats even using rigorous, systematic searches.

The fact that *Rattus tanezumi*, the dominant species by size and apparently present in most if not all the recognized habitats of Wake Atoll, was successfully eradicated suggests bait *gaps* in aerial application were not a problem for this species. A *shortage* of bait could however have made access to bait by the subordinate *Rattus exulans* more difficult (as well as any habitat or behavioral differentiation, but these will be discussed elsewhere).

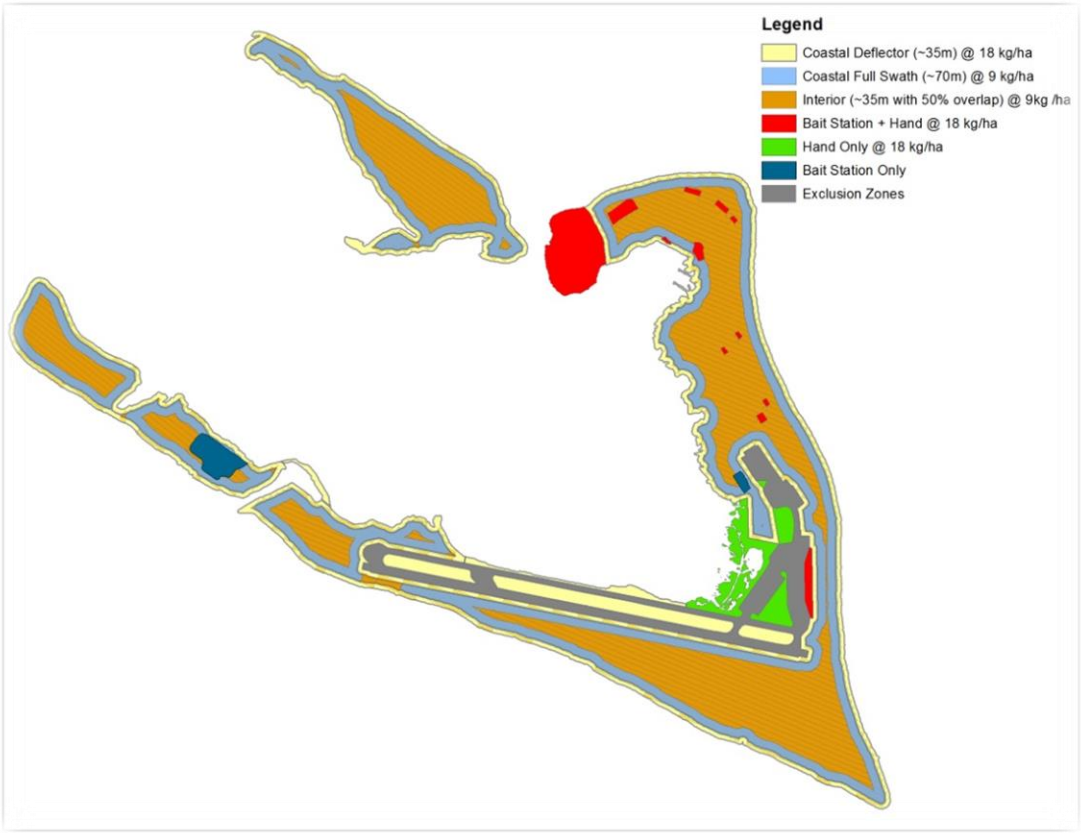

Fig. 2 Proposed baiting strategy for Peale (top), Wake (right) and Wilkes (center left) showing various baiting methodologies. The 'no baiting' zones (grey) and aerial baiting exclusion zones (red, green and dark blue areas) are shown. (*From the Wake Atoll Operational Plan (IC 2012).*

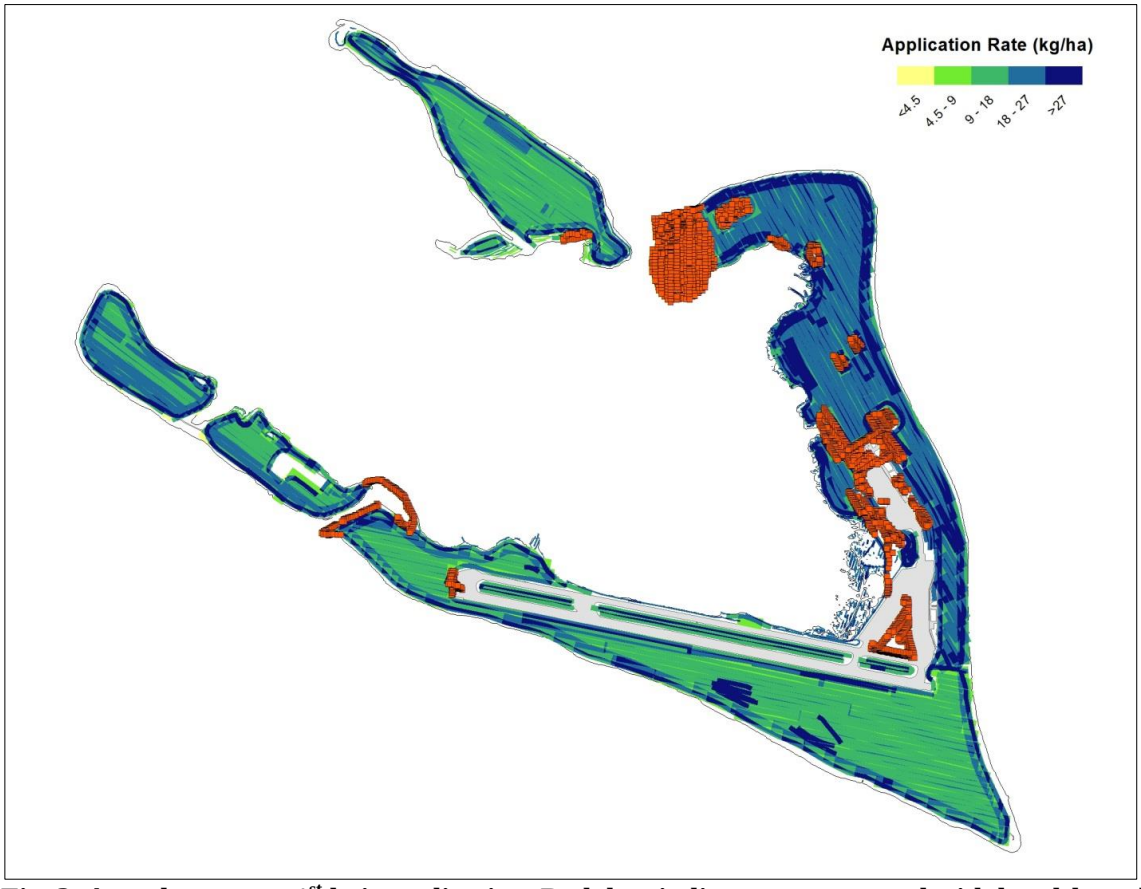

Fig. 3. Actual coverage 1st bait application. Red dots indicate areas treated with hand-broadcast coverage *(from Post-Operational Report, IC 2013).*

Gaps in the Aerial Application

Aerial bait spread appears to have been completed according to established New Zealand best practice[2] principles (overlaps between baiting swaths, two separate applications at least 7-10 days apart, GPS tracking of where baiting occurred, etc.).

The GIS baiting maps are difficult to interpret without a scale, but indicate that some very small areas did not receive bait. There are identifiable gaps at either end of the middle ('ruderal' or wasteland vegetation) strip in the middle of the main runway. Some of these appear to have been hand-treated later, while others did not. It is not clear if all such areas or just representative portions were visually ground-truthed for coverage.

There appears to have been no baiting at all along a ~1km section of the coastal strip along the northern edge of the runway (see Map 3). According to R. Griffiths (*pers. comm*.) this was a problem with the GPS navigational mapping system and the area was definitely treated. There also appeared to be very light application around the taxiing area and adjacent built-up area in the second application

[2] Best practice documents have been developed by the New Zealand Department of Conservation (DOC), 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 equivalent are the best available guide of eradication best practice.

(<4.5kg/ha, compared to the desired 9kg/ha). Apparently, this is due to the area treated with a single swath of bait (with no overlap) during the second application and covered by hand-baiting during the first application. These two apparent gaps may, or may not, be significant.

There was some concerning evidence of the helicopter pilot continuing to 'sow' bait and to record GPS tracks of such 'baiting' when in fact the bait bucket was empty. This was recorded on a Go-Pro™ camera attached to the strop-lines below helicopter. Such recording is not standard in eradication bait-spreading operations, and was not intended for this specific purpose here, so it is fortuitous this occurred here to highlight a potential problem. The camera operator should be commended on his subsequent action, where on later informal reviewing of the camera footage three separate instances of 'false sowing' (apparently only over Wake Island) were detected and reported to project managers. This record of 'false sowing' was clearly attributable to human error, as bait sowing (and the electronically-linked GPS tracking) is manually switched on and off by the pilot.

The pilot (probably the most highly experienced in the world on eradication projects) indicated that the many aerial-baiting exclusion zones and repeatedly 'stop-start' nature of baiting on Wake caused a change in the normal perspective or focus of an eradication pilot, from concentrating on baiting accuracy to instead concentrating on regulatory compliance (P. Garden *pers. comm.*). Due to the overlapping swaths and double applications recommended in New Zealand best practice and implemented in the Wake operation, it is unlikely that the gaps caused by sowing with an empty bucket created an actual 'gap' in baiting coverage. It could however have created a shortage of bait (~50% less than desired) in some areas for one application. If the helicopter is flying at approximately 40 knots (the minimum likely here), it covers ~20m/second. The longest false sowing event was timed at ~20 seconds, giving an estimated minimum area of 400m-long and 70m-wide (2.8ha) that was baited at half the intended rate, if the overlapping (adjacent) swath occurred without incident. The other two instances are less clear, but appear to last ~5 and ~8 seconds (a minimum of 0.7ha and 1.12ha respectively). It is not able to be confirmed, but it is at long odds that the empty bucket sowing occurred in the same general location on each occasion, which could have further compounded the bait shortage in a single area. The camera was not attached for the entire baiting operation, so it is feasible other such events occurred without detection.

The exclusion zones, although largely of completely sealed surfaces (runway, taxiing areas, etc.) are of concern. The total size of these was c.60 ha. However, one area, the fuel farm on Wilkes Island, was originally shown to be treated using bait stations (see Fig 2) but through an operational decision that this fully sealed and bunded area harbored no rat habitat (C. Hanson *pers. comm.*) it also became largely a 'no-baiting' exclusion zone (see Fig. 3). There appears to be an assumption that no rodents would survive in such areas, and this may be reasonable given the nature of the areas, but greater efforts to verify they were indeed completely rodent-free should have been implemented, and stated within planning documents. Some *R. exulans* are extremely small, not much bigger than mice, and could potentially survive for extended periods in such sub-optimal habitat, which might be free from competition or aggression from the larger rat species. However, experienced eradication personnel made inspections of these areas and baited wherever they thought necessary and was permissible, but regardless of this our view is that such large areas with no bait whatsoever are undesirable from an eradication viewpoint. If they cannot be baited for safety reasons, alternate methods of verifying rodent presence/absence should have been employed.

To comply with the bait product label, aerial baiting could not occur < 40m from areas occupied by people. These commensal areas had to be treated with hand-baiting and bait stations. The Post-Operation report (IC 2013) states "*restrictions imposed to avoid bait in the water or on the airstrip or*

near some buildings and other facilities caused a fairly fractured pattern to some of the aerial broadcast. In some cases these situations created boundaries or gaps that required hand spreading of baits that were less well defined. This increased the risk of leaving gaps in bait coverage". We concur with this statement. The almost impossibly complicated stop-start nature of the aerial application zones added an extra level of complexity for the pilot that greatly increased the difficulty of aerial bait deployment. While some exclusion zones have occurred in other projects (e.g. Palmyra) we are not aware of exclusion zones on such a scale or quantity from any other eradication project.

Gaps in the Hand-Broadcasting Applications

Hand-broadcast covered at least 43ha, and at least 13 different planned areas (see Fig 2), but it is known that at least one hand-treatment area, a small wetland on Peale, was also treated by hand (C. Hanson *pers. comm.*) but not shown on the maps. Perceived gaps in aerial coverage were also hand-treated (Fig 3 shows some such areas) and there may be more small areas like this. It also covered baiting of a number of uninhabited structures that were widespread across the entire atoll.

In the first application 568 abandoned 'structures' and sewer system infrastructure were baited and in the second 608. This was explained in the material we reviewed as follows: "*During the first application, 15 buildings and 3 boats were not baited because of a miscommunication about which areas teams were supposed to cover. A backlog of datasheets, and mistakes in data recording, meant that this was not discovered until some days after the first application. To remedy this situation for the second application clearer instructions were given, tidier data sheets generated, and an individual was designated to enter data at the end of each day. These solutions resolved the issues that were experienced during the first application*" (IC 2013). This is an example of the complexity of this hand-baiting operation but such 'miscommunications' should not occur. The full list of structures should have been developed well before the baiting commenced, and it is a significant oversight in planning that the methodology and resourcing for baiting, and a rapid and fool-proof method of confirmation of baiting wasn't established well beforehand.

The need for baiting of the sewer and underground infrastructure was prescribed in the operational plan, but the extent of the infrastructure had not been determined, and the method of baiting the sewerage network had not been field-evaluated. During the operation it was found that the intended technique (placement of bait on the 'floor of such structures) could not be used due to dampness of the substrate. 'On-the-spot' remedies (suspending of bait bolas) were developed to address this. There seems to have been no real consideration given to such structures in the Feasibility Study or Commensal Rat Plan, and very limited information within the Operational Plan, and this is considered a significant oversight. The plans do not provide any insight into where the structures are, an analysis of their relative risk (likely food resources, etc.), their distribution or mapping, how they would be comprehensively covered or how that coverage would be verified. Rats can and do make use of sewer infrastructure networks, and issues such as this have been raised in prior eradication feasibility studies where a sizeable human habitation occurred (e.g. for Tristan da Cunha Island, Brown 2005).

Some hand-baiting team members were seemingly over-burdened, not finishing their prescribed baiting until very late on the baiting day (IC 2013), despite more resources being allocated to this task than originally intended. The constraints on numbers of project personnel able to be on the island for the implementation appear to have created issues in completion of many tasks.

Given the very complex nature of the operation, and the multiple task requirements of each team member, there appears to have been insufficient contingency built into the operation to allow for extra staff time to be able to respond to extra work pressures or to spend time verifying baiting coverage.

Gaps in the Bait Station Operations

The operational plan for commensal rats did not provide a clear prescription as to how the bait stations were to be placed out, or the desirable minimum spacing between them, the 'set-up of the stations (e.g. elevated or not), or even clearly stating the chosen design(s) and why they had been chosen. This is an obvious oversight in planning.

The Post-Operational Report (IC 2013) does provide some indication of the strategy in hindsight - bait stations were placed "*directly against structure walls with spacing's not exceeding 50m*". Pacific rats (*R. exulans*) can be almost mouse-like in size and behavior, so 50m spacing's are considered too wide apart to adequately cater for this species. It is not clear how these spacing's were determined. The spacing of outdoor bait stations used on Wake was not so important, as all such stations were within 3m of hand-broadcast bait. However, the indoor bait stations did not have an alternative method of bait presentation near them, and treatment of such areas relied solely on the bait stations. New Zealand best practice for eradication using bait stations (Broome *et al.* 2011b) clearly advocates a spacing of 25m x 25m for *Rattus exulans.* This is supported by other literature where it is suggested that bait stations 20–25m apart may be necessary for *R. exulans* (Bramley 1999). Broome *et al.* (2011b) also recommends baiting of "*all portions*" of "*all buildings*", something anecdotal evidence suggests did not happen here, but we cannot verify this with the information available.

It appears that while bait stations were checked and recharged over several weeks following the aerial baiting operation, a few may have been removed too soon, e.g. - "*bait stations placed inside the manager's housing were removed on 2 June*" (IC 2013). A key staff member left the island as scheduled on 2 June, and as a result there was no-one left with a permit to handle bait. This appears to be an oversight in planning and staff scheduling. While checks could still occur, bait handling was not possible and "*bait stations were not able to be restocked during monitoring for the prescribed 2 months after the first broadcast. The USFWS staff holding the permit to handle bait was no longer on island after June 2 and the USAF discontinued all activities involving the handling of bait*" (IC 2013). This was only 20 days after the aerial bait application, and this duration may not have been sufficient to ensure all rats had access to bait. However, most bait stations continued to hold the pre-stocked bait and remained in operation for many weeks, and later checks and replenishments of most (but not all) bait stations in July and November showed no evidence of rat activity in any station (B. Flint *pers. comm.*).

Errors in Merging or Overlapping the Aerial and Hand-Broadcasting Zones

The multiplicity of exclusion areas for aerial baiting, and the resultant need to match and "stitch" the aerial and ground-baiting zones can only be described as extremely complex. Such a high number of exclusion zones and the buffer areas between different baiting methodologies undoubtedly would contribute to higher risk of bait gaps occurring.

The hand-broadcasting was originally intended to be done using a 20m x 20m GPS grid-point system, but this was in part abandoned due to it being too time consuming, and baiting in most of the smaller

aerial exclusion zones was largely done 'by eye' with a baiting supervisor controlling the spacing between people spreading bait. This alternative method is one that has been used successfully before in past eradications, and the tight spacing between personnel applying bait meant gaps were highly unlikely where bait was actually hand-broadcast.

However, with so many overlaps and buffers required it is quite possible that one or more aerial exclusion areas was not identified (or incorrectly identified) to be hand-treated and therefore missed by both aerial and hand-broadcast. Although the ground team conducted visual confirmation of bait deployment, which should have identified any gaps, it very well may have missed some gaps. An extremely experienced eradication technician professed that even for someone of his experience, it was sometimes "*hard to find a boundary*" in some of the smaller aerial-exclusion zones, and because of the dense shrubby habitat it "*wasn't straightforward*" determining which areas had received aerially sown bait (or enough of it) and which hadn't. A number of the personnel in the hand-baiting operation were not experienced in such work, and inexperience could have further added to the risk of errors of judgment in such situations where subjectivity is required.

Rats Surviving In Baiting Exclusion Zones

We are unfamiliar with the island, and cannot make informed comment on the possibility of rats inhabiting the largely sealed 'no baiting at all' areas such as the runway and taxiing areas and fuel farm. The operational plan and post-operational report lack any comment on whether such areas were minutely and comprehensively checked for this possibility. There appears to have been an assumption made that these areas were 100% rat-free, but we cannot find in the documentation any supporting evidence on which this assumption was made prior to the actual operation. However, experienced eradication personnel involved in the operation were confident that, in the words of one, "*everything was baited that needed to be*". Exclusion zones (i.e. where no baiting at all occurs) are extremely rare in eradication operations but did occur for the smaller runway area on Palmyra Atoll (a successful eradication) and possibly for other projects such as Midway (largely a bait-station project), and for permanent ice areas on South Georgia (an on-going project).

Rats Surviving in Areas Where Bait Could Not Reach Them.

The Operational Plan identified intertidal *Pemphis acidula* shrubland that according to the plan "*cannot be baited via aerial broadcast or hand broadcast due to flooding of the exposed ground at high tide*". Rats were observed within *Pemphis* habitat on Peale Island during the Feasibility Study work (Mosher *et al*. 2007) and supporting anecdotal information (P. Garden and M. Moran *pers. comm.*) suggested rat use of the habitat was abundant and widespread.

The New Zealand Department of Conservation's Island Eradication Advisory Group (IEAG) was one of several organizations asked to review the Wake Atoll Operational Plan. The IEAG is composed of experts highly experienced in planning for and undertaking rodent eradications and they suggested "*there is a risk area for the operation in the vegetated tidal zone northeast of the runway* [they refer here to the major *Pemphis* area]. *The detail of how this area is to be baited requires some specific planning. Discussion at the meeting suggested a combination of hand broadcasting the few dry areas (perhaps supplemented by bait stations), followed by the use of bait bolos as used on Palmyra…*" (IEAG 2012). This was reinforced by IC's own readiness check team: "*the intertidal marsh areas are a high risk area that will require attention during the operation. Thought needs to go into how these*

areas will be treated whether it be by bait station, hand baiting, aerial baiting, the use of bolas, or a combination of these methods" (Griffiths *et al.* 2012).

The combined baiting strategy suggested both by the IEAG and IC was not picked up, and instead a somewhat novel and untested solution to treating the *Pemphis* areas was proposed – a single technique of bait 'bolas' tossed from helicopter. Attempting this method during the baiting operation showed it to be inaccurate and time-expensive. An on-the-spot solution of trickle-feeding from the helicopter's bait bucket was used to place bait on such areas, but it was very unclear in post-operational reporting how verification was made that: 1) bait remained accessible in sufficient quantity to rats in the area beyond the next high tide; and 2) how all the habitat could be established as having been treated. There was follow-up ground-truthing which determined the coverage appeared adequate (R. Griffiths, C. Hanson *pers. comm.*), but others who were familiar with treatment or anecdotal observations of the *Pemphis* areas had some concern about whether the overall coverage was adequate (P. Garden, S. White *pers. comm.*). Both rat species were seemingly eradicated from Peale, but the *Pemphis* area on Peale is considerably smaller and more densely vegetated area than the larger and more 'scattered' *Pemphis* habitat on Wake Island (B. Flint, C. Hanson *pers. comm.*), which would have made baiting more straightforward on Peale.

The method finally used did not seem to tally with the statement in the Operational Plan that such areas "*cannot be baited via aerial broadcast or hand broadcast*". Either it could or couldn't, and a much clearer and pre-tested workable solution should have been developed on the basis of this well before the implementation.

Photo 2. *Pemphis* and intertidal habitat on Wake Atoll, showing the complicated mosaic of vegetation and tidal channels. ***(****Photo courtesy S. White/USFWS****)***

The Operational Plan is lacking in detail on how to deal with the *Pemphis* areas, and the novel method of dealing with it had not been field-tested. It is unclear from post-operational reporting whether the baiting of *Pemphis* habitat was adequate or kept bait in place for long enough to expose all rats living in such areas to bait, and while the area was checked by experienced personnel, the novel approach should have meant a far greater monitoring focus on these areas. Other possible options were potentially available, such as open baiting platforms or bait stations attached above tide levels on larger individual shrubs to supplement any broadcasting, or tracking pads or tunnels to confirm whether rats were still active in such areas. These alternate options would have been time- and resource-consuming, and it may be that 'quicker' options were deemed necessary in view of what appear to be quite severe restrictions on team members' time.

The larger rat species, *R. tanezumi,* was apparently eradicated – suggesting bait coverage for this species at least was not an issue. As a larger species, and presumably the dominant one, *R. tanezumi* would have presumably occupied larger territories and dominated prime foraging areas. Behavioral and habitat changes may have occurred as a result of inter-species or even intra-species competition and aggression, and some *R exulans* may have been forced into sub-optimal home ranges and locations (e.g. *Pemphis* habitat) where dominant rats may not have occurred, or occurred in lesser numbers.

It is also feasible rats survived in portions of the underground structure or sewer network. A reactive mapping and baiting program was initiated during the implementation, but it is not clear if the mapping and treatment were totally comprehensive, with some anecdotal evidence suggesting there were structures that were undiscovered during the operation that have only been located more recently.

Insufficient Bait, or Bait Not Available for Long Enough

The bait rate used here followed label bait rates, but may have been less than ideal. However, if bait uptake trials had identified a need for an increased bait rate, then the supplemental application applied for and obtained here for other reasons could also have allowed for this. On Palmyra, strong scientific evidence was gathered to justify substantial bait rate increases, but the supplemental label on Wake Atoll focused on issues such as enabling follow-up hand-baiting in localized areas, rather than increasing bait rates. Obtaining this scientific data to support a bait rate increase could have created added cost and potential delays to the Wake project, while such evidence was gathered and analyzed.

We applaud the scientific efforts made in bait uptake trials (and we note the trials conducted here were more than has been done for most other eradication projects). However, 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 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. With two rat species in apparently very high density, plus likely significant bait take by non-target species such as crabs and ants we feel that, despite the evidence presented in the bait trials, the bait application rates were marginally sufficient at best, and did not allow adequate safety margins for temporal or spatial variance across the atoll.

It is also noted that for those Wake project staff interviewed for this review, insufficient bait was the most commonly suggested reason for failure (see Appendix 2). It is acknowledged each island has its own unique circumstances, and bait rates need to reflect these, but nevertheless, bait rates used here (an overall average of 27.7kg/ha) can be compared with other operations on tropical islands (see table below).

Table 1. Bait rates and eradication outcomes of some broadcast-baited islands.

Island†	Overall bait rate (kg/ha)	Outcome
Palmyra Atoll	164*	Success
McKean Island (Phoenix Is group)	70	Success
Birnie Island (Phoenix Is group)	51	Success
Cocos Island (Guam)	21.5*	Success
Wake Atoll	27.7*	At least partial failure
Enderbury	38.4	Failure
Desecheo	29*	Failure
Henderson	17.4	Failure

[† all islands except Wake had only one species of rat; * indicates other methods (bait stations or trapping) supplemented this rate in parts of the island**]**

The bait uptake trials (Wegmann *et al.* 2009) were limited to a single site in the 'natural' environment and a single 'commensal' trial plot. Such constraints are understandable and found within most practical island situations where time and budget do not allow for more comprehensive studies. While bait remained available in most sub-plots, it was clear that a few areas had all bait consumed within 2-3 nights after the first application, with a similarly rapid bait disappearance from some plots after the second application (Fig 6, in Wegmann *et al.* 2009). There is currently no specified 'ideal' length of time that bait should remain available for, but Island Conservation have previously had an informal target of 4 days (R. Griffiths *pers. comm.*), derived from the EPA 3-day choice test criteria used for testing bait, and the minimum to achieve 100% mortality in laboratory settings, with an additional day added. Inference from NZ best practice is at least 3 nights (avoiding bait spreading in wet conditions for that minimum period to ensure bait remains available to rodents). The relative rapid disappearance of bait here perhaps could have been analyzed further particularly with respect to safety margins or 'comfort zones'.

There appear to be generalizations or assumptions made in the subsequent finding that "*we believe that the target bait application rate (18kg/ha followed by 9kg/ha) will be sufficient for the proposed broadcast-based rat eradication*". The assumptions are the areas used for the plots were representative of the entire island, and there would be no areas where significant variation to this might occur. There also seems to be insufficient allowance for scientific margins of error, or for possible variation in populations of rats or populations and/or activity of bait-eating non-target species such as crabs or ants between years.

Some specific high density crab areas or habitats have been identified, and one bait uptake site was specifically chosen for its high crab densities, but it was considered that crab (and rat) densities were highly variable across the atoll (B. Flint *pers. comm.*).The statistical means or the general trend from the trial appears to have influenced the bait rate decision, rather than the few extremes that did not fit the norm. In setting bait rates for eradication, it is the likely upper extreme confidence level that must

be catered for, not the norm. The need in eradication is to target 100% of individuals, not just the 'norms'. If there is any current issue with justifying rates (especially with adequate safety buffers) to regulatory authorities, we feel this is a fundamental issue and it needs to be addressed.

A very experienced rat eradication expert stated the rat densities on Wake Atoll were "*the highest he had ever seen*" and were noted as abundant both in 2009 and 2012 (N. Torr *pers. comm.*), and others stated the density of rats at one particular location was "*frightening*" (R. Griffiths *pers. comm.*), and "*I had never seen anything like it*" (S. White *pers. comm.*). Somehow the known very high density of rats was not translated into the planning or the determination of bait rates. We acknowledge some of this information was acquired during the bait spread operation. This was too late to be able to take meaningful response actions, primarily because the present US regulations provide little flexibility for adaptive management in response to such information. In other jurisdictions, unused or contingency bait could have been used to target any areas of concern with supplemental baiting.

Mosher *et al.* (2007) stated "*Wake Atoll hosts a substantial population of hermit crabs (Coenobita perlatus), and little is known about how much bait land crabs consume in one day, or over several days. Reports from rodent eradication work in the Phoenix Islands suggest that individual C. perlatus can consume bait at a rate of 10 g/day, and at high densities can consume up to 40 kg/ha/day (R. Pierce pers. comm.). Given these uncertainties, an application rate higher than 14.4 kg/ha, but within the label maximum, should be considered*". This comment further accentuates the need for close examination of the bait rate. However, it is unclear from this statement whether the recommendation to stay below the label maximum was on scientific evidence or a desire to comply with the regulations as they stood.

An independent review (IEAG 2012) of the Operational Plan suggested "*the overall rates and methods described look adequate to meet the goals and constraints on the project*" but did warn - somewhat contradictorily - that "*the constraint on total average sowing rate has implications that require careful planning*".

During the actual baiting, an initial error in disk size selection for the bait bucket caused first application bait rates on Wilkes Island to be lower than planned, but the problem was quickly identified and resolved, and the resultant GIS maps show no subsequent area of concern where aerial treatment occurred.

Any nursing female rat would have had access to bait over two different baiting periods. 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.

Land crab densities were apparently highest on Peale Island (Mosher *et al.* 2007), but it appears rats of both species appear to have been successfully eradicated from this island, with no rats at all being found in any post-eradication monitoring thus far. This suggests bait-take by non-target species such as crabs was not a significant factor in the failure. However, there remains a possibility that there were undetected or insufficiently delineated pockets of higher densities of crabs elsewhere, and some areas

such as the heavily wooded areas on the eastern (windward) coast of Wake and on or near Wilkes Island have been suggested (B. Flint *pers. comm.*). Similarly, feral chickens were still present during the operation and could have consumed appreciable quantities of bait in localized areas. Again though, it appears most chickens were on Peale Island, where rat eradication was successful.

Ants were mentioned within operational planning documents, but relatively little attention paid to their relative abundance or the possible extent of their impact on bait consumption, and subsequently we are unable to comment on whether this was a significant factor or not. One post-baiting report (Haagsma and Breidenbaugh 2013) did suggest "*it appears that ants might be a significant competitor for the ground based baits*", and provided evidence of bait consumption.

Eighteen bait monitoring transects were established during the baiting operation to measure bait uptake. This action is highly commended, and monitoring of bait uptake immediately post-baiting is an important facet in acquiring useful information for all future eradications, and for reviews such as this if the eradication attempt fails. These showed that, at least where these were located, bait remained available for rats for at least 4 days after the first application and for 6 days after the second, and longer in some locations. This indicates bait was available for a reasonable length of time to allow all rats to find a lethal dose of bait. However the transects were only representative, and none of these transects occurred in the key *Pemphis* habitat, and few in the wooded areas of possible high crab density A high variability in bait uptake was noted, but largely because of the maximum bait-rate constraints any 'adaptive' baiting, i.e. special treatment zones or supplemental applications were not possible (B. Flint *pers. comm.*).

We can find no clear evidence that there was a shortage of bait, only that the rates seem light in relation to bait rates used on other islands and in the circumstances prevailing here, with two rat species, high rat densities, and variable bait-take by land crabs. However, if bait rates were only marginally adequate, there would be an insufficient safety margin for any application error that could have created under-sowing in localized areas.

Tolerance to Toxicant, and Toxicity of Bait

Although some instances of increased tolerance have been noted, resistance by rats to brodifacoum has never been encountered even at sites where it has been used repeatedly for long periods of time (Lund 1984, Bailey *et al.* 2005). It is therefore unlikely that the survivors on Wake Atoll had a higher resistance to the toxicant, but this possibility cannot be ruled out entirely.

The established LD50 (the per-weight dose required to kill 50% of the population) for *Rattus exulans* (0.32mg/kg) is not appreciably different to other rat species (0.17-0.26 for *R. norvegicus*, 0.46-0.73mg/kg for *R. rattus*, Broome *et al.* 2012). Because of their smaller size, only ~1.3gm of bait is required for a LD50 dose for average-sized *R. exulans*, cf. *R. rattus* requiring ~5.8gm (IEAG 2012b).

It is possible that because of the prior use of brodifacoum some rats in this population had an increased tolerance (as opposed to resistance). Where such rats were only able to access small amounts of bait, they may not have been able to receive sufficient bait for a lethal dose.

In trials conducted in 2007 on Wake Atoll (Mosher *et al.* 2007) 30 captive rats were presented with brodifacoum pellets along with an alternative food. Of the 30 rats, only 14 died between 144 and 408 hours (6-17 days), but because data was not collected on food intake, it is unclear whether the surviving

16 rats ate any toxic (brodifacoum) bait at all but they did not die within 17 days. Both rat species were involved in the trials but not distinguished in results. The length of time for some rats to die was appreciably (3-4 times) longer than expected based on known information from many eradication operations using brodifacoum, and longer than known from almost all other research studies where brodifacoum has been used. The fact that some may have eaten bait but not died is a major concern, as is the possible avoidance of bait by some rats. Although there were some issues around the way the trials were conducted, the results were far from the desired 100% effectiveness, and should have instigated a high-priority response, including possible further investigation and analysis. Some concern on these issues was highlighted (e.g. various comments in Appendix D of the Finding of No Significant Impact (FONSI) report, USAF 2009) but it is unclear how or if these concerns were addressed.

Assuming that any increased tolerance or resistance is genetically transferable to progeny, this could be tested by capturing a sample of surviving rats and testing their response in LD tests (e.g. LD50 and LD100 doses), to compare with other rat populations of this species.

Bell Labs' Brodifacoum 25 bait has been used in numerous successful eradications (e.g. several islands in the Galapagos, Anacapa (California), Rat Island (Alaska), Palmyra, 3 small islands in Pohnpei, Tahanea (French Polynesia), Isabel, San Pedro Martir (Mexico) and 5 other islands in the Caribbean, Allen Key in the Bahamas, and others for which success is yet to be confirmed).

It has two versions, 25-W for wet conditions and 25-D for dry conditions. 25-W has a slightly different manufacture process than 25-D, with pellet formulation including an agent that makes the pellets more resistant to splitting and cracking particularly in a damp or wet environment. Conservation 25-W is the type used on Wake Atoll. See Table 2 for a summary of eradications using these bait types.

Table 2. Summary of Eradications Using Bell Labs Conservation 25 Baits
(From IC *unpublished data*).

Bait Type	No. of Eradication Projects	Successes	Outcome Unconfirmed	Failures	Success Rate (outcome known)
25-W	6	3	1*	2	60%
25-D	29	20	8	1	95%

[*Wake Atoll is deemed 'outcome unconfirmed' as it may have been as successful in eradicating *R. tanezumi* but this has yet to be officially confirmed]

It can be assumed that the manufacture of such bait is highly regulated and subject to regular internal quality control checks, so the end product should be 'standardized'. Bait for Wake Atoll was tested at Bell Lab's own facility and the samples showed an appropriate mean level of brodifacoum content of 28.3ppm (IC 2013).

Independent analyses have not been conducted for the bait used at Wake Atoll, but have been carried out on Conservation 25 bait from other operations. The samples showed a wide variance in toxicant levels (~14-31 ppm); however the toxicant levels were high enough to suggest any 'normal' rat (based on published LD50's) would only have to eat 1-2 baits to receive a lethal dose.

A small amount of non-toxic bait (397kg), intended for bait-bucket calibrations and to pre-bait external bait stations) was shipped to the island in conjunction with the toxic bait. It is always a concern when non-toxic bait is in proximity to toxic bait, as there is a potential for it to be inadvertently mixed in with the toxic bait. Active bait for Wake Atoll was packed into pails and pods, while it appears the inert bait was in paper sacks, so should have been easily distinguishable to all those that knew inert bait was present. However a mix-up was not a possibility here, as inert bait had been used up in prior 'pre-feeding' in bait stations and for off-shore bait bucket calibration trails (C. Hanson *pers. comm.*). Inert bait did not appear to be used for bucket calibrations on-island – this was achieved using toxic bait on the first day of aerial bait application. Total toxic bait used was within 6.9kg (possibly due to rounding of figures) of the total toxic bait brought to the island minus that remaining at the end of operations, so it appears unlikely that inert bait was accidentally used.

Bait Aversion

Rodents have been present for many years on Wake Atoll and control measures have been on-going for some time, because the rats posed a health hazard to humans and impacted the Air Force mission by burrowing under foundations and chewing wires (USAF 2012). Rat control on Wake involved a combination of rodenticides including brodifacoum. Control efforts were centered on residences and associated facilities, but also included mission-essential areas such as the missile defense area (MDA), fuel area, and selected buildings.

This history of prior rodent control conceivably could have impacted the operation. While there is no scientific evidence to support this, the extensive prior use of toxicants on Wake Atoll could have initiated some learned behavioral response to either the bait itself or the way it was presented. The apparent avoidance or tolerance of bait in both the bait uptake and bait toxicology trials was unexpected, and may indicate either pronounced neophobia amongst some individuals or a previously undocumented issue.

The bait toxicology trial (Mosher *et al.* 2007) did not definitively test either tolerance or preference, but showed a surprisingly high percentage of captive rats either not eating any bait or not eating enough bait to receive a lethal dose (the trials did not measure intake). Biomarker trials (Wegmann *et al.* 2009) showed a less than 100% acceptance of non-toxic bait amongst commensal rats on Wake, with 3 rats (of 33 sampled) clearly within the trial's commensal zone not exhibiting evidence of taking bait. The study considered it "*unlikely that the biomarker-negative rats were recent incursions into the core sampling area*", and therefore had been exposed to ample bait over a number of days but had chosen not to eat it. The study did suggest alternative foods in the gardens were the reason for the rats not eating bait, and efforts were made to eliminate these food sources, with considerable but not absolute success, prior to and during the toxicant baiting operation. These findings should have raised significant concern amongst the operational planners (as it did among some reviewers) and should have instigated further investigations or trials.

These studies provide evidence that rats do not have a 100% acceptance of the bait under all conditions.

We also considered whether bait quality (i.e. condition of the bait after transport and storage) was satisfactory. While some crumbling of bait and 'dust' was observed, particularly at the bottom of bulk bags, this is normal and there was no indication from project staff that bait condition on Wake was any

different to previous projects. It appears that the bait was in good condition, without mold, insect attack or any other possible quality-related issues when spread.

Bait Station Aversion

There was a large number of bait stations used in the operation, though precisely how many is difficult to establish. Within a single report, (the Post-Operational Report (IC 2013)) two different figures (1500 and 1344 stations) are given, while a power point presentation by David Will states 1344, but the operational plan's Baiting Strategy stated "*Bait stations (n = 1,100) were established 5 months prior to the bait broadcast to overcome neophobia by rats*" – the assumption is that either some pre-existing stations were not counted in this total, or more were added later. This confused situation cannot have helped to ensure all stations were in the correct place well ahead of baiting, or that all bait stations were being checked and re-baited as required.

Some stations were clearly established within buildings and some outside buildings. The Post-Operational Report suggests 699 stations outside and 645 stations within a total of 266 buildings. It appears that bait stations were the only eradication method used within inhabited or used buildings.

The operational plan's baiting strategy stated that "*during the active baiting period, the baiting manager may decide to employ glue boards (sticky traps) and snap-traps inside buildings to capture station-shy rats*". While acknowledging the possibility of 'station-shy' individuals, there was still a100% reliance on these bait stations during implementation to cover some commensal areas, and there seemed to be no 'testing' or quality control of their effectiveness through use of other devices including those suggested above. This seems counter-intuitive, but staff shortages may have again played a role in preventing such quality control evaluations.

Clapperton (2006) cites evidence of heightened neophobia within commensal rat populations (compared to non-commensal populations), and that the response varies not only between species but also between populations of the same species and between individual animals. Thus, a few individuals with heightened neophobia could avoid entering bait stations and therefore cause operational failure in areas where reliance was 100% on bait stations, especially newly established ones or those with somewhat novel designs.

Bait station use on islands with land-crab species can be problematic, with crabs taking large amounts of bait and/or densely occupying the bait stations physically preventing rat access. The New Zealand Department of Conservation's eradication best practice for use of bait stations (Broome *et al*. 2011b) recommends that bait stations are *only* used where aerial spread and hand-broadcasting are not practical options. In this situation, EPA regulations would have required a specific exception for aerial broadcast within 40m or hand-broadcasting within 3m of inhabited buildings. While bait stations were clearly necessary inside buildings, the outdoor bait stations were used in the 3 meter-wide 'hand-broadcast exclusion zone' around inhabited structures (as required under the operational conditions), and were probably a redundant measure, but were useful in allowing an extended period of bait availability within such commensal areas.

At least two different bait station designs appear to have been used, but little information is available on these. Both the Operational Plan and the Commensal Rat Plan provide a poor level of detail on the design of bait stations and their prior use, if any, in successful eradications. Furthermore, there was no direction on how many were to be used inside buildings and how many outside, or any indication or

instructions as how to best place them in rodent-favorable sites, or critically, in our view, any clear directive on how they should be laid out in a comprehensive grid to provide a minimum acceptable level of coverage within each of the buildings in which they were deployed, and to cover every conceivable rat home range within such buildings.

In our view bait station trials (and hence in selection and use in the operation) placed too much emphasis on factors other than appeal and accessibility to rats. This should be the absolute fundamental driving selection factor. For example, Clapperton (2006) give several examples of preference within rodent species for certain materials and colors of bait stations. The design of the bait station appears to have been at least partly chosen again for the wrong reasons – ease of service, as opposed to what the primary objective should be – to ensure that *all* rats will willingly enter them. There appears to have been a reliance on commercial designs (which are often designed with priority to human safety, ease of use, cost of manufacture, and other factors not strictly relating to attractiveness to rodents), and inadequate testing of the 'Wake Island version' had been carried out. In our view it is not sufficient for eradication purposes to prove that *some* or *most* rodents *will* enter a novel bait station design – it is the ones that do not enter it (even if they represent a miniscule proportion of the population) that will be the problem. Bait stations in eradication operations should be those designs known and proven in past bait station-based eradication projects for that particular species of rodent. Any deviation from this should be openly acknowledged in planning as an added risk factor.

Of the designs tested for outdoor use on Wake that were successful at excluding crabs, rats had to jump a minimum of eight inches (200mm) to access them (Mosher *et al.* 2007). While unlikely to have contributed to the eradication failure, we have concern that a bait station design was used on Wake Atoll that had not been trialed on *R. tanezumi* and a similar but not identical design had only limited prior eradication use (against *R. exulans* on Cocos Island in Guam, Pitt *et al.* 2012). The placing of bait stations on top of buckets was initiated to overcome non-target interference (largely from crabs) but no consideration appears to have been given to the possibility that the novel design could deter some rats. However, as these raised bait stations were only used outdoors within 3m of a building, they were always in close proximity (≤3m) to broadcast bait, and they were probably a redundant measure.

The use of bait stations where two different species of rodent are present is also a risk factor due to potential exclusion of one species by the other through aggression and site-dominance, smell markers, etc. Here we define 'bait stations' as closed-in or covered devices that require physical entry by a rat, and not necessarily open dishes or trays, though our comments may also be applicable to those bait presentation methods too. New Zealand Department of Conservation's established best practice for use of bait stations in New Zealand eradication operations (Broome *et al.* 2011b) clearly advocates avoiding the use of the bait station method where sympatric species of rodent occur. The dominant species could prevent or deter access to the subordinate species, which could over time help develop 'station-averse' individuals. These subordinate rats, through negative experiences (injuries, aggression, etc.) may consequently avoid all bait stations where they could be potentially 'cornered' by the dominant species. Testing of bait stations on Kapiti Island in New Zealand showed that *Rattus exulans* would not enter bait stations previously used by *R. norvegicus* (K. Broome *pers. comm.*). It is quite possible that a few *R. exulans* here would not enter bait stations dominated or previously visited by *R. tanezumi*, and that bait station aversion may have been more likely here given their extensive prior use on Wake Atoll.

Bait station design (especially if relatively 'novel' ideas like using buckets as bases are to be used), a mock set-up should have been clearly shown in the operational plan. It should also have clearly prescribed instructions on where and how the bait stations should be placed, while the maximum

distance apart for placement of bait stations should also have been recorded in the operational plan and/or baiting strategy.

Clapperton (2006) cites evidence that rats which have survived poisoning operations are more neophobic than those never exposed to poison, and that behavioral resistance can be exacerbated by the presence of ample alternative foods so that the rodents are not pressured to eat the poison baits, and by other ecological factors.

Inter-Species Competition

It appears that the eradication attempt successfully eradicated one species, *R. tanezumi*, but did not eradicate the other species. This may provide some clues as to the possible cause of failure (or more accurately partial failure), but this information would have been far more valuable if it was known how the two species relatively utilized the different habitats and food resources on Wake Atoll. The Biomarker Study (Wegmann *et al.* 2009) acknowledged the "*ecological overlap [is] poorly understood*", and the Feasibility Study (Mosher *et al*. 2007) stated "*we have no indication of how these two species interact in a competitive foraging scenario*". This was also raised by reviewers in the National Environmental Policy Act (NEPA) process (USAF 2009).

It is unclear from the limited studies on Wake Atoll if there is any separation of the relative abundance or dominance of the two species by habitat type. This would have been useful information for operational planning and for this review. Partly this lack of information is due to the difficulty in distinguishing between the two species – some rats collected were clearly misidentified. Anecdotal observations suggest that *R. tanezumi* were dominant in areas of high food abundance (the tern colony, refuse dump) while *R. exulans* were more common in grassland habitats (A. Wegmann *pers. comm.*), and Hebshi & Colvin (2008) suggest *R. tanezumi* was dominant around commensal areas but *R. exulans* were also present in these areas.

It is possible that when a larger (naturally allopatric) rat species is present, *R. exulans* may become more 'mouse-like' in behavior to further differentiate the ecological niches of the two species. Competition from *R. tanezumi* may also have pushed some R. *exulans* into using sub-optimal habitat (see Gap in Coverage section).

Within previous eradication projects there has been some discussion about the length of time between bait applications, especially where two or more rodent species are present. If one species is behaviorally prevented from accessing bait, lengthening the time between bait applications may give the subordinate species time to adapt behaviorally to the decrease or even disappearance of the dominant species in the first bait drop (e.g. as planned for in the multi-species eradication on Rangitoto and Motutapu Islands (Griffiths *et al*. 2013). The shortening of the proposed period between bait drops from the planned 14 days down to 10, in order to fit in with USAF priorities may have decreased the probability of *R. exulans* eradication. Any bait gaps in suboptimal areas would further decrease the likelihood of effectively eradicating *R. exulans*.

Natural or Commensal Food Resources & Rat Behavior

Alternative Natural Food Sources

There were a number of brown and red-footed boobies present on Wilkes Island and a colony of sooty terns on both Wilkes and Peale during the latter stages of the aerial baiting (IC 2013). It is unclear what stage the terns were at in their breeding cycle but probably it was not well-advanced, as several observers prior to or during the first bait application did not recall observing breeding activity. The eggs and young chicks of terns in particular can provide a significant food resource for rats. Past eradication projects provide conflicting evidence of this – Palmyra was successful even though terns were breeding there, while the likely cause of failure on Teuaua Island in French Polynesia was a major tern breeding event (IEAG 2012).

There was also a noted seeding event for the ironwood (*Casuarina*) trees on the island during the baiting operation, and the seeds of this species are actively sought by rats (A. Wegmann, N. Torr, R. Stansbury *pers. comm.*). Anecdotal evidence suggested there also appeared to be a termite hatch two days before the first baiting application which would not have been able to be foreseen by anyone, but which may have provided alternative food resources in localized areas.

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, nor is that assumption automatically transferable to commensal foods. In one of the cited cases in the Henderson review, a natural food (coconut) was preferred over commercial bait (Alifano & Wegmann 2010), although this did not prevent successful eradication from Palmyra where the trials were conducted.

Meehan (1984) cautioned that "*it is impossible to say which particular foodstuff will be preferred by individual rats or even whole populations—there is no such thing as a universally acceptable bait*". However, a very high percentage of successes in previous rat eradication projects have probably led to an over-confidence and even an assumed 'infallibility' of the bait types used in rat eradication.

Bait uptake trials on Wake Atoll (Wegmann *et al*. 2009) showed some rats clearly not taking inert bait pellets when it was freely available to them. Furthermore, toxicology trials on Wake (Mosher *et al.* 2007) showed that for some rats a "*preference of the chow [commercial laboratory rat food] over the rodenticide was a major contributing factor in the lower-than-expected mortality rates*". Some rats in the study may not have eaten the bait at all. This was a very concerning result, and one which should have generated further research and evaluation. Again, this was raised by some reviewers but not adequately considered or addressed within documentation by planners.

All of these indicators should have provided clear warning about the presumption that the rodenticide bait was attractive to *all* rodents at *all* times and therefore infallible. While recent failed rat eradications have occurred on islands with considerable differences in circumstances, one of two clear aspects they had in common was the availability of significant alternative food resources (sometimes appreciably higher than predicted, but apparently not in this situation for Wake Atoll) at the time of the operation. The other aspect was an active breeding status for rats (see discussion below).

Commensal Food Resources

The Operational Plan (Island Conservation 2012) and Biomarker Study (Wegmann *et al*. 2009) discuss the anecdotal risks associated with gardens and how they could compromise successful rat eradication, because they could provide rodents with a consistent source of food. The Operational Plan stated that "*ideally, all gardens would be removed prior to the eradication. However, this action was determined inappropriate for Wake Atoll residents*". There is no doubt that this added risk to the operation's success.

The 2009 Biomarker Study on Wake Atoll *very importantly* found that three rats did not appear to have fed on biomarker baits, despite being captured < 10 m from biomarker bait stations and having access to them and remaining broadcast bait for five days beyond a second bait application and for even longer periods since the first application (Wegmann *et al.* 2009). All three biomarker-negative rats were captured ≤ 30 m from a commensal food source (garden, open chicken coop, or unsecured garbage can). Perhaps tellingly, all three rats not eating bait were *Rattus exulans*, the species that survived the eradication attempt.

This finding should have triggered significant concern, and did initiate attempts for appropriate management of gardens and to remove all sources of food for rats well before the eradication is initiated. The Operational Plan and Biomarker Study recommended two alternatives: 1) that all gardens will be removed prior to the eradication, or 2) if complete removal is not acceptable, then all fruit and plant parts commonly eaten by rats need to be removed from the gardens and consumed or kept in rat proof containers. Alternative 1 is clearly the preferred situation from an eradication perspective, but alternative 2 was chosen for other reasons, but in the end was not fully implemented. The amount of food in gardens available to rats during the bait spread is unclear, with some suggestions there was not enough food left to support any rats, but other evidence to suggest some "*lower risk garden species*" were permitted to remain (IC 2013).

Additional observations in the immediate pre-baiting period noted the presence of an extensive subterranean sewer network. This is a clear failing in the planning – with a considerable human population, sewer and grey-water drains should have been an obvious issue, and considered at the Feasibility Study stage, as occurred with the feasibility study for Tristan da Cunha (Brown 2005). Clear prescription on the extent of the sewer network and how to deal with it should have been part of the Operational Plan or Commensal Rat Plan.

Reducing commensal food resources available to rodents was a concern identified at several stages in the planning process "*although zero food waste at the dump was achieved, cooking and eating with restrictions was allowed to continue at some locations outside of the food hall. An understanding of zero food availability was not consistent amongst project partners*" (IC 2013).

There appeared to be a significant difference in the appreciation between agencies on the justification for and priority of some actions around commensal rat and waste management. The Post-Operational Report stated that "*upon the initiation of the eradication there was still resistance by some individuals to modify their behavior and a general lack of understanding why these changes were important (particularly by important authorities on island)*". While there were genuine attempts to foster buy-in and support for the project from those living and working on the island the results were not as positive as would have been desired. This indicates the technical requirements around commensal waste management may have been well known to the key eradication staff, but for some reason the attempted communications failed to a degree, possibly due to the different stakeholders operating and thinking at

different levels. This is highlighted in the comment of one interviewee - "*there were three levels of eradication expertise in the three agencies, and a lot of assumptions were made on the prior knowledge of all the participants in the project*". There somehow appeared to be a 'disconnect' between the eradication experts and the rest of the stakeholders on what actions were critical to success of the project, and on the degree or extent of the compliance desired.

Of huge concern were survey results indicating that 44% of residents on the island were unsure of or indifferent to the proposed rat eradication (Appendix 1 in the Commensal Rat Plan USFWS 2011). A particular sector of the inhabitants, the Rat [Hunters] Club had a staggering 93% of responses indicating they were unsure of support within the club for the proposed eradication. Only 14% of all respondents professed to a 'complete' understanding of the eradication, while 21% had little or no understanding. This is a completely unacceptable situation for an eradication, which will by its nature rely heavily on the co-operation of the island's inhabitants, whether they are private individuals, military personnel, or military contractors. It appears language barriers with some contractors may have contributed somewhat to this, but cannot be entirely to blame.

It appeared that as well as the apparent 'disconnect' between agencies and individuals, there was seemingly also little incentive for individual compliance. It appears that buy-in by individual inhabitants was a more important factor than might have been assumed in planning. While Wake is a military base, and operates to a strict chain of command, most of the staff present are contractors and therefore one step removed from the military chain of command. Efforts were made by base managers to limit the effect of the eradication operation on morale and the normal operating procedures and the almost sacrosanct off-duty 'freedom' of staff, and these efforts may have compromised efficacy of the intended eradication measures to some degree. Comments from staff of the implementing agencies suggested decisions made by base managers were in some cases made much more democratically than they had expected.

Rat Breeding

Rats were apparently at very high density during the eradication, and breeding was considered likely (IC 2013 and *K. Rex pers. comm.*). This is confirmed by the first rat sighted after the baiting being a very small newly weaned juvenile, with the timing indicating that rearing of young had been occurring *during* the baiting operation.

Breeding only tends to occur when there are sufficient natural food resources. It is quite feasible (though currently unproven) that behavioral changes in a tiny proportion of breeding females meant they fixated on particular natural or commensal foods and deliberately chose not to eat bait. Active breeding at the time of baiting is one of a very few common features in recent failed rat eradications (Enderbury, Henderson, Desecheo and Wake). It is acknowledged that *some* eradication projects have succeeded where rat breeding is occurring but it is clearly not a universal trait amongst breeding females to avoid bait, and may relate to only a very small percentage of them. If breeding status is a factor, consequent success or failure of eradication may be related to the 'intensity' of the breeding event, or even purely to chance.

Alternatively, the bait may not have remained available for long enough for some rat pups emerging from natal nests to find a lethal dose. The shortening of the period between baiting applications could have exacerbated the situation by making the time-frame over which bait was available less than originally planned. Rat breeding during a baiting operation does not automatically mean that the project

will fail, but the more breeding is occurring, the more likely that non-exposed pups or any potentially neophobic females may occur at some location on the island. The latter is speculative, but there is some evidence breeding female rats are difficult to attract to bait (e.g. Thorsen *et al*. 2000) so it is worthy of consideration and investigation.

Conclusion for Objective 1– What Caused the Wake Atoll Rat Eradication to Fail?

While other more 'straightforward' eradication operations have also failed recently (e.g. Henderson, Enderbury, Desecheo), the possible reasons for failure there seem considerably more limited. The sheer complexity of the Wake Atoll project makes it far more difficult to pinpoint possible causes. A number of planning and operational issues have been identified, but we cannot determine if any of these actually caused the failure – we can only say that they cumulatively added to the risk of failure.

When viewed along with the other recent failed eradications, the reason for the Wake Atoll failure may be attributable to a factor in common with these operations (e.g. entirely unrelated to commensal rodents, the complex baiting strategy or unusual environments) but related instead to some common aspect of tropical island environments and rat ecology or behavior. It may also be dangerous to assume a single common causal factor – while we can look for similarities between the projects, each island has its own unique set of circumstances.

We therefore cannot say conclusively what caused the failure of the Wake Atoll rat eradication. It may have been a single issue, or any combination of some of the factors examined, or even some aspect we have not thought to consider.

However, a number of factors are identified that may have contributed to the failure:

- Overall bait rates may not have been sufficient, or may not have had sufficient 'buffer' or margin for error. Any errors in baiting could have created pockets of land where lower than desirable bait rates were applied that could easily have led to a small number of rats not being able to readily access bait.

- Prior long-term use of rodent baits and bait stations may have caused some increased tolerance to toxicants and/or aversion behavior amongst commensal rodent populations.

- The extent and nature of structures (above and below ground) was poorly known before implementation and could have resulted in a few areas not being adequately treated.

- The baiting methodology for dealing with the *Pemphis* habitat was poorly planned and largely untested and unproven, and this may have led to inadequate bait or baiting gaps in such areas.

- There was a very complex array of different treatment zones for the rest of the island. The merging of the different treatment zones via hand-baiting was somewhat *ad hoc* and open to subjective assessments by sometimes inexperienced operators, so it is feasible that baiting gaps or under-application occurred in the treatment of one or more of the buffer areas.

- There were large total exclusion zones where no bait was applied at all, and these appeared to be identified only subjectively as 'rat-free', or at least it was considered an acceptable risk to exclude them from bait spread.

- Rats were assumed and later proven to be breeding during the baiting operation, and a small proportion of the *R. exulans* population may have exhibited atypical behavior that meant they did not eat bait, and/or some juveniles within nests or in subsequent post-emergence did not have access to bait.

- Anecdotally, there were abundant alternative natural food options (as per usual on Wake and many tropical islands) present at the time of the baiting operation, including obviously targeted foods such as ironwood seeds, and termite hatches very close to the time of baiting, and this could have exacerbated any bait palatability or bait aversion issues.

- The numerous exclusion zones for aerial baiting would have created a very difficult 'stop-start' nature to the aerial baiting for the pilot, while some evidence of false sowing (baiting being recorded when the bucket was in fact empty) would have created pockets of land where bait density was considerably lower than planned.

- Commensal rodent eradication methodology was not ideal, and commensal waste management did not go according to plan, meaning there were identifiable risks including possible baiting gaps within buildings or in merging of treatment methodologies, doubts over comprehensiveness of coverage, possible alternative food sources, and possible competitive exclusion from bait stations.

- The Wake Atoll project was a challenging and ambitious project, a step up in complexity from most previous eradication projects. The entire project possibly suffered from under-resourcing, while the confidence of implementing agencies toward eradication here was not matched by appropriate levels of preparedness in some aspects of the planning and implementation. The obvious complexities of the project demanded more thorough and detailed early planning particularly with regard to baiting strategy for the *Pemphis* habitat and underground structures, the possibility of bait-averse rats, the resource requirements and strategy around hand-baiting). Greater resources were required in some aspects of the implementation of the operation. Shortfalls in resourcing and preparedness can accentuate risk of errors.

- The eradication inexperience of many staff involved in the Wake project may have elevated the risk of errors being made.

- Results of bait acceptance and bait toxicology trials during the Feasibility Study should have triggered concern amongst operational planners (and been reflected in subsequent planning or research) that some rats on Wake Atoll had either bait aversion or bait tolerance issues.

- Total reliance on bait stations in some areas on Wake is highly undesirable from an eradication standpoint where two species of rodent are present, as individuals of the subordinate species may be excluded from access, while the design of the bait station types used may have deterred some rats.

- If bait coverage was an issue, it was an issue only for *Rattus exulans*, and not for *R. tanezumi*, which appears to have been eradicated. This may have been the result of chance alone, but

suggests a behavioral or niche separation that had not been adequately determined prior to the operation and which remains unknown.

- The period between the two bait applications was reduced by four days (from the planned 14 down to 10) due to external factors. This will have reduced the overall potential time for 'un-exposed' juveniles to emerge from natal nests and still have access to bait.

From these possibilities we have attempted to define the most probable contributory factors. The apparent eradication of both rat species from Peale Island may be instructive. The success on Peale and failure on Wake may have simply been the result of chance, but it could be due to a difference in the methods used or conditions on the islands. Peale Island was predominantly achieved by aerial baiting, with very limited exclusion zones, in contrast to Wake and Wilkes islands with three bait distribution techniques with many areas of merging required, multiple aerial exclusion zones, large 'no bait' zones, commensal rats with greater anthropogenic food sources and presumed greater extent of prior use of rodenticides for control purposes. Peale used the same overall bait rate as the other two islands, and had some limited *Pemphis* habitat and some underground structures but not to the extent of that on Wake. It presumably also had similar environmental conditions in terms of non-commensal rat ecology and breeding status.

We consider the most important contributing factors include at least one and probably an interaction of some or all of the following issues:

- Bait preference/aversion issues coupled with availability of alternative natural or commensal foods

- Bait gaps or localized shortages in bait availability created by poor understanding of habitats such as *Pemphis* and underground and abandoned structures, inadequately designed baiting methodology in commensal and intertidal environments, and complicated combinations (and integration) of various baiting methodologies, all exacerbated by low overall bait rates with insufficient buffer and some known application errors or difficulties;

- Rat breeding during the operation causing temporal or spatial unavailability of bait to juveniles emerging from natal nests, or more speculatively, behavioral avoidance of bait by a small percentage of females;

- A poor understanding of the interaction between the two species that may have provided inadequate bait accessibility for *R. exulans*.

Although by no means definitive, these proximate causes of failure are consistent with our intuition and that of many involved in the project.

Table 3. An Assessment of the Possible Contributing Factors of Eradication Failure

Possible Factor	Assessed Likelihood	Key Reasons for	Key Reasons against
Bait gap or bait shortage (aerial)	Moderate	Known 'false sowing' events Large numbers of aerial-exclusion zones adding complexity to aerial baiting Novel treatment for *Pemphis*	*R tanezumi* probably eradicated showing coverage was adequate for them. 50% overlap in baiting swaths meant gaps *per se* were unlikely. One major false sowing event, surviving rats were in multiple areas.
Bait gap or bait shortage (bait station)	Moderate	Spacing wider than recommended for *R. exulans.* Unclear strategy and coverage	Surviving rodents did not appear within commensal areas
Bait gap or bait shortage (hand-broadcast) and/or merging of zones	Moderate	Number of zones, under-resourcing and inexperience of some staff, complexity and known difficulties on the ground; eradication successful on Peale where largely done by aerial means.	Visual confirmation by teams of bait coverage in each area
Bait not out long enough, or overall bait rate insufficient.	Mod-High	Shortened interval between the two applications; shortened duration of some bait station operations; limited trials numerically & geographically to determine the bait rates; very high rat numbers; lower bait rates than other operations; known false sowing issues; rats breeding so bait may not have lasted long enough for some rat pups to get access.	Bait uptake monitoring plots showed bait lasted for a minimum of 4 days after the 1st application and 6 days after the 2nd application Eradication successful on Peale with same bait rates.
'No bait at all' Exclusion zones	Low	Large areas where no bait at all applied, contrary to best practice principles.	Largely sealed concrete – visual confirmation of no habitat? Some surviving rats not close to these areas.
Structure baiting	Moderate	Not fully mapped or investigated prior; some structures missed 1st application; underground structure network still not yet fully understood.	Few food resources available in such structures, little anecdotal evidence of rat usage beyond as a refuge
Pemphis habitats	Mod-High	Unproven strategy and concerns over adequacy of coverage	Some surviving rodents did not appear near major *Pemphis* zones. Rats eradicated on Peale

			with small area of *Pemphis* habitat.
Bait toxicity	Low	History of rat control on Wake using brodifacoum	Bait testing showed appropriate toxicant levels. Not a known issue elsewhere.
Bait aversion	High	Bait trials showed avoidance of bait by some rats (it is unclear if these were of just one or both species); neophobia known to be higher in commensal rats; possible aversion due to breeding and alternative foods.	Probably not an issue for *R. tanezumi* as they were apparently eradicated.
Bait Station Aversion	Moderate	Sympatric rodent species may have resulted in aversion by subordinate species; learned aversion through prior bait station use for control; bait stations in use in or near areas where most surviving rats seen.	Some surviving rodents did not seem to appear in or near 'bait-station-only' zones.
Interspecies competition	Low-Mod	Dominant species eradicated, subordinate species not.	Both species eradicated from Peale
Commensal management	Moderate	Commensal waste management not ideal, known feeding resource for rats. Both species eradicated from Peale where commensal issues are low.	Surviving rodents did not appear initially within commensal zones
Alternative natural foods	Low-Moderate	Rats during the operation observed feeding on known alternative foods which were abundant; high rat numbers and breeding activity suggested high natural food supply; supporting evidence from other failed projects.	Not an issue for some tropical eradication projects such as Palmyra where alternative foods also occurred.
Breeding behavior or ecological aspects of *R. exulans*	Moderate	Rats breeding during operation; possible increase in neophobia or targeted feeding for breeding females; supporting evidence from other failed projects.	Some eradications have been successful where rat breeding was occurring (e.g. Palmyra). Both species eradicated from Peale.

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

Planning

A correct planning sequence was followed, with a number of necessary or desirable tasks being carried out, often in considerable detail. These included:

- a feasibility study
- biomarker studies
- DNA collection
- a commensal rodent plan
- a FONSI environmental assessment
- a peer-reviewed operational plan
- pre-eradication 'readiness checks'
- post-operational bait availability and bait degradation monitoring
- on-site presence of staff until c.6 weeks after first bait application
- immediate post-operational review
- longer-term project review

However, it was noted by several people interviewed that planning and preparation for the Wake Atoll project was not their sole focus, and they struggled to achieve the necessary tasks and organization in time.

We also note that the input from most individual eradication experts appears to have been somewhat piecemeal, with various people drawn in for singular tasks. As a possible consequence, there may have been no single experienced practitioner that had the complete 'big picture' view of the project from the outset.

There appeared to be a 'disconnect' between some plans, possibly as the result of different agencies holding responsibilities for production of plans and the multiple individuals involved in each. The Operational Plan and Commensal Plan should have been meshed together, but instead appeared as separate, non-integrated plans, and some issues (e.g. sewer and underground structures) seemed to fall unnoticed in the gaps between them. The Feasibility Study, which should have fed significantly into both, was not comprehensive enough to be of much value for many pertinent issues.

We also question the thoroughness of some planning, and discuss these concerns below.

Feasibility Study

A feasibility study was carried out for Ascension Island (Brown 2003) which although a considerably larger and more populous island had a strikingly similar situation to Wake (a military airbase, a resident 'disinterested' human population, likely exclusion zones, commensal rodents, etc.). It

concluded there that the issues were too complicated, the human population wasn't likely to be wholly supportive or cooperative, and on-going biosecurity risks meant an eradication attempt wasn't worthwhile. Advances have been made in eradication success and confidence even in the short time period since then, but there is an indication that for Wake Atoll the full range of issues wasn't given sufficient weight of consideration, and the feeling is that operational decisions appeared to sway towards the optimistic side, with an unspoken decision to 'keep going' despite worrying signs.

A feasibility study needs to be all-encompassing and more critically appraising – most are undertaken by agents in favor of the eradication and they naturally tend to favor positive conclusions while potentially negative aspects are sometimes glossed over or not fully explored. It is suggested that all feasibility studies follow a set 'template' to ensure as far as possible that all issues are addressed sufficiently. The template available on the Pacific Invasives Initiative Rodent Eradication Resource Kit website is recommended as a start point.

For an extremely complicated project like Wake, the Feasibility Study needs to have been far more detailed, and *very importantly* needed to be critically reviewed by independent eradication experts. While some aspects are covered excellently in the Feasibility Study, it failed to address numerous key issues that perhaps should have been obvious candidates for further examination, e.g. the unfavorable toxicology results; the intertidal *Pemphis* habitat and how to comprehensively treat this for rats; the sewerage infrastructure and the possibility of harboring rats and how to deal with this; commensal rodent issues; and the interaction between rat species in terms of habitats or exclusion from bait stations. It mentions, but does not adequately address, prior extensive use of toxicants and the behavioral changes this may have had on some rats. The plan also did not seem to pay sufficient attention to crab density and how much bait they would consume (even though they were aware of advice from elsewhere that crabs could potentially eat more bait in a night than would be applied in total here). An independent review of the Feasibility Study would have picked up at least some of these issues at an early stage of planning.

Very importantly, feasibility studies for inhabited islands and for islands with complex regulatory issues need to have explicit social and political sections. Social sections should have plans to educate and incentivize local inhabitants with clear benchmarks and measures of success. Political plans should have strategies and timelines to obtain necessary permits. In our view, feasibility planning was overly focused on ecological rather than social and political issues, while some of the main obstacles to success may have been the attitudes of local inhabitants and the regulatory and agency-imposed constraints.

It appears the Feasibility Study was carried out with a very limited amount of time on the island, and a great deal of the time was spent on ultimately diversionary issues (e.g. a focus on the possibility of using traps as a principal eradication technique), making it in the words of one participant "*pretty much non-relevant*" to the operation as it developed. In our view the feasibility study is a critical component of eradication planning especially in regards to complex operations such as Wake Atoll, and should set the framework for and identify all the key issues that need to be addressed in subsequent research and operational planning.

Biomarker Trial

The Biomarker Trial was well carried out, but did not generate sufficient concern to some rats not eating bio-marked bait in the trials. It made the conclusion that the rats were unlikely to have been new

immigrants into the area, and therefore they were considered most likely to have chosen not to have eaten the bait, rather than not yet having accessed it. Biomarker studies are only indicators, not guarantors of bait palatability, but if a biomarker trial does not achieve a 100% uptake by rats in the study area, this is of enormous significance to an eradication project and there should be a thorough evaluation of the possible reasons. It made a perhaps logical conclusion that some rats that were not eating bait due to the availability of fruit and vegetables in nearby gardens or other commensal sources (it also made the tacit assumption that these commensal foods would not be available during the eradications, which according to some sources was largely achieved but not entirely the case). The trial's conclusion failed to consider other possibilities – e.g. that the rats had prior experience of bait and were deliberately avoiding it, or were not taking it for other (behavior-related) reasons.

Reviews and Readiness Checks

It is unclear as to whether there was enough time for personnel involved in reviews or readiness checks to fully read and assimilate the considerable volume of material. Our reasonably thorough review of documents (still under time constraints) identified many areas of concern that should have triggered some further discussion or research. While we do not for a second doubt the ability, knowledge or expertise of any reviewers, we do from experience wonder whether they had, or had been allocated, enough time for a review of sufficient detail to identify and highlight all areas of concern.

Many groups reviewed the plan as part of the National Environmental Policy Act (NEPA) process. Other groups had comments that suggested concerns with the planning. Some important recommendations and questions (e.g. questions around methods to treat the *Pemphis* zones raised by the IEAG (2012a), and a strong suggestion to acquire a thorough knowledge of potential [underground] refuge sites be developed (a submission by Eisemann, Witmer and Pitt in Appendix D of the FONSI report (USAF 2009)) were indeed raised by external reviewers, but there appeared to be no formal response to either these independent checks or of the internal readiness checks provided. Some recommendations made and questions presented did not seem to make it through to the final operational plan.

It is recommended that 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. This would demonstrate that all concerns have been seen and considered.

Strategy & Design

The project responsibility was split between agencies, and in effect had multiple project managers or people in decision-making roles. We believe this was a critical decision within the operational process. We are not entirely clear on the reasons for this split of tasks and responsibilities (and it is effectively beyond the scope of this review), but can say that this significantly added to planning and implementation difficulties. The separation of the responsibilities for commensal rat management and the non-commensal areas should not have occurred, or at least should have been placed under a single decision-making and ultimately accountable operational manager.

The project had many restrictions placed upon it with respect to methods, areas and timing by the site managers (USAF). However, the decision to proceed with these impositions in place was made by all

the groups involved, and implied that the project could be successful even with these restrictions, and in effect, this was an agreement of the restrictions imposed. The technical planners of this operation should have made clear to all partners before proceeding that there was an added risk to the operation from such restrictions. While apparently the risks of the imposed restrictions were clearly identified to partners verbally, we did not see this in any of the documentation, and such potential compromises to the ideal eradication methodology should have been clearly spelled out in key planning documents.

Given the unprecedented nature of the regulatory, social and biological conditions and the potential for interactions between them that favor the survival of rats, this project cannot just be seen a scaling up or extrapolation from previous rat eradication efforts, but a considerable extension of the current boundaries of eradication capability. Had we been offered the task of eradicating rats from Wake Atoll with the sets of conditions that were imposed upon certain areas and baiting methodology, we would have likely refused due to the high potential for failure. The fact that the eradication in all probability succeeded for both species on Peale Island and one species on Wake and Wilkes islands is perhaps testimony to the outstanding efforts of the field team.

For aerial bait application, the strategy appeared to follow NZ Department of Conservation best practice principles (the only documented best practice currently available) wherever possible, but attempts to comply with regulatory and site-management constraints had a major impact on the project design.

The choice of bait rates paid insufficient attention to the limitations of the trial and did not sufficiently allow for adequate margins of error. Eradications need to target 100% of the rodents, so all trials and subsequent evaluation of bait rates need to consider the realistic 'worst case scenario', incorporate confidence levels within results, and base the entire baiting strategy around that.

Where two species of rat were present, the reliance on bait stations as the only eradication method (as within buildings in commensal environments here) is not recommended by NZ best practice. It should have been supplemented with other control and detection methods. A clear strategy in the placement and spacing of bait stations was not obvious from the operational documents, and indoor bait stations appeared to be spaced too far apart.

The uninhabited structures were very numerous (>600) and these seemed to fall unnoticed between the commensal operations and the rest of the operation until during the implementation phase. The need for baiting these should have been identified at the feasibility study stage, and they should have all been individually identified and map-referenced well before the implementation phase.

The Commensal Plan

For the Commensal Plan there may have been a lack of appreciation of the subtle but significant differences between the normal long-term measures used for rodent control, and the substantially more focused, time-aligned and comprehensive efforts required to achieve eradication.

The Commensal Rat Plan set out a commendable strategy for dealing with some issues but was weak in other aspects, and sometimes seemed to be misdirected into control issues (e.g. plugging gaps in building walls to prevent rodent access) that had only minor relevance in an eradication project. In contrast it did not adequately address or inform the methodology for numbers, siting, spacing of indoor bait stations, or of testing the efficiency of the bait stations by independent means.

Working on Someone Else's Patch, and Them Calling the Shots

Ideally for any eradication it is desirable that the operational team have the freedom to conduct the ideal activities at the ideal time, in order to optimize the chances of eradication. It seems here that too many compromises had to be made to fit the project within existing management regimes on the atoll.

There were impositions placed on the overall number of eradication staff able to be present. The result appeared to be that individuals were each assigned a range of different eradication- and monitoring-related tasks, and that in many instances they were hard-pressed to achieve all of these, especially when vehicles became in short supply. The foresight of sending bicycles to the island inside shipping containers is to be applauded, and the operation could have been far more difficult without them. It is a concern that there appears to have been a gap between agencies what was expected in terms of such things as vehicle availability, or a failing in the planning as to the actual on-ground requirements – we cannot distinguish which.

The Post-Operational Report says "*Integrating the planned rat eradication on Wake into ongoing activities on the Air Force Base was identified early on in the planning process as being potentially problematic. Although significant planning had gone into establishing what was required from whom, who was responsible for what, and what was going to happen, problems still arose that detracted from the smooth running and efficiency of the operation. As a result, tension and confusion were present and this could have posed a greater risk to project success*".

The Post-Operational Report states "*The commensal rodent plan prepared by USAF mandated that the project have a minimal impact on base operations. This mandate affected the operational plan by limit to the number of eradication staff allowed to be present on Wake, preferences concerning operational timing and details, and a leniency in original commensal regulations*". This highlights a significant concern, that all project partners did not fully grasp the 'essentials' of a rat eradication, and the temporary changes needed from normal operating procedures on the atoll, or that this was not fully communicated (either externally or internally) to the key individuals within the responsible agencies that make the decisions in relation to Wake's daily operations.

Project Implementation

Consistency with Plans

The Post-Operational Report identifies a significant number of deviations from the Operational Plan and Commensal Rat Plan. The reasons for some of these deviations were unexplained. This is not a desirable situation for an eradication project.

According to numerous sources, it became quickly apparent that the commensal waste management plan agreed to on paper was not being achieved in practice. Project personnel had to step in and create an uncomfortable situation between parties because of on-going commensal waste management and commensal rodent issues.

Project Managers / Project Control

There were three separate IC project managers assigned to this operation. The last was brought in only nine months before the baiting operation. This is a highly undesirable situation that, while in no way reflecting on any individual involved in this project, may have contributed directly to project failure. A single project leader who was in charge from planning and permitting through implementation and spent more time on the island, working with island residents would most likely have:

1) been less willing to compromise efficacy to meet self-imposed, regulatory and site-specific requirements;
2) placed less reliance on spreading operational responsibilities between several independent and somewhat inexperienced organizations to implement key technical components of the plan;
3) had earlier, higher quality and first-hand information about on-island social and environmental conditions; and,
4) been more willing to postpone the project when concerns had been raised throughout the planning process, and/or when critical pre-operational conditions were not met.

Any of these steps may have been sufficient to prevent the failure of *R. exulans* eradication from Wake and Wilkes islands.

This was the first time the IC Project Manager in charge of implementation had run such an eradication project for rodents. The complexities and challenges of the operation were clearly apparent to us on first reading of the operational plan. Such a difficult and complex project should in our view have been allocated to the most experienced eradication manager available.

The Post-Operational Report states "*a liaison/management/command structure was in place though the efficiency and effectiveness of the project's incident command structure often proved to be cumbersome. The hierarchy of the structure was at times unclear; there often seemed to be several people making management decisions outside of the chain of command. This led to confusion and team members sometimes receiving conflicting sets of instructions. This was likely compounded by some members of the command structure having little to no experience of rodent eradications and in some cases a lack of understanding of what was planned*". This was supported by some interviewees who said that many roles and responsibilities were not well defined.

Involvement and 'buy-in' of all the co-operating agencies is essential, so it is probably not possible in all situations to allocate roles solely on levels of experience. However, it should be possible in the future that, for example, 'technical' issues are clearly allocated as the responsibility of those most skilled in that field to make the call, and not allocated just by agency representation or 'seniority'.

Staffing

It appears that a large proportion of staff employed for the hand-broadcasting aspects of the operation were inexperienced in that practice. New Zealand eradication best practice documents (e.g. Broome *et al.* 2011b) suggest that team selection should ensure "*at least 50% of all field staff have prior eradication experience if at all possible, so each 'novice' can be assigned an experienced on-site 'mentor' or supervisor*".

To add to that, many people on the team were unfamiliar with the island, and therefore took considerably more time to orientate themselves, adding to the confusion around the structure baiting and other tasks.

The project field staff deserves praise for the dedication shown to tasks above and beyond their initial responsibilities. They responded admirably to some unexpected situations (e.g. mapping and baiting of structures, waste management issues, an under-resourcing of the hand-broadcasting operation) and worked long hours to ensure the tasks were completed. In the words of one staff member, they in effect "*did what they had to, to get the job done*" but better prior planning and resource allocation would have greatly reduced the demand for their 'extra' efforts. The failure of the project should in no way be a reflection on their efforts, skills or dedication.

There was only one GIS specialist used in the operation, and this person also had other part-time tasks allocated to him. A project with such a complex array of exclusion zones, structure mapping, and merging of different treatment zones should have highlighted the need for a second GIS person. More flexible time in these roles could have aided real-time use of GPS to ensure the merging or 'stitching' of different treatment zones, and could have streamlined structure mapping and other tasks. It would have also been desirable to have a second fully competent GIS person in the team to cover for injury or illness in this critically important role.

Inter-Agency Co-operation and Working Relationships

Some information suggests that the hand-baiting operation had been either under-planned or under-resourced, and that personnel or volunteers from other agencies had to step in to bolster this critical aspect of the operation. Some of the project team may have thus been inexperienced and unfamiliar with key tools such as hand-held GPS units, and this compounded staff shortage issues.

Individuals within all agencies reported some difficulty in working with or understanding the different mind-set or operational approach of some of the other agencies.

The situation here was quite unusual in that most eradication operations have a single 'project manager' who can in effect make instantaneous decisions to respond to circumstances. While often backed by on-site advisory support, the single project manager in most other eradication projects has been ultimately accountable for all decisions. Here, the implementing agencies were not the agency controlling the island, and the split in roles between agencies also caused some confusion over who was controlling what.

Because of its hierarchal structure and necessarily rigid operating procedures, the flexibility of the USAF in responding to requirements of the eradication operation may have created some challenges, but in part USAF-related staff involved directly in the project reported many uncertainties and contrary decisions in the eradication project and therefore found it difficult to relay information to other USAF staff – effectively they reported they "*couldn't communicate what they didn't know*".

Because of the number of issues that had not been fully resolved in planning phases, or had not been fully adhered to in the lead-up to the implementation phase, the actual fieldwork seemed to have a far too large 'reactive' component that demanded considerable resources. As a result, some tension developed between individuals and agencies that would not have assisted in working towards a common goal.

Post-Operational Monitoring

The amount of post-operational monitoring was perhaps better than for most island eradications, it was still very limited and could have been improved significantly, especially given the exceptional complexity of this operation and higher than normal risk factors associated with it. In contrast to many 'eradication islands' Wake Atoll is readily accessible and the infrastructure is in place to support personnel and make their efforts very time efficient (e.g. roads and vehicles would vastly improve efficiency of monitoring coverage).

It is acknowledged that it is far easier to see in hindsight, but greater emphasis could have been given in the planning and resourcing of the Wake Atoll project to follow-up work. Immediate follow-up with detection devices is rarely used in eradication projects, due to the extra cost and logistical efforts to maintain a field crew for extended periods. However, it is recommended in future that for tropical islands such as Wake (that are relatively easily accessible, provide good accommodation and logistic support, and are easily searchable) strong consideration is given to the use of proven alternative means of detection in immediate follow-up work. Tracking tunnels, traps or indicator baits, and especially use of rodent-detecting dogs (as is occurring on the Macquarie Island project, and more widely for rodent incursion events on islands) could potentially be employed to great effect on such islands. Subsequently such actions could identify earlier and with greater accuracy the prime areas where any survival occurs (with consequent better definition of the prime reasons for operational failure); or, successful eradication prospects could possibly be improved through this means (although this is hypothetical and currently untested, it is recommended within NZ best practice and should be considered for future use where practical). 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, Objective 2.

Many of the issues identified within this review derive from a deviation from established best practice procedures that have been developed overseas but which are largely directly applicable everywhere, including here. These deviations from best practice should have been apparent in the project design if personnel involved were more aware of such best practice resource material, and/or each key document was independently peer-reviewed.

A structured project process (as set out in the Pacific Invasives Initiative Rodent Eradication Resource Kit) would have helped identify and resolve many issues, while independent reviews of documents (especially the Feasibility Study and Commensal Rat Plan) should have identified many issues needing further investigation.

The piece-meal or 'on-off' approach to the project over a number of years no doubt contributed to a lack of flow or linkage within the documents, and may have led to a possible lack of 'ownership' of the whole project process.

The project possibly also suffered from the apparent inability of some key people to fully commit to the project or focus on its planning, as they had obligations elsewhere. Such work pressures may have resulted in people struggling just to meet deadlines rather than having the ability to adequately plan and thoroughly review each stage in the project.

A lack of knowledge of the island by some key project staff may have led to some errors and omissions in planning documents.

From the documentation reviewed, both independent and internal critical review was apparently not sufficiently heeded in some aspects of the planning and design of the project, and comments from these reviews were not assimilated into the planning documents.

The many highlighted concerns regarding methodology and the number of information gaps in the planning should in our view have led to serious consideration of postponing the project until those issues were more fully addressed.

Finally, the diffusion of responsibility for project success or failure across multiple project managers and multiple organizations increases the probability of failure for any important project. One dedicated project manager from start to finish, with a core staff and the support of an advisory team would have more likely been aware of project weaknesses and either fixed or mitigated them.

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

Despite what we consider to be one of the most challenging eradication projects ever undertaken, the Wake Atoll project came very close to success, and stakeholders can take pride in achieving eradication of one rat species.

All eradication projects, successful or not, can provide learning opportunities. We consider that with only one rodent species now present, and if the lessons derived from the 2012 operation are fully taken into account, there is a high prospect for success if another eradication attempt was made on Wake Atoll with some key changes.

The key lessons we think that have come from the 2012 project are:

1. Existing eradication best practice documents, built upon many years of experience, have been developed largely for temperate islands in New Zealand. While generally applicable to tropical eradications, these could 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, and any deviations from such best practice principles need to be justified within such documents.

2. It is recommended that for all eradication projects, a thorough and connected planning process is followed (an example of such a process is already available via Pacific Invasives Initiative's website) with attention to ensuring all aspects of each step is addressed adequately. Vital components of the planning process such as the Feasibility Study and Commensal Rat Plan need to address all the key issues and need to be critically reviewed by independent eradication experts.

3. Compliance with regulations and island manager-imposed conditions is a necessity, but 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. Wherever federal or site-specific requirements compromise efficacy, this is identified as early as possible in the planning process so that a special exemption can be sought, or the risks openly acknowledged by all parties, and the eradication project is considered to be pushing the boundaries of our current understanding.

4. Agreements on paper need to match the practicality of achieving this on the ground. All agencies need to be fully aware of the practical implications before 'signing up' to any agreement. Once agreed upon, resources and staffing should be allocated to ensure the agreement terms are met in practice.

5. A far greater focus needs to be given to the residents of any inhabited island, and how they can be incentivized individually and collectively to behave in a way that maximizes the likelihood of a successful eradication. This typically involves a social marketing campaign with a dedicated staff and budget and outside expert advice and review. Such a marketing campaign

can include information, endorsements from people they trust or admire (ideally from their own community), employment by the project, rewards for good behavior, penalties for bad behavior and the linking of financial or other incentives based on project outcomes. It is important in lead-up planning that potentially problematic issues are identified and fully assessed not only by administrators and planners within each agency, but by those people most likely to be affected by it. Without their support, eradication is more risky and biosecurity more likely to be given lower priority and eventually fail.

6. There needed to be greater demonstrated response to prior data and to reviews of project documents and methodology. Concerns originating from data produced (e.g. biomarker study, toxicity trial) and from comments made during the planning and NEPA processes are examples of issues that need to be more formally addressed in subsequent planning documents. Specific individual experts should be involved in as much of the process from start to finish, and should be provided with as much information as possible to maximize their appreciation of the specific circumstances of that island, and therefore of the value of their contributions, and perhaps also their individual accountability.

7. Optimizing circumstances for eradications will be difficult when there are over-riding priorities on the island (i.e. operation of a USAF air-field). Greater effort and contingency planning is needed from both sides to ensure only the most essential operations occur during the brief window of active bait distribution.

8. Streamlining the chain of command and the number of agencies involved in the 'on-the-ground' aspects of an eradication project seems possible, and would be recommended to firstly clarify and speed the decision-making process, and secondly to reduce the potential for misunderstanding and miscommunication of the roles and expectations between the various agencies. A single 'project manager' should be selected to lead complex eradications such as this, and that person should have a high degree of eradication expertise and should be allowed to operate relatively freely and with some flexibility within the bounds of an Operational Plan that has been approved and 'signed off' by all key stakeholders. This person should be supported by a technical advisory group, and have clear pre-determined decision-making processes. The success or failure of the eradication should be attributable to that person and the organization that employs her or him.

9. Key staff within the planning and eradication team should have considerable familiarity with the island, its inhabitants and its off-island managers, and ideally the project manager should be directly involved in the project from beginning to end. Planning and resourcing are likely to be far more appropriate with good working knowledge of the on-site situation, including accurately recorded maps of structures, caverns, sewer networks and other 'special treatment' areas.

10. Greater robustness is required in the determination of bait rates, either by more detailed bait uptake research or building in a more appropriate margin for error in the bait rates. Allowances ideally need to be permitted for 'adaptive' situations, such as extra baiting levels in special treatment areas or supplemental application where baiting has been deemed insufficient. For eradications, the bait rates should not be determined by the 'norms' alone, as it is the extremes and likely 'high-side' variances that must specifically be identified and catered for.

11. The presence of a substantial resident human population and resultant commensal rodent

population does not simply increase the complexity of an eradication project, but probably increases them by an order of magnitude. The degree of planning and resources allocated to inhabited islands need to reflect this.

12. Where there are differences between the islands 'controlling' agency and other eradication stakeholders, there needs to be thorough negotiation and clear agreement on terms for creating optimum eradication conditions. Stakeholders should be prepared to postpone the project if pre-determined conditions are not met at pre-determined times.

13. The Feasibility Study is the 'investigative start point' for eradication projects and should identify all issues of concern, and subsequent work should attempt to resolve these before the operational planning commences. Should a second attempt be made on Wake Atoll, the entire feasibility assessment and subsequent planning process needs to be revisited and the key issues addressed more fully.

14. Wake Atoll is relatively quickly and easily accessible, has infrastructure to support eradication personnel, has a resident human population capable of assisting with monitoring, and is generally very easily searched in terms of vegetation and terrain compared to most eradication islands. Where future eradications occur on such 'visitor-friendly' islands, there could be more resources allocated for post-operational monitoring. This is above and beyond current standard measures on almost all eradication projects, (but is - without reference to precise timing - recommended within NZ best practice). This is practically feasible on a limited number of islands such as Wake, and therefore is recommended here. Options such as post-operational use of rodent-detecting dogs to detect any surviving rats are a relatively small added cost when considering the overall cost of the project, and any detections made could be followed up by pre-determined 'emergency responses' measures (such emergency responses should also be clearly spelled out within standard biosecurity documents).

15. There is now some circumstantial evidence to suggest that compared to temperate islands, standard rodenticides used in aerial-based eradications are not as universally accepted in tropical situations where abundant natural food resources occur. 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.

16. More investigation is highly desirable on the risks of undertaking eradications when rat breeding is occurring. Research is particularly needed on the foraging behavior of female rats when pregnant and nursing young. Research focus should include 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.

17. Alternative baiting strategies such as increased time between bait drops or the addition of a third bait drop should also be considered and tested on small, easily accessible islands. Aspects such as the ideal minimum length of time bait should remain available to rats after spreading should be investigated and subsequent findings incorporated into development of best practice.

18. Greater emphasis may need to be placed on possible rat behavior where control measures have been underway on the target island for some time prior to the eradication attempt.

19. More data should be collected on rat population and breeding indices, in conjunction with plant phenology (especially known rat food sources) and year-to-year climate cycles and variation, to further refine the optimum times to undertake eradication on Wake Atoll and other tropical islands.

20. Immediate pre-drop monitoring is completed on rat and crab densities, to ensure as far as possible that populations (or crab activity) are comparable to earlier data. Any increases should warrant re-consideration of the intended bait rates.

21. It is strongly recommended that personnel for eradications are selected with a focus on prior experience for their intended roles. At least 50% of staff in any field team should have prior experience of the tasks they are undertaking.

22. Staff scheduling should ensure all legal and critical staffing requirements (such as presence of authorized pesticide handlers and GIS personnel) are covered at all stages of the project where such people are necessary or potentially required. Potential replacements also need to be identified and be available if required, rather than have the project compromised by loss of a key person.

Wider Tasks, Not Specific To Wake Atoll

- There could be a major revision and even a fundamental re-design of bait bucket technology, if the money is found to fund specific research. The current buckets are old technology and were not originally designed for the high-precision work of rodent eradication, where accuracy and consistency of bait sowing is a fundamental aspect of eradication principles. A number of issues are known that could warrant attention (P. Garden *pers. comm.*). One specific factor that could be looked at toward ensuring 'sowing' is not being recorded when the bucket is in fact empty. This could include development of a device to warn of an empty bucket and/or bait not going through the aperture (e.g. a sensor that automatically stops GPS tracking if bait is not passing through the aperture, or an infra-red beam or weight-sensitive detector that sends an auditory signal to the pilot when bait levels fall below a certain point in the bucket). A 'head-up' display of the bucket via a small video screen, reversing camera technology or similar could also be investigated, so the pilot does not always have to awkwardly lean out the door and look down as is currently the case to confirm the bait flow and volume of bait remaining in the bucket. Alternatively, or as an interim measure, a small amount of bait should be left in the bucket at the completion of each bucket-load, and the loading team could verify this each time before refilling, and/or use of video-monitoring of the bait bucket (as used informally in this instance) is adopted as a regular feature.

- Research is needed on individual rats behavior and reaction to bait stations – a study with known individual rats (with radio collars or PIT tags, etc.) and record via infra-red camera or similar the behavior of *all* individuals reactions to bait stations in a natural situation. While hopefully not directly applicable to Wake Atoll any more, the response to a smaller rodent species living sympatrically needs to be evaluated also – will all individuals of that species go into a bait station with the smell of or presence of a larger species? Further research and evaluation is needed on crab-proof but rodent friendly bait stations (and is currently underway (WP, *pers. obs.*)). Prior eradications (successes and failures) should be analyzed for respective bait station design, rodent species and methodology to help derive tropical best practice recommendations.

- Evaluation of any differences in habitat preference or niche separation between the two species would have been beneficial to both the operational strategy and examination of possible causes of failure. It was not possible here because of a demonstrated unreliability in distinguishing between the two species. To enable reliable identification in future, field identification guides need to include *R. tanezumi* and its diagnostic features in them. A possibility might be to revise and update the "Guide to the Identification and Collection of New Zealand Rodents" (Cunningham and Moors 3rd Edition, 1996, Department of Conservation), or refine Aplin *et al.'s* (2003) "Field methods for rodent studies in Asia and the Indo-Pacific" to a field-friendly guide understandable to all conservation personnel which would then have use across most rat eradication situations in the tropical Pacific.

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Appendix 2. People Interviewed for This Review and a Summary of Their Reasons for the Project Failure.

Island Conservation:

Richard Griffiths
Chad Hanson
Alex Wegmann
Gregg Howald
David Will
Rory Stansbury (written comments only)

USAF and Service Contractors:

Matt Moran
Kristen Rex

USFWS:

Susan White
Beth Flint

FWS/IC Volunteer:

Nick Torr

Helicopter Pilot:

Peter Garden

The various people interviewed (n=12) had a wide range of views on what caused the failure, and these are summarized in the table below. Each person was asked the same question – "*what did they think were the major reasons for the failure of the eradication operation here?*" They could opt to present a single reason or a combination of factors, but all interviewees suggested two or more, and up to five. We do point out that some interviewees may not have had a full appreciation of some aspects of the operation that they were not personally directly involved in, and this needs to be borne in mind. However, the ranges of possible reasons for failure have some correlation with our findings, and also highlight the complexity of the project.

Believed Main Causes of Failure	**No. of Respondents**
Not enough bait / too many rats or crabs	8
Bait not out long enough, or baiting interval between applications not wide enough.	3
Baiting gaps	2
Commensal waste management or commensal rodent management.	7
Shortfalls in structure baiting	5
Rat breeding	3
Alternative natural foods	3
Planning and/or trials insufficient or dated	2
Baiting of the *Pemphis* habitat	4

Appendix 3. Recommendations for preparing for a second rat eradication attempt on Wake Atoll.

[The lead agency responsibility is identified in *italics*]

GENERAL

- Maintain the existing biosecurity program and conduct periodic assessments of its effectiveness - *USAF*

- Maintain the food waste management program that was developed for the eradication - *USAF*

- Investigate how to increase the likelihood of success for a future rat eradication attempt by investigating ways to reduce the risk of gaps in bait spread, reviewing the areas to be excluded from aerial bait spread and improving the methods of applying bait in these areas. – *Implementing Agency to lead in collaboration with USAF*

- Establish a clear method to maintain continuity through any possible staff turnover on the project. – *Implementing Agency to lead in collaboration with USAF*

- At least 12 months prior to a future eradication operation, establish a position on Wake to act as an on-island liaison and ensure full implementation of the commensal plan. – *Implementing Agency*

SPECIFIC

- In 2014 reconfirm the species and distribution of rats present on Wake by completing a capture/species identification study across all three islands of Wake Atoll (this may be done in association with the tasks below). – *USAF*

- Complete further seasonal bait availability/exposure studies to reassess bait availability in Wake's current eradication environment, and link this with rodent and crab indices below. Include "high risk" habitats in the assessment e.g. the dump area, *Pemphis* habitat, the marina or areas of high rat or crab density – *Implementing agency or contractors*

- Document seasonal changes in rodent abundance, breeding status and population demography in key differentiated habitats via index trapping. Include "high risk" habitats in the assessment e.g. the dump area, *Pemphis* habitat, the marina or areas of high rat or crab density. - *USAF*

- Document seasonal and inter-annual changes in crab abundance/activity. - *USAF*

- Develop and implement a community engagement plan. – *USAF in collaboration with implementing agency*

- Design and test baiting methods suitable for *Pemphis* habitat – *Implementing Agency or contractors*

- Reassess the design and efficacy of bait stations placed in and around inhabited structures - *Implementing Agency or contractors*

- Reassess the palatability and efficacy of 25W-brodifacoum bait on Wake's population of *R. exulans* using probable bait availability timing. - *Implementing Agency or contractors*

- Using baseline information from the 2012 eradication attempt, develop a comprehensive map, with individual structure numbers and GPS references, of all abandoned, subterranean and other uninhabited structures that could provide refuge for rats – *USAF*

- Identify if a subsequent eradication attempt can be undertaken using the existing Environmental Assessment (EA) or if a new EA is needed - *USAF*

The Authors

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William Pitt is the field station and project leader for the US Department of Agriculture APHIS Wildlife Services, National Wildlife Research Center (NWRC) Field Station in Hilo, Hawaii. His research combines expertise on wildlife populations and behavior to reduce the effects of invasive terrestrial vertebrates (including rodents, mongoose, brown tree snakes, and tree frogs) on natural resources, economics, and human health and safety. He received an M.S. and Ph.D. in wildlife ecology from Utah State University. In addition to his appointment at NWRC, Dr. Pitt serves as an adjunct/affiliate faculty member at University of Hawaii at Manoa and Hilo. He has been involved in numerous projects on invasive species and related pesticides projects including at Palmyra Atoll, Guam, Micronesia and in Hawaii.

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