Factors leading to successful island rodent eradications following initial failure

Araceli Samaniego1 | Peter Kappes2,3 | Keith Broome4 | Steve Cranwell5 | Richard Griffiths6 | Grant Harper7 | Pete McClelland8 | Russell Palmer9 | Gérard Rocamora10 | Keith Springer11 | David Will6 | Shane Siers2

1Manaaki Whenua—Landcare Research, Auckland, New Zealand
2USDA APHIS Wildlife Services, National Wildlife Research Center, Hilo, Hawaii
3Coastal Research and Extension Center, Mississippi State University, Biloxi, Mississippi
4New Zealand Department of Conservation, Wellington, New Zealand
5BirdLife International, Suva, Fiji
6Island Conservation, Santa Cruz, California
7Biodiversity Restoration Specialists, Murchison, New Zealand
8Invercargill, New Zealand
9Science and Conservation Division, Department of Biodiversity, Conservation and Attractions, Kensington, Western Australia, Australia
10Island Biodiversity & Conservation Centre, University of Seychelles, Mahé, Seychelles
11Canterbury, New Zealand

Abstract

Island rodent eradications are increasingly conducted to eliminate the negative impacts of invasive rodents. The success rate in the tropics has been lower than in temperate regions, triggering research and reviews. Environmental factors unique to the tropics (e.g., land crabs and year-round rodent breeding) have been associated with eradication failure. Operational factors have also been important, but these have not been comprehensively assessed. The environmental and operational factors using global cases where rodent eradication initially failed and subsequent attempts occurred were compared. It was determined whether operational factors explained the initial failures, whether operational improvements explained subsequent successes, and whether re-attempting eradication after failure was worthwhile. About 35 eradication attempts on 17 islands, each with 1–2 species from a total of 5 species (Mus musculus and 4 Rattus spp.) were identified. On 14 islands (82%), eradication was achieved on the second (86%) or third attempt (14%). On the remaining 3 islands, eradication was not achieved. Evidence of operational faults for all failed attempts was found (e.g., poor planning, low quality bait, and gaps during bait application). In some cases, operational faults were unequivocally the
cause of failure, but in others, it was impossible to discriminate from confounding, environmental factors. Nonetheless, failures appeared to be mainly the result of not exposing all rodents to a lethal dose of toxin, violating a crucial eradication principle. This can cause operational failure on any temperate or tropical island. However, there may be less tolerance for errors such as gaps in bait coverage on tropical islands, mainly due to bait consumption by land crabs. The findings on factors leading to eradication success (e.g., expert reviewed plans, realistic funding and permits, high standard baiting operations) reflect current best practice recommendations. Strict adherence to best practice is expected to increase overall rates of eradication success.

KEYWORDS
best practice, eradication principles, Mus, Rattus, rodenticide, tropical island

1 | INTRODUCTION

Invasive rodents (Mus musculus, Rattus exulans, R. norvegicus, R. rattus, and R. tanezumi) have been inadvertently spread around the globe by humans; their detrimental impacts on island ecosystems (Angel, Wanless, & Cooper, 2009; Kurle, Croll, & Tershy, 2008; St Clair, 2011; Towns et al., 2009; Towns, Atkinson, & Daugherty, 2006) and the benefits of their removal (e.g., Bellingham et al., 2010; Jones et al., 2016; Rocamora & Henriette, 2015; Towns, 2009; Towns, 2011) are well documented. Pioneered in New Zealand, rodent eradications were largely accidental at first (1960–1976), when rodent reduction efforts unexpectedly resulted in complete extirpation of the target species. Rodent eradications then entered an experimental phase (1977–1986) and, since the late 1980s, have become systematic operations (Towns & Broome, 2003). Likewise, the first successful trial of the aerial broadcast technique occurred in 1990 (Garden, McClelland, & Broome, 2019). Following New Zealand developments, eradications have had a similar history elsewhere (e.g., Rocamora & Henriette, 2015; Samaniego et al., 2011), with increasing success rates over time despite increasing island size (Figure 1). About 600 islands have been cleared of invasive rodents (DIISE, 2019), with many projects comprising complex multi-species eradicalutions (e.g., Macquarie and South Georgia Islands, Springer, 2018; Martin & Richardson, 2019) or operations in challenging habitats such as mangroves (Samaniego et al., 2018). Advances in methodology (e.g., use of helicopters to spread second generation anticoagulants using GPS guidance), confidence from past successes, and positive outcomes driving funding have allowed such increases in size and complexity (Holmes et al., 2015; Howald et al., 2007; Russell & Broome, 2016).

The core eradication principles currently in use include: (a) all target animals are put at risk by the eradication technique(s); (b) target animals must be removed at a rate exceeding their rate of increase at all densities; and (c) immigration must be zero (Cromarty et al., 2002; Parkes, 1993). Best practice for meeting these principles was developed for temperate islands by the New Zealand Department of Conservation (DOC) and other agencies (Broome et al., 2011a; Broome et al., 2011b; Broome et al., 2017; Broome, Golding, Brown, Corson, & Bell, 2017; Keitt et al., 2015; Phillips, 2019; Thomas, Varnham, & Havery, 2017). The New Zealand system emerged from the advisory work of the Island Eradication Advisory Group (IEAG; Cromarty et al., 2002; Broome et al., 2011). Best practice advice was collated from this group and first labeled “best practice” in 2006, although all the recommended practices had been in use for some time by DOC (Cromarty et al., 2002; Thomas & Taylor, 2002). Once declared “best practice” it provided a benchmark for projects against which improvements could be formally adopted and promulgated in subsequent iterations. Through adaptive management and strict adherence to best practice, New Zealand has achieved an outstanding rate of success (Russell & Broome, 2016; Towns & Broome, 2003) even for invasive mice—once thought to be difficult to eradicate (Broome et al., 2019). Although house mice appear to require proportionally higher doses of anticoagulants than some rat species (Broome, Fairweather, & Fisher, 2012), and lab trials have suggested conventional bait is not as palatable as other foods (Cleghorn & Griffiths, 2002), house mice can be reliably removed, even on large islands (e.g., Antipodes Island; Broome et al., 2019; Horn, Greene, & Elliott, 2019). Indeed, all mouse eradications in the past 14 years have been successful (Figure 1). Laboratory trials are useful to assess efficacy of baits and
devices, but there is a need for follow-up trials in natural situations (e.g., Wanless et al., 2008) as well as detailed documentation during actual eradications.

The smaller number of islands and cumulative area treated in tropical regions compared with temperate regions can be partly explained by the evolution of rodent eradications. There was a delay between the pioneer work in temperate New Zealand and its application to tropical regions, where several organizations have been building capacity in addition to adapting best practices designed for temperate regions. Mexico and Seychelles are good examples of countries that have developed national capacity while adapting techniques for tropical regions (Aguirre-Muñoz et al., 2018; Rocamora, 2019). However, the overall lower eradication success rate in the tropics (Russell & Holmes, 2015) is more difficult to explain, and the causes are unresolved (Samaniego et al., 2020). Guidelines for rat eradications on tropical islands were developed to improve the success rate, acknowledging the existence of critical knowledge gaps (Keitt et al., 2015).

A statistical analysis by Holmes et al. (2015) found factors unique to the tropics, such as warm temperatures, presence of land crabs and coconut palms were clearly associated with eradication failure. A later review of a selected subset of tropical island cases (4 successful and 4 unsuccessful) using a qualitative approach (Griffiths et al., 2019) suggested that rat breeding and diet might be contributing causes of eradication failure. However, recent research on these aspects (Samaniego, Griffiths,
Gronwald, Holmes, et al., 2020) concluded that eradica-
tions on tropical islands can be successful despite abun-
dant natural food, high density of land crabs, and high
density of reproductively active rats, which is consistent
with other studies (Merton, 2001; Merton, Climo, Labo-
udallon, Robert, & Mander, 2002; Rocamora & Henriette,
2015). Crucial to eradication success is exposing
all rodents to a lethal dose of highly palatable bait. There
are two possible scenarios that can explain failure to
achieve this: bait availability (all rats could not eat a lethal
dose of bait) and bait palatability (all rats would not eat a
lethal dose of bait) (Brown, Pitt, & Tershy, 2013). Reviews
so far have focused on the latter (Griffiths et al., 2019;
Holmes, Griffiths, et al., 2015); therefore, we focused on
the former and set out to investigate the role of opera-
tional factors as causes of eradication failure.

Our review is complementary to those by Holmes,
Griffiths, et al. (2015) and Griffiths et al. (2019), but
approaches the topic from a different direction by study-
ing cases where rodent eradication initially failed and
subsequent attempts occurred. We compared project
management, and operational and environmental factors
for each attempt. We asked: (a) can operational factors
explain the initial failures? (b) can improvements to oper-
tional factors explain the subsequent successes? and
(c) is it worth re-attempting eradication after initial fail-
ure? Our findings are relevant for pest eradication pro-
jects in all biomes.

2 | METHODS

We focused on eradication attempts from 1990 onwards,
which represents the modern era of systematic eradica-
tion operations. We used the Database of Island Invasive
Species Eradications (DIISE, 2019) to identify island erad-
ications on the basis of the following criteria: (a) target
taxa: Muridae; (b) type: whole island eradication,
(i.e., excluding incursion response and restricted range
operations); (c) primary eradication method: toxicant
(i.e., excluding trapping); (d) toxicant type: known
(i.e., excluding unknown); (e) year of eradication: 1990
onwards; (f) eradication status: known or “to be con-
irmed” (i.e., excluding unknown, invaded and trials;
those with “to be confirmed” status were either updated
to failed or successful, or discarded if unknown); and (g)
quality of data: good or satisfactory, with the latter either
improved to good quality with our supplemental research
(1 case) or discarded if the required information was not
available (4 cases).

We then identified the islands where eradication had
been attempted more than once for the same target spe-
cies. This approach allowed us to focus on the changes
between attempts, given that other important parameters
such as island size, location, topography, local environ-
ment, and human influence remained constant. On each
island, 1 or 2 species of a pool of 5 invasive rodent species
were the targets: house mouse (M. musculus), Asian
house rat (R. tanezumi), Norway rat (R. norvegicus),
Pacific rat (R. exulans) or ship rat (R. rattus). The
resulting list included 44 eradication records on 18 islands,
noting that simultaneous multi-species eradica-
tions are listed as several records (1 per target species).
For 2 islands (Mokoia, New Zealand and Teuaua, French
Polynesia) additional attempts before 1990 existed; we
added those earlier attempts to give a complete eradica-
tion history of these islands. One island with 4 records
(Matakohe, New Zealand) was excluded as it is most
likely subject to continuous reinvasion given its proxim-
ity (<500 m at low tide) to the mainland. The final list
included 35 eradication operations (some targeting multi-
ple islands or rodent species) comprising 17 islands or
atolls and 8 countries (Table 1).

We assessed potential causes of eradication failure, and
compared management, operational and environ-
mental factors between initial and successful operations.
This included the factors identified by Holmes, Griffiths,
et al. (2015) and Griffiths et al. (2019) as the main factors
associated with failure on tropical islands: presence of
coco-nut palms, land crabs, agriculture and human habi-
tation, and year-round breeding rodent populations
(Table 2). Published and unpublished literature was
reviewed, and direct communication with project man-
gers took place for some cases. Collectively, the authors
of this article were involved in most reviewed projects,
conducted fieldwork related to the implementation of
these eradications, and have extensive experience in pest
eradication worldwide. This partly alleviates the fact that
written information is scarce and was difficult to obtain
in several cases.

3 | RESULTS

Of the 17 islands with two or more eradication attempts,
success was achieved on 14 islands (82%; range
5–1,020 ha) at the second (86%) or third attempt (14%)
(Table 1), despite 9 of these islands (64%) having one or
more high risk environmental factors (e.g., land crabs or
human settlements) (Appendices S1 and S2). On the
remaining 3 islands (range 10–294 ha), rodent eradica-
tion was not achieved despite 2 or 3 attempts. However,
on Kayangel, the larger, and potentially dominant, of the
two rat species was removed (Table 1). On 2 of these
3 islands, one or more high risk environmental factors
were present (Appendices S1 and S2).
Considering all 35 eradication attempts (Table 1), we found a higher success rate (58%) in operations that used methods comparable with today's best practice, compared with those that did not (19% successful). Examples of divergence from best practice include use of bait containing Bitrex (bittering agent intended to prevent accidental ingestion by children and pets), baiting grid too wide, or aerial application of bait without navigational guidance (GPS). We found that all failed attempts had operational issues (e.g., suboptimal bait type and gaps in bait coverage) that violated one or more of the three main eradication principles (Table 2). Importantly, some of these issues (e.g., only one bait application instead of the recommended two applications when using aerial or hand broadcast methods) were also present in successful attempts (Table 2, Appendix S2). High risk environmental factors were common in both failed (60%) and successful (40%) attempts; the most common being tropical weather and presence of land crabs (Table 2).

We found a variety of potential reasons for eradication failure (e.g., insufficient bait, land crabs, poor bait product, alternative human-sourced food, and spatial or temporal bait gaps). We categorized and broke down all reasons according to their relationship with the eradication principles, to help practitioners visualize, manage, and document these factors (Figure 2). Insufficient bait was the most common general cause of eradication failure across temperate and tropical islands, and it can be

### TABLE 1  Island rodent eradications targeting the same species twice or more (1990–2018), by country and date of first attempt

| Country | Island | Initial attempt(s) | Successful attempt | Target species | Notes |
|---------|--------|--------------------|--------------------|---------------|-------|
| **Temperate islands where eradication was achieved in a subsequent attempt** | | | | | |
| New Zealand | Mokoia | 1989, 1996 | 2001 | *Rattus norvegicus*, then *Mus musculus* | First attempt targeted rats only |
| New Zealand | Coppermine | 1992 | 1997 | *Rattus exulans* | |
| **Tropical and subtropical islands where eradication was achieved in a subsequent attempt** | | | | | |
| Australia | Varanus | 1994 | 1997 | *Mus musculus* | Targeted recent introduction |
| Australia | Crocus | 1996 | 1997 | *Rattus rattus* | Part of Montebello |
| Australia | Hermite | 1996, 1999 | 2001 | *Rattus rattus* | Part of Montebello |
| Australia | Primrose | 1996 | 1997 | *Rattus rattus* | Part of Montebello |
| French Polynesia | Vahanga | 2000 | 2015 | *Rattus exulans* | |
| French Polynesia | Teuaua | 1986, 2009 | 2017 | *Rattus exulans* | |
| Mexico | Isabel | 1995 | 2009 | *Rattus rattus* | |
| Seychelles | Ile Denis | 2000 | 2002 | *Rattus rattus* + *Mus musculus* | Also known as Denis Island |
| Seychelles | Ile du Nord | 2003 | 2005 | *Rattus rattus* | Also known as North Island |
| **The United Kingdom (Bahamas territory)** | Low Cay | 1999 | 2000 | *Rattus rattus* | |
| **The United States (Pacific territory)** | Palmyra | 2001 | 2011 | *Rattus rattus* | |
| **The United States (Puerto Rico)** | Desecheo | 2012 | 2016 | *Rattus rattus* | |
| **Tropical islands currently invaded where multiple attempts failed** | | | | | |
| Australia | Adele | 2004, 2011, 2013 | N/A | *Rattus exulans* | |
| Palau | Kayangel | 2012, 2018 | N/A | *Rattus exulans* + *R. tanezumi* | Pacific rat still present |
| **The United States (US Virgin Islands)** | Congo cay | 1990, 2004, 2006 | N/A | *Rattus rattus* | |

*Year of baiting.
### TABLE 2  Violations of eradication principles, and environmental factors, analyzed for 35 island rodent eradication attempts

| Violations of eradication principle 1 | Presence of factors | Failed attempts | Successful attempts |
|---------------------------------------|---------------------|----------------|-------------------|
| **Presence of factors**                | No. (%)             | No. (%)        |
| **Violations of eradication principle 1** |                     |                |
| **Could not eat a lethal dose**        |                     |                |
| Insufficient bait: Coverage or density|                     |                |
| Poor design                           | 11  (85)            | 2  (15)        |
| Social constraints                    | 2  (100)            | 0  (0)         |
| Coverage gaps general                 | 13  (93)            | 1  (7)         |
| Insufficient bait                     | 13  (93)            | 1  (7)         |
| Coverage gaps: Coastal gaps           | 8  (89)             | 1  (11)        |
| Regulatory constraints                | 3  (75)             | 1  (25)        |
| Only 1 aerial bait application        | 2  (67)             | 1  (33)        |
| Peer review lacking                   | 8  (67)             | 4  (33)        |
| Poor implementation                   | 15  (88)            | 2  (12)        |
| Budget constraints                    | 5  (100)            | 0  (0)         |
| Time constraints                      | 8  (100)            | 0  (0)         |
| Equipment failure                     | 4  (100)            | 0  (0)         |
| Coverage gaps general                 | 17  (94)            | 1  (6)         |
| Coverage gaps: Coastal gaps           | 14  (93)            | 1  (7)         |
| Poor skills/capabilities              | 10  (91)            | 1  (9)         |
| Land crabs                            | 12  (63)            | 7  (37)        |
| Multi target species                  | 2  (50)             | 2  (50)        |
| **Would not eat a lethal dose**        |                     |                |
| Poor bait product                     |                     |                |
| Inefficient toxin                     | 4  (80)             | 1  (20)        |
| Bitrex present                        | 4  (80)             | 1  (20)        |
| Poor bait matrix                      | 9  (64)             | 5  (36)        |
| Alternative food                      |                     |                |
| Naturally occurring, abundant, highly attractive | 9  (60) | 6  (40) |
| Human sourced, accessible to rats     | 7  (58)             | 5  (42)        |
| **Violations of eradication principle 2** |                     |                |
| Removal not faster than breeding      |                     |                |
| Spatial gaps                          | 5  (100)            | 0  (0)         |
| Temporal gaps                         | 7  (88)             | 1  (13)        |
| **Violations of eradication principle 3** |                     |                |
| Reinvasion                            |                     |                |
| Human activities                      | 5  (63)             | 3  (38)        |
| Within swim range                     | 5  (63)             | 3  (38)        |
| Other environmental factors           |                     |                |
| Agriculture/farming                   | 5  (71)             | 2  (29)        |
| Large island (>1,000 ha)              | 2  (67)             | 1  (33)        |
| Coconut palms                         | 7  (64)             | 4  (36)        |
### TABLE 2  (Continued)

| Presence of factors                          | Failed attempts | Successful attempts |
|----------------------------------------------|-----------------|---------------------|
| People (permanent settlement)                | 5 (63)          | 3 (38)              |
| Tropical weather with extended wet periods   | 13 (59)         | 9 (41)              |
| Year-round rodent breeding                   | 5 (56)          | 4 (44)              |

Notes: Detailed results by island are available online (Appendix S2).
*Attempt partially successful (i.e., 1 of the 2 rat species was removed).

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**FIGURE 2** Reasons for island rodent eradication failure. Asterisks indicate relation to eradication principle 1 (*all target animals are put at risk by the eradication technique), 2 (**target animals must be removed at a rate exceeding their rate of increase at all densities), and 3 (**immigration must be zero)

**FIGURE 3** Factors leading to successful island rodent eradications
the result of gaps in bait coverage (e.g., planned because of permit restrictions, due to poor training of hand baiters, or accidental because of bait bucket failure), poor treatment of inhabited areas, insufficient general bait density (less common), or a combination of these and other factors. The significance and interconnectedness of the 33 factors analyzed (Table 2) changed considerably across islands (which included temperate, tropical, low-lying, and rugged islands) and attempts (covering all rodent eradication techniques). For example, lack of reviews or work done by inexperienced staff had different impacts depending on the complexity of the project and the novelty of the situation. Hence, island descriptions and detailed accounts per attempt are included to assist practitioners planning future rodent eradications (Appendix S1). Limited information on some factors and islands (Appendix S2), particularly for initial attempts, prevented us from performing inferential statistical analysis. Yet, we calculated percentages of failed and successful attempts in which each factor occurred (Table 2).

Finally, from the qualitative comparison of failed and successful attempts per island (Appendix S1) we identified the following factors as associated with eradication success: thorough planning, detailed island knowledge, realistic funding and permits (i.e., enabling best practice), good management structure, and high standard baiting operations. We then broke these factors into their constituent components as they relate to the eradication principles (Figure 3).

4 | DISCUSSION

Island rodent eradications are highly effective conservation interventions (Jones et al., 2016). Project managers are largely in control of such interventions via thorough planning and implementation, despite environmental factors influencing eradication strategies. Our findings indicate that many eradication failures can be attributed to human error. We believe that most eradication attempts, including those in the tropics, have similar chances of success provided the operational design meets the eradication principles, plans are independently reviewed, and plans are meticulously implemented.

Flaws within initial eradication attempts included poor planning, low quality bait, inadequate bait coverage, inexperienced pilots with no navigational guidance, inadequate baiting around human structures, insufficient treatment of infestation hotspots such as long-term accumulation of green waste (e.g., coconut piles), and deviations from operational plans. Not surprisingly, attempts preceding the development of best practice typically had more operational issues than more recent attempts. Correcting these issues in a latter operation often resulted in eradication success. This iterative process continues to refine best practice.

For some initial attempts (e.g., Teuaua and Desecheo) quality of planning was high, and potential omissions during implementation did not become apparent until the project was reviewed. There are also complex cases where operational and environmental factors were confounded, that is, the eradication strategy was refined but island conditions were also more favorable during the subsequent successful attempt. In cases such as Isabel, the timing of implementation was changed to the dry season; in others such as Desecheo, conditions were drier during the same period for the second attempt. Eradication planning requires consideration of seasonality with potential interannual deviations (Will et al., 2019). Moreover, flexibility in implementation to allow for dynamic environmental or social factors should be explicit (Harper, Pahor, & Birch, 2020). Finally, in a few cases it is likely eradications succeeded but rodents reinvaded (e.g., Congo Cay), which is still considered a project failure. Planning an eradication without appropriate biosecurity measures is poor planning (Kennedy & Broome, 2019).

In a nutshell, failed attempts did not meet the eradication principles of exposing all rodents to sufficient toxic bait, and of having zero immigration. This can cause operational failure on any island, although there appears to be less tolerance for gaps in bait distribution on tropical islands, where nontarget bait consumers can quickly enlarge bait gaps (Samaniego, Boudjelas, Harper, & Russell, 2019). Documentation, via trail cameras, of a high proportion of bait consumed by nontarget species on Desecheo is a good example (Shiels et al., 2019). Nonetheless, high risk factors have been overcome after initial eradication failure in a variety of island settings (Appendix S1). Factors leading to these successes can be summed up as thorough planning in line with best practice, and a high standard of bait application. This breakdown is useful for planning island pest eradications in general (Figure 3). Innovative thinking is required for unprecedented scenarios such as rodent eradications on mangrove islands greater than 1,000 ha.

As for our questions:

1. Can operational factors explain the failures? Mostly, yes. A variety of operational issues were identified in all initial attempts. Similarly, significant operational issues occurred during follow up attempts on the three islands where eradication was not achieved.

2. Can improvements in operational factors explain the subsequent successes? Mostly, yes. Although in some cases (e.g., Desecheo and Isabel) more favorable
environmental conditions during the second attempt may have contributed to success, there were also cases where environmental conditions were less favorable during the later successful attempt (e.g., Ile du Nord and Teuaua).

3. Is it worth re-attempting islands after initial eradication failures? Absolutely. Evidence suggests that with an experienced team for both the planning and the implementation phases, the chances of success are high, even for challenging tropical islands where environmental conditions are less favorable (e.g., mesic tropical islands) or more unpredictable.

Yet, commonly underestimated issues require more attention. In addition to land crabs interfering with bait and devices (Samaniego et al., 2019; Wegmann, 2008), cliffs require specific attention to ensure adequate coverage and intertidal areas are underestimated as potential rodent habitat and food sources (Siers, Berentsen, McCuliffe, Foster, & Rex, 2018). Mangroves, which are permanently or frequently flooded, are inhabited by rats but are challenging to treat (Harper, Dinther, & Bunbury, 2014; Samaniego et al., 2018). Accuracy of baiting grids, often un-documented, is essential to avoid gaps (Samaniego et al., 2020). Baiting of human structures and removal of alternative food sources require special care (Harper et al., 2020; Rocamora, 2019). At some sites, intensive post-baiting surveys (e.g., camera trapping, chew tags, detection dogs) can be used to aid the detection and removal of survivors, especially where complex eradication strategies are used (Harper et al., 2020).

The importance of organizational and staff management is also often under-appreciated. For example, complex management structures can create confusion and lead to conflict (Brown et al., 2013; Stringer et al., 2019). Staff must be well trained and have a professional and eradication mindset (Cromarty et al., 2002; Samaniego, Kappes, & Siers, 2020). Morrison, Faulkner, Vermeer, Lozier, and Shaw (2011) provide an excellent discussion on the non-science components of eradication programs and propose a framework for creating resilience.

Each eradication attempt represents a unique combination of factors. Some factors are predictable, and some are situational, and need to be addressed with conservative design and capability within a team to make informed decisions. Experience with the methods, the specific island, and country regulations are essential. Aerial broadcast operations have a high success rate but they still have logistical, regulatory, and environmental challenges. Will, Howald, Holmes, Griffths, and Gill (2019) discuss the challenges and explain why discrepancies between planned and actual bait rates are common, thus requiring flexible permits to ensure eradication principles are met.

Eradication projects must be adequately budgeted, with an appropriate contingency to respond to unexpected challenges (Kappes, Bond, Russell, & Wanless, 2019). Multispecies or multisland eradications require extra planning, resources and flexibility (Martin & Richardson, 2019; Springer, 2016). When establishing protocols for nontarget species and environmental protection, the perceived benefits of bait application restrictions, such as bait deployment away from coastlines, should be adequately evaluated. Environmental legislation in some jurisdictions (developed in the context of mitigating harm from industrial development for which little environmental benefit is accrued) does not allow for the benefits of successful eradication to be weighed against short term contamination. Therefore, opportunities for net gains are overlooked by seeking to mitigate the contamination at the potential expense of the success of the eradication. Such policies can have a chilling effect on eradication attempts if practitioners elect not to implement projects in the face of restrictive environmental compliance or they are driven to suboptimal methods.

Practitioners are better at reporting successes than failures, and postoperation reviews are mostly not conducted (except in New Zealand) nor publicly available. In addition, there is a tendency to avoid discussion of potential human errors, which can preclude objective assessments of the significance of factors influencing operations. For this review we ameliorated the issues of scarcity and limited availability of operational reports by inviting managers involved with the projects to contribute. However, improving the quality and quantity of reports for all operations, successful or not, is a necessary step to learn from failure and clarify what is required for success. Every eradication project should include a comprehensive postoperational report as part of the overall strategy, so time and funding must be allocated in advance, and such reports should be independently reviewed to maximize learning for future projects. Keitt et al. (2015) provide a list of the main subjects that any post operational report should include; the list analyzed for this review (Table 2) is also a good guide.

Overall, our results are encouraging. In most cases successful eradication of the target species was eventually achieved, the conservation community has learned significantly from its failures, and techniques and theory are constantly improving. Comprehensive best practice documents are available, giving practitioners significant advantages over their predecessors (Broome et al., 2011a; Broome et al., 2011b; Broome, Golding, Brown, Corson, & Bell, 2017; Broome, Golding, Brown, Horn, et al., 2017;
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CONFLICT OF INTEREST
The authors have no conflict of interest to declare.

AUTHORS CONTRIBUTION
Araceli Samaniego: Designed the review and led writing of manuscript, with important contributions from Peter Kappes and Shane Siers. All authors contributed published and unpublished documents, and comments on specific case studies. All authors provided critical feedback on several versions of the manuscript and approved the final version. Shane Siers: Provided administrative oversight.

DATA AVAILABILITY STATEMENT
All data are available either in the main manuscript or in Supporting Information.

ORCID
Araceli Samaniego https://orcid.org/0000-0001-7182-3790

Peter Kappes https://orcid.org/0000-0001-6029-5355
Shane Siers https://orcid.org/0000-0001-7961-5072

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**SUPPORTING INFORMATION**

Additional supporting information may be found online in the Supporting Information section at the end of this article.

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