Mouse eradication on Midway Atoll: a review of the record

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November 2016

Summary

Invasive house mice *Mus musculus* are negatively impacting the Midway Atoll's ecosystem. In response, the feasibility of a mouse eradication is being assessed. As a first step, an overall review on mouse eradications was conducted. It has been suggested that mouse eradications are more challenging than rat eradications; however, the increasing success rate, particularly on large islands, suggests that complex mouse eradication operations are feasible—the record is Macquarie Island (12,873 ha). Over the last decade, the success rate of mouse eradications was a remarkable 93.3% (n= 31), most likely reflecting the development of best practice guidelines and more international cooperation sharing knowledge and lessons learnt. At Midway Atoll, house mice have been reported on Sand Island (the atoll's largest at 486 ha); their status on the other two islands is uncertain. Sand Island is slightly larger than other tropical islands where house mouse eradications have been implemented. Most physical and biological characteristic of the Midway Islands have been faced and managed in past mouse eradications, including the presence of large seabird colonies. However, the large commensal environment (i.e., the human settlement including the remnants of the larger military base) is a potential constraint. Further on-site research and a full feasibility assessment is recommended.

Contents

Background

- Midway Atoll (three islands: Spit (2 ha), Eastern (135 ha) and Sand (486 ha), the latter with large area of human infrastructure) is one the oldest atoll formations in the world and provides nesting habitat for millions of seabirds (USFWS 2016). The accidental introduction of rats in 1943 caused dramatic negative impacts in the seabird community and the insular ecosystem (Fisher and Baldwin 1946).
- A successful rat eradication across all three islands took place between 1994-1996 using traps and bait stations (Witmer et al. 2011); house mice, not deliberately targeted, survived.
- The arrival date of house mice at Midway Atoll is unclear. Fisher and Baldwin (1946) only mention rats, whereas Seto and Conant (1996) mention mice in 22.83% of their rat traps in 1993-1994, just before the rat eradication. Rats, but apparently not mice, were considered a threath for seabirds (Seto and Conant 1996).
- Mouse eradications appear to be more challenging than rat eradications (MacKay et al. 2007, Rauzon 2007); nonetheless, several large-scale mouse eradication operations have been successfully implemented and more are being planned (Parkes 2014).
- For rat eradications, the historic failure rate in the tropics is higher than the rate for temperate regions (Russell and Holmes 2015); the failure rate for house mouse in the tropics has not been assessed.
- As the first step on a feasibility assessment for the eradication of mice from sub-tropical Midway, Island Conservation commissioned PII to undertake a literature review on past mouse eradications. The objective was to identify the general issues and recommendations that pertain to doing the work at Midway.

Invasive mice vs. rats

Of the four invasive rodent species that are of major concern (Pacific rat *Rattus exulans,* brown rat *R. norvegicus,* black or ship rat *R. rattus* and house mice *Mus musculus*) (Amori and Clout 2003), black rat is the most frequently targeted species for island eradications whereas house mouse is the least frequently targeted (DIISE 2016; Howald et al. 2007). For decades, house mice received less attention than rats due to the perception of being less damaging to island ecosystems (Cuthbert and Hilton 2004). However, it's now clear that mouse impacts were underestimated. Recent research has proven that on islands where house mice are the only invasive mammal, as is the case at Midway, they can have devastating, ecosystem-changing effects (Angel et al. 2009; St Clair 2011), including ferocious predation under certain circumstances (Jones and Ryan 2009).

Rodent eradication statistics

The number of island rodent eradications since the first global review by Howald et al. (2007), which reports 332 attempts, has significantly increased. By 2015, 944 attempts of rodent eradications (including 10 target species) had taken place on 692 islands, of which 87 (9.2%) represent house mouse attempts (sometimes as part of multi-species attempts) and include 76 islands in 17 countries. For house mice, 32 (36%) attempts have been conducted within the tropics, with similar increasing success rates to overall patterns (Table 1). Island size of successful operations has also increased dramatically (Figure 1); Macquarie (12,873 ha) was recently confirmed and other large islands (e.g., Floreana at 17,300 ha) are planned (Figure 1).

Table 1. Mouse eradications on islands for which the result was known by 2015, based on the DIISE (DIISE 2016).

	No. attempts		No. attempts on islands ≥ 400 ha		No. attempts between 2005-2015	
	Successful (%)	Failed (%)	Successful (%)	Failed (%)	Successful (%)	Failed (%)
GLOBAL						
Total (all methods)	61 (70.1)	26 (29.8)	7 (70)[1]	3 (30)	28 (93.3)	2 (6.7)
Using brodifacoum	48 (68.6)	22 (31.4)	7 (70)	3 (30)	28 (93.3)	2 (6.7)
Using diphacinone	1 (50)	1 (50)	none	none	none	none
TROPICAL & SUBTROPICAL[2]						
Total (all methods)	24 (75)	8 (25)	none[3]	none	9 (90)	1 (10)
Using brodifacoum	12 (66.7)	6 (33.3)	none	none	6 (85.7)	1 (14.3)
Using diphacinone	1 (50)	1 (50)	none	none	1 (100)	0

N.B. Only records for island-wide attempts with good quality data were included.
[1]One more attempt, on Antipodes Islands, New Zealand in 2015 is awaiting confirmation.
[2]Islands situated between the parallels 28°N and 28°S.
[3]One attempt, on Mer Island, Australia between 2009-2012 is awaiting confirmation; trapping over 2012 yielded no rodents.

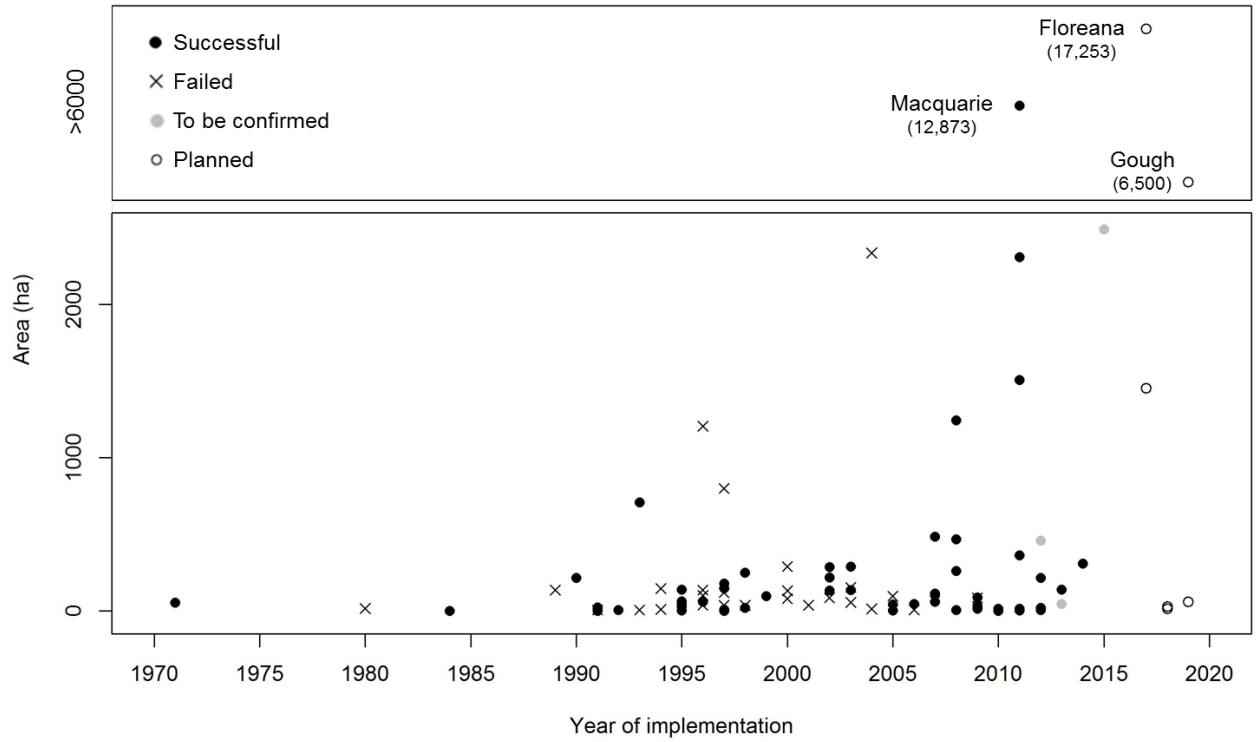

Figure 1. Global house mouse eradication attempts on islands, over time and by island size. Source: DIISE 2016.

Successes are on the rise

The overall rate of success for mouse eradications (70.8%) is lower than the overall rate for rat eradications (87%) (Russell and Holmes 2015), which reinforces the perception that mice are particularly difficult to eradicate. However, the rate of success for mouse eradications over the last decade (2005-2015) is a remarkable 93.3% (n= 31) (Table 1, Figure 1), most likely reflecting the development of best practice guidelines (Box 1) (Broome et al. 2014; Keitt et al. 2015) and more international cooperation sharing knowledge and lessons learnt (Veitch et al. 2011). Moreover, recent successful projects include six of the 10 operations on islands >400 ha, all of which faced the larger complexity of targeting two or more species for eradication and all were conducted in temperate regions. Within the tropics, the largest mouse eradication attempt (Mer Island at 459 ha) is awaiting confirmation. Of the three largest attempts with known result (219-289 ha), two were successful.

For all the largest successful projects (Table 2), the principles and constraints that have to be met or overcome as for any eradication attempt (Box 1) were carefully evaluated and managed for each specific environment, following best practice guidelines (Box 1). Owing to the confidence of established procedures (e.g., aerial broadcast of rodenticide bait), several large-scale operations targeting solely house mice are either awaiting confirmation of success after implementation (e.g., Antipodes Island at 2,489 ha) or in the planning stage (e.g., Gough Island at 6,500 ha and Marion Island at 29,000 ha). On Lord Howe Island (1,455 ha), a multi-rodent (mouse and rat) eradication is also being planned.

Table 2. Largest successful mouse eradications on temperate and tropical islands up to 2015.

Island	Island size (ha)	Country	Main eradication method	Main baiting method	Other target mammals?	Year of eradication
TEMPERATE						
Macquarie	12,873	Australia	Brodifacoum bait	Aerial broadcast	Yes	2013
Rangitoto/Motutapu	3,820	New Zealand	Brodifacoum bait	Aerial broadcast	Yes	2009
Coal	1,245	New Zealand	Brodifacoum bait	Aerial broadcast	Yes	2008
TROPICAL[1]						
Flat	250	Mauritius	Brodifacoum bait	Bait stations	Yes	1998
Fregate	219	Seychelles	Brodifacoum bait	Aerial broadcast	Yes	2000
Varanus	147	Australia	Pindone and brodifacoum bait	Bait stations	No	1997

[1]Another attempt, on Mer Island, Australia (459 ha) is awaiting confirmation.

Box 1. Principles and best practice guidelines for island rodent eradications.

Eradication of invasive species from islands is based on core principles (Cromarty et al. 2002):

1. Every individual must be put at risk with the proposed technique(s).
2. The technique(s) has to kill them faster than they can breed.
3. Immigration must be zero.

For rodent eradications, Best practice guidelines were developed to maximize the probability of success.

The goal is to ensure toxic bait is put into every rodent territory and is available long enough for every rodent to consume a lethal dose (Howald et al. 2007).

- For temperate islands, refer to the Current Agreed Best Practice developed by the New Zealand Department of Conservation (Broome et al. 2014).
- For tropical islands, refer to the Best Practice Guidelines for rat eradication on tropical islands, developed by an international team of eradication experts (Keitt et al. 2015).

Failures can be explained

In 2008, Parkes (2008) assessed the feasibility of eradicating mice from Gough Island (6,500 ha). Parkes reported that mice had been eradicated from 30 islands around the world and that attempts had failed in 17 operations on 13 islands, although success was achieved on three of these islands at later attempts. After evaluating the unsuccessful projects, he concluded that the causes of several of the failures were known or suggested, and should not be repeated on Gough Island if best practices were followed. Parkes stated that 'The improved understanding of the technical systems used in aerial application of bait (e.g. DGPS, sowing buckets, overlapping and multiple baiting to ensure no gaps in bait distribution, pilot skills) and perhaps the absence of rats *Rattus* spp. increase the likelihood of success on Gough Island – irrespective of its size and remote location'. The mouse eradication on Gough Island is scheduled for 2019 (ACAP 2016).

A few years later, Mackay (2011) dedicated his Doctoral research to investigate house mouse biology with the aim of improving mouse eradication attempts, with emphasis in New Zealand. MacKay reported that the global failure rate decreased from 38% in 2007 to 33% in 2011, which continues declining and is 6.5% for the last decade (Table 1). His review of failed projects suggested that one of the main reasons for mouse eradication attempts failing could be gaps in poison coverage. MacKay's overall conclusion was that 'with proper planning it is possible to eradicate mice from islands and to maintain mouse-free sanctuaries'.

Recently, Parkes (2014) updated his first review of mouse eradications (Parkes 2008) while assessing the feasibility of a mouse eradication on sub-Antarctic Marion Island (29,000 ha). Parkes reported a significant improvement regarding mouse eradications both in the number of cases and in the scale of the projects, with an order of

magnitude increase in the size of the largest islands. Once again, the conclusion—'Eradication of mice from Marion Island is definitely possible with a high chance of success'— is partially backed by discussing how specific operational issues resulting in past failures (e.g., single bait drop, no overlap of swaths, no use of DGPS) can be managed.

Importantly, for some of the failed eradications it is not clear if the eradication operation failed or if the islands were rapidly reinvaded (Mackay 2011, K. Broome, pers. com.). Likewise, mouse eradications are commonly part of multispecies eradication operations but haven't been deliberately targeted in all cases (Parkes 2014, K. Broome, pers. com.), which means planning may not have been to the standard required for reliably targeting mice. A closer look at the failed projects on islands >400 ha, i.e. of similar size to Midway Islands, confirms that operational factors are always listed as potential causes of failure (Table 3).

For the tropics, additional ecological challenges, which explain the lower success rate in this region, have been identified (Harper and Bunbury 2015; Russell and Holmes 2015; Samaniego-Herrera et al. 2014; Wegmann et al. 2011). Holmes et al. (2015) assessed the factors associated with rodent eradication failure and found that they appear to be many and potentially multiplicative. Particularly for tropical environments, the presence of land crabs, coconut palms and agriculture are associated with failure. The main recommendation for future projects is to follow best practice, which for tropical islands was recently outlined in the Best practice guidelines for rat eradication on tropical islands (Keitt et al. 2015).

Conducting applied research alongside rodent (mouse and rat) eradication projects, (Samaniego-Herrera 2014) focused her Doctoral research on rodent ecology on tropical islands, in relation to eradication operations. After a review of failed rodent eradications and being directly involved with many successful operations, Samaniego concluded that 'Rodent eradications on tropical islands have inherent challenges which vary between dry and wet islands. However, more and larger tropical islands can be cleared of rodents if directed research informs planning and implementation'. For example, year-round breeding populations of house mice have been eradicated from islands with year-round breeding seabirds in the Mexican tropics (Russell et al. 2016; Samaniego-Herrera et al. In press). In summary, any mouse eradication on a tropical island has a high probability of success if best practices are followed at the highest standard.

Table 3. Failed mouse eradications on islands >400 ha. Mice were not deliberately targeted on Deserta Grande.

Island	Year of attempt	Main eradication method	Main baiting method	Other target mammals	Suspected reasons of failure	Reference
Australia, France (2,100 ha)	2005	Brodifacoum bait	Aerial broadcast	Ship rat	Not clear	DIISE (2016)
Deserta Grande, Portugal (1,000 ha)	1996	Brodifacoum bait	Bait stations	Rabbit	Gaps in bait coverage	Bell (2001)
Saint-Paul, France (900 ha)	1997	Brodifacoum bait	Aerial broadcast	Rabbit, ship rat	Single bait drop Gaps in bait coverage	Micol and Jouventin (2002)

The Midway case

At present, island rodent eradication is considered a standard conservation tool (Russell and Broome 2016), highly effective at protecting the world's most threatened species (Jones et al. 2016). The lessons learnt over several decades and the development of best practice guidelines have increased the rate of success; however, it is crucial to highlight that such guidelines are only the starting points from which each specific project should be crafted (PII 2011). Each island project is unique, both in the environmental and the socio-political aspect. Also, the available information and experience varies depending on the target species. As previously noted, house mouse eradications represent <10% of the global rodent eradication attempts. Of these, over half (52%) have been implemented in temperate New Zealand, revealing house mouse eradications in the tropics as a relatively new field (Figure 2). Still, the overall patterns of success are also increasing (Table 1), although the achievements within the tropics are modest compared to those in temperate regions (Table 2).

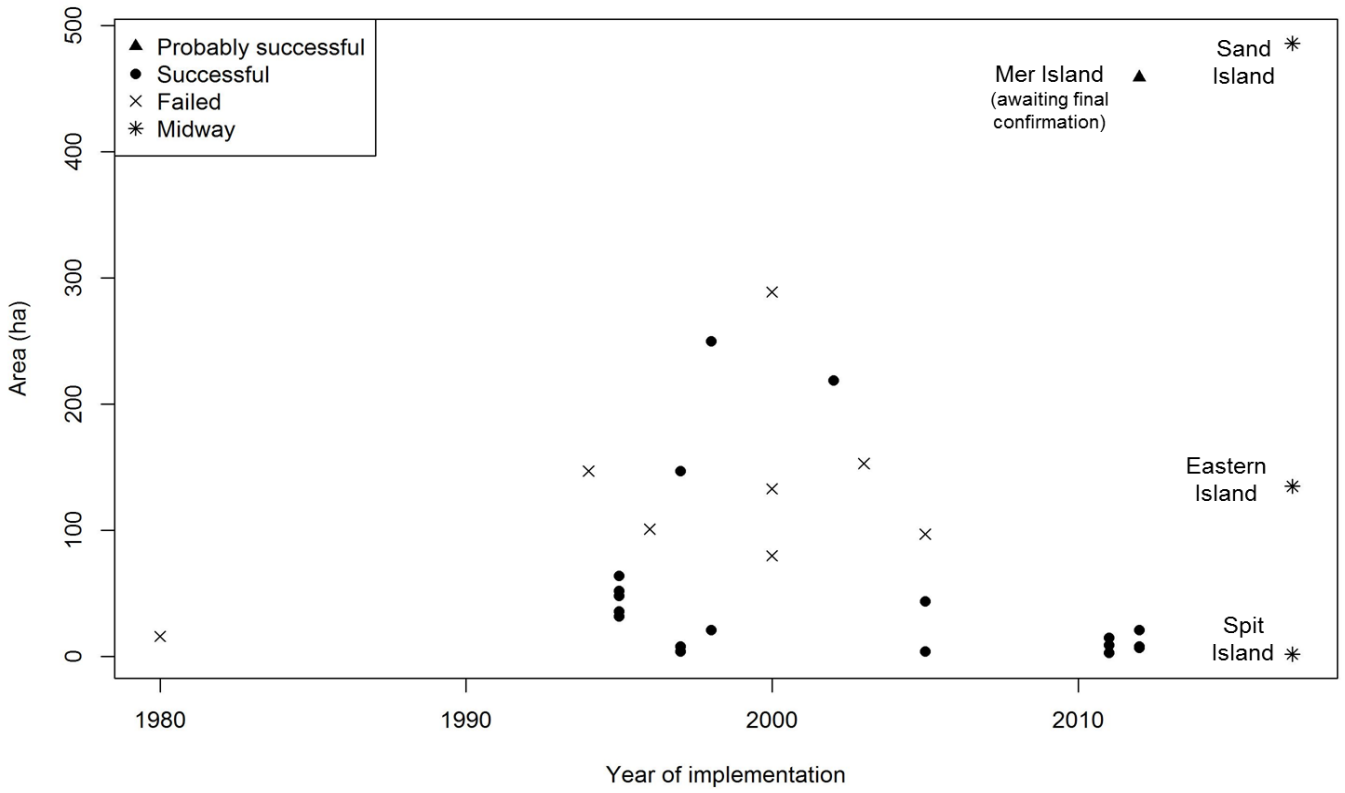

Figure 2. Size of Midway Islands with respect to past house mouse eradication attempts on tropical and sub-tropical islands.

The Midway Islands, ranging 2-486 ha, are of similar size to other tropical islands where house mouse eradications have been implemented (Figure 2). However, Sand Island (the largest) would be a new record for the tropics. Fortunately, the achievements and plans for other regions and invasive rodents show that island area is not a limiting factor (Parkes 2008, 2014). Moreover, the successful rat eradication at Midway Atoll (1996) is a good

precedent of feasibility. For a mouse eradication attempt, research and meticulous planning should result in an operational strategy with high probability of success; alternatively, the process may identify factors that give it an unacceptable risk of failure, for example the large commensal environment around human infrastructure. Nonetheless, most physical and biological characteristic of the Midway Islands have been faced and managed in past mouse eradications, including the presence of large seabird colonies.

At Midway, the Islands fit the description of savanna or 'dry' tropical islands (Weigelt et al. 2013), which is an advantage because their low rainfall and primary productivity are usually correlated with lower abundances of rodents, land crabs (bait competitors) and smaller arthropods (preferred mouse food) compared to wet tropical islands (Table 4). Mouse population dynamics should be investigated for Midway Islands, as baseline data for the target population are a crucial component of planning, implementation (Keitt et al. 2015) and evaluation (Samaniego-Herrera et al. 2013) of rodent eradications. Importantly, research should be carried out on the two largest islands of Midway Atoll, even though mice are thought to be present only on Sand Island (P. McClelland, com. pers.). Recent research has shown that even subtle changes in the environment of neighbouring islands, which could involve both bottom-up (e.g. habitat and food availability) and top-down processes (e.g. predators and competitors), can derived in significant differences on rodent diet and population dynamics (Shiels et al. 2013, Samaniego-Herrera et al. In review). In other words, house mice may be also present on Eastern Island but at lower density than on Sand Island, making them harder to detect. Determining the status of the house mice across Midway Atoll should be a priority of a feasibility study, which is highly recommended.

Table 4. General characteristics of dry and wet tropical islands, in relation to eradication planning at dry Midway Atoll.

Characteristic	Dry islands	Wet islands	Recommended actions for Midway Atoll
Rodent abundance	Low-medium	High	Assess mouse abundance, distribution and reproduction during wet and dry seasons
Land crab abundance and seasonality	Low for burrowing crabs	High for burrowing crabs	Assess richness and abundance of land crabs
Favourable climatic window for eradication	Long	Short	Identify the driest period
Flooded areas	None-seasonal	Large, permanent	Confirm absence of wetlands
Three-dimensional habitat for rodents	None-limited	Common	Assess rodent nesting activity in the canopy
Bait type	Most formulations work	Special formulations required	Trial bait resistance to physical conditions
Bait consumption	Low during dry season	Medium-high	Assess bait consumption rate

Acknowledgements

Thanks to Pete McClelland for helpful information and comments on the document.

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